A Design Toolkit to Integrate Distributed Manufacturing into Product-Service Systems Development

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Key Words: Product-Service Systems; Distributed Manufacturing; Design Toolkit

ABSTRACT

Implementation of Product-Service Systems (PSS) has a great sustainability potential. However, PSS are not widely put into practice because of a number of barriers. The authors of this paper propose that Distributed Manufacturing (DM) can be applied to improve PSS development. Existing, yet very fragmented attempts made by other scholars illustrate potential applications of DM features to PSS. However, the absence of practical support of

DM and PSS combination encouraged authors to develop a DM applied to PSS design toolkit. This paper describes the research process which has been carried out to develop the design toolkit and define the proposed design process. Empirical toolkit's applications with companies, design practitioners and students show the potential of the toolkit to support sustainability-oriented idea generation for each PSS life cycle stage.

1. INTRODUCTION

Product-Service Systems (PSS) is an offering model made of *"a mix of tangible products and intangible services designed and combined so that they are jointly capable of fulfilling final customer needs"* (Tukker and Tischner, 2006). Integration of products and services has the potential to improve environmental, social and economic sustainability, at the same time providing competitive advantage for companies delivering PSS (Cooper and Evans, 2000; Mont, 2002; Vasantha et al., 2012). However, PSS implementation is not a straightforward process. It requires companies to adopt different competences compared to those needed to implement traditional product-based business offerings (Besch, 2005). Key implementation barriers are related to organisational mind-set, customer consumption habits and lack of supportive regulations (Ceschin, 2013; 2014; Vezzoli et al., 2015).
The hypothesis of this paper is that Distributed Manufacturing (DM), described as a shift from conventional mass production to small-scale manufacturing carried out at the point of need (Kohtala, 2015) can help to address some of PSS implementation barriers. Literature describes existing attempts made by other scholars to improve PSS development through the application of DM features, such as mass customisation (Suominen et al., 2009; Mourtzis et al., 2018), digitisation and cloud manufacturing (Lerch and Gotsch, 2015; Charo and Schaefer, 2018), additive manufacturing (Despeisse and Ford, 2015) and direct consumer engagement (Sinclair et al., 2018). However, these attempts are still very fragmented: none of the scholars aim at addressing PSS implementation barriers and focus only on individual DM features without providing a complete overview of the potential of DM as a whole. Existing contributions by other scholars illustrate the potential of DM to support PSS development, however, scholars agree that systematic knowledge about potential DM application to improved PSS development is needed, as well as practical validation of this knowledge. (Ford et al., 2015). In addition, there is a need to translate this knowledge into practically applicable tools to support PSS development. The research presented in this paper aims to fill this knowledge gap by answering the following research question:
How to practically support PSS development through the application of DM?

This paper presents the process and outcomes of three-year research framed within the LeNSin project (EU-funded, 2015-2019) and carried out to develop DM applied to PSS design toolkit. The aim of the design toolkit is to facilitate companies, design practitioners and students in considering potential DM applications in each PSS life cycle stage, in order to improve PSS development. The toolkit has been empirically tested with experts, companies, design practitioners and students in order to evaluate and improve its completeness, effectiveness and usability. This paper presents only the final version of the toolkit, describes it elements, a proposed design process and toolkit's compatibility with other tools and methods. Initial research findings, evaluation studies and the initial version of the toolkit are described in Petrulaityte et al. (2017), Petrulaityte et al. (2018) and Petrulaityte et al. (2019).
The paper is structured in four sections. Section 2 describes the methodology adopted in this research and outlines each element of the DM applied to PSS design toolkit. Section 3 discusses application of the design toolkit and a its sustainability implications. Section 4 concludes the research.

2. DEVELOPMENT OF THE DESIGN TOOLKIT

2.1. Methodological framework

The research activities have been framed within the Design Research Methodology (DRM) framework (Blessing & Chakrabarti, 2009). The DRM provides a plan of action for the formulation and assessment of theoretical knowledge and the development and validation of a practical support (in this case a design toolkit) built on these theoretical findings. DRM approach is particularly relevant for this research, since it frames the collection and analysis of theoretical findings about PSS and DM, the development of the design toolkit (design support) and the iterative process of its testing, refinement and validation.
The research process was split in nine stages [Table 2.1]. The research started with the literature review aiming to collect PSS implementation barriers and DM opportunities (RC). Later, semi-structured expert interviews and DM research seminar were carried out to gather most recent knowledge about DM (DS-I). All collected theoretical knowledge was later used to develop a set of DM applied to PSS near-future scenarios which were later integrated into a DM applied to PSS design toolkit (PS-I). The design toolkit has been tested in three rounds of empirical

applications (DS-II, DS-III and DS-IV) with improvements being made after each round (PS-II, PS-III and PS-IV). First four research stages - RC, DS-I, PS-I and DS-II – are introduced and discussed in Petrulaityte et al. (2018). In particular, PS-I stage framing DM applied to PSS near-future scenario development is presented in Petrulaityte et al. (2019).

Table 2.1 *Research stages according to DRM with corresponding data collection methods and outcomes*

DRM stages	Research methods	Outcomes
Research Clarification (RC)	• Literature review	• Collection of existing PSS implementation barriers and promising DM opportunities
Descriptive Study I (DS-I)	• Semi-structured expert interviews • DM research seminar	• Validation of literature review findings regarding DM; • Collection of the most recent knowledge and near-future trends of DM
Prescriptive Study (PS-I)	• Literature review • Scenario development • Scenario integration into the design toolkit V1.0	• Analysis of scenario planning techniques • Development of DM applied to PSS near-future scenarios; • Development of the first version of the DM applied to PSS design toolkit
Descriptive Study II (DS-II)	• Workshop with design students	• Evaluation of usability and effectiveness of the first version of the toolkit
Prescriptive Study II (PS-II)	• Development of the design toolkit V2.0	• Development of the second version of the toolkit based on DS-II findings
Descriptive Study III (DS-III)	• Structured expert interviews • Workshops with manufacturing companies and design agencies • Workshop with PSS design students	• Evaluation of completeness, usability and effectiveness of the second version of the toolkit
Prescriptive Study III (PS-III)	• Development of the design toolkit V2.0	• Development of the third version of the toolkit based on DS-III findings
Descriptive Study IV (DS-IV)	• Workshop with design students	• Evaluation of usability and communication elements of the third version of the toolkit
Prescriptive Study IV (PS-IV)	• Development of the final version of the design toolkit	• Development of the final version of the DM applied to PSS design toolkit based on DS-IV findings

In total, 9 PSS and/or DM experts, 81 professionals from companies, 13 design practitioners and 74 students took part in toolkit's testing activities [Figure 1]. Participants evaluated different aspects of the toolkit and defined recommendation for improvements. Furthermore, three rounds of practical design toolkit's applications helped to define a proposed and alternative design processes briefly discussed in Section 3.

Figure 1 *Empirical toolkit's applications with DM and/or PSS experts (1), companies (2), design agencies (3) and students (4)*

2.2. DM applied to PSS design toolkit

The final version of the toolkit presented in this paper is designed to achieve the following goals: 1] to provide knowledge about potential DM opportunities; 2] to encourage its users to generate ideas for each PSS life cycle stage; and 3] to stimulate creative future-oriented thinking. The central component of the design toolkit [Figure 2] is 40 near-future scenario cards illustrating application of DM features to PSS development. Each card is double-sided. The front side (1) describes and illustrates the scenario, summarises PSS life cycle stages and implementation barriers scenario addresses. The back side of the card (2) provides a DM example, benefits and challenges of the scenario and idea triggering questions. In order to classify scenario cards and facilitate their selection process three scenario cards selection diagram are provided alongside the cards. Each diagram is related to a specific purpose. The *stage-by-stage DM and PSS connection* scenario cards selection diagram (3) intends to help to *create* a new

Product-Service System. *The Distributed Manufacturing features* scenario cards selection diagram (4) aims to help *innovate* an existing Product-Service System. *The Product-Service System implementation barriers* scenario cards selection diagram (5) helps its users to *address issues* of an existing Product-Service System. Each diagram has been supported with idea-triggering questions and numbers referring to near-future scenario cards. The decision sheet has been developed to help toolkit's users to identify their intention (6). The final component of the toolkit is the idea generation diagram created for generated idea categorisation according to PSS life cycle stages and DM features (7).

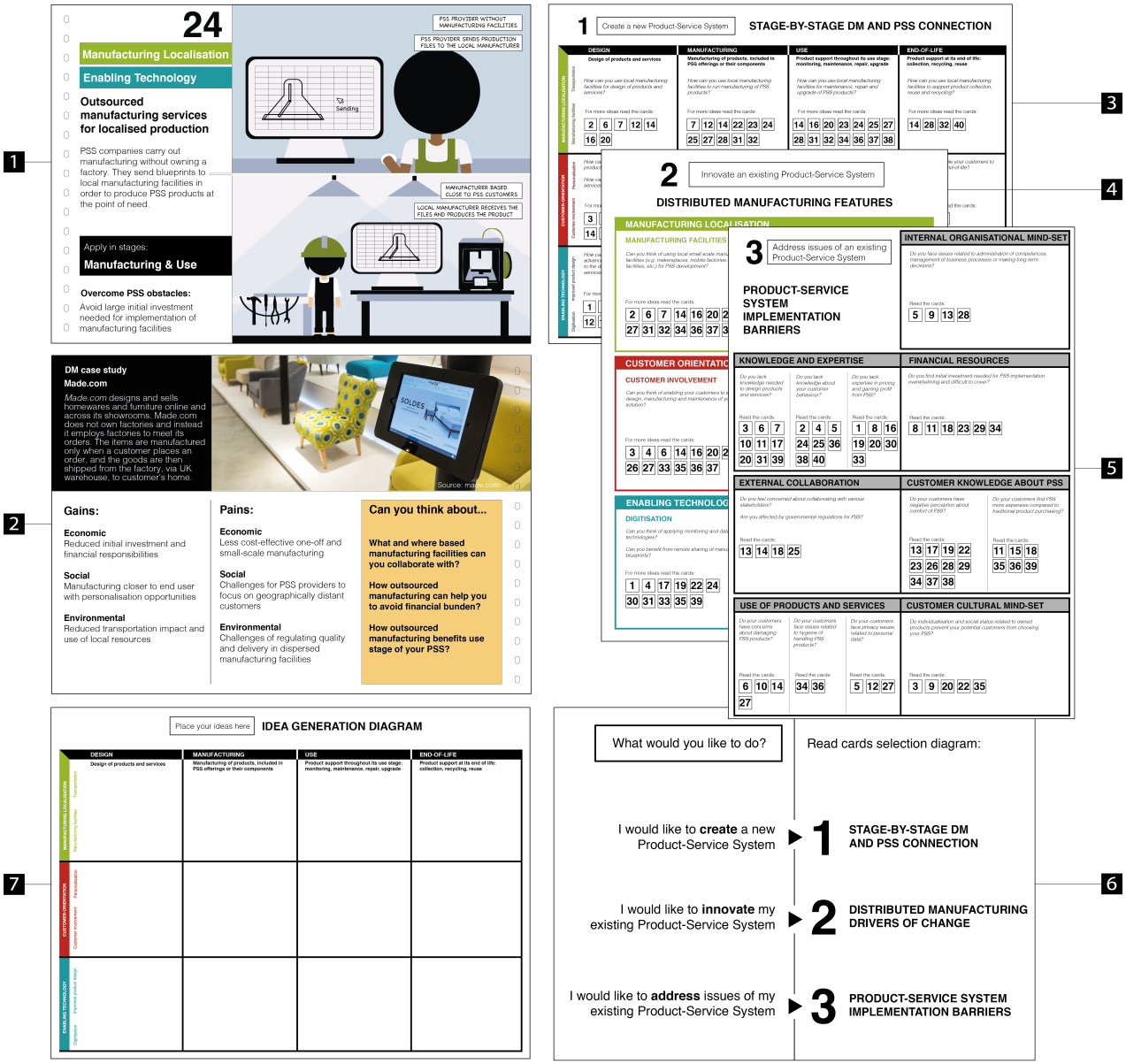

Figure 2 *DM applied to PSS design toolkit*

3. DISCUSSION

A number of PSS tools and methodologies have been developed and are widely described in the literature. However, none of them include Distributed Manufacturing aspects in any stage of PSS development. The literature review conducted at the early stage of this research showed the growing interest on DM applications to PSS. Empirical toolkit's testing activities with manufacturing companies, design agencies, academics and students proved that additional support to PSS development through the application of DM is needed. The studies showed that the DM features described in the toolkit facilitated participants engagement in idea generation process. Certainly, such user interest was caused by DM dependence on topics particularly relevant nowadays: innovative manufacturing technologies (e.g. 3D/4D printing), unconventional manufacturing facilities (e.g. public spaces, home, etc.), open-source data, improved personalisation, etc. Furthermore, the studies with companies allowed to observe, that most of the manufacturers were already planning of innovating their PSS business offerings with DM solution, thus did

not know how to strategically frame such innovations. Design students who participated in toolkit's testing shared that the toolkit provided valuable knowledge about DM and PSS and they were planning of integrating gained knowledge in other ongoing university projects.

3.1. Design process

Each element of the DM applied to PSS design toolkit is created to be used in the purposeful order [Figure 3]: first, identification of the goal using the decision sheet (1); second, selection of relevant scenario cards using the scenario cards selection diagrams (2); third, DM applied to PSS idea generation using near-future scenario cards (3) and, finally, positioning of developed ideas on the idea generation diagram (4). The design process evolved from its empirical applications with various user groups. It has been observed that the design process using the toolkit can vary depending on the users' background and the amount of time appointed for the idea generation process. Firstly, initial DM applied to PSS ideas can be generated using only scenario cards selection diagrams by answering questions provided on them. Secondly, idea generation process can be carried out by reading all near-future scenario cards. This method is useful for educators and students, because reading all scenario cards help to build an in-depth understanding about DM opportunities and their role in PSS development. Finally, generated ideas written on post-it notes can be clustered in a way chosen by toolkit's users without using the idea generation toolkit. On the other hand, the idea generation diagram can be used to sketch and visualise ideas. It can be summarised that the toolkit enables its users to adopt flexible ways of applying it depending on their background, abilities and time constrains.

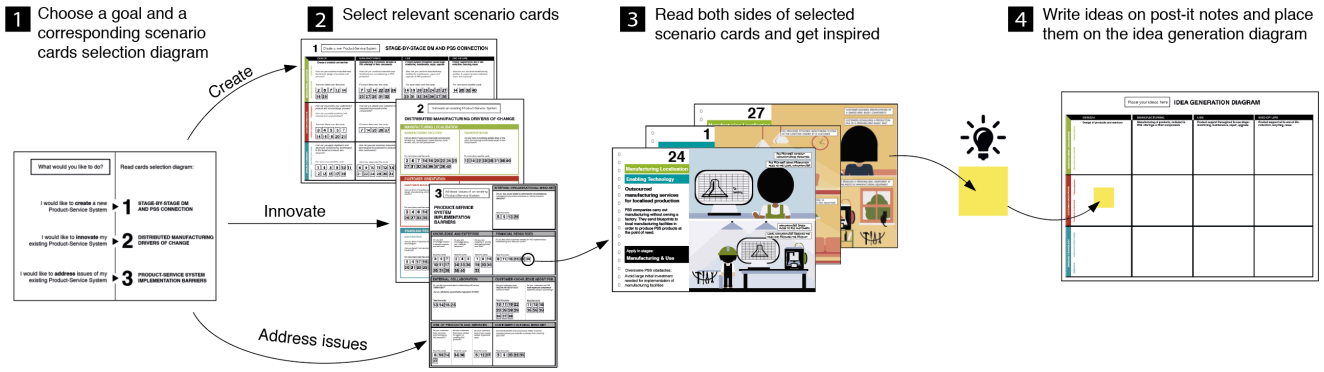

Figure 3 *A design process using DM applied to PSS design toolkit*

The DM applied to PSS design toolkit is made to provide knowledge about DM and support idea generation process of DM applied to PSS development. However, for building an all-inclusive PSS solution, the toolkit must be applied alongside other tools and methods. Evaluation studies showed that user profiles, field observations, customer journeys, system maps, storyboards and sustainability blueprints can be applied prior and after using the design toolkit. It can be summarised that the DM applied to PSS design toolkit can be integrated into a complete PSS design process: benefit from the information collected using initial design methods and contribute to further project development stages.

3.2. Sustainability implications

The research on DM and PSS combination focused on two sustainability-oriented models. The rise of DM is caused by increasing sustainability awareness and its potential to become an alternative to wasteful centralised manufacturing (Stai et al., 2016; Angeles-Martinez et al., 2018). Furthermore, it is well known that properly implemented PSS shows the potential to improve environmental, social and economic sustainability (Cooper and Evans, 2000). According to Vasantha et al. (2012), innovative value adding PSS can only be created combining products and services throughout the life cycle stages. Mont (2002) argues that the majority of existing PSS are fragmented because of the lack of complete life cycle stages perspective. For this reason, DM applied to PSS design toolkit enables its users to focus on a complete PSS life cycle. The key sustainability implication of DM is decreased environmental impact caused by transportation linked reduced distances between manufacturing facilities, customers and resources and ability to send digital files globally and produce products or spare parts close to or at the actual point of need. Localisation of manufacturing facilities enables PSS companies to collaborate with local start-ups and SMEs, support local producers and potentially benefit local communities. On-demand production and direct customer involvement enables development of relevant and potentially lost-lasting PSS solutions. Additive manufacturing machinery used in DM networks allows to reduce number and amount of materials,

simplify components for easy disassembly, re-manufacturing and upgrade, as well as reduce waste production during the manufacturing stage. It can also optimise (and localise) maintenance services potentially reducing time and resources needed to support PSS offerings. Application of DM features in each PSS life cycle stage shows the potential to improve sustainable PSS development.

3. CONCLUSIONS

If properly implemented Product-Service Systems business models show the potential to improve environmental, social and economic sustainability. However, PSS implementation is still limited by organisational, cultural and regulatory barriers. There are existing, yet very fragmented attempts to improve PSS development through the application of Distributed Manufacturing features. This paper has described the research process which was carried out to develop a design toolkit, aiming to support idea generation process for PSS. The research partially answered the initial research question: How to practically support PSS development through the application of DM features? The DM applied to PSS design toolkit contains 40 double-sided near-future scenario cards describing applications of DM features in different PSS life cycle stages and addressing specific PSS implementation barriers. These cards are classified on three scenario cards selection diagrams supporting relevant cards selection. Finally, the idea generation diagram is provided for positioning generated ideas. The design toolkit aims at supporting companies, design practitioners and educators in gaining knowledge about DM and generating future-oriented ideas to create new or improve existing PSS solutions. The toolkit can be used following a proposed design process or in a flexible way depending on users experience and time constrains. The toolkit can be also applied before and after other PSS design tools and methods. It enables its users to focus on a complete PSS life cycle thus increasing the potential to create truly sustainable PSS.

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