FACILITATING INDUSTRIAL ADOPTION OF DESIGN METHODS FOR PRODUCT-SERVICE SYSTEMS

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Abstract

In contrast to increasing evidence detailing both economic and environmental advantages of Product-Service Systems (PSS), the number of PSS provided in the market is still limited. Limited adoption in general can in part be linked to a limited implementability of PSS-focused design methods.
This paper aims to provide a first account of characteristics intended to support developers of PSS design methods in providing high levels of implementability and usability. Since fields adjacent to PSS design, such as engineering design or eco-design, have experienced similar challenges in method adoption, literature focusing on this was reviewed. The applicability of the challenges found for PSS design methods was subsequently evaluated with a questionnaire among practitioners involved with the trial of a PSS design method over an extended timeframe. In order to tackle the challenges identified, beneficial properties found in the literature on PSS design methods were utilized in order to derive six characteristics. These are intended as a first orientation for developers aiming to facilitate a broad adoption and use of PSS design methods, and as a discussion basis in the research community.

Keywords: Design methods, Method implementation, PSS Design

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1 INTRODUCTION

1.1 Background and Objective

As resources are steadily becoming scarcer and the implications of growing greenhouse gas emissions are becoming more and more apparent, ways are being sought to reduce the impact of the western lifestyle on the environment. Among other means, one way of tackling this problem is at its very root – reducing the extensive use of resources. With the vast majority of mankind still living in poverty (depending on definition, up to 95%; see Ravallion *et al.* (2009)), degrowth, as argued e.g. in Schneider *et al.* (2010), does not appear to be a viable option at this time. Therefore, the use of resources and energy must be reduced by decoupling it from economic growth – in one word: Dematerialization. Product Service Systems (PSS) may be a useful approach when moving in that direction. PSS are a combination of physical products and services which are optimized with a focus on the entire life-cycle and customer value (see Meier *et al.* 2010). Goedkoop *et al.* (1999) see dematerialization as one cornerstone of their definition of PSS. More recently, authors have begun delivering data that suggests the research community is moving in the right direction (see e.g. Lindahl *et al*. (2014)). Further, PSS may be one facilitator of a circular economy where resources re-enter the economic cycle at the end of the lifetime of a good (Tukker, 2013). However, environmental benefits alone will not convince companies to use PSS as their business model, and industrial adoption is still low (Baines *et al.*, 2007). More recently, this was in part attributed to the lack of fitting methods (Hänsch Beuren *et al.*, 2013).

Due to obstacles encountered when introducing new methods with industrial partners, the authors of this paper argue that rather than a mere lack in quantity, the methods provided by academia are lacking in characteristics that are aimed to facilitate industrial implementation. Therefore, in addition to issues such as path-dependency (Cook *et al.*, 2006), lacking implementability of methods may be a hindrance for companies to more widely adopt PSS.

Based on the above, the objective is to identify general method characteristics that may improve implementability and usability of PSS design methods. To achieve this, an extensive literature review was performed in the area of PSS design as well as adjacent fields. The applicability of the challenges found for PSS design methods was evaluated with a questionnaire among practitioners. In order to tackle these challenges, beneficial properties identified in existing PSS design methods were utilized to synthesize characteristics, which are intended as a first orientation for developers of PSS design methods and as a basis of discussion in the research community.

1.2 Structure

This paper is structured as follows. First, the methodology employed for the literature review and questionnaire is detailed in Section 2. Section 3 then examines relevant literature in fields that are related to PSS to identify key challenges for method adoption. Next, PSS design methods are reviewed in Section 4 in order to isolate properties that may facilitate method implementation and use. In Section 5, attributes are derived based on the challenges in fields related to PSS, which are then evaluated through a questionnaire for importance with respect to PSS design methods by practitioners. Lastly, Section 6 discusses six characteristics based on a synergy of the challenges and beneficial properties found, which may promote a PSS design method's implementation and use.

2 METHODOLOGY

2.1 Literature Review

With regard to method properties and adoption in fields related to PSS, the starting point was Lindahl (2005). This reference was chosen since it gives a comprehensive overview of the state of the art in environmentally-focused design methods. This refers to both the immediate field of eco-design as well as engineering design-focused publications discussing requirements for the broad adoption of methods. Lindahl (2005) was examined with focus on major references. It was then studied which works referenced Lindahl's main sources in the chapters relevant to the focus of this paper *after* 2005. This gives a concise but still comprehensive overview of the research in the field in recent years. In addition, other references from these papers and their citations were taken into account, spreading the

scope of the literature in a tree diagram fashion. Further, a keyword-based search in Scopus was performed, while limiting results to literature from 2005 and later from the outset. Search terms used included *design methods, method adoption, engineering design method, and design tools*. This approach confirmed that the relevant literature had been well-covered by the snowball approach.
With respect to method design for PSS, the main source was a review conducted on literature contained in the Scopus database. Search terms used for this search were, amongst others, *PSS, IPSO, IPS2, Design, Methods, Tools* and combinations thereof. In addition, the functionality of the database, allowing restricting the publishing dates and research fields to be taken into account, was utilized. Three recently published literature reviews (Boehm and Thomas, 2013; Hänsch Beuren *et al.*, 2013; Tukker, 2013) also served as major sources, along with the method-focused review by Vasantha *et al.* (2012).

2.2 Questionnaire

The questionnaire was carried out in October of 2014. It was completed by seven employees, all of whom are working in product/service design in an international manufacturer in the energy sector. All participants were involved in the trial usage of a PSS design method with their own products and services over an extended time period. The questionnaire was focused on retrieving feedback for this process and the method itself. The relevant part of the questionnaire, focused on "influential factors for implementation", was designed by the first author of the paper, together with the third author.
After isolating critical factors for method adoption (Section 3.2) and method properties that may be beneficial with regard to method implementation and use (Section 4.3), the findings of both directions were combined to provide seven properties that were thought to have an impact on the implementability/usability of the PSS design method. These factors were to be rated for importance on a five-point Likert-type scale. Through this, sufficient differentiation was enabled without over-measuring a subjective assessment on a complex and unfamiliar topic (see Hair *et al.* 2009).

3 CHALLENGES FOR METHODS IN FIELDS OUTSIDE PSS

It is often the case that methods in the field of PSS are derived from methods in engineering design (Tukker (2013) referring to Aurich *et al.* (2006)). Based on this, one must assume that the field of method design for PSS can greatly profit from the lessons learned in adjacent fields, such as eco-design and product design (see e.g. Lindahl *et al.* (2007)), as they both share a common heritage in engineering design. Designers and engineers are, by the nature of their daily tasks, confronted with great epistemic uncertainty in the decision-making process, leading to them constantly working "at the extremity of their current knowledge" (Ball & Christensen (2009), mentioned in Daalhuizen (2014)) - regardless of whether they work in PSS or with product-type offerings. Assisting practitioners in this area by providing more useful methods is therefore a self-evident goal. Here, major challenges are identified to guide the efforts of improving the implementability of PSS design methods.

3.1 Understanding the value of Methods

A number of researchers, as detailed in this section, have discussed the value a method provides to the user, particularly in the field of engineering design. Further, contributions are discussed which compile information with regard to particular topics in this area.
Daalhuizen (2014) concludes that methods assist the reasoning and decision-making conducted by engineering designers, rather than solely providing support as systematic procedures to follow in order to attain a certain goal. Further, he makes the point that methods are of particular use in non-routine situations or in high uncertainty. In order to understand the motivation to create and assess design methods, Daalhuizen (2014) describes two main views discussing methods for design: Either they are seen as an aid to the skill development of the engineer focused on an improved outcome as a result of a learning process (Schön, 1983), or the view is such that methods should be understood as best practices, leading to a certain outcome with great reliability (Simon, 1969). Andreasen (2011) stresses that researchers must examine the circumstances that lead to valuable results from using methods instead of focusing on their efficiency and elegance. Jensen & Andreasen (2010) challenge the common view of methods being "prescribed roads that will allow an engineer to take a particular problem through [a] number of steps, which will lead to a particular goal". The reality in companies

observed by the authors is rather that methods follow the preconditions, requirements and goals of the respective users. They also stress the relevance of the interaction of actors jointly using a method.

3.2 Challenges for Method Adoption

Although the criticism is not as vocal and explicit as with engineering design and eco-design, PSS-focused researchers have voiced concerns with regard to the insufficient adoption of methods produced in academia (Sakao and Mizuyama, 2014). Companies have been struggling to adopt product design processes that address their challenges in an effective way (Unger and Eppinger, 2011). Some of the issues of great relevance that have been identified in the literature, and which may be applicable to the PSS field, are introduced in the following paragraphs.

López-Mesa & Thompson (2006) identified a number of methodological and procedural difficulties that may lead to a sub-par adoption rate of methods that focus on selection of items **under uncertainty**. For example, weighting and rating under great uncertainty may lead to a lack of trust in the results by the users. In addition, suboptimal formulation of decision-making criteria leads to a lack of reliability in the results. Methods are perceived by users as being **very time-consuming**, further pointing out that there is insufficient awareness of the fact that some methods are adjustable to the time and resources available (López-Mesa and Thompson, 2006; Lopez-Mesa, 2006). The authors have also found a lack of adoption after a **low number of tryouts** of a new method.

Furthermore, López-Mesa and Thompson (2006) also point out that methods are often **ill-formatted for actual company use**. This is attributed to the style of lengthy text descriptions in manuals, or intranet-based documents which generate a low interest in being read. Geis *et al.* (2008) have in their research found the need of practitioners for methods "focused on output and less theoretical ballast". Jänsch and Birkhofer (2007), as noted by O'Hare (2010), point out that academically-produced methods are often presented in an overly scientific and abstract way, which is unattractive to practitioners. Knight and Jenkins (2009) particularly stress the **need for new methods to fit with the established processes** at a company. Similarly, there is a need for better integration of methods with established processes (Geis *et al.*, 2008). **Overly ambitious implementation efforts** are also seen as a reason for lacking method adoption (Wallace 2011 based on Birkhofer *et al.* 2002).

Vasantha *et al.* (2012) call for more refined and precise methods in order to fit the individual task at hand. However, Tukker (2013) argues that this may lead to overly detailed approaches lacking more universal applicability. Similar requests from industry with regard to **adaptability and customization** of methods have been noted (Geis *et al.*, 2008; Le Pochat *et al.*, 2007).

Lofthouse (2006) has found the need for methods that are able to work in an environment where the data present is not a perfect match for the method, or only **low-quality data** is available.

Knight and Jenkins (2009) argue that general "strategy tools would generally be overruled by customer specifications", and that these tools should not be utilized before an eco-design culture is well established. Since the industrial application of PSS design culture is still in its early days, this argument applies to this field as well. Birch *et al.* (2012) suggest **specific rather than strategy-oriented** applications in order to achieve optimal performance out of the use of the method.

Lofthouse (2006), states that the users are often **dissatisfied with workshop-style methods**, since, in addition to the time-consuming nature of these events, the way of working does not reflect their day-to-day practice. Methods that allow for an implementation into daily tasks are regarded as beneficial.

4 METHODS IN PSS DESIGN

When assuming Goedkoop *et al.* (1999) as the starting point of research in the field of integrated offerings of products and services that takes into account issues of sustainability, the area has seen over fifteen years of intensive research. A substantial portion of it focused on providing methods for design, implementation and optimization of PSS. Three major reviews of research on the field were published in 2013, namely Tukker (2013), Boehm & Thomas (2013) and Hänsch Beuren *et al.* (2013).

4.1 The Importance of Methods for the Industrial Adoption of PSS

PSS mark a departure from established product design through their integration of products and services and therefore require their own methods, e.g. for requirements definition (Morelli, 2006). Having a sound body of literature in the field of methods may even be seen as an indicator for the maturity of the field as a whole (Tukker, 2013). Meier *et al.* (2010) also state the requirement that the

development of specific methods for PSS design is needed. A number of different methods were introduced in the past ten years aimed at supporting the design of PSS. It appears, however, that similarly to established engineering design (see e.g. Andreasen (2011); Jänsch & Birkhofer (2007)), the methods developed lack broad acceptance and use in industry. An approach frequently taken when developing methods for PSS design is, while building on established methods in adjacent fields (Baines *et al.*, 2007), to introduce a method and verify it on a defined case. Often, effectiveness of the method is claimed, though quantifiable performance data may be lacking (Baines *et al.* 2007).

4.2 Methods Evaluated in Order to Isolate Beneficial Properties

This subsection briefly introduces eight methods created by researchers and aimed at industrial use. These methods were selected out of a larger number of sources, as they all contained aspects that may benefit their implementation and use in an industry context. Further, focus was laid on more recent publications in order to take into account the current status of method design. An effort was made to include methods with different aims in the field of PSS.

- Aurich *et al.* (2006) have proposed a methodology for jointly designing products and services in an integrative manner. The process they describe has substantial depth and is formulated in the character of a roadmap. The process proposed is modular so that parts of the methodology can be integrated into the existing routines by an industry partner.
- Sakao and Shimomura (2007) discuss a new discipline called service engineering and introduce a methodology to design services. Next to the elaborate discussion of their approach and the design process, they introduce a Java-based software, Service Explorer (first presented in Arai & Shimomura, 2004), to assist designers in the development of service offerings. The application of the methodology is extensive and spans two different examples.
- Müller *et al.* (2009) introduce the PSS Layer Method, which is geared towards visualizing concepts and outcomes of different PSS designs at an early stage of development. This is achieved by assessing the effects of certain "Lifecycle Activities" in the PSS and their respective outcome in several layers (or classes) such as deliverables, actors, value and needs. The method is displayed with strong focus on the eventual industrial users.
- Matzen and McAloone (2006) present the Activity Modelling Cycle, a method that assists the user in conceptual development of PSS through the modelling of service activities. The authors illustrate the development of the model through repeated application, followed by lessons learned. In addition, strengths and weaknesses of the method are discussed at length, giving a clear picture of what to expect from utilizing the Activity Modelling Cycle.
- Pezzotta *et al.* (2013) discuss a framework for the design of product-related services and the identification of suitable PSS solutions. They build on the Service CAD tool (Arai and Shimomura, 2004) and extend it through discrete event simulation. Eventually, they propose a framework comprised of five phases as well as a sample case.
- Bertoni *et al.* (2013) have introduced a method that visualizes value on a component level at an early design stage by means of color-coded CAD models. By implementing this method, the authors hope to increase awareness of a lifecycle-oriented perception of value in a PSS environment. The scoring required in order to be able to assign colors to different components is handled by an established method. The functionality of the method is subsequently demonstrated with examples showcasing its capabilities.
- Fujita *et al.* (2013) introduce a method to support PSS business idea generation. Through the utilization of self-organizing maps and commercially available software, they align business cases collected from the literature with current and other PSS businesses. Through topographical proximity, the user may discover new PSS-type business cases worthwhile of examination.
- Lim *et al.* (2012) describe a method that assists with the visualization of the entire PSS process. The goal is to display the interaction between customer and provider and to assist the users in improving their offering. The method proposed is customizable, and additional depth can be added to each of the nine dimensions described.

4.3 Method Properties Facilitating Industrial Adoption

In developing the methods described above, the authors take various approaches to improve the value of their results for industrial users. What all of these efforts have in common is that in none of them

the aim for increased industrial adoption and maximum utility is explicitly stated. Many of them mention the need for substantial further research in order to fulfill certain conditions for optimal utility. However, with sights set on broader industrial adoption of PSS, the research community is keen to provide the means of implementation to industry at every step of the way. Particularly when focusing on the sustainability side of PSS, one may argue that the time for optimizing methods is quickly running out.

Several authors (e.g. Matzen and McAloone, 2006; Müller *et al.*, 2009) report improvement of their results through industry tryouts, workshops and feedback sessions. Methods that are reported with strong focus on these practical applications appear to have particular value to industrial users of PSS.

The way the papers introduced above attempt to accommodate industrial users was examined; the results of this examination are shown in Table 1. The methods are individually evaluated to extract factors that may benefit industrial adoption. The number of industrial adoption promoters mentioned allows no conclusions regarding the utility of the respective methods, as the goal is solely on gathering information. Each promoter, though it may appear in more than one method, is only mentioned once.

Table 1. Facilitating industrial adoption of PSS design methods in the literature

Author	Industrial adoption promoters
Aurich *et al.* (2006)	• Modular methodology, allows for partial implementation without turning around the entire design process at the company
Bertoni *et al.* (2013)	• Based on CAD systems present within companies • Value-in-use clearly demonstrated
Fujita *et al.* (2013)	• Use of commercially available tool • Strong visualization
Lim *et al.* (2012)	• Can be carried out on paper
Matzen and McAloone (2006)	• Improved and refined in many iterations • Clear and extensive discussion of pros/cons
Müller *et al.* (2009)	• Extensive and visual documentation • Value-in-use clearly documented • Customizable method with substantial lessons learned • Company use and acceptance documented (Workshop conducted with industrial partners by Kebrir and Müller in 2009)
Pezotta *et al.* (2013)	• Link to previous method development in the field of PSS • Tangible results provided (performance evaluated in monetary terms)
Sakao and Shimomura (2007)	• Presence of a software tool • Enables industrial trials with reduced academic support • Reduces aversion to implement external processes

5 PRACTICIONERS' EVALUATION OF PSS DESIGN METHOD PROPERTIES

The ongoing trial of a PSS design method provided the opportunity to gather practitioner's feedback on properties that may be relevant to method implementation and use. The development of the properties used in the questionnaire as well as its results are discussed in this section.

Deriving the properties: Section 3 has focused on challenges that have occurred with regard to method implementation in fields *outside* of PSS. The main challenges identified are shown in Section 3.2 in bold print. After having worked with the company on the trial use of a PSS design method over a number of years, the authors critically reflected upon this method trial with respect to these challenges, while also considering the properties thought to facilitate industrial adoption of PSS design methods in Section 4.3. The seven properties shown in Table 2 are the result of this process.

Results and discussion: Overall, the seven participants regarded the properties presented as important. One must take into account that these responses come from a particular context within the company, and should be generalized with caution. It can be said, however, that the given properties for implementation are relevant for the adoption of the PSS design method at this company. Table 2 displays properties and results of the data collection. Column 1 contains the properties, while the numbers in each cell represent the number of times the respective answer was given. The two last columns show the average and median, respectively.

Table 2. Results regarding importance of properties for implementability of PSS methods

Influential properties for implementation	Importance					Avg	Med
	1	2	3	4	5		
Time required to use the method			2	1	4	*4.3*	*5*
Format and presentation of the method (e.g. forms, software, etc.)			1	4	1	*4.0*	*4*
Compatibility of the entire method with the established processes		1	1	4	1	*3.7*	*4*
Customizability/flexibility of the method to be adapted to processes			2	2	2	*4*	*4*
Availability of information with sufficient quality required for decision-making in using the method				4	2	*4.3*	*4*
Capability of decision-making under uncertainty when evaluating		1	2	3	1	*3.6*	*4*
Level of collabor. efforts required to use the method across company	1	1	2		3	*3.4*	*3*

Time requirements for the use of the method appeared to be of large importance, with no evaluation below 3 and an average of 4.3. The same can be said about the *format and presentation* of the method, which received an average and median importance rating of 4. The *compatibility of the new PSS method to established processes* was also seen as important, at an average evaluation of 3.7 – whereas the median remained at 4. *Information availability* was seen as equally important as the factor time requirements. The *capability of decision making under uncertainty* received an average score of 3.6 with the median at 3, and appears to be of lesser importance to practitioners in this case, presumably as uncertainty is something they are faced with regardless of the method used. Even more so, the requirement of *collaboration with other groups* was evaluated with the lowest average importance of 3.4 and a median value of 3. The wide spread of evaluations in this case may be attributed to varying roles and working principles of the participants within the method trial as well as within the company in general. This issue calls for further investigation.

6 DEVELOPING GUIDELINES FOR PSS DESIGN METHODS

6.1 Deriving characteristics facilitating Implementation/Use of PSS design Methods

Up to this point, this paper has addressed two topics grounded in the literature. On the one hand, the challenges experienced in fields adjacent to PSS (e.g. engineering design) with respect to method adoption are discussed. On the other hand, beneficial aspects of existing PSS design methods, which may facilitate their industrial implementation, are collected. The applicability of the challenges experienced in other fields in the area of PSS is assessed through a questionnaire with practitioners, who were involved with a trial of a PSS design method at their company. Although a single questionnaire is available at this time, this data point suggests the relevance of the main challenges identified in Section 3.2 (bold print) for the field of PSS. The following six characteristics are aimed to resolve these challenges. To achieve this this, the beneficial aspects isolated from PSS design methods in Section 4.3 are utilized (see Table 1). *This synthesis is assumed to effectively tackle the challenges discussed while efficiently utilizing the beneficial properties identified.* Although the authors acknowledge that not all characteristics apply at all times, or that they may occasionally be insufficient, the characteristics proposed are suitably general to be applicable to the development of a wide range of methods for PSS design, while being adequately specific to yield useful information. The aim of these characteristics is not only to be a first reference for developing PSS design methods focused on implementability, but also to provide ground for discussion among researchers in the field.

6.2 Six Characteristics in Focus for Implementability and Usability of PSS design Methods

Modularity: This issue is of particular importance when considering methodologies or extensive methods that cover several subjects, as is the case with most multi-step procedures, as e.g. shown in the methodology developed by Aurich *et al.* (2006). Further, a modular approach may be helpful to reduce the time required to use a method, which is a critical factor (Lopez-Mesa, 2006). In these cases, it may be beneficial to allow for the use of the individual steps through allowing the input of data that was not explicitly processed by a previous step. This will allow for the use of lower-quality data while providing results that may not be optimal, but still justify the use of the method. Particularly in a

relatively new field like PSS, where experience and solid data is often lacking, this may be of help. In addition, a particularly worthwhile module may act as a trailblazer for the approach as a whole.
Simplicity: Even though it may seem trivial, providing a simple method with "just enough" functionality mitigates many of the reasons given for the low adoption rate of PSS-focused methods. This further contributes to reduce time requirements as indicated under "Modularity" and to support the output focus as requested by Jänsch & Birkhofer (2007). If researchers critically assess the method designed, they may realize that often, a Pareto distribution applies. Focusing on simple solutions helps alleviate issues such as excessive time consumption. As with modularity, a simple method yielding helpful results may make way for more sophisticated solutions. When assessing the field of PSS in this regard, taking some of the complexity out of the approaches may persuade some smaller companies to experiment with these offerings, even without access to direct academic consultation.
Clarity: It is quite obvious that academic papers are not the ideal medium to communicate new input in the form of methods to companies – often this is the only way it is communicated at all. López-Mesa and Bylund (2010) mention the need for a "champion showing enthusiasm for the method". These are people who follow developments in academia. Getting their attention is vital to produce a successful method. Providing a picture of what can be expected from a method may be done through referring to a screencast, or by a simple software tool that allows anyone interested to perform a test run. In addition, it can serve as a good measuring stick, whether or not a colleague with an engineering background, but with no deeper knowledge in the field of PSS, is able to comprehend and carry out the method provided with just this information. If this criterion is applicable depends on the depth of the method and what level of PSS -knowledge is expected to be present at a company that may use it.
Customizability: Pointing out clear ways for practitioners to make a method "their own" may be useful in underlining industrial applicability. This is particularly relevant in the case of PSS, where the offerings are required to be highly customizable – the same should be said for the methods used to conceive them. The PSS Layer Method (Müller *et al.*, 2009) may serve as an example as to how customizability in PSS design methods can be realized. Having a flexible method to integrate in the existing development process that e.g. allows individual (non-workshop) use during daily tasks would greatly reduce the perception of methods as a time hog and increase the usability.
Tangibility: Providing clear and specific outcomes and displaying them clearly in the presentation of the method is of substantial value. When demonstrating a case, even when presenting a methodology which, by its nature, provides strategic rather than concrete outcomes, and making these outcomes tangible through displaying a process conceived or discussing before-and-after scenarios, may be of great value. Further, providing a software tool, as done e.g. by Arai & Shimomura (2004) and Sakao & Shimomura (2007), can be the essential instrument to convince a potential user of the value of a method – this may be as simple as providing a spreadsheet-based template.
Flexibility: Many methods require scoring of some sort, which is often associated with great uncertainty (Ball and Christensen, 2009), particularly considering the often-present lack of previous knowledge in PSS. It should be clarified to potential users that even under uncertainty, most methods provide value-in-use through learning effects and experience, even when the actual output appears to be insufficient or less than what may be expected under different circumstances.

6.3 Towards an Operationalization of the Characteristics

This subsection aims to provide a first overview of how the topics mentioned before may be operationalized for use by researchers in PSS design. The criteria given are qualitative, and therefore subjective and dependent on individual assessment. The main trajectory of further research on this topic is to reduce this subjectivity by providing a score sheet as a tool to increase the comparability of assessments performed by different persons. However, since the tool is intended for the research community, a first target is to gather additional input and to provide a discussion basis for this. Here, examples of how researchers may check their work for conformity with the topics are given. The items provided in *italics* may be used as a checklist during method development.
In order to check a method with regard to **modularity**, it is important to consider *whether the method can be used in part*, and whether it is able to *handle data of lower quality*. The **simplicity** of the model can be assessed by asking the question: *What can be achieved when only 20% of the method is utilized?* Also, allowing the *use of the method on paper* may be beneficial. With respect to **clarity**, it would certainly be helpful to perform an external *evaluation of the goal of the method* (e.g. by a colleague working outside PSS). Further, it helps to assess the documentation provided. Is it

sufficiently *visual and easy to understand*? When evaluating **customizability**, one may critically consider whether a method *allows adjustment to the individual conditions* in a company. Further focus can be laid on how well the method is related to PSS development and product development processes, and whether it provides *interfaces* to these processes. Putting focus on **tangibility**, it may be useful to investigate, if the results provided by the method are *clear and understandable* so that the prospective user can easily see the value. Providing computer-based support (Spreadsheet-based etc.) may be considered. To assess whether a method fulfils the **flexibility** requirement, it can be checked whether it provides *value even under great uncertainty*, e.g. through learning effects through its use.

7 CONCLUSIONS AND ONGOING RESEARCH

Industry practitioners are still struggling with the adoption of PSS. One of the reasons for this may be the lacking implementability and usability of PSS design methods developed in academia. This paper has derived characteristics intended to function as a reference, as a common ground to start a discussion about facilitating the adoption of PSS design methods. To identify the main challenges, an in-depth review of the literature in fields adjacent to PSS was carried out. The relatability to PSS was examined with a questionnaire among industry practitioners. Six characteristics were derived, which are aimed to support researchers in increasing industrial implementability, thus remediating the challenges identified by applying the positive attributes found in PSS design methods.
Although the questionnaire responses indicate the applicability of the challenges found to the PSS field, further verification is required. At this point, the characteristics are grounded in the literature – empirical verification is therefore needed. As a first step, the authors are applying the characteristics to a method evaluating PSS design choices. It is the aim to then retrieve feedback from professionals to whether an improvement has been achieved. In addition, input from the research community is desired in order to further develop the characteristics. A tool lowering the subjectivity of the assessment will be created, taking into account the input from industrial application and the research community.
The goal is to support the provision of methods for PSS design that are easier to implement and use may lead to higher adoption rates for PSS as such, as hurdles preventing this can be lowered. As indicated in the introduction, this may make a tangible difference on the path to a circular economy, and a world that relies less and less on physical resources to create value.

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REFERENCES

Andreasen, M.M., 2011. 45 Years with design methodology. J. Eng. Des. 22, 293–332.
Arai, T., Shimomura, Y., 2004. Proposal of Service CAD System - A Tool for Service Engineering -. CIRP Ann. - Manuf. Technol. 53, 397–400.
Aurich, J.C., Fuchs, C., Wagenknecht, C., 2006. Life cycle oriented design of technical Product-Service Systems. J. Clean. Prod. 14, 1480–1494.
Baines, T.S., Lightfoot, H.W., Evans, S., Neely, A., Greenough, R., Peppard, J., Roy, R., Shehab, E., Braganza, A., Tiwari, A., Alcock, J.R., Angus, J.P., Bastl, M., Cousens, A., Irving, P., Johnson, M., Kingston, J., Lockett, H., Martinez, V., Michele, P., Tranfield, D., Walton, I.M., Wilson, H., 2007. State-of-the-art in product-service systems. Proc. Inst. Mech. Eng. Part B J. Eng. Manuf. 221, 1543–1552.
Ball, L.J., Christensen, B.T., 2009. Analogical reasoning and mental simulation in design: two strategies linked to uncertainty resolution. Des. Stud. 30, 169–186.
Bertoni, A., Bertoni, M., Isaksson, O., 2013. Value visualization in Product Service Systems preliminary design. J. Clean. Prod. 53, 103–117.
Birch, A., Hon, K.K.B., Short, T., 2012. Structure and output mechanisms in Design for Environment (DfE) tools. J. Clean. Prod. 35, 50–58.
Birkhofer, H., Kloberdanz, H., Sauer, T., Berber, B., 2002. Why design methods don't work and how to get them to work. Proc. Eng. Des. Integr. Prod. Dev. 3rd Int. Semin.
Boehm, M., Thomas, O., 2013. Looking beyond the rim of one's teacup: a multidisciplinary literature review of Product-Service Systems in Information Systems, Business Management, and Engineering & Design. J. Clean. Prod. 51, 245–260.

Cook, M.B., Bhamra, T.A., Lemon, M., 2006. The transfer and application of Product Service Systems: from academia to UK manufacturing firms. J. Clean. Prod. 14, 1455–1465.
Daalhuizen, J.J., 2014. Method Usage in Design: How methods function as mental tools for designers. TU Delft.
Fujita, K., Akasaka, F., Kimita, K., Nemoto, Y., Kurita, Y., Shimomura, Y., 2013. Supporting Idea Generation in Business Design in Manufacturing Industries. Int. J. CAD/CAM 13, 63–71.
Geis, C., Bierhals, R., Schuster, I., Badke-Schaub, P., Birkhofer, H., 2008. Methods in Practice – A study on requirements for development and transfer of design methods, in: Design 2008 - 10th International Design Conference.
Goedkoop, M.J., Van Halen, C.J.G., Te Riele, H.R.M., Rommens, P.J.M., 1999. Product Service systems, Ecological and Economic Basics. Econ. Aff. 36, 132.
Hair, J., Black, W., Babin, B., Anderson, R., 2009. Multivariate Data Analysis, 7th ed. Prentice Hall.
Hänsch Beuren, F., Gomes Ferreira, M.G., Cauchick Miguel, P.A., 2013. Product-service systems: a literature review on integrated products and services. J. Clean. Prod. 47, 222–231.
Jensen, T.E., Andreasen, M.M., 2010. Design Methods in Practice - Beyond the "Systematic Approach" of Pahl & Beitz, in: Design 2010 - 11th International Design Conference.
Jänsch, J., Birkhofer, H., 2007. Imparting Design Methods With the Strategies of Experts, in: ICED07: 16th International Conference of Engineering Design.
Knight, P., Jenkins, J.O., 2009. Adopting and applying eco-design techniques: a practitioners perspective. J. Clean. Prod. 17, 549–558.
Le Pochat, S., Bertoluci, G., Froelich, D., 2007. Integrating ecodesign by conducting changes in SMEs. J. Clean. Prod. 15, 671–680.
Lim, C.-H., Kim, K.-J., Hong, Y.-S., Park, K., 2012. PSS Board: a structured tool for product–service system process visualization. J. Clean. Prod. 37, 42–53.
Lindahl, M., 2005. Engineering Designers' Requirements on Design for Environment Methods and Tools. KTH.
Lindahl, M., Sundin, E., Sakao, T., 2014. Environmental and economic benefits of Integrated Product Service Offerings quantified with real business cases. J. Clean. Prod. 64, 288–296.
Lindahl, M., Sundin, E., Sakao, T., Shimomura, Y., 2007. Integrated Product and Service Engineering versus Design for Environment - A Comparison and Evaluation of Advantages and Disadvantages, in: Takata, S., Umeda, Y. (Eds.), Advances in Life Cycle Engineering for Sustainable Manufacturing Businesses.
Lofthouse, V., 2006. Ecodesign tools for designers: defining the requirements. J. Clean. Prod. 14, 1386–1395.
Lopez-Mesa, B., 2006. Design Methods and their sound use in Practice, in: Design Methods for Practice. 87–94.
López-Mesa, B., Bylund, N., 2010. A study of the use of concept selection methods from inside a company. Res. Eng. Des. 22, 7–27.
López-Mesa, B., Thompson, G., 2006. On the significance of cognitive style and the selection of appropriate design methods. J. Eng. Des. 17, 371–386.
Matzen, D., McAloone, T., 2006. A tool for conceptualising in PSS development. 17. Symp. Des. X.
Meier, H., Roy, R., Seliger, G., 2010. Industrial Product-Service Systems-IPS2. CIRP Ann. - Manuf. Technol. 59, 607–627.
Morelli, N., 2006. Developing new product service systems (PSS): methodologies and operational tools. J. Clean. Prod. 14, 1495–1501.
Müller, P., Kebir, N., Stark, R., Blessing, L., 2009. PSS layer method - application to microenergy systems, in: Sakao, T., Lindahl, M. (Eds.), Introduction to Product/Service-System Design. Springer London, 3 – 30.
O'Hare, J.A., 2010. Eco-Innovation Tools for the Early Stages: An Industry-Based Investigation of Tool Customisation and Introduction. University of Bath.
Pezzotta, G., Pirola, F., Akasaka, F., Cavalieri, S., Shimomura, Y., Gaiardelli, P., 2013. A Service Engineering Framework to Design and Configure Product-Service Systems, IFAC Proceedings 263–268.
Ravallion, M., Chen, S., Sangraula, P., 2009. Dollar a Day Revisited. World Bank Econ. Rev. 23, 163–184.
Sakao, T., Mizuyama, H., 2014. Understanding of a product/service system design: a holistic approach to support design for remanufacturing. J. Remanufacturing 4, 1.
Sakao, T., Shimomura, Y., 2007. Service Engineering: a novel engineering discipline for producers to increase value combining service and product. J. Clean. Prod. 15, 590–604.
Schneider, F., Kallis, G., Martinez-Alier, J., 2010. Crisis or opportunity? Economic degrowth for social equity and ecological sustainability. Introduction to this special issue. J. Clean. Prod. 18, 511–518.
Schön, D., 1983. The reflective practitioner: How professionals think in action. Basic Books.
Simon, H.A., 1969. The Sciences of the Artificial. MIT Press, Cambridge, Mass.
Tukker, A., 2013. Product services for a resource-efficient and circular economy – a review. J. Clean. Prod. doi:10.1016/j.jclepro.2013.11.049
Unger, D., Eppinger, S., 2011. Improving product development process design: a method for managing information flows, risks, and iterations. J. Eng. Des. 22, 689–699.
Wallace, K., 2011. The Future of Design Methodology, in: Birkhofer, H. (Ed.), . Springer London, 239–248.
Vasantha, G.V.A., Roy, R., Lelah, A., Brissaud, D., 2012. A review of product-service systems design methodologies. J. Eng. Des. 23, 635–659.