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Human-Centred Design in the context of Servitization in Industry 4.0. A Collaborative Approach

Nguyen Ngoc Hien, Ganix Lasa, Ion Iriarte

Mondragon Unibertsitatea: Design Innovation Center (DBZ) - Faculty of Engineering

The competitiveness of the business today will depend on empowering human intelligence and creativity, capturing and capitalizing on available information and knowledge for the total product and service lifecycle. To realize this beyond technical aspects, the collaborative work of multidisciplinary and inter-sectoral teams is constituted to develop an appropriate methodology of human-centred design (HCD) with advanced service innovation in industry 4.0. Based on the state-of-the-art analysis and industrial requirements, the methodology is tested with European industrial cases in various sectors to validate its implementation and benefits. This paper aims to provide the well-rounded collaborative framework to deliver the new HCD methodology.

1. Introduction

The transition of industry 4.0 has impacted on different aspects across the product lifecycle from design, production, through maintenance to end-of-life management (Kong et al. 2019; Mazali 2018; Pereira Pessôa & Jauregui Becker 2020; Wang et al. 2017). This leads to the increasing dependence of the economic sustainable growth on maintaining and further expanding a resilient and robust manufacturing sector whose competitiveness replies on maximizing the utilization of all available resources, empowering human intelligence and creativity, capturing and capitalizing on available information and knowledge for the total product and service lifecycle. Alongside with the challenges that the new manufacturing paradigm of Industry 4.0 imply, the advances of technologies, such as computing power, intelligent control and connectivity, have facilitated a reorganization of both manufacturing and service processes to make the most of the information and communication for enhancing value proposition (Fu et al. 2019; Lee & Abuali 2011; Leoni 2019). Those enabling technologies allow for the development of smart products and services in their lifecycle but also pose radical changes in several other areas. One of them is related to innovation in which the practice of product design has expanded in both economic and social impact and in technological complexity, leading to demands on innovative service systems (Imran et al. 2018; Lee & Abuali 2011; Turetken et al. 2019). Furthermore, the data-driven services based on the advantage of internet of things (IoT) provide manufacturers of technical products the opportunity to become providers of services, which enables the manufacturers to catch up the increasing number of the modern requirements in the age of mass customization (Ardolino et al. 2016; Mourtzis et al. 2018). As the movement of value exchange in selling products to providing services, smart services enable new business models based on completely new relationships among manufacturers, customers or users of physical goods, operators and stakeholders (Anke 2019; Benabdellah et al. 2019). This phenomenon in which a manufacturing company is transformed toward Product-Service Systems (PSS) is called as the servitization, allowing traditional manufacturers to become smart manufacturers and improve their competitiveness by the incorporation of the customer experience in their product and service development processes (Cheah et al. 2019; Leoni 2019; W. Zhang & Banerji 2017).

However, the development of such smart PSS is characterized by high complexity and uncertainty due to the dynamics of service systems, such as the turbulent fluctuations in market demand, the increasing variability of products , the emergence of multichannel services, and the complexity of processes requiring appropriate skills, methods and tools during the deployment of PSS (Anke 2019; Benabdellah et al. 2019; Iriarte et al. 2018; Patrício et al. 2018). To cope with the challenges, manufacturing companies will need to incorporate HCD, as a human-centred approach to the design and development of services (Costa et al. 2018; Iriarte et al. 2018; Teso & Walters 2016), to link deep customer knowledge, with resources and digital data flows in one single system. This system is to enable manufacturers to design these humans (users and customers), machines (products), and digital data systems, and transform them into marketable advance product-service solutions in which design as a driver and enabler of human-centred innovation could complement Industry 4.0 offerings beyond technological innovation manufacturing. To realize this, the paper aims to provide a well-rounded research collaborative approach to deliver a new approach of HCD in the context of servitization for smart manufacturing.

The paper starts with the background of servitization in which HCD is applied as the design and development of services. The section also emphasizes on the challenges for manufacturing sector in industry 4.0 to deploy such approaches, leading to the need of a comprehensive collaborative research in which industrial experts and researchers are join forces to develop, verify and validate a new methodology of HCD with advanced service innovation. This will be clarified and provided in Section 3, followed by the research agenda and conclusion.

2. Human-centred design in the context of servitization

The paradigm of mass individualization poses social manufacturing as a new business model allowing prosumers to build personalized products with their providers through integrating inter-organizational manufacturing service processes, reconfiguring the relationship among stakeholders on the whole value chain (Fu et al. 2019; Leng & Jiang 2017; Mazali 2018; Santoni de Sio & van den Hoven 2018). This phenomenon is enabled by the digitalization process facilitating the inter-linkages in industry processes, changing value propositions and opening up towards greater collaboration and customer integration (Anke 2019; Chauhan et al. 2020; Grieger & Ludwig 2019; Kymäläinen et al. 2017; Pereira Pessôa & Jauregui Becker 2020; Wang et al. 2017). Moreover, manufacturers today are called to respond to a new demand, which is less based on the purchase of tangible or intangible products separately, as customers increasingly demand to be able to purchase a complete solution (Leoni 2019; Zhu et al. 2015). This implies a transformational change from a product-oriented business model towards a new one in which a bundle of products and services are integrated and named as PSS, integrating different stakeholders, devices, functions, and data into coherent systems of value co-creation (Baines et al. 2009; Pezzotta et al. 2018; Turetken et al. 2019). This approach is different from many conventional design methods that do not consider the influence of customers as humans in the centre of design during the planning phase. There is also lack of relationship between physical products and services in the early design phase. Besides, those design methods are usually based on the product structure and functional requirements. The obtained solutions only meet the functions of product, without considering the functions of services in accordance with the customer requirements (Zhu et al. 2015). PSS have been getting attentions of global manufacturing to provide high-value added services in addition to their traditional product development and manufacturing business model, which is also explained as the process of servitization (Haber & Fargnoli 2019; Leoni 2019; Zhu et al. 2015). This approach is regarded as a sustainable strategy through cooperation and interaction of heterogeneous stakeholders to satisfy the demands of customer and simultaneously enhance their value, differentiate themselves from competitors, and achieve significant increases in turnover (Confente et al. 2015; Iriarte et al. 2018; Nudurupati et al. 2016; Valtakoski 2017; H. Zhang et al. 2020). However, as already recognized by the literature, the path toward servitization is challenging and does not always allow manufacturing companies to realize the expected profits (Leoni 2019; Turetken et al. 2019).

This contradictory effect is called as “service paradox” and deservitization. The first one is a result in which servitized manufacturing does not succeed in developing a profitable service business to complement an existing product business while the later one is explained as the scenario in which a manufacturing company reduces the role of services in their business, or completely remove the service components (Cheah et al. 2019; Kowalkowski et al. 2017; Valtakoski 2017). Specifically, servitised manufacturing faced higher internal and experimental risk of bankruptcy compared to non-servitised manufacturing companies, due to the lack of internal capabilities in dealing with the strategic, structural and cultural changes associated with risk management on the path of servitization (Benedettini et al. 2015; Cheah et al. 2019; Valtakoski 2017). Moving to this paradigm has significant implications on the way in which the changes in business requirements for services and the complexity of value networks required to meet these requirements will increase further, posing challenges the business may face during the transition (Mourtzis et al. 2018; Turetken et al. 2019). These challenges are categorized in three following dimensions including the enterprise, stakeholder, product-service lifecycle as described by Figure 1.

The challenges on the enterprise layer refer to the changes of internal structures to support business transformation. It includes the organizational structure, business model, development process, customer management and risk management (Cheah et al. 2019; Confente et al. 2015; Leoni 2019; Nudurupati et al. 2016; Salonen 2011; W. Zhang & Banerji 2017). Those changes require the transition from a cultural mindset from a product-centric to a customer or service-centric organization whose synergy across functional departments and organizations needs to be enhanced to support the development and delivery of integrated product-service offerings. The refinement of the business model is also challenging due to the changes in value proposition, resource utilization, mechanism of costing and pricing, and supplier collaboration, resulted from the extension of the services complementing to the product offerings. Another requirement during the transition is the integrated development process where tools, methods and techniques, performance measurement, and customer engagement channels need to be defined to servitize product offerings. The development process is required to support the customer management by matching customer needs, service levels, ownership transfer, long-term relationship building, value co-creation, and information sharing among producers and customers. These changes increase the risk of servitization because uncertainties are triggered in different phases of the business change, requiring a proper risk management of financial, operational and external factors.

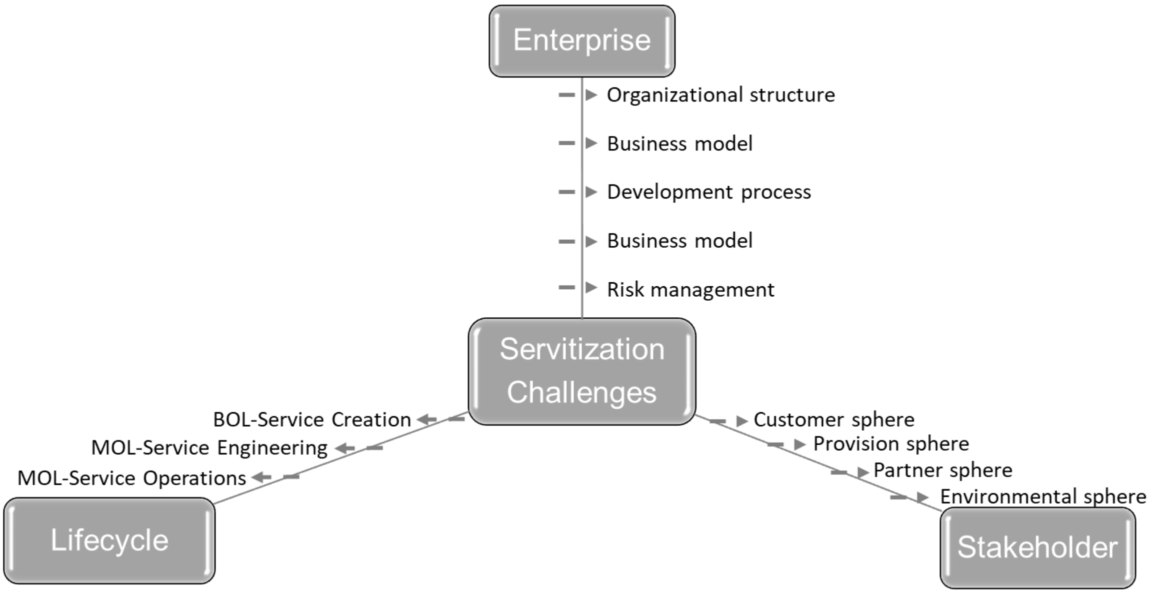

Figure 1 Servitization challenges

Beyond the enterprise boundary, a successful value proposition relies on the enterprise´s ability to meet the interests of stakeholders, providing benefits among them (Gilles & Christine 2016). It is not always clear who are the main stakeholders of PSS and companies are not always fully aware of which individuals or groups should be considered as stakeholders. This becomes even more challenging due to the interrelated networks of stakeholders who may involve in the process of servitization at different extents of impact (Mourtzis et al. 2018; Nenonen et al. 2014). Therefore, the identification of the stakeholders is one of the challenging steps when designing PSS towards value proposition. Generally, the stakeholders can be structured into four groups: customers (e.g., customers, consumers, users); providers (e.g., manufacturers, installation and service providers, suppliers, local providers); partners (e.g., financial partners, legal partners, design partners, recycling third parties); and market actors (e.g., competitors, industry interest groups, universities and research institutes) (Fernandes et al. 2019; Tantalo & Priem 2016). Each stakeholder has different roles associated with various impacts in different design contexts of PSS. Although literature well recognizes the importance of stakeholder consideration during servitization, but this is not always the case. Specifically, stakeholders that act in the final stages of lifecycle, such as the case of recycling third parties, have not been well-approached since the early stages of the design process even though their roles could be reflected in the development of a sustainable and circular economy (Fernandes et al. 2019).

Finally, producers must also embrace new responsibilities for the entire lifecycle of products and services, resulting in increasing sensibility regarding value creation in terms of technical, economic, social and environmental aspects (Beuren et al. 2013; Cheah et al. 2019; H. Zhang et al. 2020). In this context, it becomes even more important to understand the stakeholder requirements throughout the lifecycle. Furthermore, one aspect when designing and developing new or improving existing products and services is how to effectively capture, manage and share information and data throughout product-service lifecycle which can be defined by three main phases (Gilles & Christine 2016; Wuest & Wellsandt 2016) as Figure 2.

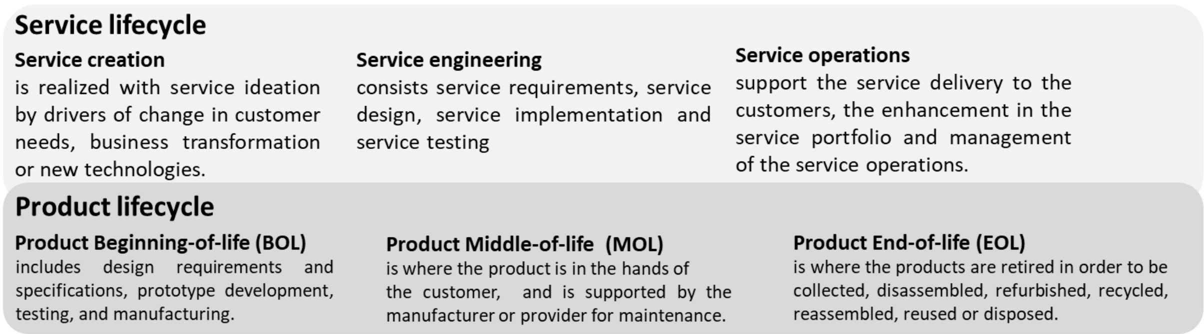

Figure 2 Product-service lifecycle

These challenges in servitization require a new design methodology to enable manufacturers to pursue the transition, overcome these hinders and minimize the market failures. In literature, most researchers only focussed on the definition, architecture, organization, and implementation mechanism of PSS (Pezzotta et al. 2018; Zhu et al. 2015) while a lack of systematic design methodology was strongly highlighted (Grieger & Ludwig 2019; Harwood et al. 2019; H. Zhang et al. 2020). This shows a need of a methodology able to pinpoint all design requirements, support the integration of the product and service components. Besides, the enhancement of the coordination between the back-end and the front-end internal capabilities and management of interphase conflicts in design goals among stakeholders throughout product-service lifecycle were also highlighted (Pezzotta et al. 2018). Moreover, the digitalization technologies supporting for the requirements must be emphasized; however, literature likely limits its values in allowing companies to pave the way for advancement in the servitization (Dinges et al. 2015). Furthermore, there was a scarce adoption in the manufacturing context with multiple case studies to establish chain of evidences for the validation of the proposed methodologies in the direction of generalization of research findings (Adrodegari & Saccani 2020; Pezzotta et al. 2018).

In the design literature, one of the design-oriented approaches in both research and practice is HCD. It is a design philosophy and methodology for and with people considered across a continuum of the design process that considers “users” or “customers” as subjects towards “users” or “customers” as partners (Lofthouse & Prendeville 2018; Norman & Verganti 2014). Its diverse toolbox is continuously developed based on the adaptation of tools from other disciplines (Hanington 2003), such as ethnography or computer sciences, and also applied as an human-centred approach to the design and development of services. Moreover, HCD is not only considered as the design on product or service levels, but it proves its usefulness, appropriateness and value to organizational design and innovation management (J. Auernhammer 2020; J. M. K. Auernhammer & Leifer 2019), which functions as a bridge for business internal capabilities. In the age of industry 4.0, HCD has played critical roles in digital manufacturing design from automation, IoT connected to social-technical systems

(Fernandez-Carames & Fraga-Lamas 2018; Longo et al. 2017; Lu et al. 2020), enhancing the integration among humans and other cyber physical systems.

Therefore, to address the challenges and take full potential of digitalization, a new methodology of HCD needs to be developed to mechanize the process of servitization. To realize this, the following comprehensive collaborative research in which industrial experts and researchers as join forces is proposed to develop, verify and validate the new proposed methodology with advanced service innovation. The industrial challenges, requirements, and specifications are also taken into account in various digital manufacturing contexts.

3. Research methodology

3.1. Collaborative research

Disciplinary and reductionist approaches are being substituted by interdisciplinary and systemic approaches through a collaborative research in which researchers and experts across disciplines come together to achieve common research objectives via cross-domain teams exchanging ideas, sharing information, and coordinating both practical- and research-driven activities (Baskerville et al. 2017; Bukvova 2010; Löhr et al. 2018). It brings the advancement of scientific disciplines, meaning that a multidisciplinary research requires diverse knowledge and expertise in order to make significant advances and this requirement often can only be met by pooling one's knowledge and expertise with others (Katz & Martin 1997). This particular approach is well suitable for the human-centred approach driven servitization in the context of digital manufacturing that constitutes the challenging problems due to its multidimensionality leading to the needs in the cooperation of multi-domain researchers and industrial experts (Mourtzis et al. 2018; H. Zhang et al. 2020).

In the context, the research program of Digital Manufacturing and Design (DiManD[1]) is a collaborative partnership comprising a network of total 19 universities, research centres and industrial partners. This is a research platform for the interdisciplinary, cross-sectorial, and international perspectives across European countries, including Italy, Portugal, Republic of Ireland, Spain, Sweden and the UK, with multiple key sectors such as automobile, aerospace and medical devices. The collaborative platform combines cross-domain expertise in computer science, manufacturing engineering, mechatronics, human factors, business and management distributed across the four universities (University of Nottingham, Kungliga Tekniska Hoegskolan, Mondragon Goi Eskola Politeknikoa, Instituto de Desenvolvimento de NovasTecnologias - Associacao), two research centres (STIIMA, FundacionTecnalia Research & Innovation), two industrial partners (Petronor Innovación, TQC Ltd) and other partner organizations as described by Figure 2. This will provide synergy between the academic and the non-academic sector in order to realise the full potential of research for the benefit of the

[1] DiManD aims to develop a high-quality multidisciplinary, multi-professional and cross-sectorial research and training framework for Europe with the purpose of improving Europe's industrial competitiveness by designing and implementing an integrated programme in the area of intelligent informatics driven manufacturing that will form the benchmark for training future Industry 4.0 practitioners (https://dimanditn.eu/en/dimand-itn, retrieved on Nov, 12 2020).

economy and society. The collaborative research aims to provide an advancement of in both practical and scientific deliveries on three key research challenges in the core of the industry 4.0 vision: big data analytics, industrial IoT and autonomous systems control. The research will ultimately support the development of a holistic framework for future intelligent, adaptable and responsive manufacturing infrastructure. This is based on looking for the appropriate sectors, scales, products and volumes; taking the impacted lifecycle stages from design to manufacture, maintenance and end-of-life management into account; comprehending how the lifecycle data impact on new product design and manufacturing; and finally examining how cloud manufacturing influences and enables local on-demand supply of components and service future products.

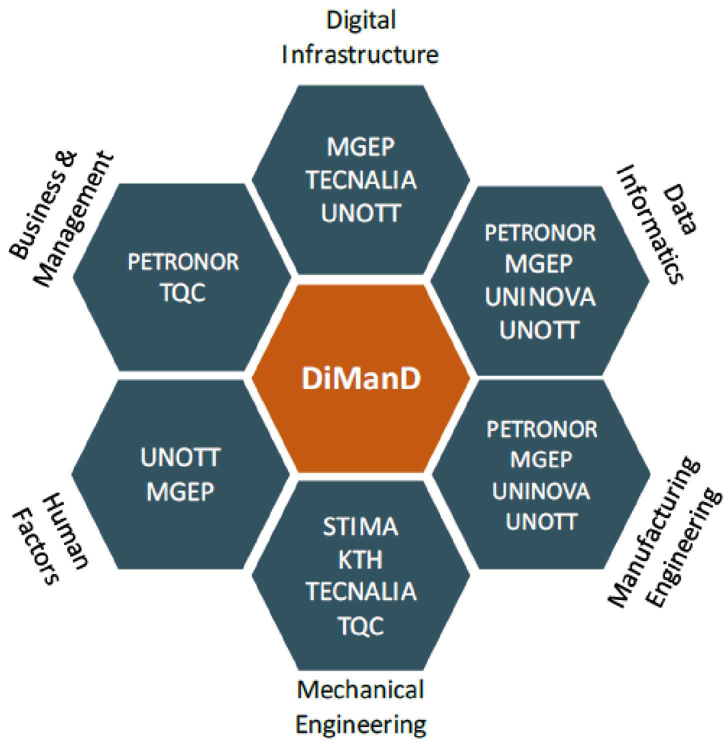

Figure 3 DiManD collaborative platform with synergies between partners

Beyond the technical developments, developing a new appropriate method of HCD is also one of DiManD deliverables, allowing manufacturers to create advanced product-services in Industrie 4.0 scenarios. The objective is to enable manufacturers to design these humans (users and customers), machines (products), and digital data systems, and transform them into marketable advanced product-service solutions in which design as a driver and enabler of human-centred innovation could complement Industry 4.0 offerings beyond technological innovation. Specifically, the outcome will obtain to: (i) overcome internal organizational barriers for digital manufacturing offerings; (ii) identify the needs of the different value network stakeholders through user research techniques; (iii) co-create and prototype with the different value network stakeholders in order to offer more complete product-service offerings minimising market failures; (iv) visualise and develop product-service scenarios using system visualisation tools to help customers and providers understand how advance product-service offerings work; and (v) develop and deliver the appropriate customer solutions. To realise the full potential, the HCD methodology will be developed and validated in different European manufacturing sectors with diverse digital manufacturing contexts associated with multiple case studies, followed by the following well-rounded research design.

3.2. Design of multiple case studies

First of all, the literature review is systematically conducted to understand the current development in literature regarding HCD in industry 4.0. The strong emphasis during the systematic literature review will be given to lessons learnt derived from case studies to capture the most prominent findings and limitations. This is because these case studies are useful sources in which the frameworks or methods of HCD are explored, described, explained, tested and even refined. A case study here as an empirical research method is specifically used in situations not only where the contextual details have to be analyzed, but it is good at investigating how and why questions, particularly suitable for developing new theory and ideas and can also be used for theory testing and refinement (Adrodegari & Saccani 2020; Voss et al. 2002; Williams 2007). It has been consistently applied as one of the most powerful research methods in diverse fileds, such as a medical research studying a rare illness (event), political science research on a presidential campaign (activity) or operations management. The structure of a case study should be the problem, the context, the issues, and the lessons learned or patterns found that connect with theories. Besides, its data collection is extensive and draws from multiple sources such as direct or participant observations, structure or unstructure interviews, archival records or documents, physical artifacts, and audiovisual materials (Creswell 2012; Franz & Robey 1984; Williams 2007). This method is also truly interdisciplinary, with influences from engineering sciences, sociology, psychology, and economics. Those characteristics of the case study approach make it become a suitable and core research method for this paper whose research objective is to develop and validate a new methodology oriented to humans in the context of servitization.

However, a case study method is often critized. One of the most frequent objections to case study research is the issue of generalization in which a case study result cannot be generalized to another case. It is worth emphasizing again that the case study objective is not to test one or more hypotheses that is statistically and universally rejected or accepted, but to arrive at a theory or knowledge that is valid for a set of propositions. In spite of that, it is possible to generalize from a single case, which depends on the case and the way the case is chosen, such as the falsification logic by which if a theory or knowledge is not true for one case, it cannot be generally true. Therefore, while conduting case studies, it is crucial for the selection of cases which are critical (Creswell 2012; Flyvbjerg 2006; Voss et al. 2002). Moreover, the implementation in case study research does not provide systematic guidelines and is believed to be biased as being influenced by the subjectivity of researchers (Creswell 2012; McComas 1998). In literature, there is even not always available for the information or data regarding about the verification and validation of case studies as Barth et al. 2011 revealed 37 per cent out of 71 articles reviewed in the international journal „Research in engineering design“ from November 2005 to November 2009 did not have any validation. Validation here refers to the justification of knowledge claims or confirmed theories as the result of case studies. Validation often goes along with verification, which is widely described as the distinction between „doing the right thing“ (validation) and doing it right“ (verification) (Isaksson et al. 2020).

Even though these concerns are present, but major objections to case study method are invalid as long as the essence of the case study method lies in its design, which is often not rigorously followed (McCutcheon & Meredith 1993; Teegavarapu et al. 2008). To realise the validity and effectiveness in the proposal of new HCD methodology, the established rigorous method protocol is adapted from Le Dain et al. 2013, Pederson et al. 2000, Seepersad et al. 2006, Teegavarapu et al. 2008, and Voss et al. 2002 to establish as Figure 2 .

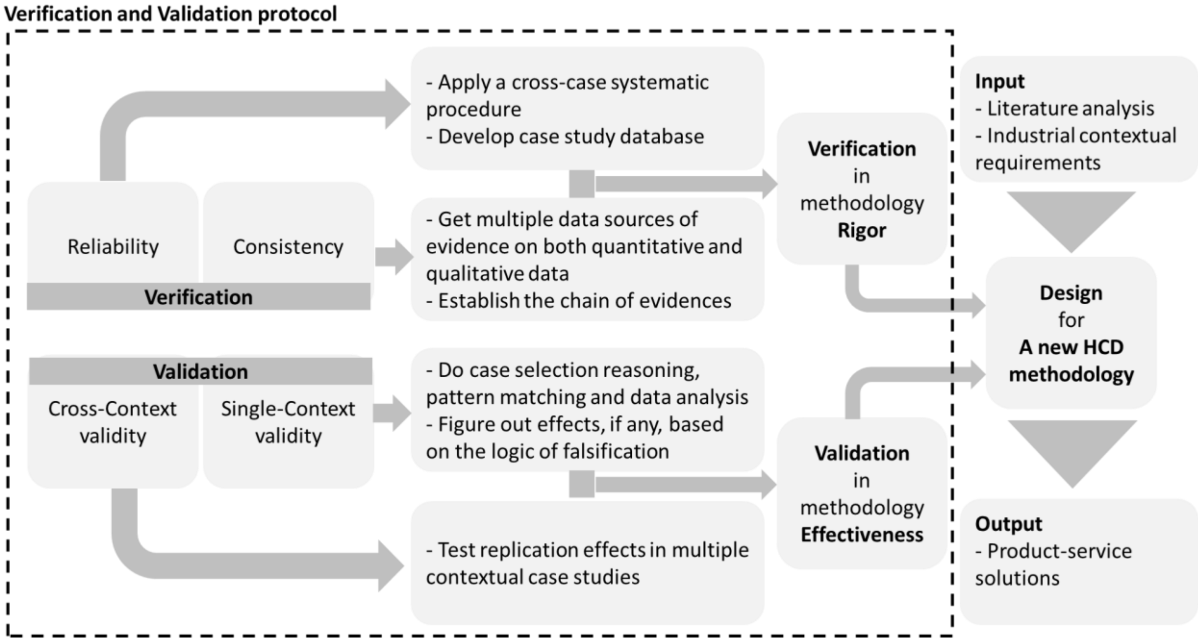

Figure 4 Validation and verification in research design for the proposed new HCD methodology

The design process starts with literature analysis focusing on the lessons learnt derived from case studies to capture the most prominent findings and limitations on existing processes of HCD as human-oriented approaches of servitization in the context of industry 4.0. Industrial contextual requirements are also defined and obtained via multiple sources, and one of them comes from the on-site experts in diverse disciplines and industries. Both academic and industrial inputs serve as starting foundation for the new design methodology. This methodology should be verified as an rigorous and systematic way to minimize research bias and validated as an effective methodology to claim knowledge and contributions in both research and industry.

To certify both the verification and validation, the research design will follow the well-defined protocol as Figure 2, begining at the establishment of reliability via the consistent implementation of procedure across case studies whose database are also collected and stored in coding systematic mannners. Multiple data sources of evidence on both quantitative and qualitative data are also defined, collected and connected to form the chain of evidences, resulting in the consistency during the implementation of case study design. This helps to remove any biases induced by researchers´ subjectivity (Flyvbjerg 2006; McCutcheon & Meredith 1993; Teegavarapu et al. 2008; Yin 2018). For the validation, the reasoning on the case study selection in a particular context and appropriate data analysis, such as pattern matching and quantitative analysis, needs to be provided as well. Besides, unexpected effects leading to the falls in design outcomes are also investigated for continuous improvements in the new HCD methodology. By following this, the single-context validity can be achieved and subsequently the advancement of robustness in the design methodology can be done by going through cross-context validity on the way that tests replication effects in multiple contextual case studies. By following this protocol, the objections to the new HCD methodology can be avoided, its validity and generability in various contexts can be tested. The following section clearly indicates the diverse digital manufacturing contexts will be used to develop the design methodology.

4. Research agenda

As a part of DiManD project in which industry 4.0 is mainly a focus point, three digital manufacturing contexts located in Europe are selected to represent the current status of industry 4.0 in manufacturing sector as described by Figure 3. Each industrial context has multiple case studies to reinforce the design validity of the new HCD methodology. The first context is given to a large enterprise specializing in the field of machining process, machinery design and manufacturing, and automated production systems for composite structural components. It operates in diverse sectors including aerospace, railway, automotive, energy, oil and gas, and metal forming. The second context is intentionally assigned to a small-and-medium sized enterprise providing designs and solutions for the manufacturing of containers via blow moulding technologies for food and household industries. Lastly, the application is also implemented on the advanced manufacturing demonstrator of an automated aerospace assembly line which is highly intelligent, configurable and embodies various components of cyber physical systems on which human acts as controlling activities.

Not only are real industrial requirements and specifications taken into account, but knowledge in literature combined with cross-domain researchers and industrial experts is gathered to realize full potential of the new HCD methodology.

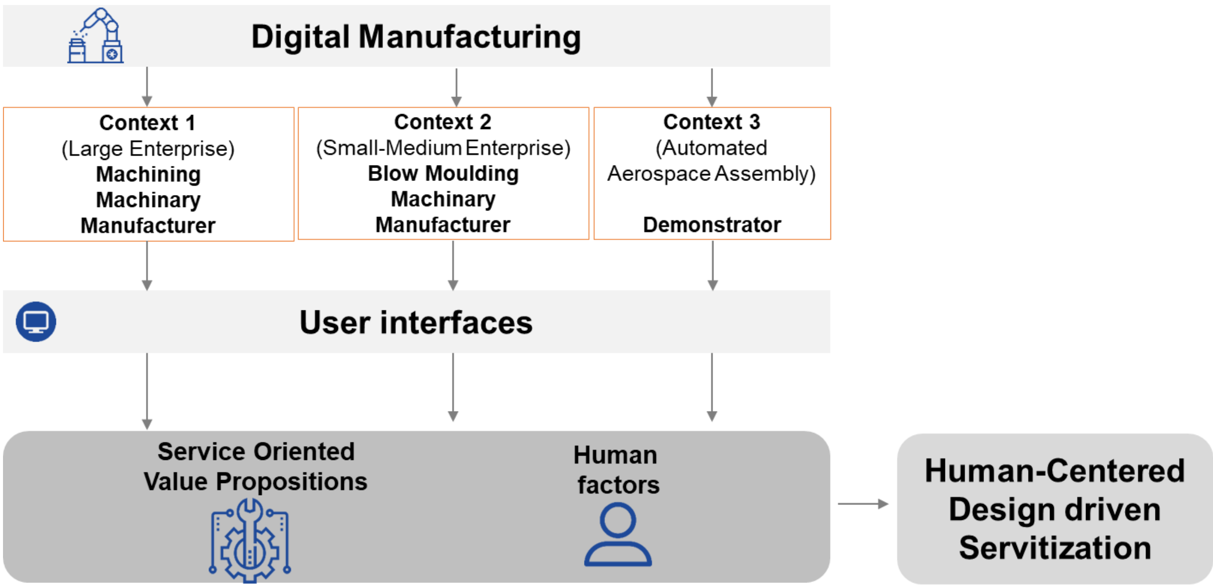

Figure 5 Collaborative research model

5. Conclusion

The transition of industry 4.0 has brought many advances in technologies and changes in economy and society as a whole. However, it also poses challenges in social-technological systems. One of the challenges is the direction of human roles in the transition in which servitization is one of the paths toward the enhancement of value propositions. Servitization itself has challenges from the lens of enterprise, stakeholder network, and lifecycle that may hinder the advancement of servitization. Even though increasing interests and studies have been witnessed to claim contributions in the path realization, but there is still a need in the development of a new design methodology to enable manufacturers pursuing the transition in servitization which requires an interdisciplinary to overcome the challenges and minimize the market failures.

This turns out that a collaborative research is appropriate for human-centred approach driven servitization in the context of digital manufacturing that constitutes the challenging problems due to its multidimensionality leading to the needs in the cooperation of cross-domain researchers and industrial experts. The DiManD research program is a collaborative platform for the interdisciplinary, cross-sectorial, and international perspectives across European countries, which aims to provide an advancement in both practical and scientific deliveries on the core of the industry 4.0 vision. Beyond the technical developments, developing a new appropriate method of HCD is one of DiManD deliverables, allowing manufacturers to create advanced product-services in Industrie 4.0 scenarios. The objective is to enable manufacturers to design and transform humans (users and customers), machines (products), and digital data systems, into marketable advanced product-service solutions in which design as a driver and enabler of human-centred innovation could complement Industry 4.0 offerings beyond technological innovation. To realise the full potential, the HCD methodology will be developed, verified and validated through the well-rounded protocol in diverse digital manufacturing contexts associated with multiple case studies. This paper provides the protocol for the purpose by overcoming usual objections of the case study design in order to gain the new HCD methodology driven servitization that is valid in various digital manufacturing contexts.

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Author(s):

Hien, Nguyen Ngoc, PhD candidate
Mondragon Unibertsitatea
Design Innovation Center (DBZ) - Faculty of Engineering
Loramendi, 4; 20500 Arrasate - Mondragón (Gipuzkoa), Spain.
nhneguyen@mondragon.edu

Ganix Lasa Erle, PhD
Mondragon Unibertsitatea
Design Innovation Center (DBZ) - Faculty of Engineering
Loramendi, 4; 20500 Arrasate - Mondragón (Gipuzkoa), Spain.
glasa@mondragon.edu

Ion Iriarte Azpiazu, PhD
Mondragon Unibertsitatea
Design Innovation Center (DBZ) - Faculty of Engineering
Loramendi, 4; 20500 Arrasate - Mondragón (Gipuzkoa), Spain.
iiriarte@mondragon.edu