ENGINEERING DESIGN RESEARCH METHODOLOGIES IN PRODUCT-SERVICE SYSTEMS: WHEN THE COMPLEX GETS TOUGH

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Abstract

The research field of Product-Service Systems (PSS) emerged within the engineering design field to address sustainability and radically lower environmental impact from production and product use stages. PSS research has progressed insights of the industrial phenomena, but are often grounded in either product or service development, and the sustainability perspective had diminished over time. The deviation from what was intended might depend on research methodologies that do not meet the requirements of PSS multidisciplinary research. Some reflections of our research and craftsmanship are thus needed, which is also the purpose of this paper. PSS are used in the paper as a framework to highlight some of the facets of engineering design research activities. The paper suggests that multidisciplinary research has to manage different methodologies and different theories, this can be achieved if underlying assumptions are made transparent and if contradictions between those and the conclusions are discussed. Finally, the paper make an effort to encourage discussions about research methodologies to improve not only research but also implementation in industry.

Keywords: Product-Service Systems (PSS), Multi- / Cross- / Trans-disciplinary processes, Research methodologies and methods, Research philosophy, Theoretical baseline

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1 INTRODUCTION

Product-Service Systems (PSS) is in an early report explained from three different perspectives (Goedkoop et al., 1999, p. 14). First, from the society's perspective where PSS could become an instrument to an environmentally efficient society. Second, from a product company's perspective where PSS by adding services to commodities bring forward growth with less ecological impact. And third, from a service company's perspective where PSS could spark innovation by connecting the qualities of "the physical world" to service offerings. Manzini and Vezzoli (2000) describe PSS as stimulating a shift in focus from selling standalone products to selling the core utility as a mix of products and services, notably stressing the optimal goal of lowering environmental impacts. They also describe that production has to expand towards sustainable consumption by changing consumer patterns. Such intentions concern both the developer (e.g. providing sustainable solutions to customers) and the consumer (e.g. making sustainable choices). PSS seem to be more attractive in business-to-business situations. Rexfeldt and Hiort (2009) made a review on consumer acceptance of PSS and found a number of issues, e.g. transaction costs in relation to availability to the function, reputation and image of service provider and changes in roles in the relationship between supplier and consumer, and they concluded that the environmental attitudes among consumers may have relatively small importance when compared to the other issues. Manzini and Vezzoli (2000), nevertheless, conclude that PSS should take economic, social and environmental perspectives into account by greater use of a life-cycle perspective. Marketing oriented research describes the transition towards a PSS service perspective by comparing the logics of how products and services are developed, and conclude that they are totally different from each other (for example Grönroos, 2000; Vargo and Lush, 2004). Lush and Vargo (2006) emphasize that words and distinctions convey, not only different connotations, but also specific logics. They suggest a terminology to support an organizational change towards PSS or, in their words, service dominant businesses. The terminology describes shifting viewpoints *from* products via offerings to experiences, and *from* value-added via co-production *to* co-creation of value, and *from* profit maximization via financial engineering *to* financial feedback/learning and so on (p.286). Earlier, Elkington (1999) suggested a similar "*from-to*" approach to address sustainability, for example from hard values to soft values, from product to function, and from competitive partnerships to collaborative. Such "from-to" descriptions have similarities with how a paradigm shift is described. In short, a paradigm shift can be discerned when the existing thought patterns is taken for granted even though there are difficulties to fully explain and understand the new phenomenon, i.e. a collective truth exists and hinders new knowledge build up. The collective truth is broken only when some put forward arguments that explains how the new phenomenon is part of a different worldview (Kuhn, 1970). PSS research is, as argued above, not restricted to one paradigm. Accordingly, we need a research community capable of managing opposing views.

In parallel with research on PSS, the insights of environmental aspects have progressed quickly within the sustainable development paradigm and research field. During the end of 1990, when the first PSS reports were published, the focus was on reduction of waste, material and energy consumption. In hindsight, such focus (note not its solutions) is fairly modest compared to how sustainability is described today. The environmental dimension of sustainability is commonly defined by planetary boundaries, for example loss of biological diversity, ocean acidification, land-system change and climate change (Rockström, et al., 2009). The social dimension of sustainability is built upon an international agreement in which human rights, sound working conditions, good operating practices, society involvement and development are important (ISO, 2010). The economical dimension of sustainability was early on related to full cost accounting, meaning that monetary profit should not cause societal or ecological harm (Elkington, 1999). In hindsight, the economic benefit of PSS was early on often interpreted in terms of traditional profit. Nevertheless, profit was now also related to also binding customers into long-term relationships (see for example Alonso-Rasgado et al., 2004). Sustainability is hence, if using Elkington's terminology, described as three interlinked perspectives of economic prosperity, environmental protection and social equity, i.e. triple bottom line or 3Ps, which all have equal importance.

Some researchers now argue that sustainability has diminished from the PSS research field (for example Reim et. al., 2015; Annarelli et al., 2016). And, some researchers add "sustainable" to PSS (see for example this paper, but also Ny et al., 2013) to emphasize what actually should be obvious if building

on the original PSS vision. PSS should hence combine product development with service innovation and sustainability, each one of those relationally complex and multidisciplinary in their nature. How are we as a research discipline within engineering design dealing with such complexity? Cantamessa (2001) draws the conclusion that the different disciplines are loosely coupled, researchers are probably not used to study and refer to literature from other disciplines, and as a result research efforts are not guided effectively, leading to results that are developed in isolation. A typical result from an academic paper is some sort of theoretical model, framework, guideline or similar. In engineering design research, which is based on a technical paradigm, (Finger and Dixon, 1989), theoretical models are commonly presented to demonstrate a proposed solution. However, the problem and goal for which the model is the solution to is seldom described (see for example Blessing, 2002). It might be plausible, nevertheless also provocative, to say that there is a collective truth taken for granted, e.g. that we know exactly what we are doing and why we are doing it, so theorizing, problematizing and reflecting are just matters for other research domains. Dixon concludes in 1988, that the shortcomings of engineering design research might relate to its relative youth, that researchers from different disciplinary backgrounds are involved and that there is no specific part of the natural sciences from which the field comes from. More than a decade later, Cantamessa (2001) is emphasizing the same issues. And, research might still suffer from these problems.

PSS and its sustainability vision are now an emergent focus of the engineering design research community and adds to those previously known challenges of multidisciplinary research. Moreover, also bringing in research paradigm related issues where different rules and standards for its scientific practices reign (Kuhn, 1970). The combined elements of product *and* services in PSS should jointly promote sustainable change in traditional businesses (cf. Goedkoop et al., 1999), and are thus, for example, also a matter of cultivating business relationships as well as a matter of organizational transformation (Frishammar et al., 2015). A debate about what PSS is and is not, what services is and is not and so forth, might depend on incommensurability between respective research field's operative paradigms. Incommensurability, in a scientific theoretical sense, means, for instance, that the paradigms cannot be compared and that they lack a common quality. Furthermore, the fact that the meaning of common terms differ between two established paradigms is natural, e.g. service in service research is different from service in engineering design research. Such differences in philosophy and terminology should not be seen as barriers to accomplish better understanding of PSS, but rather as an opportunity to create innovative new solutions. Nevertheless, collaboration across research communities is a prerequisite since PSS solutions go beyond isolated domains (Edeholt, 2004). Progress will happen under the conditions that multidisciplinary research improves.

Some reflections of our research and craftsmanship are thus needed, which is also the purpose of this paper. We are using PSS research as a framework to highlight some of the facets of multidisciplinary engineering design research activities. Reflections are uncomfortable and can easily be perceived as criticism. Bear in mind that our aim is to encourage discussions rather than to criticize our peers (or ourselves), and that in this particular case being absolutely right, or wrong for that matter, is out of the scope for the paper.

2 HISTORY, TRADITION AND BACKGROUND

Any research study should at least present some information about (1) the history and research tradition, (2) the theoretical paradigms and perspectives, (3) the research strategy, and (4) data collection and analysis (Denzin and Lincoln, 2000). Providing such information is a key of intentional multidisciplinary research (e.g. Edeholt, 2004), mainly because it visualizes the viewpoint of the study. The tradition of our own research community is to address early phases of product development, e.g. planning, idea generation and concept development. This tradition rests upon the idea to bring information from later stages into the decision making of, e.g. manufacturability, actual use of the product, reuse, recycling and/or remanufacturing. Integrated product development, e.g. Andreassen and Hein (1987), is part of our history and tradition. Basically, our research tradition originates from engineering design, but we have specifically added the perspectives of Needfinding (Faste, 1987; Patnaik and Becker, 1999), innovation processes, service logics (Vargo and Lush, 2004), and design thinking (Brown and Katz, 2009). Our educational competences derive from different backgrounds, e.g. informatics and systems science, mechanical engineering and innovative technology and entrepreneurship.

Our research perspective is grounded in the research philosophy of interpretivism. Basically, experience is socially constructed and can be accessed through structures, e.g. words, shared meanings, but also through the design and design processes of artifacts. It should though be noted that obtaining and analyzing quantitative data can, and are often done, by researchers leaning on the interpretivist perspective. Hence, the qualitative or quantitative concepts have a relation to the type of data that is collected, and not to the research perspective or methodology. The interpretivist attitude is to gain insights into real world situations by having an inclusive approach, this is in opposite to positivism where *only* observable facts and measures are considered as valid knowledge. An interpretivist perspective allows subjective matters to be seen as knowledge, as for example that a service is differently perceived by different customers in different situations. Reich (1995) describes positivism vs. interpretivism as a tension between the beliefs that truth exists and can be extracted vs. finding out what is true. Hevner et al. (2004) might have a point when concluding that interpretivism take artifacts (technology) for given and that positivism overemphasize artifacts and thus fails to maintain a relevant theory base.

Engineering design has, by its technical perspective and relation to natural sciences, inherited a positivistic research philosophy (see for example Finger and Dixon, 1989). A positivistic standpoint typically describes "either or" lines of argumentation. Such argumentation works very well when the phenomena under scrutiny is a technical artefact. Bluntly, an artefact either works or not. Adding knowledge domains rooted in social sciences to the research efforts mean that also the subjective, interpretive and messy aspects of humans have to be addressed in analyses (Silverman, 2000). This means that the bits and pieces of information obtained in studies are aggregated to a larger whole that, *"…analytically speaking is more than the sum of its parts."* (Miles and Huberman, 1994, p.260). Such research results are often held as journalism, unscientific, only exploratory or even political (Denzin and Lincoln, 2000), and rightly if research perspectives, tradition and context are not transparently described. It might have been such observations that made Blessing (2002) conclude that there was a lack of scientific rigor in contributions from engineering design studies.

What about data collection and analysis for this particular paper then? In general, the idea for this paper comes from active participation in different research projects on PSS and sustainable development since 2001. The research projects are in close cooperation with industrial partners (small to large companies) mostly from manufacturing industry. The projects build thus on applied research, or, as it nowadays also is called, industrial research, meaning that the research is formed to address real industrial problems. The way we interpret those problems have an effect on (A) what type of solutions we suggest, (B) which means we use to conduct our studies, and (C) what guides our paths of inquiry (Schön, 1983). That is, our interpretation of the industrial problems directs how we formulate our research questions and conduct research activities. Since our research rests upon a multidisciplinary tradition each PSS study is complemented with theory from other fields. The selection of relevant theories, in turn, depends on the identified problems in industry. Nevertheless, this paper has the purpose to reflect on the research and craftsmanship within our own research community. Providing references to examples of research studies, which we–from our delimited perspective–find well or badly performed are to criticize our peers. So, the data for the discussion in this paper comes instead from literature on research methodologies from both engineering design research and from scientific methods and theory.

3 METHODOLOGY, ENGINEERING DESIGN, RESEARCH

Research methodologies include, from a scientific theory point of view, the principles and rules of a discipline, as well as methods and techniques related to the research tradition (paradigm). Scientific rigor comes from transparency in methodological alternatives and choices. Cross (1993, referencing to Alexander, 1971) describes how design methodology was rejected by early pioneers, e.g., *"call it a method and I get turned off, call it a methodology and I do not want to talk about it"*. And truly, we still meet such rejections and reluctance to discuss the topic among our peers. Cross (1993) conclude that a lack of "confidence" in research methodologies exist, as is also indicated by recent researchers in engineering design (Blessing, 2002; Cantamessa, 2001). Getting turned off or not talking about it does escalate our shortcomings, and not our improvement. Reich (1995) conclude that indifference or ignorance towards research methodology within a research community make research students just follow the tradition of senior peers. As a result, underlying assumptions become part of a limited, implicit and unarticulated research culture, in turn preventing development of new theories.

Reflection includes reconsidering the commonly used terms that build up a research culture. Simon (1996) describes engineering with two keywords, i.e. synthesis (as in intended or composed) and artifice (as in craftsmanship). The general designer or the engineer, *"…is concerned with how things ought to be…"* (p.5). Engineers are typically described as problem solvers. Simon separate science from engineering with another keyword, i.e. analysis. When doing so, the distinction that a researcher's craftsmanship concerns how things (or a phenomenon, or behavior, or processes, or practices, and so on) *actually are* appears. Researchers hence have to have the ability to analyze. The term design can be used as a noun or a verb. When design is used as a noun within the engineering design domain the focus is typically on the outcome as a physical artefact. The use of design as a verb points out a shift from the outcome to the processes or activities of doing design (Hubka and Eder, 1996). Simon (1996) makes it clear that design is not restricted to the outcome of artifacts, but concerns the *"…courses of action aimed at changing existing situations into preferred ones."* (p. 113). Thus, the researcher is in some sense also a designer for example when we are deriving theoretical models from the analysis of the obtained empirical data (may they be based on interviews, observations, experiments and so forth). Cross (1993) provides a review of science and design methodology in which he describes how design methods/methodologies emerged within the engineering design field and he also reflects on the terms "design science" and "science of design" within that specific context. He concludes that "design science" includes not only the use of scientific knowledge of artefacts but is also design as a scientific activity. Also, he concludes that "science of design" refers to our craftsmanship of progressing our understanding of the area by applying scientific methods of inquiry. Cross uses the words *"so let us conclude here…"* which can be interpreted in two ways. First it can mean "this is *the* definition!", second it can mean "this is *a plausible* definition" for this specific context. The latter indicates that operational definitions often emerge in a certain context and provide for learning and reflection, i.e. progressing knowledge production. But also, that behind interpretations stand the subjective profile of the researcher, e.g. background, tradition and culture (Denzin and Lincoln, 2000). There are hence, as exemplified above, different ways for researchers to interpret a text (from literature, in a transcribed interview, when reading field notes and so on).

Simon (1996) introduces the perspective of satisficing as a counterweight to the positivistic reasoning of optimal in engineering design. Satisficing, when used to describe research methodologies, can relate to providing a logical chain of arguments and transparency of assumptions. Such chain of arguments strengthens the proposed theoretical model, since theory in emerging research fields, as engineering design, is often approximations (Weick, 1995). There is, of course, different perceptions on what constitute a strong theory, while there is more consent in established research fields on that, for instance references, data, diagrams and hypotheses, are not theory. However, in emerging theory development disregarding those elements will make the progress slower (Sutton and Staw, 1995). Accordingly, those embryonic aspects are important in young disciplines and needs to be managed consistently. Observing patterns, making metaphors, subsuming particulars into the general are steps in a typical process of theory building from empirical studies (Miles and Huberman, 1994). The importance to tie isolated studies to overarching *"across-more-than-one-study propositions"* can be achieved by moving up from *"the empirical trenches to a more conceptual overview"* (Miles and Huberman, 1994). Thus, logical chains of arguments are built upon reasoning at different levels of abstractions.

4 RESEARCH AS REFLECTIONS AND ABSTRACTIONS

A research study becomes totally different if seen from another perspective than intended, the difference can even become paradoxical. This uncertainty or puzzlement should be embraced as a natural and desired state of mind. Yet, we tend to quickly solve contradictions by putting one in favor of the other, and by doing so we miss out the excitement and complexity any phenomenon consists of (Edeholt, 2004). Contradictions between assumptions and conclusions are not managed when going directly from details of obtained data to the development of a theoretical model. In those cases, there is often a tendency to see more in the results than actually are there, or even see results that cannot be there. Miles and Huberman (1994) name such patterns "consensual delusion" or "effort justification", and suggest that better explanations can be supported if moving up to another level of abstraction.

The fact that many researchers just inherit or follow a methodology without questioning it or being acquainted with its underlying assumptions is one reason for poor studies (Reich, 1995). Research is not done in isolation from the researcher, instead everyone approaches a phenomenon with a set of ideas,

some theory that specifies a detailed set of questions, which finally are analyzed by applying a certain methodology (Denzin and Lincoln, 2000). All these decisions are grounded in assumptions that we make about or research. If our chosen research methodology is left unquestioned the craftsmanship is not progressing, e.g. routinely applied even though circumstances changes. When the assumptions, their testing and the belief of any benefit from a proposed solution are not expressed, they are thereby not validated either (Reich, 1995). This type of unclear studies receives limited response from a research community, and consequently remains unbothered by industry also. Blessing and Chakrabarti (2009) propose a methodology, Design Research Methodology (DRM), that iteratively directs researchers to articulate assumptions by agreeing on "success criteria" for the study as an initial task. A key function of success criteria is to assess the adequacy of the coming studies. Blessing and Chakrabarti (2009) describe that the successful outcomes of engineering design research are new knowledge aggregated into guidelines, methods and tools, in the end supporting industry. Simply, if we start by defining the criteria for our own achievement and by reflecting on the questions, what, why and how, there is a chance that the underlying assumptions receive attention and self-critique, or at least self-reflection. Hence, research supports better conclusions and theoretical models.

One general problem in applied industrial research is the closeness with real world industrial problems and that the researcher often also should prescribe a change, i.e. suggest, demonstrate and evaluate solutions like guidelines, tools or methods. What differentiate a researcher from a consultant, or any company representative, in those cases? One portion of the answer should probably be the ability and skill to systematically reflect, analyze and make abstractions. In social sciences, different levels of abstraction are used to position research studies into a larger whole. This also implicates that different research methodologies and theoretical domains can be used at each abstraction level. The levels are, micro-level which is the smallest unit, meso the in-between and macro the largest unit. Macro could for example be focusing a machine, meso the organization, and macro sustainable PSS. One issue in PSS research is that isolated studies on micro level jump directly into conclusions on a macro level, e.g. *fix the bolt like this and it will be a successful PSS*, or *implement this business model and it will be a successful PSS*. If so, there are contradictions between the one-dimensional suggestion and the multi-facetted PSS phenomenon. To maintain a consistent line of argumentation some common features of the unit of analysis, i.e. the focus of the study, have to be repeated on each level, which in turn insists on clarifying the assumptions for the study. Here we argue for not neglecting the meso level in studies, since this is the level where the challenges, needs, requirements and so forth for making the transition *from* one state *to* another are discovered (cf. terminology provided by Lush and Vargo, 2006). For example, on micro level *"fix the bolt like this"* the assumption may be to speed up production and thus lower energy consumption for a particular machine, on mesa level the assumption is that this will happen under the conditions that the batches are large, and on a macro level the assumed contribution for sustainable PSS are limited to decreasing energy consumption of a particular machine and only at the production of large batches. And, for example, on macro level *"implement this business model"* the assumption may be to apply another contract type than common to provide leasing or rental, on mesa level the assumption is that the organization decrease their production and that customers actually are prepared to sign the contract, and on a micro level the assumption is a change in "engineering thinking" while still maintaining quality products based on long-term contracts. The point here is that conclusions (some only tentatively) can only be drawn if revealing assumptions and delimitations of the study, and from that relate to or suggest other studies.

Perhaps the reflection and discussion in this paper is restating what we all already know? If so that is great, and it is still fruitful to reconsider our craftsmanship to progress it further. Reflections will inspire to build up a toolbox of research methodologies, so we will not be in the hands of only one. By this, the past is not rejected or found obsolete, we are not giving privileges to one research methodology above another. And, suggesting using different methodologies for different situations will not lead to chaos but to confidence and rigor in managing PSS complexity.

5 A CONCLUDING REMARK AND IMPLICATION

The purpose of this paper was to reflect on the research within our community of PSS research, in particular the craftsmanship of multidisciplinary research methodologies. The trigger for the reflection was found in our own participation in the research community, e.g. that sustainability is more peripheral rather than being the core in the production of theoretical baselines. There are those who question

whether a scientific theory of engineering design research is possible, since there are too many fundamental differences among the various design fields, and too many people and organization variables. Here we have discussed that our research community of PSS might need to acknowledge that one research methodology, or one common theory for that matter, is not within reach, simply because the very core vision of PSS includes several perspectives, i.e. is multidisciplinary. In this type of young research, making the underlying assumptions transparent is a key to progress the development of scientific rigor and thus also address conclusions that contradict those assumptions, and vice versa. This is a more optimistic view suggesting that different methodologies and useful theories will evolve within the community from careful and reflective research directed to discover them.

When discussing research methodologies, which is a craftsmanship that indeed is closely tied to the individual researcher, a quick reaction of dislike is more common than liking and reflection. This happens independently if the link is subconscious or expressed (just think of any review of your own research production that you have got). Reich (1995) describe that discussions on research methodologies can be perceived as criticizing the intellectual skills of the researchers and is more or less understood as a demand to change methodology. Such reaction (and review) might come from assuming that there is only one fixed methodology, instead of acknowledging and demonstrating that research methodologies in engineering design is under improvement and a subject worth study. However, one implication that might give more interest to reconsider research methodologies is that they are often also used in industry. This is because the industrial problems are more complex than before and often include social human issues. As a research community, we have to be able to prove that our profession is at the frontline, not only in research outcomes but also in how and why we reach such results. The craftsmanship of our research activities needs to be continuously reflected upon, not only in the field of engineering design or PSS-research. An increased quality in research depends on our capability to confront our "routines" and our tradition. This is done in dialogues with our colleagues and is one vital instrument to progress the research frontier, unfortunately such talks are nowadays rare. We would, however, like to suggest some topics to discuss:

- How to identify and formulate research questions or purpose, and how to be careful if combining both questions and purpose so that they do not conflict each other.
- How to delimit the study, and how to make sure that conclusions can be made on the topic.
- How to avoid speculations, but to make generalizations that are valid to the delimited study.

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