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The study of co-design in the area of manufacturing

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Abstract. The study is devoted to the co-design concept which is not widely studied in the manufacturing industry area. The concept is just practiced but not theorized and not investigated enough, although it greatly deserves it because of its perspectives and advantages potential in the technology changes era. This study aims to present an investigation of literature views on co-design in manufacturing operations, with the comparison to service literature where it is widely discussed; the study also aims at in-depth investigations of co-design occurrences in two industrial cases of product development to understand their nature and circumstances. In addition, the influence of Industry 4.0 technologies and their coexistence with the concept of sustainability will also be strongly taken into consideration in the empirical part of this study. The process of the individualized production of the industrial line for animal food packing and cardboard packaging production has been studied according to case study methodology. The study demonstrates that co-design could contribute to bettering the process of new product development and achieving products more accurate for the final users' requirements. It goes hand in hand with one of the core ideas of sustainability, which is to have long-lasting products, exploited by the customer with a high level of satisfaction for a longer time. The study implies that the technologies of Industry 4.0 could support wider and more effective co-design exploitation by manufacturing entities.

Key words: co-design; manufacturing; sustainable production; Industry 4.0; simulation.

1. INTRODUCTION

As a widely known concept, sustainability brings many challenges magnified by the current intensive technological changes. Sustainability is a vibrant idea to meet the current needs of society without compromising the ability to also meet the needs of future generations [1, 2]. Generally, sustainability is about responsible and long-term thinking about production and consumption, and the use of resources; it affects the social sphere, economic sphere, and especially the environmental sphere [3]. Thus, the issues of manufacturing processes with their effective organization lie at the very heart of sustainability. Currently, a trend to re-orient enterprises towards the so-called mass customization of production [4, 5] is becoming increasingly intensive. Mass customization is about offering an efficient delivery of non-standard products, adapted to the specific needs of customers, sometimes at a higher price, which reflects the extra effort and costs covered by the manufacturer. The literature [6] states that the strategy of mass customization is the future of business. Additionally authors [7, 8] underline the importance of the potential improvement together with mass customization.

The mass customization strategy means the adaptation of products to the individual requirements of customers, consequently placing a strong emphasis on customer interaction along all the steps of product development. So, the issue of the design with the active participation of the user becomes crucial. Co-design itself has different meanings, but first of all, this is a process that thoroughly engages the customer in product development [9–11]. Co-design ensures products are much more tailored to the individual desires and needs of customers. Without a doubt, co-design has a positive impact on the product development process through the involvement of the main stakeholders in activities undertaken within this process beginning from the early stage of product development. However, across management literature, the concept of co-design is very widely explored regarding service operations as a means of closer and better cooperation with the customer, and as a method to engage him/her in value co-creation. At the same time, concerning manufacturing operations, there is a noticeable lack of conceptualizations, methodologies, and in-depth studies. There are several typical areas of the manufactured product development process where the end user of the product is involved. However, this involvement has merely been studied in the context of value co-creation and merely conceptualized. Simultaneously, the co-design concept applied to manufactured products brings many specific benefits. Definitely, co-design must be investigated in the context of the product development process as it is conceptualized by the literature and technological changes referred to as Industry 4.0.

Additionally, when considering the changes occurring in industries, we need to underline the meaning of the product, especially now in the era of servitization, and navigate an environment in which good products are even disappearing. Nowadays, customers more often aim to buy and consume market products that have a heavy product component/core along with several services accompanying this [12, 13]. Noticeably, the boundaries between services and goods are less designable and will be increasingly less recognizable as technology changes and Industry 4.0 will likely influence all sectors of the economy.

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The business model called "product as a service" is increasingly being adopted by companies. So, in such circumstances, the research on co-design regarding manufactured product development looks important and promising.

This study aims to review the literature on co-design regarding service products, and compare them to manufactured ones; afterward, it will conduct an in-depth investigation of co-design occurrences in two industrial cases of product development considering the existing means of cooperation and information exchange with final users, and finally to conceptualize possibilities of further co-design development by the utilization of a technology named as Industry 4.0, including the benefits that can be achieved. The empirical study will be primarily focused on a comprehensive understanding of the customer role within the product development and execution processes. This step is perceived as the crucial one because it facilitates reliable and accurate conceptualizations in further stages. The empirical investigation also considers the sustainability issue, particularly when it comes to new technologies applied to the field of company-customer interactions striving for the superior design of the product.

2. VIEWS ON PRODUCT DEVELOPMENT PROCESS AND CO-DESIGN

The manufacturing product development process according to the literature is a lengthy process which starts with a strategic product plan or market requirements analysis and ends with the product withdrawal [14–16]. Authors [17] mention the four steps model of the product design process. Step one – product ideas generation and the assessment which follows. Step two – product concept design and further development. Step three – testing the product and trials, including the prototype. Step four – launching the manufacturing process of the product. A Big Picture model [15] proposes several product development processes imposing a holistic and integrated view on this issue. It is characteristic of several paths considering uncertainty and risk, dealing with gathering appropriate pieces of information, and finally different types of innovations [18]. It is symptomatic that the design activities perceived as creations and innovations usually consist of such activities as the setting of product assumptions, modelling of the product, prototyping, testing, and preparing the product for the manufacturing phase [15, 16, 19].

When carefully analyzing product development process conceptualizations proposed in the literature, one noticeably sees a tendency of limited feedback loops at the junction in between the steps. They make the whole process more costly and more time-consuming. This is suggestively presented in the stage-gate process model by Cooper [20, 21]. The stage-gate model is based on the assumption of a superior need for formal and structured reviews between stages to ensure that the design meets the requirements, and it is ready to be transferred to the next process step. Another literature model [22, 23] is focused on knowledge management and treats it as a crucial element of product development, combining knowledge domains of companies and customer-appropriate capabilities are obtained to successfully create an innovative product.

Co-design is another fundamental concept for this study. For its understanding, it is advisable to start with the service approach and the co-creation concept developed in the service science area. The concept of co-creation is very widely discussed by service scholars; however, it is general in its sense and so applicable to any kind of business activity. According to Prahalad and Ramaswamy [24], value creation itself and the value of co-creation with customers is the essence of any business activity. Moreover, it is closely tied to business competitiveness. Other scholars [25] mention that any kind of business activity is service-centric, even if it is mentioned as a manufacturing one because co-creation between parties and collaborative activities constitute the basis of market exchange. Wind and Rangaswamy [26] state that "what can we do for you?" is the traditional business mindset, while this is being replaced with another approach, which could be expressed as "what can we do together?" In the marketing world, this paradigm change is the foundation of so-called relationship marketing.

The terms "co-producer, co-designer, and co-developer" are used when mentioning customer participation in the service process [27, 28]. According to Payne *et al.* [29], the service process in the part in which the customer participates is a place to conduct a successful co-creation and it happens during interactions between two parties: a service provider and the customer. Eichentopf *et al.* [30] state that the responsibility for crucial service process outcome characteristics, namely the quality and added value, are even shared with customers who are participating in the process. The knowledge factor seems to be the most important in the whole of co-creation [29, 31], and co-creation within the service process is mainly about gathering knowledge from customers, together with detailed customer expectations, along with customized service provider actions and winning customer satisfaction. In the literature, there are studies examining the knowledge approach regarding service co-creation. One such study is by Chang *et al.* [32], who examined the knowledge management concept and discovered several indispensable conditions for the effective co-creation of service innovations. They revealed *inter alia* that service providers need to develop and practice measures for involving customers and set a user-friendly platform for facilitating the involvement of customers.

Finally, the co-design concept is perceived in the literature as a component of co-creation where the customer in this instance is engaged in the design stage of the service. Authors also name this phenomenon "collaborative design" [11]. However, first of all, this is an opportunity to exploit the unique and hidden needs of the customer [33]. Others mention that co-design is a strategy enabling users to contribute with their particular knowledge and skills to new service products [34]. The customer can contribute to all stages of product development, from the raising of the idea to the sending of the product to the market. Customer engagement with co-design can significantly improve the value of the product and the value proposition, and as a concept in the marketing literature is more likely to meet the end user's desires. It needs to be underlined that service literature features studies on the practical implementation of the co-design procedure in the service product development process, as examined

by Hurley *et al.* [34]. Nevertheless Ostrom *et al.* [35] state a limited understanding of co-design and not sufficient knowledge of the advantages and benefits of co-design in the service sector.

Co-design as a management concept, and even as a notion itself, is not widely exploited by manufacturing literature. However, some closely related concepts exist, and they have great importance. One of them is the concept of customer-driven innovations [36], which is mainly focused on technology changes and having the customer in the center whilst working on new technologies and/or breakthrough products. Being an important concept in the world of dynamic technology changes, it does not offer much in terms of the practical product development process with active customer participation. At the same time, service studies [37, 38] determine several challenges for research on the co-design issue which need to be explored and possibly developed regarding manufactured product development. Fundamental issues such as practical organizational methods are important when establishing close cooperation with customers aiming at successful product/innovation outcomes. These are the main intentions of this study. First, it seeks to understand the existing means of cooperation with customers within the product development process. Second, it aims to explore the potential for more advanced and better customer engagement in this process.

3. STUDY METHOD

The study aims to present an in-depth understanding of some of the phenomena that exist in a business organization. For this purpose, a qualitative investigation strategy has to be employed. Among some possibilities, the case study methodology looks to be the most convenient and most beneficial one. According to Baxter and Jack [39], the case study methodology facilitates the exploration of an interesting phenomenon along with the context and many kinds of data from different sources. The insight from multiple viewpoints and perspectives is appropriate for this method. Rowley [40] states that the case study method can be applied in many ways; however, the exploratory aim is the most typical – this means understanding a phenomenon under its real conditions. Another fundamental aim of a case study is to build a framework for new theories and/or new concepts. Both these aims are applied in this study.

The methodology employed in this study assumes two research phases. The first one is the comprehensive analysis of the process of product development in two business organizations. All the process steps will be identified, and special attention will be devoted to interactions with the customer, including information exchange, obtaining knowledge, asking for opinions, etc. This is to examine and understand the role of the customer in the product development process in the considered organizations. The cases to be examined are characteristic of non-standard products where the role of the customer must be substantial. One of the studied organizations delivers industrial production machine sets for food processing, and the second one produces printing packages for premium recipients. Further characteristics of the studied organizations will be presented in the next part of the study.

As mentioned above, the current state of co-design will be determined and clarified, and the second phase of the study is on the conceptualization of the possible state of co-design in these two product development processes. This stage aims at systematic conceptualizations of the possibility of the co-design concept deployment regarding diagnosed processes obtaining more benefits from deep customer participation in the process. In this stage, an assumption is considered that the huge potential of co-design deployment is in new digital technologies, namely Industry 4.0. All the tools, techniques, and system features possible to be employed in the process are considered along with the utilization of such technologies, e.g. virtualization of manufacturing, real-time data exchange, digital simulations, digital twins, fast prototyping, and so on.

Several visits have been conducted to each of the investigated companies, and the process of product development has been comprehensively analyzed. The field investigation process includes documentation analysis and direct observation by investigators along with unstructured interviews with company managers and operators. The conceptual phase has been supported by unstructured interviews and open talks with engineering staff and managers to obtain as many opinions as possible and solicit feedback regarding the methods of co-design deployment.

4. INDUSTRIAL MACHINES MANUFACTURER

The first analyzed case is a company that provides non-standard technologies to producers in the food industry. The role of co-design was investigated here in the example of the development of the technology of an industrial production line for packaging pet food. The company is a technology supplier and provides comprehensive services from design through manufacturing, and assembly at the customer's site, to product servicing for a specified period. It should be emphasized that in this case the terms technology and product will be used interchangeably because from the point of view of the researched company (producer/technology provider) the process of developing the technology of an industrial production line is analyzed, while from the point of view of the customer (buyer/recipient of the technology) the developed technology is a product [41].

The co-design of a new product in the form of a line for packaging pet food was analyzed from the moment the customer established contact with the tested company, until the implementation of the technology at the customer's site, as shown in Fig. 1. Blue color marks the activities in which the customer was involved, thus participating in co-designing a new product. The dashed line marks the activities in which it is possible to use Industry 4.0 tools.

The beginning of the product development process was the submission of an offer inquiry by the customer, in which the initial functional requirements of the product were specified. After their detailed analysis, the technological and design requirements were defined, which were used in the next step to develop a parametric model. A 3D model of the production line was created in the CAD environment, which is a digital equivalent of the designed product. This initiated a period of intense cooperation between the producer and the recipient, including

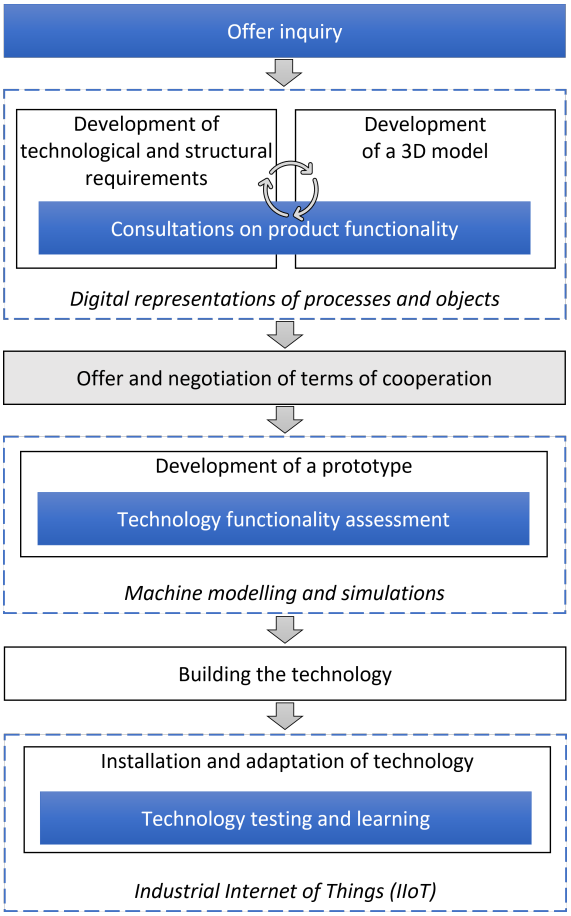

Fig. 1. The process of co-design a line for packaging pet food using Industry 4.0 tools

several consultation loops on refining the functionality of the product, during which subsequent models and computer simulations of the operation of the production line were created. Thanks to this, it was possible to clarify the assumptions of the technology and create a product ideally suited to the customer's needs. The activities conducted by the company can be improved and accelerated thanks to the use of tools offered by Industry 4.0. At this stage, a good solution seems to be the digital representation of processes and objects (digital twins), which allows you to quickly and precisely analyze the functional parameters of the designed product [42].

The results of the conducted activities were reflected in the offer prepared by the company, which contained all detailed information about the product and related costs, and thus the terms of further cooperation, which depend on the results of negotiations with the customer. This is an important stage for the company, as it may involve the risk of losing the customer (resignation from further services), and thus no compensation for the costs incurred so far. Obtaining the customer's approval and concluding a commercial contract begins the period of formal cooperation and the start of the production process.

The next stage of co-design can be observed during the development of the production line prototype. This is the stage in which the first version of the technology is created based on a previously developed 3D model. It contains the necessary modifications to the technological and design requirements that were not visible from the parametric model level. The functionality of the prototype is tested and analyzed under simulated operating conditions on the premises of the production plant. Thanks to the use of simulation tools, you can also involve the customer in this process, without the need for his physical participation. VR/AR technologies used in simulations allow users to "see and test" the finished product before it is produced, and the creation of a digital twin allows them to check its functionality. Unlike traditional computer simulation, an important feature of VR/AR is the constant presence of the user in a virtual environment. In the case of the production line being created, VR technology will help to place the device model created in the CAD system, in any virtual environment, next to other facilities available to the customer and to simulate the conditions of its work in conjunction with other peripheral devices, if necessary [43, 44]. However, for the final presentation of the project, AR technology can be used, thanks to which it is possible to visualize a virtual object in a real spatial context [45] and verify the design requirements. Thus, the customer assesses the functionality of the product using the tools enabling machine modelling and simulations and, if necessary, reports the need for modifications. The role of the customer at this stage is therefore to approve the functionality of the prototype. Thanks to this, the manufacturer will be able to complete the product (technology) design stage and start the production stage.

During the construction of the technology, all technical problems are solved, optimization activities are conducted as well as other activities that are necessary for the proper operation of the animal feed packaging line. This requires the coordination and integration of works performed by constructors, mechanics, automation engineers, and electricians. At this stage, the co-design of the company with the customer was not observed, but their cooperation was intensified after the installation of the finished product at the customer's premises.

The installation of the industrial line at the customer's premises is from the customer's perspective tantamount to the implementation of the product, while from the manufacturer's perspective it is the beginning of the testing phase in real conditions. This stage can be defined as technology co-design at the production stage, in which the manufacturer accompanies the customer for a specified period during tests (product use) and at the same time provides him with technical support during the "learning" of the technology. The manufacturer's task is to conduct the necessary training and adapt the product to the real needs of the user, already identified during work in the production plant, including necessary modifications and repairs. Supported activities can be provided by the involved parties with integrated tools, sensors, and software that will provide full insight into the production processes and the ability to control them, which can be defined by the common slogan Industrial Internet of Things (IIoT) [46]. Thanks to this, the manufacturer can solve some problems remotely. This approach allows the surveyed company to fit into the sustainability concept. Thanks to co-design, the customer receives a product ideally suited to their needs.

5. INDUSTRIAL MACHINES MANUFACTURER

Co-design was also the subject of research at a printing company. The production process of a refined packaging cardboard product intended for manufacturers of branded products from the cosmetics and food industry was analyzed. It included offset printing, die-cutting, hot-stamping, automatic folding, and various handmade finishing operations. The case study investigated the scope for co-design within the new product development process. Attention was paid to the potential of using Industry 4.0 tools in this process. It should be emphasized that the production of packaging has, to some extent, the features of subcontracting, but the printing manufacturer has a large impact on the product because it adjusts and modifies it in terms of technological requirements and optimizes the quality and price effects for recipients, at the same time taking care of sustainability [41]. The packaging product development process, taking into account cooperation with the customer in the field of product design, is shown in Fig. 2. Similarly, to the previous section, activities in which the customer was involved are marked in blue, while the dashed line indicates activities in which it is possible to use Industry 4.0 tools.

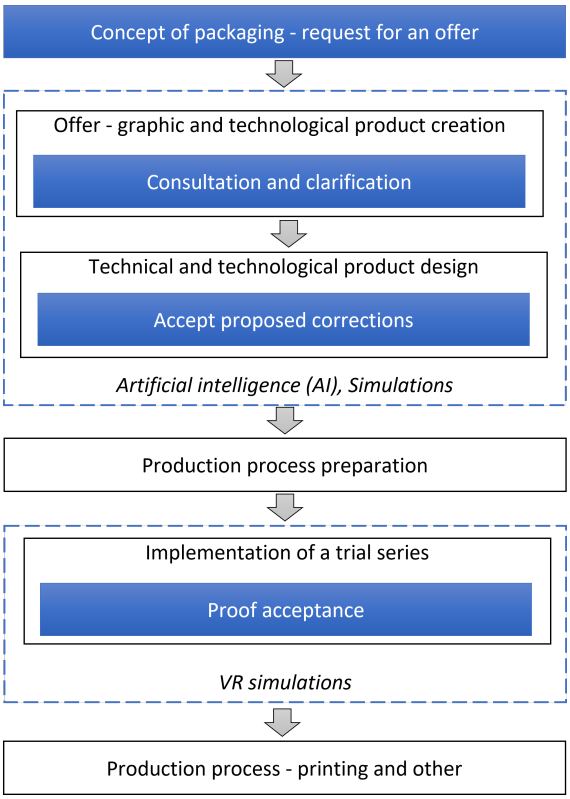

Fig. 2. The process of co-design cardboard packaging for printing with the use of Industry 4.0 tools

The analyzed process begins with the customer (recipient) reporting to the printing company (producer) with the concept of the packaging graphics that they need for their products. It is also the stage of the inquiry, as a result of which the manufacturer performs a preliminary analysis of the requirements and begins activities related to the preparation of the price offer.

As part of this activity, there is intense cooperation between the customer and the manufacturer. The company prepares several variants of the packaging concept with an indication of the production technologies that can be used. The variants are analyzed by the customer in terms of graphics and functionality and then sent back with proposed changes. This is the stage of creation and consultation aimed at clarifying the customer's expectations, thanks to which in the further stages of cooperation it will be possible to minimize the risk of errors and complaints. The result of the activities is the preparation of a business offer containing the terms of cooperation and packaging production costs. After accepting the offer and concluding a business agreement, the company begins to develop technical and technological assumptions for the product, during which minor changes may occur that require customer approval. At this stage of co-design, tools based on artificial intelligence, enabling product simulations, for example, related to the selection of patterns and materials, can be a great support for the parties involved [47]. In addition, such systems can support customers in the self-preparation of products by providing them with "automatic" guidance on printing products. AI-powered solutions will help customers learn from other procurement experiences and then intelligently guide them through the product preparation process. Moreover, simulations may be supplemented with augmented and virtual reality technologies facilitating "seeing" the finished product, which is of great value both from the marketing point of view and from the perspective of building relations with the customer and also accelerates the decision-making processes.

The next stage of the process is to prepare the packaging production process. The manufacturer cooperates here with subcontractors responsible for the supply of matrices but does not involve the customer in it. The result of the activities is setting the machines and selecting the appropriate printing parameters. One of the key production processes requiring customer involvement is printing, as a result of which all the visual features of the product are obtained. This step, especially in the case of new products, requires customer acceptance in terms of color, print quality and efficiency, product appearance, and other parameters important for the customer. The available virtual reality simulation tools can support the process as they offer the possibility of influencing the user's visual and hearing senses. In addition, they also provide tactile feedback through the use of tactile devices presented in the literature [43, 44], which facilitates effective and quick implementation of changes in the project and contact with the customer. Obtaining the final customer approval allows the manufacturer to proceed with the production process and the preparation of finished products, which at the same time allows them to complete the process.

6. CONCLUSIONS

Traditionally, the product development process requires manufacturers to operate in conditions of limited access to information on the expectations of potential users, which may result in the preparation of solutions that do not meet market needs and are not accepted by customers. The solution to this problem

may be the use of the concept of co-design, which is increasingly popular in the literature and implies the customer's involvement in various stages of the process. While it has already been disseminated in the service sector, the scientific literature does not pay much attention to this issue in the manufacturing sector, although the customer is also involved in product development in the industry. This study shows that co-design is an important issue in manufacturing and has great potential for the future, so further theoretical and conceptual work as well as designing organizational and process solutions are necessary.

A case study conducted at work in two companies operating in the B2B market allowed us to trace the co-creation of a new product. In the analyzed processes, the presence of the customer is noticeable at almost every stage of the design and production of a new product, which contributes to the creation of more personalized products. There is also a noticeable effort to support cooperation with modern technologies. The employed Industry 4.0 concept makes it possible to support the integration and connection of existing physical objects and processes at different stages of the product and service life cycle and thus can create a completely new potential for co-design. It is estimated that the use of tools based on modelling and simulations might lead, first of all, to lowering the costs of the product development process and improving the quality of manufactured products. At the same time, it could provide a shorter reaction time to process disturbances and introduce changes, which will increase the personalization of the product and avoid costly mistakes. It will also shorten the implemented decision-making processes. It can therefore be expected that co-design supported by Industry 4.0 technologies should lead to an improvement in the competitiveness of products. However, the mere use of Industry 4.0 tools does not guarantee success. To understand their value, it is first necessary to obtain knowledge about the product and its origins. However, it should be emphasized that the adopted research method and scope of data collected did not allow us to accurately estimate the costs of implementing Industry 4.0 technologies as well as the adversities related to organizational culture, knowledge and skills of employees in the field of new technologies.

In addition, the product preparation processes analyzed in the work clearly show that probably the most important factor in co-design is good communication between the parties involved in the process (producer and customer). It should primarily concern the effectiveness of communicating visual impressions, concerning the parameters of the designed products, among other things, which will facilitate interaction and creative teamwork, and thus contribute to the emergence of innovative solutions. The use of Industry 4.0 tools in combination with co-design shows a very high potential for positive benefits. However, Industry 4.0 is still an area of wide-ranging concepts and experimental work, lacking extensive empirically proven and stable solutions.

There is a great demand for research and implementation work in this area, extended by the use of these solutions in the field of broadly understood co-design of industrial products. It seems that there are a lot of research challenges in front of co-design in the manufacturing process, along with the utilization of Industry 4.0 technologies. Future research should consider first the concept itself, it needs further elaborations including building a comprehensive theoretical background, such as with the existing service sector, including the taxonomies and references to different industries. Second, it should consider the practical tools and techniques to involve other parties in the design process with customers in the first place and additionally provide several possible advantages for a business entity. Third, another important issue is the influence of co-design on the competitive advantage of manufacturing companies. Fourth, a separate issue is the development of procedures and routine activities as well as building organizational knowledge to facilitate co-design within an organization. Fifth, the comprehensive scientific work on the co-design development supported by new technologies is also of primary importance. Finally, how co-design, along with emerging technologies, can support the growth of manufacturing and its sustainability.

To conclude, co-design could contribute to a better new product development process along with products much more accurately concerning the final user requirements. It goes together with one of the core ideas of sustainability, which is to create a long-lasting product, exploited by the customer with a high level of satisfaction for a longer time. The study has considered co-design along with emerging technologies and is a demonstration of how these technologies can contribute to one of the pillars of sustainable business development. The technologies of Industry 4.0 in the demonstrated cases are a real facilitator of a business shift toward sustainability.

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