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10th CIRP Conference on Industrial Product-Service Systems, IPS^2 2018, 29-31 May 2018, Linköping, Sweden

Towards Service 4.0: a new framework and research priorities

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Abstract

The merging of services and digital technologies generates remarkable opportunities in manufacturing, by allowing more efficient processes, adding value to products, and supporting improved managerial decisions with richer, faster and sounder information. Although the importance of this phenomenon, the scientific knowledge is not sufficient. By analyzing the emerging trends of digitization and servitization in manufacturing we tried firstly to identify the key digital technologies to the servitization by studying different frameworks and the national industry 4.0 policy initiatives in Europe. Secondly to describe and explain if and how they enable this transformation. This paper aims specifically to provide a framework which is able to rationalize and systemize the existing knowledge on the topic by conducting a literature review. This study is considered as the first step of a research program on how these two megatrends are jointly disrupting resources, competences, skills and consequently business models. We show that the knowledge about how digital technologies support servitization in manufacturing is still at an early stage and rather limited so future research should aim at better understanding the links between digital and service transformation. Greater knowledge of the impacts of digital technologies on the servitization process will pave the way for the development of contingency models that can support and guide academics and practitioners alike.

Peer-review under responsibility of the scientific committee of the 10th CIRP Conference on Industrial Product-Service Systems.

Keywords: digital servitization; digital technologies; framework; literature review; future research

1. Introduction

Servitization, the growth of services and integrated solutions in the business model of manufacturers, has been addressed by a growing number of scientific studies. Literature agrees that this transformation can bring plenty of benefits such as economical, organizational, environmental, etc. [1,2]. Another trend deals with the introduction of digital technologies that enable new opportunities for developing deeper relationships with customers, for personalizing the product-service offerings, for value co-creation [3]. These technologies are concerned as factors that facilitate the shift to the service business, as they radically reshape the way companies create value through either existing and new digital services [4]. Despite this agreement and the fact that this field has gained increased importance in the academic arena, little attention has been set from literature until now on how these results are achieved. Theoretical insights and empirical research about how companies introduce digital technologies such as Cloud Computing, Industrial Internet or Predictive Analytics, to successfully servitize their business, are still very limited and are vital to understand better the topic. Following this standpoint, this paper aims to:

(i) identify the digital technologies, by analysing the literature and different national industry 5.0 policy initiatives in Europe, that are key to the servitization of manufacturing companies, and provide a framework that can be used to rationalize and systematize the emerging theories on this topic,
(ii) identify four knowledge gaps and suggest opportunities of future research on digital servitization (see definition in Section 2).

In order to achieve these objectives, we conducted a systematic literature review so to identify, collect and systematize the current research knowledge.

This paper is structured as follows: section 2 provides a brief research background on digital servitization, Section 3 describes the technology framework; section 4 outlines the methodology we used to select and review the literature on this

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topic, whereas section 5 presents the research findings. Finally, section 6 discuss the literature gaps, draws conclusions and sets directions of future research.

2. Digital servitization

In recent times, manufacturers are under a continuous pressure to adapt to a changing business environment. In response to that, new trends such as the servitization of manufacturing have emerged. Servitization refers to the transformation in which manufacturers are increasingly offering services that are more and more core of their value propositions [5]. Over the years, the adoption of servitization as a competitive strategy has been studied by several authors, who have identified a number of significant financial and strategic benefits [6], the reductions of resource consumptions, such as energy and materials, the possibility of fulfilling heterogeneous needs and of co-creating value with customers [7]. As said, digital technologies can accelerate this transformation, as far as they enable a novel product-service offering [8]. In fact, technologies such as Cloud Computing, Industrial Internet and Predictive Analytics are radically changing the way services are delivered. Thus, their adoption can be crucial to move towards more service-oriented business models [9]. In addition, digitization is considered a new layer of connected intelligence, that can be used to automate processes, transform data, augment the range of actions and markets, increases insights, control and knowledge about the tangible world [10]. Companies from diverse industries are adopting these technologies to reshape or disrupt their business models and industry boundaries. In this sense, the service and the digital transformation should be considered as two sides of the same coin [11]. In fact, manufacturers during the service transformation, introduce digital technologies so to increase the efficiency of service delivery and raise the value of their product-service offerings. At the same time, they change their business models, their manufacturing and service delivery processes. Although previous studies agree on the relevance of digital technologies to the service transformation, the intersection between business digitalization and servitization has been poorly explored. Thus, a comprehensive view is still missing and there is the need to systematize the existing knowledge to better analyze the role of digital technologies in servitizing firms under the heading umbrella of digital servitization. Therefore, in this paper we use the term “digital servitization” to point out *the development of new services and/or the improvement of existing ones, through digital technologies that enable new business models and the shift to the service business of product-centric companies*. The next section describe which technologies are core to the digital servitization of manufacturing firms.

3. Technologies enabling digital servitization

As we consider servitization and digital transformation of manufacturing companies two sides of the same coin, we refer specifically and mostly to digital technologies that are core to the forth industrial revolution. Although classifications may vary, there is a good consensus that some technological breakthroughs are more and more introduced by manufacturing companies to digitize their business, and eventually increase their service orientation [9]. Therefore, we focus on the following categories:

Industrial Internet of Things: The Industrial Internet (of Things) can be described as the integration of some technological developments. Products and industrial equipment can be connected to provide large amount of data. These are stored in data lake and then used to create insights into the status of equipment, to predict breakdowns or other kinds of occurrences, and to deliver smart services such as predictive maintenance, remote control, operations, and optimization, fleet management, spares management, etc.

Big Data and Analytics: Big data and analytics refer to the techniques that are used to mine and process large structured and unstructured dataset, in order to identify patterns, develop predictive models and generate insights that are valuable in a business context.

Cloud Computing: This technology allows ubiquitous access to a shared pool of computing resources – such as servers, storages and operating systems – that can be convenient, configured and provisioned on-demand, with minimal management effort

Cyber Security: This technology controls and protects processes and systems that operate on the internet, recognizes changes and vulnerabilities, and verifies that who has access to the system is an authorized user. It ensures the security principle of need-to-connect between different secure cells or between components of the production network and outbound devices is quite often disregarded.

Mixed reality: These are technologies that allow the operator to have an augmented perception of objects. A digital model and reality can thus be integrated, offering viewpoints of the activity under way. Mixed reality is the merging of real and virtual worlds to produce new environments and visualizations where physical and digital objects co-exist and interact in real time.

Advanced manufacturing solutions: Advanced manufacturing solutions are mostly made of cyber-physical systems and collaborative robots. These machines and robots can physically interact with humans in a shared workspace to reach common goals, as they are equipped with sensing technologies that made them aware of contextual conditions, and are guided/moved by artificial intelligence software.

Additive manufacturing: This technology also referred as 3D-Printing, is a fabrication technique involving the progressive deposition of material onto a substrate, layer by layer. It enables the creation of high-complexity parts that either require personalised goods or geometry-driven performances.

Simulation of connected machines: The combination of these technologies is the best option for saving time and resources because it evaluates the changes and behaviours in the configuration of machines, process flow and plant designs and it tests the effectiveness of the changes without them being realized.

Horizontal and vertical system integration: This technology is the first step to make the vision of industry 4.0 reality and

achieve their goals, for the systems as a whole are analysed in the productive flow, in this sense, it proposes structural changes in organization and management of physical objects, as well as the establishment of connections with information systems.

Artificial intelligence: This technology has been used to simulate the thinking and behaving process of human beings. One of the most active niche of AI is machine learning that benefits preventive decisions.

4. Research methodology

We conducted a systematic literature review to identify, collect and organize the current knowledge on digital servitization of manufacturing companies. Our review encompassed English-speaking peer-reviewed papers covering the period from 2000 to 2017. As a first step a structured keyword search was designed and conducted in the Scopus (www.scopus.com) database. As said, the research domains of manufacturing's servitization and digitization have been developed in isolation. Therefore, we combined keywords belonging to two domains. The first set of keywords related to the service transformation of manufacturing companies and includes "servitization", "product-service system(PSS/IPSS)", "integrated solutions", "service transformation / infusion", "smart services / servitization", "smartization", "smart manufacturing". The second set is associated with the use/adoption of digital technologies in business contexts: "digitization", "digitalization", "Industry 4.0", "emerging / digital/ new technologies", "digital manufacturing / transformation", "IoT", "big data", "remote control / monitoring", "predictive analytics / maintenance", "platform", "cloud computing", "additive manufacturing", "3D printing", "augmented/virtual reality", "ICT". In order to consider all the contributions that address digital servitization, we scanned the combinations between the keywords sets. The search yielded to 2.176 articles excluding duplicates and papers without authors or abstracts. In order to ensure that only quality publications were considered, we excluded contributions such as lecture notes, whitepapers, etc. that did not appear on scientific journals with impact factors. At this step we also excluded also the papers published in journals outside the fields of engineering, business, management, operations, services, manufacturing, life, computer and social science. 1.217 papers were thus left. The next step was to scrutinize them based on the title and abstract, selecting only contributions that discuss/apply digital technologies in the servitization process of manufacturing (207). Finally, the papers that met the inclusion criteria were read in detail and analyzed. Simultaneously, a cross-reference analysis completed the database search in order to overcome possible limitations of the keyword search. 68 papers were in the end analyzed in order to define the intellectual territory of the digital servitization research field and to identify possible knowledge gaps and directions to further develop the existing body of knowledge. All articles were coded in terms of: name of authors, title, published date, journal, research method, stream, industry, technologies, perspective, results, conclusions, limitations and future research. In the next section we describe the findings of the literature review.

5. Findings

The features of the considered papers are described in this section. Figure 1 shows the temporal distribution of the 68 analyzed papers. They are distributed from 2005 since the end of 2017. The first publication was in 2005 [12] and a gap of three years has followed until 2009. Then a steady growth comes, highlighting the emergence of the digital servitization research stream and the increased interest in the scientific research world. Thus, our review's goal is to organize the existing knowledge and identify opportunities of future research.

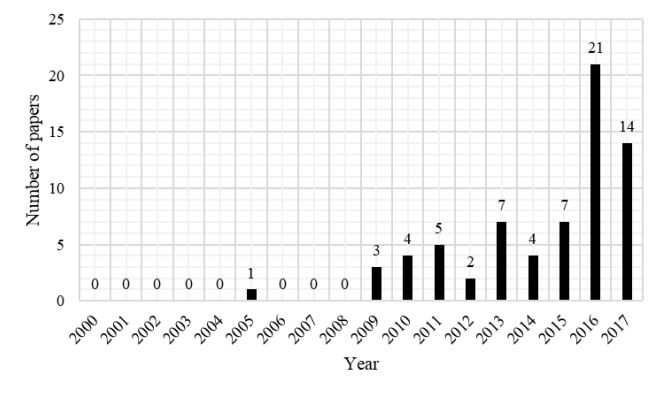

Fig. 1. Temporal distribution of the reviewed studies

Another investigated aspect is the journal distribution which is reported in Table 1, indicating a concentration on 12 journals that published half of the papers while the remaining papers were published in 35 different journals. The smooth journal frequency distribution highlights that in this early stage, most studies come from different fields like operations management; information technology and computer science; marketing and strategy. The relatively high impact factor of the considered journals strengthens the quality and value of the seminal contributions to this research stream. Few contributions focus explicitly on the role of a digital technology for servitization, rather than discussing the conundrum of all the technologies.

Table 1. Journal distribution of the reviewed papers.

Journal	No. of papers	Percentage	Impact factor
Journal of Manufacturing Technology Management	5	7%	1.75
International Journal of Advanced Manufacturing Technology	4	6%	2.2
International Journal of Production Economics	4	6%	3.49
Computers in Industry	3	4%	2.69
Journal of Service Research	3	4%	6.84
Industrial Marketing Management	3	4%	3.16
International Journal of Production Research	3	4%	2.32
International Journal of Operations and Production Management	2	3%	3.93
International Journal of Automation Technology	2	3%	1.19
Communications of the Association for Information Systems	2	3%	1.47
CIRP Journal of Manufacturing Science and Technology	2	3%	2.76
Others	35	51%	-

We additionally categorized the above journals based on their Scopus Subject Area. Digital servitization gets more attention from an Engineering (31), Business, Management and Accounting (23), Computer Science (8), Social Sciences (6) and Mathematics (1) perspective. Geographical distribution is another investigated aspect which shows that digital servitization seems to be mainly a European phenomenon: Germany (10), UK (9), Sweden (8), Finland (5) with a general tradition in services and servitization seem to dominate in terms of publication number. China has an exceptional position with nine publications. Another important element is the citation number obtained by paper. Table 2 lists the 8 papers that obtain almost the 60% of the total citations and can be considered as the most relevant by number of citations.

Table 2. Most cited papers.

Author	Title	Cit.
[2]	Moving forward and making a difference: Research priorities for the science of service	489
[13]	Industrial Product-Service Systems (IPS2): Paradigm shift by mutually determined products and services	104
[12]	Four strategies for the age of smart services	97
[14]	eMaintenance—Information logistics for maintenance support	91
[15]	Developing integrated solution offerings for remote diagnostics: A comparative case study of two manufacturers	87
[16]	Service Research Priorities in a Rapidly Changing Context	71
[17]	Requirement management for product-service systems: Status review and future trends	60
[18]	Cloud manufacturing: From concept to practice	51

It is noted that the most cited papers in the list were in 2010 and 2011 when the first exploratory research results of digital servitization came up.

We group the papers based on the three main streams in order to analyse if there is a dominant approach of servitization in the digital servitization area. The Product-Service System (PSS) strand gets the greater attention with 41%, Servitization 37%, Solutions 6% and Smart Services 15% of the scrutinized papers. The PSS is emerging rapidly due to various research efforts [18, 19] from different areas as mechanical, software or management engineering [20,21]. Another reason for the popularity of the PSS stream is associated with the developing concept of circular economy and manufacturing sustainability [22].

The used methodological approach is another essential aspect to be evaluated when dealing with an emerging research stream. The results indicate that single (n=22) and multi-case studies (n=21) are the most employed methodology followed by eleven literature reviews focused on a specific technology [23,24] and six Delphi studies [25, 26]. Moreover, there are four conceptual papers [27, 28, 29] and three surveys. The frequent usage of the case study research methodology offers a more viable option for studying information-rich cases, as compared to surveys. Some of the papers use more than one methodology. These results are in line with the assumption that the research on digital servitization is still in its early stage.

The dominant industries represented in the empirical studies are: machinery, automotive and aerospace, because their digital servitization potential is important. [30] for example present an automotive case which stresses the importance of technology and service combination to manage a successful digital servitization. [31] rank and analyse machinery companies based on their IoT aided servitization success. [32] focus on developing a service ontology in aerospace industry to support maintenance, repair and overhaul and create solutions for service providers using the Web-based PSS. Figure 2 illustrates the classification of the selected papers according to the technology addressed. It has to be noted that some of the papers use more than one technology.

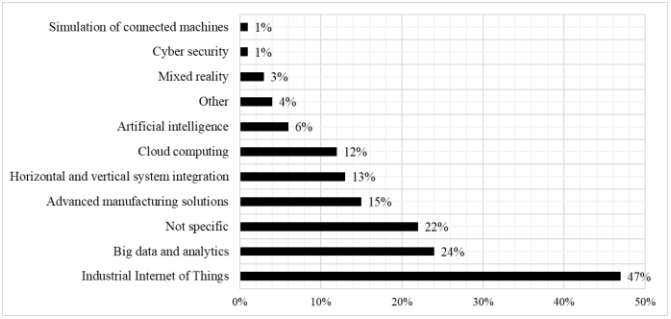

Fig. 2. Classification based on the used technology

The proposed framework aims at providing a better understanding of how companies could achieve the digital servitization, by using Industrial Internet/IoT which is the most popular technology to support the development of smart/digital services such as condition monitoring, and the gathering of relevant data about the usage of products. The IoT adoption opportunities for servitization are highlighted by [33] in the machinery industry and describe a set of IoT applications providing smart services in different areas like smart manufacturing and smart grids. [34] propose a method for the IoT enabled PSS adoption and focus on the business implications of IoT. [31] suggest a framework which provides a better understanding on how companies could create value based on the IoT technology. The role of remote monitoring technology in supporting servitised strategies is studied by [35] and how this technology is used in practice to support service-oriented value propositions of manufacturers.

Big data impacts on manufacturing competitiveness by uncovering opportunities for new service offerings and by capturing and analysing service-related information for real-time decision making [16]. Firms also develop fully new business models [36] like the installed base management which provides very accurate data and deep insights enabling to fulfil specific customer requirements, and enables new outcome-based contracts (e.g. pay-per-availability). Based on the Annual Service Symposium in 2013, [37] stress out the need of big data to be human-centred and focused on co-creating value.

Advanced manufacturing technologies have been hailed as enablers to make industrial products and operations smart [38]. Another example concerns the service systems which are fundamental for service innovation and value creation. In this

context, service systems are related to cyber physical systems and depend on the interconnectedness among system components [25].

To support the manufacturing industry and enhance global competitiveness, several countries have established research and technology transfer schemes showing that manufacturing intelligence has become crucial. The main object of these activities are the cyber-physical systems and the application potentials of CPS are described by [39].

Cloud computing provides access to a remote infrastructure so users are able to run operating systems and applications, have direct access to software applications [40]. It is highlighted by [9] the importance of cloud platforms for facilitating the formation of ecosystems and knowledge sharing.

In the artificial intelligence category, we included the human machine interface which is designed to monitor the operation of equipment and collect the shop floor information. A common-HMI that is capable of collecting data for heterogeneous equipment and presenting clear, visual information to the user is introduced by [41].

A cloud-based service-oriented system that implements augmented reality technology for remote maintenance by enabling cooperation between the technician and the manufacturer is proposed by [42].

Although cyber security receives a high interest from companies [43], only one study concerns it. As an example, Canon which developed the cloud platform eMaintenance in order to overcome difficulties related to the printers' internet connection which create security issues [9].

Even though, the benefits of additive manufacturing technologies are many, such as mass customization, agile manufacturing, on demand production, etc. it is worth mentioning that we found no research papers on this topic.

In the category "other" we included the papers that mention technologies which are not in our framework like electric road systems [30] and electric vehicles [44].

Papers that do not focus on the mentioned technologies, but instead investigate how ICT as a whole enables servitization, are classified in the "not specific" category. [44] illustrate how operations are configured to successfully deliver advanced services. [45] investigate products' and customers' support services and help managers to understand their key specificities and interrelations.

Table 3 (Appendix) classifies the papers according to the considered digital technologies and time period. It has to be noted also that some papers are classified in more than one category because they refer not only to one technology but a number of them.

6. Conclusions

Despite the fact that the role of digital technologies in the servitization of manufacturing firms is still under-investigated, the findings from a literature review discussed in this paper stress the digital servitization's potential. Because of its early stage of knowledge, future research should focus on understanding better the links between the digital and servitization transformation. This research work attempts to systemize this rapid increasing body of knowledge and to prevent the risk of research developments fragmentation, aiming to facilitate a common understanding of this phenomenon also outside the research community. In particular, our analysis identifies the following gaps that represents future avenues of exploration.

1. ***A theory for "digital servitization" is yet to come***

We recognized a lack of contributions on systemizing the current knowledge, instead of that researchers use overwhelmingly case studies as the main methodology to investigate digital servitization. It is necessary to develop and propose conceptual and theoretical works. Moreover, future research should make more reference to the existing literature to achieve a harmonization of the terminology. This will improve the practical relevance of theoretical results.

2. ***Further studies of technology potential for servitization are needed***

Some of the digital technologies seem to be more popular among researchers creating the question if the under investigated technologies are less important or less considered. Academics in order to answer this question should support companies on how they can leverage these digital technologies to support their servitized business models. A generalization of the servitization perspective is important in other manufacturing sectors so to create a greater diversity, which leads to increased value.

3. The most suitable trajectories for digital servitization

Empirical research is needed specifically focused on understanding in detail the integration of servitization and digital technologies, also from a managerial point of view. Through the extension of the empirical research a classification framework of services and digital technologies might be designed and validated to help companies find the best trajectories to "digital servitized".

4. ***Digital servitization is not only a matter of technology***

The implementation of different digital technologies in the servitization journey demands the better understanding and acquisition of competences, experience and knowledge. Thus, future research should focus on an in-depth analysis of the existing knowledge in the emerging topic of digital competences within organizations.

This study is exploratory in nature and should be considered as a starting point The research avenues we presented above are suggestive and certainly not complete.

Appendix A. Papers classification based on the technology addressed over years

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	2000 - 2002	2003 - 2005	2006 - 2008	2009 - 2011	2012 - 2014	2015 - 2017	
Industrial Internet of Things		Allmendinger (2005)		Brax (2009) V. D Heuvel (2010) Nybacka (2010) Ostrom (2010) Huang (2011) Schuh (2011) Geum (2011)	Wünderlich (2013) Baines (2014) Grubic (2014)	Ren (2015) Kwak (2015) Demirkan (2015) Georgakopoulos (2016) Zancul (2016) Jiang (2016) Li (2016) Eloranta (2016) Belvedere (2016) Ban (2016)	Shih (2016) Grubic (2016) Wan (2017) Rymaszewska (2017) Thoben (2017) Wiesner (2017) Uhlmann (2017) Ardolino (2017) Cenamor (2017) Bokrantz (2017) Holler (2017)
Big data and analytics				Geum (2011)	Teixeira (2013) Baines (2014)	Opresnik (2015) Ostrom (2015) Demirkan (2015) Song (2016) Jiang (2016) Li (2016)	Rakyta (2016) Weinman (2016) Uhlmann (2017) Ardolino (2017) Bokrantz (2017) Lenka (2017) Holler (2017)
Cloud computing				Ostrom (2010)		Ren (2015) Dermikan (2015) Jiang (2016) Weinman (2016)	Uhlmann (2017) Mourtzis (2017) Ardolino (2017)
Cyber security						Ostrom (2015)	
Mixed reality						Demirkan (2015) Mourtsis (2017)	
Advanced manufacturing		Allmendringer (2005)		Kim (2009)		Kwak (2015) Coreynen (2016) Jiang (2016) Peters (2016)	Thoben (2017) Wiesner (2017) Uhlmann (2017) Kamp (2017)
Simulation of connected machines				Ostrom (2010)			
Horizontal and vertical integration				V.D Heuvel (2010) Baines (2011)	Baines (2014)	Ren (2015) Li (2016) Cao (2016)	Wen (2016) Thoben (2017) Mourtzis (2017)
Artificial intelligence						Kwak (2015) Lee (2016)	Kamp (2017) Holler (2017)
Other					Sakao (2013) Tongur (2014)	Schmidt (2016)	
Not specific				Meier (2011)	Zhu (2012) Hernandez (2012) Kowalkowski (2013) Wünderlich (2013) Belvedere (2013) Durugbo (2013) Baines (2013)	Opresnik (2015) Valencia (2015) Coreynen (2016) Paluch (2016)	Cuadrado (2016) Vendrell-Herrero (2016) Pagoropoulos (2017)