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Systematic Review

Operationalizing Mass Customization in Manufacturing SMEs—A Systematic Literature Review

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Abstract: With the emergence of the fourth industrial revolution, market globalization, and growing customer demands, companies are being forced to rethink their ways of doing business to remain competitive. Small and medium-sized enterprises (SMEs) in the manufacturing sector must also adapt to personalized customer demands. This context forces companies to migrate towards mass customization. The literature proposes several strategies for adapting to this new paradigm but does not offer an implementation sequence for successfully operationalizing mass customization within an SME. Based on a systematic review of the themes surrounding Industry 4.0 and mass customization in the literature, this article aims to highlight the different strategies and factors to be put in place to successfully implement mass customization. This research reveals the lack of a prioritization of factors that favour the operationalization of mass customization. Lastly, the literature does not detail the tools and their levels of maturity resulting from the factors to be implemented. This article highlights the gaps in the literature related to mass customization.

Keywords: Industry 4.0; SME; agility; modular design; mass customization; modularity; digital transformation; supply chain

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1. Introduction

The global market has changed significantly in recent years. According to a 2016 report by the United Nations, the number of multinational companies has increased ten-fold over the past five decades [1]. Small and medium-sized enterprises (SMEs) are an important component of most industries and manufacturing value chains [2]. SMEs in the manufacturing sector are important contributors to regional economic development, especially since they are considered a real engine of development due to their geographic reach, their employment intensity, and their growing number [3]. The Organisation for Economic Cooperation and Development (OECD) defines SMEs as companies with fewer than 250 employees and an annual turnover of less than EUR 40 million [4].

With the goal of enabling technology interconnectivity, Industry 4.0 is increasingly put forward as the new paradigm for increasing manufacturing companies' productivity, agility, and sustainability [5]. First introduced in 2011 in Hannover, Germany, Industry 4.0 aims to maintain a competitive advantage following the emergence of technologies in the industrial context [6]. These exponentially growing technologies include smart sensors, artificial intelligence (AI), robotics, nanotechnology, additive manufacturing, big data, the cloud, and the Internet of Things [2]. The digital transformation driven by Industry 4.0 seeks to connect machines to factories, suppliers, and humans with elements that enable control, monitoring, optimization, and autonomy [2,7]. This interconnection makes it possible to create intelligent networks, factories, manufacturing, and value chains [2]. In the context of the fourth industrial revolution, the emergence of new technologies and their connectivity results in the development of new processes, products, and services [8]. In addition, the skilled labour shortage is a more significant issue than ever in the manufacturing sector [9].

Consumers still want products tailored to their preferences, tastes, needs, and lifestyles, which forces companies to achieve high standards in meeting customer demand [10].

This context of market globalization, the emergence of new interconnected technologies, labour scarcity, and personalized customer demands is forcing companies to review their business models [5]. Mass production is no longer appropriate for meeting the new demands of the current context [5]. Customization is therefore an avenue for meeting customers' needs [11]. However, as stated by Cannas, Masi, Pero, and Brunø [11], the transition from pure customization (engineer-to-order) to mass customization is complex and requires reducing variety to achieve customizable mass production. Pure customization (engineer-to-order) entails high manufacturing costs [11].

To meet the growing personalized demand, there is room for a paradigm shift in production by moving more towards customized mass production adapted to customers' needs [10,12]. Faced with an increasingly volatile, uncertain, complex, and ambiguous (VUCA) environment, it is important for organizations to adapt to the changes brought about by this context [13]. Agility is therefore essential in such an environment [13,14].

Furthermore, in order to evolve competitively in this context, organizations must innovate to find ways to offer these customized products in a responsive manner [13]. Thus, in order to meet the new expectations of customers in a VUCA environment, companies must be more agile and responsive to increase their competitiveness in the face of personalized demand [5]. When SMEs in the manufacturing sector are competitive, it favours the regional economy, generating jobs and stimulating economic growth and the development of the manufacturing industry [15].

Based on this need for agility, the literature discusses ways in which Industry 4.0 and distributed networks can operationalize the requirements of mass customization [16,17]. However, companies are not adequately equipped to undertake the shift to Industry 4.0 [5]. Unprepared and under-resourced small and medium-sized enterprises (SMEs) are slow to make the digital transformation to mass customization [18,19]. This inability to undertake the digital shift implies a lack of understanding of the concepts of Industry 4.0, agility, and mass customization [18]. In this regard, no detailed and validated strategy for operationalizing mass personalization and increasing SME agility currently exists.

This article presents a systematic review of the literature to highlight the importance of establishing such a strategy. To address the need to migrate to mass customization, this study proposes the success factors to be put in place based on a systematic review of the literature on the topics surrounding mass customization to establish an operationalization strategy. This literature review reveals the gaps in the implementation of mass customization within SMEs in the manufacturing sector. The results of this study may offer solutions to facilitate the implementation of such a production. This article is part of a larger research program on the development of strategies to implement Industry 4.0 in a mass customization context in manufacturing SMEs.

The remainder of the article is organized as follows: Section 2 presents the methodology used for the literature review. Section 3 presents the results of the literature review. Section 4 discusses the proposed success factors. In the final section, the development of the strategy is discussed.

2. Research Methodology

A literature search was conducted to identify existing research on personalization in the context of Industry 4.0 in SMEs. A search on SCOPUS targeted several relevant scientific articles, scientific reports, and conference papers related to personalization, Industry 4.0, and SMEs. Figure 1 details the steps of the PRISMA methodology used to cover the breadth of scientific knowledge available on the topic.

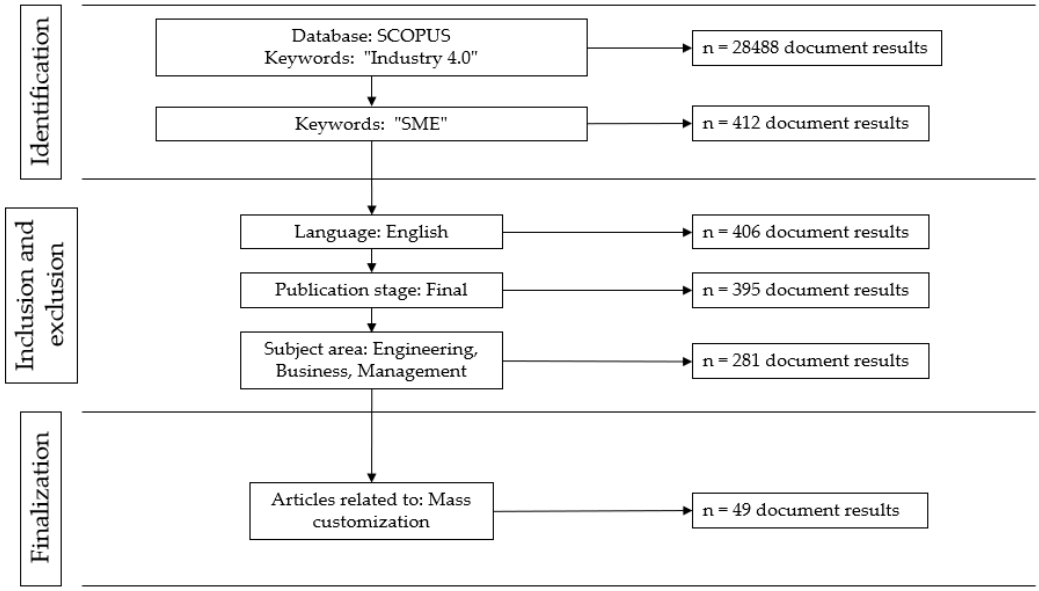

Figure 1. Systematic literature review using the PRISMA methodology.

As can be seen in Figure 1, this literature review concerns a total of 49 publications. Using the SCOPUS database and "Industry 4.0" as the keyword, a total of 28,488 publications were returned. By adding "SME" as a keyword, a total of 412 publications were returned. By adding "English" as an inclusion and exclusion criterion, "Final" as the publication stage, and "Engineering, Business, Management" as the activity area, a total of 281 publications were filtered. Finally, by finalizing the search by sorting the articles related to mass customization, a total of 49 publications were returned and could be analyzed. This literature review was then expanded by analyzing each publication, which in turn, referenced other publications.

Figures 2 and 3 show profiles of the results using the exclusion and inclusion criteria of language, stage of publication, and field of activity. The items included in the research are represented in green.

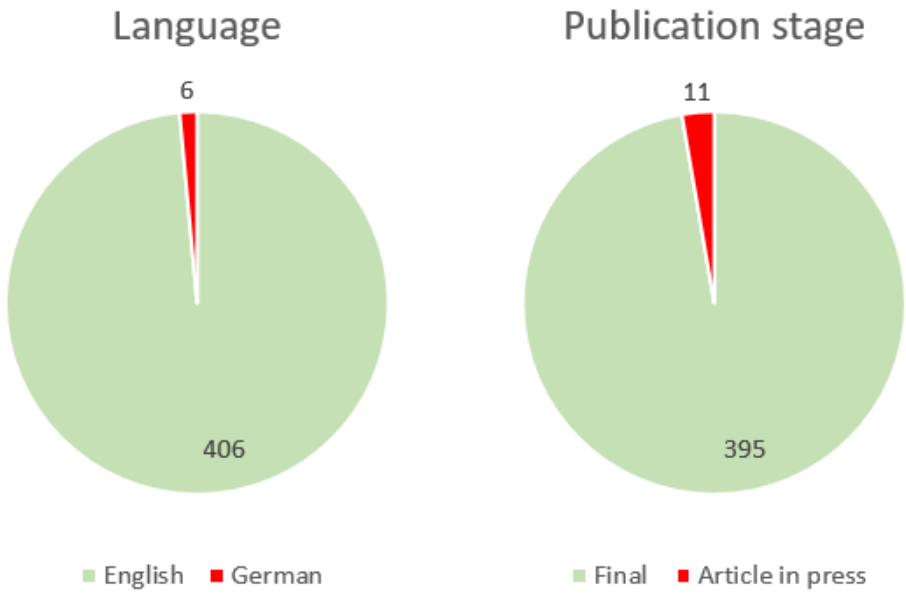

Figure 2. Inclusion and exclusion criteria: language and publication stage.

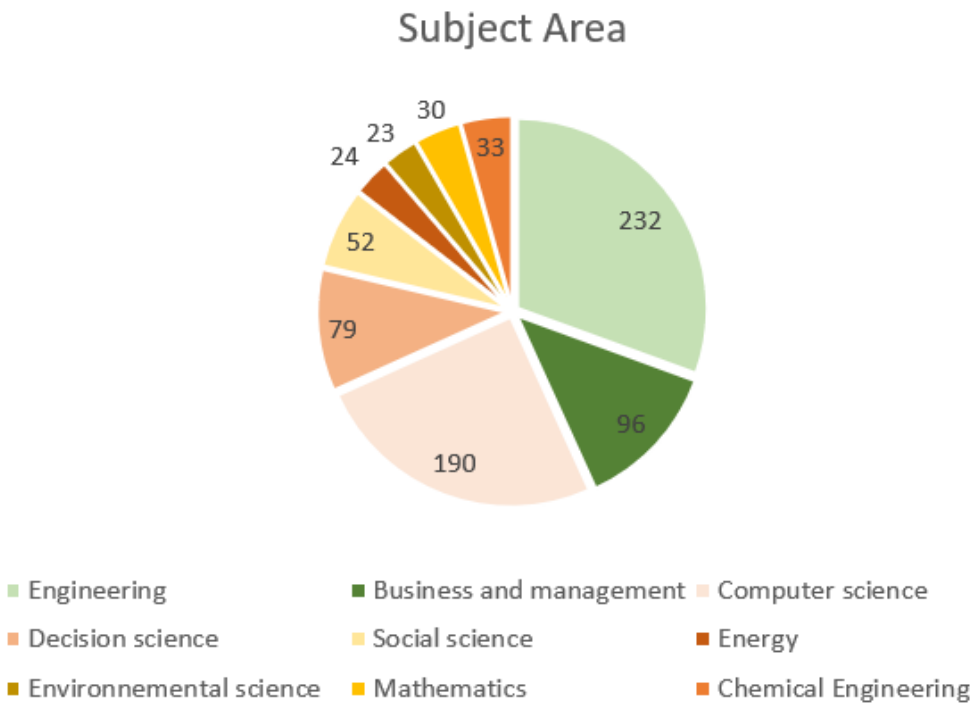

Figure 3. Inclusion and exclusion criteria: field of activity.

Figure 4 shows the distribution of publications used in this literature review by year from 2017 to 2023.

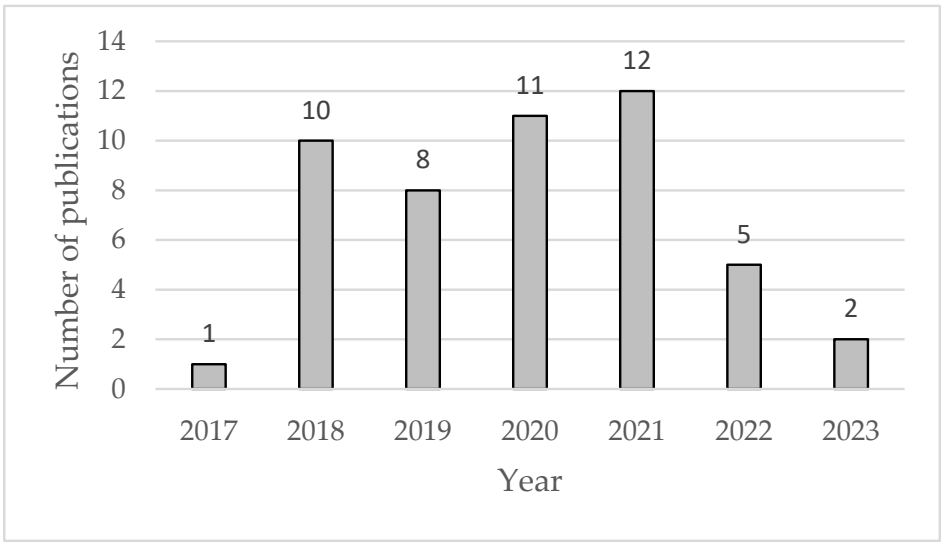

Figure 4. Number of publications per year of this literature review.

In addition, Table 1 details the sources of the publications in the literature review. The names of the sources and the number of publications per source are presented.

Table 1. Sources of publications in the literature review.

Source	Number of Publications
2020 IEEE Student Conference on Research and Development	1
2021 IEEE International Conference on Engineering, Technology and Innovation	1
Analyzing the Impacts of Industry 4.0 in Modern Business Environments	1
Big Data in Small Business: Data-Driven Growth in Small and Medium-Sized Enterprises	1
Computers in Industry	2
Energies	1
Expert Systems with Applications	1
IEEE Engineering Management Review	1
IEEE International Conference on Emerging Technologies and Factory Automation	1
IET Collaborative Intelligent Manufacturing	1
Industry 4.0 for SMEs: Challenges, Opportunities and Requirements	2
International Journal of Computer Integrated Manufacturing	1
International Journal of Mechatronics and Applied Mechanics	1
International Journal on Interactive Design and Manufacturing	1
Journal of Computational Design and Engineering	1
Journal of Intelligent Manufacturing	2
Journal of Manufacturing Systems	2
Journal of Manufacturing Technology Management	1
Journal of Risk and Financial Management	1
Journal of Science and Technology Policy Management	1
Lecture Notes in Information Systems and Organisation	1
Lecture Notes in Mechanical Engineering	3
Management and Production Engineering Review	1
Managing Technology for Inclusive and Sustainable Growth	1
Operations Research and Decisions	1
Procedia Manufacturing	4
Proceedings—2018 6th International Conference on Enterprise Systems	1
Proceedings of International Conference on Computation, Automation and Knowledge Management	1
Proceedings of International Conference on Computers and Industrial Engineering	1
Proceedings of the 20th International Conference on Engineering and Product Design Education	1
Proceedings of the International Conference on Industrial Engineering and Operations Management	1
Sinergie	1
Springer Proceedings in Business and Economics	1
Studies in Systems, Decision and Control	1
Supply Chain Management	1
Sustainability (Switzerland)	2
Technological Forecasting and Social Change	1
TEM Journal	1
Thunderbird International Business Review	1

3. Literature Review

3.1. Industry 4.0

Industry 4.0 is now a popular research topic in the scientific field, but one question keeps recurring: how can it be implemented successfully? In their work, Sony and Naik [20] examined how to successfully implement Industry 4.0 in companies. At the end of their study, based on a literature review, Sony and Naik [20] were able to highlight the importance of having a strategy adopted by all members of the company and the need to have clearly established management procedures as well as the need to review products, processes, and IT tools. Hoyer et al. [21] sought to use a literature review to establish a knowledge base to guide future research to better understand the complexity of Industry 4.0. The importance of using IT tools, the processes in place in the company, and the characteristics of the company as well as the shared vision of the company's actors were underlined as being factors that can influence the successful implementation of Industry 4.0. However, although this study used a literature review to target factors that have an impact on the successful implementation of Industry 4.0, this study put forward the idea that the factors are interrelated without knowing the extent [21]. The authors suggested that future research should focus on assessing the importance of these factors [21].

Moreover, Ghobakhloo et al. [22] used a systematic literature review to present a comprehensive study of the factors that could affect the adoption of Industry 4.0 technologies in SMEs. With the objective of highlighting the main technological, organizational, and environmental determinants of Industry 4.0 technology adoption in SMEs, the study conducted by Ghobakhloo, Iranmanesh, Vilkas, Grybauskas, and Amran [22] was a systematic review of the literature. By targeting 37 publications using a systematic review related to Industry 4.0 technologies, the study targeted 8 technological determinants, 11 organizational determinants, and 8 environmental determinants favouring the adoption of Industry 4.0 technologies. Figure 5 details the different determinants. These determinants make it possible to define important concepts to be considered to promote the implementation of Industry 4.0.

The study highlighted the determinant in each category most frequently cited by the different authors as facilitating the implementation of Industry 4.0 technologies in SMEs [22]. Table 2 details the authors who targeted the favourable determinants for implementing Industry 4.0 technologies within an SME. Table 2 shows the determinants identified as most important in each category by the authors.

Table 2. Determinants favouring the implementation of Industry 4.0 technologies within an SME.

Success Factors	Perceived Benefits of Implementing Industry 4.0 Technologies	Digital Knowledge	External Support
Huang et al. [23]			X
Chatterjee et al. [24]	X		
Somohano-Rodríguez and Madrid-Guijarro [25]		X	
Ghobakhloo and Ching [26]	X	X	
Hopkins [27]		X	
Horváth and Szabó [28]	X		
van Lopik et al. [29]		X	X
Ratnasingam et al. [30]	X		
Ghobakhloo and Iranmanesh [31]		X	X
Stentoft et al. [32]	X		

Table 2. *Cont.*

Success Factors	Perceived Benefits of Implementing Industry 4.0 Technologies	Digital Knowledge	External Support
Moeuf et al. [33]		X	
Pech and Vrchota [34]		X	
Garzoni et al. [35]	X		X
Türkeş et al. [36]	X		
Arcidiacono et al. [37]		X	
Cimini et al. [38]		X	
Ali et al. [39]	X		
Ghobakhloo and Fathi [40]		X	X
Total	8	10	5

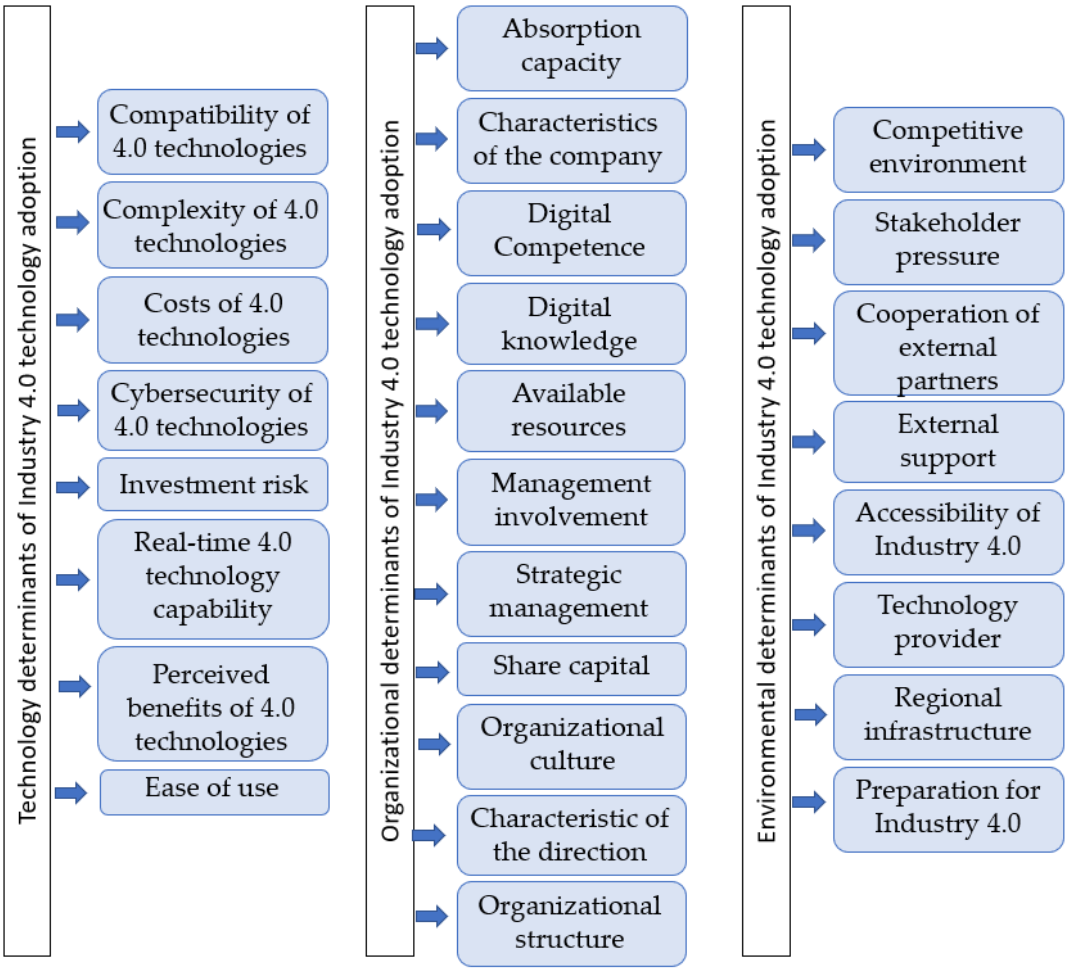

Figure 5. Technological, organizational, and environmental determinants of Industry 4.0 technologies adapted from Ghobakhloo et al. [22].

The technological determinant with the greatest significance in the publications reviewed in this study was the perceived benefits of implementing Industry 4.0 technologies. Indeed, according to the case study conducted in the work of Garzoni, De Turi, Secundo, and Del Vecchio [35], the idea of improving the efficiency of all processes and reducing operation costs drives SMEs to want to implement Industry 4.0 technologies. The organiza-

tional determinant with the greatest significance in this literature review was the presence of digital knowledge and expertise within the SME. Indeed, the presence of digital expertise favours the successful implementation of various Industry 4.0 technologies in an SME [23]. Finally, the environmental determinant with the greatest impact in this study was the presence of external support. Considering governmental support, external financial aid, and help from external partners via a collaboration network, external support was the determinant that most favoured the implementation of Industry 4.0 technologies [41]. In addition, the organizational culture and structure, senior management support, and collaboration with a network of partners also emerged as frequently cited factors for successful Industry 4.0 implementation [22]. However, although the literature identified factors that favoured the implementation of Industry 4.0, it offered limited information on the precedence relationships between these different factors [22]. It would be useful to identify the interactions and inter-relationships of the success factors and define how to prioritize them in a digital transformation context led by Industry 4.0 in an SME.

Beyond the need to identify success factors for implementing Industry 4.0, there is also the question of whether implementing it is necessary. At the end of their research on the subject, using a literature review coupled with a case study, Davies et al. [42] concluded by stating that the central issue of whether to implement Industry 4.0 lies not only in the potential gains generated by the implementation but also in the probable consequences that result from not adopting Industry 4.0. The study revealed that, in the past, companies that set aside new technologies often lost market share and, in some cases, are no longer dominant players. In some of the worst cases, these companies have simply ceased to exist [42]. Keeping up with technology can help to maintain or even gain a significant competitive advantage in a globalized market [42]. Adherence to emerging technologies applies to both production methods and the various technical characteristics of the products [42].

In their research, using a qualitative approach combining a literature review, a conceptual analysis, a content analysis, and a case study, Han and Trimi [2] stated that an SME can increase its organizational agility, adaptability, and resilience to compete in a competitive environment by taking advantage of Industry 4.0 technologies. Leveraging technologies can enable an SME to become an important partner in the network of suppliers, businesses, and customers. On the other hand, according to Han and Trimi [2], the literature shows that SMEs have not yet found a way to take full advantage of Industry 4.0 technologies since they are often only selectively adopted. By making it easier to operate in a context of market globalization and to migrate to personalized mass production, Industry 4.0 forces companies to review their business models and their production methods in order to keep or increase their competitive advantage [5]. Although the need to implement Industry 4.0 has been advanced by various authors [2,5,20,21,42,43], the literature contains few methods for increasing SME agility through Industry 4.0. On the other hand, adopting Industry 4.0 offers an interesting opportunity for a large number of SMEs [44]. It would be informative to explore the implementation of Industry 4.0, including the potential gains, limiting factors, and success factors specifically targeting SMEs.

3.2. Small and Medium-Sized Enterprises (SME)

Certain characteristics differentiate SMEs in the manufacturing sector from other companies. Different authors [33,45–48] have examined characteristics that define SMEs in the manufacturing sector. Table 3 summarizes the characteristics according to different authors.

Table 3. Characteristics of SMEs in the manufacturing sector.

Characteristics	Torres [45]	Moeuf, Lamouri, Pellerin, Tamayo-Giraldo, Tobon-Valencia, and Eburdy [33]	Castagna, Centobelli, Cerchione, Oropallo, Shashi, and Strazzullo [46]	Harris, Yarbrough, Abernathy, and Peters [47]	Mittal, Khan, Purohit, Menon, Romero, and Wuest [48]
Significant management involvement	X				
Short-term strategic planning	X				
Absence of experts in specific functions	X				X
Low production volume	X			X	
High production cost	X				
Strategy focused on flexibility and responsiveness		X	X	X	
Proximity to customers		X			X
Variety of products			X	X	X
Dependence on a collaborative network					X
Low complexity and rather informal organizational structure					X

As can be seen in Table 3, flexibility and reactivity, a variety of products, proximity to customers, low production volume, and the absence of experts are characteristics that several authors used to describe SMEs in the manufacturing sector. By focusing on flexibility and reactivity, SMEs offer an environment conducive to agility [49]. Moreover, because of this agility, SMEs can increase their ability to compete in changing market conditions [50]. This need to be agile for SMEs also leads to the implementation of systems that are adaptable and reconfigurable as well as the creation of collaborative networks [51–53]. Moreover, having a low production volume with a wide variety of products makes it all the more important to be agile in the face of this changing demand [47]. In addition, the absence of experts is a reality in the SME manufacturing sector, which often impacts the desire to implement new technologies. As discussed by Han and Trimi [2] in their research, as they do not know how and in what order to implement Industry 4.0 technologies, SMEs often fail to benefit from the competitive advantages they offer.

In addition to facing the various challenges of implementing Industry 4.0 technologies, SMEs in the manufacturing sector are faced with competitive challenges in order to stand out and be competitive in a context of personalized demand and market globalization [5]. The labour shortage and employee retention are other challenges that affects SMEs. In a context of labour scarcity, Industry 4.0 technologies can be solutions for overcoming this problem and increasing productivity. [5]. In their works, based on case studies, Abdulnour, Baril, Abdulnour, and Gamache [5] and Bouchard et al. [54] argued that in order to face this new reality, SMEs must rethink their design and production methods to be more competitive and agile. However, Abdulnour, Baril, Abdulnour, and Gamache [5] highlighted that SMEs are not adequately prepared and lack the resources to undertake this digital shift.

The digital shift, which many SMEs have been slow to operationalize due to factors including a lack of knowledge, could allow SMEs to better position themselves through suppliers, customers, and competition [2]. Leveraging the competitive advantages offered by new technologies could enhance collaborative network relationships [2]. The authors highlighted the importance of collaboration between the various manufacturing actors

through the integration of technologies in SMEs in the manufacturing sector [2]. Moreover, as explained by Dutta et al. [55] in their work based on surveys of more than 250 SMEs, SMEs face many organizational challenges, as they are increasingly confronted with complex products and a trend towards mass customization. A survey on the maturity of these SMEs highlighted several challenges. These challenges included a lack of understanding of Industry-4.0-related concepts and a lack of knowledge of the new Industry 4.0 emerging technologies. Indeed, although Industry 4.0 technologies can allow for greater flexibility in production and greater agility, this digital shift also creates many challenges for SMEs [55]. The lack of digital knowledge and the absence of networked collaboration between the various manufacturing players limit the gains obtained from manual SMEs in the manufacturing sector [56]. It would be useful to explore how SMEs could take advantage of the benefits offered by operationalizing the digital shift in the context of creating agile collaborative networks.

3.3. Agility

In their work, based on a literature review, Maganha et al. [57] highlighted 17 principles that describe Industry 4.0 and help companies to operationalize it [5]. These principles include flexibility, modularity, product customization, and agility. The 17 principles are also interrelated. As explained by Abdulnour, Baril, Abdulnour, and Gamache [5], modularity allows for greater flexibility, agility, and product customization. In addition, using a literature review and an analysis based on a database of 148 SMEs in Quebec, Gamache et al. [58] put forward 24 best practices to adopt in the context of the digital shift in SMEs in the manufacturing sector. These best practices include encouraging agility and innovation. Agility therefore seems to be a component at the heart of implementing research on the implementation and operationalization of Industry 4.0.

Agility is defined as the ability to react quickly to an unexpected change and is a key concept in the operationalization of Industry 4.0 [5]. Indeed, many researchers define agility as the ability to cope with a dynamic and turbulent business environment. In such an environment, agility allows an organization to adapt and respond quickly to demands as they arise [5,54,59,60]. In the context of Industry 4.0, strategic agility is a set of activities that are implemented to add value in the face of changing conditions [59]. In addition, using Industry 4.0 technologies has many impacts at different levels. Gajdzik [59] used a questionnaire to study the impacts of these technologies on productivity, agility, customization, business competitiveness, profitability, labour reduction, delivery improvement, resource savings, operational cost reduction, technology adaptability, and machine accuracy. Of these factors, customization, agility, and adaptability emerged as the top three factors for improving business operations in the companies studied in his research [59]. The use of Industry 4.0 technologies to operationalize mass customization, thereby increasing the agility of SMEs in the manufacturing sector, appears to be a promising avenue to explore in this research.

The concept of agility also applies to manufacturing systems. A manufacturing system must be reconfigurable to be agile [5]. According to Abdulnour, Baril, Abdulnour, and Gamache [5], certain characteristics allow for the quick and easy adjustment of production functions, allowing for a reconfigurable system: a flexible product divided into product families, a dynamic work cell organization, and multidisciplinary employees. In addition, different factors contribute to increasing SME productivity gains. In their work, Abdulnour, Baril, Abdulnour, and Gamache [5] concluded that developing agility, developing a modular product structure, and automating manufacturing processes lead to an increase in productivity gains for an SME. As for Gajdzik [61], using a literature review and a data analysis of steel Industry 4.0 technologies as part of his research, he implemented Industry 4.0 in the steel sector to study the growth potential and development of this industry in a context of market competition. He concluded that a company's agility facilitates better implementation of Industry 4.0 and therefore increased growth of the company in this manufacturing sector.

Therefore, the question of the order of the implementation of agility and Industry 4.0 remains. Mrugalska and Ahmed [60] argued that many studies claim that agility is a direct consequence of implementing Industry 4.0 technologies, while other studies show that implementing Industry 4.0 technologies first requires establishing conditions such as agility. In an effort to understand the relationship between Industry 4.0 and agility, Mrugalska and Ahmed [60] addressed this topic in their research using a literature review. According to the authors, organizational agility is essential for operationalizing Industry 4.0 and gaining a competitive advantage. The authors also cited agility's ability to increase a company's resilience, i.e., its ability to recover from unexpected events from an internal or external source [60]. The research results therefore led the authors to note that agility in the context of Industry 4.0 can provide an organization with the ability to innovate and to be flexible and dynamic, with the aim of better organizing, predicting, and managing of a company's strategic objectives [60]. The authors, therefore, concluded that agility is an essential aspect of the infrastructure offered by Industry 4.0 and that agility and Industry 4.0 technologies therefore go hand in hand [60]. From this perspective, a manufacturing SME that demonstrates agility in its products, processes, IT infrastructure, business plan, and human resources increases its chances of successfully implementing Industry 4.0. It would be interesting to explore how agile SMEs are able to take advantage of the benefits offered by the operationalization of the digital shift in the context of creating agile collaboration networks.

3.4. Mass Customization

Cohen and Pine Li [62] defined mass customization as an efficient, low-cost production capable of delivering a customized product in high volume [63]. A term coined in 1989 by Davis [64], "mass customization" provides a competitive advantage over other companies, with the ability to offer mass customized goods [63]. Mass customization thus seeks to offer a product that meets customer expectations while offering a reaction time and efficiency similar to mass production [65,66]. According to Dwivedi et al. [67], mass customization is a strategy for producing custom products while benefiting from mass production costs. Table 4 summarizes the objectives of the different production paradigms. As represented in the table, mass customization seeks to take advantage of both mass and unit production by focusing on a customized product, low manufacturing costs, a large production volume, and a high production speed.

Table 4. Objectives of the different production paradigms [62,63,65,67,68].

-	Product	Manufacturing Cost	Production Volume	Production Speed
Mass production	Standard	Low	High	High
Production per unit	Personalized	High	Low	Low
Mass customization	Personalized	Low	High	High

However, as Salvador et al. [69] asserted, just because mass customization seeks to produce at mass production costs according to customer needs does not necessarily mean that it does so [70]. Indeed, according to the authors, a company cannot precisely know the needs of its customers and respond to them at a cost as low as mass production [69,70]. Rather, mass customization seeks to move towards this ideal process [69,70]. To move towards this ideal, companies can incorporate three essential capabilities, as defined by Salvador, De Holan, and Piller [69] and shown in Figure 6 [70].

Developing solutions, designing robust processes, and customer integration allow for further migration towards mass customization by seeking to obtain the cost advantages of mass production combined with the customized product of unit production.

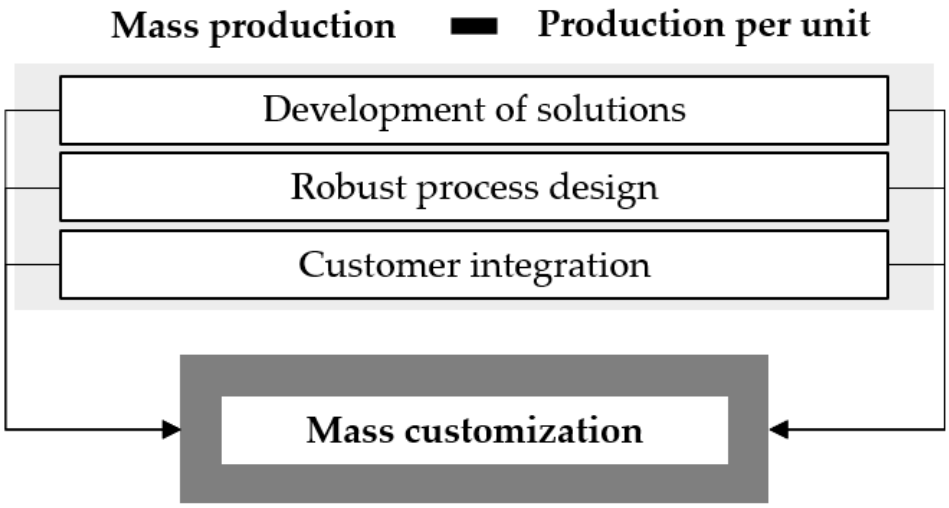

Figure 6. Continuity of mass production and unit production adapted from Korneeva et al. [70].

This shift in the production paradigm towards personalized mass production at mass production costs is forcing companies to offer personalized products to the market and therefore to change the current way of producing. This new way of doing business is more oriented towards greater interaction between companies and their consumers. In their research, based on a survey investigating the expectations and preferences of consumers related to customized products, Saniuk, Grabowska, and Gajdzik [10] emphasized the importance of the collaborative network. In addition, they observed that customers' involvement in the product design process distinguished them from consumers of a generic, non-customized products [10]. The interaction between customer and manufacturer is important and very present [10]. Indeed, through a study based on an approach analyzing the sales data of configurable products, Kusiak et al. [71] also cited the importance of the link between the customer, the manufacturer, and the employee in the context of Industry 4.0. The authors also advanced the need to develop new business models that are more focused on networked cooperation, allowing companies to better respond to customer needs [71].

These new relationships between companies and their customers force manufacturing systems to adapt to this new reality. Manufacturing systems are therefore continually evolving in terms of design, operation, principle, and control in response to external influencing factors, technological advances, and business models [72]. Manufacturing systems are moving more towards flexible and reconfigurable systems to meet the changing demands of production volumes and product variability [72]. In their work, ElMaraghy, Monostori, Schuh, and ElMaraghy [72] used several industrial case studies to investigate the evolution of manufacturing systems. Figure 7 illustrates the areas of development of manufacturing systems over time.

In their work, the authors noted that this manufacturing system evolution has been driven by technological and production advances, the alignment of companies' business plans, and increasing product complexity, along with attempts to reduce production costs, increase product durability, and increase company profitability [72]. The four areas of development of manufacturing systems emerged as essential factors in the migration to mass customization, as companies were forced to review their existing manufacturing systems [72].

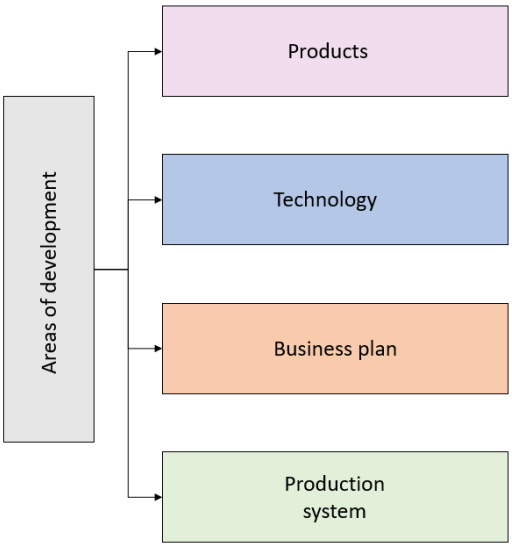

Figure 7. Four areas of development of manufacturing systems adapted from ElMaraghy et al. [72].

3.5. Integration of the Principles of Mass Customization

Although ElMaraghy, Monostori, Schuh, and ElMaraghy [72] argued in their work that the product is one of the axes that is key to the evolution of manufacturing systems, Kusiak [73] has been interested in product-based specification systems. In his work analyzing developments in the manufacturing sector, Kusiak [73] asserted that the product is therefore a decomposition of assemblies and components that can be used to feed different production system models. Figure 8 illustrates the manufacturing systems resulting from product specification.

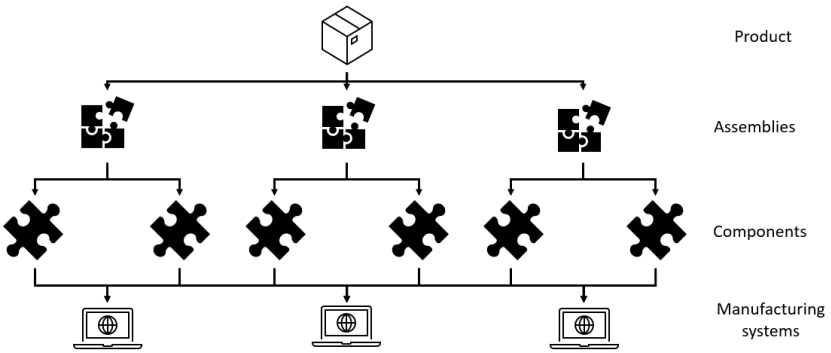

Figure 8. Product-based specification adapted from Kusiak [74].

Different production processes can therefore be set up in a manufacturing system to produce complex products using distributed manufacturing [73]. Figure 9 illustrates this concept, which translates into distributed manufacturing. As can be seen, different products can be traded through production processes using distributed manufacturing.

The studies conducted by Kusiak [73] and ElMaraghy, Monostori, Schuh, and ElMaraghy [72] showed that the production system structure, product decomposition, the use of technologies, and a company's business plan have impacts on increasing SME agility. It would therefore be instructive to explore how to set up an agile network to operationalize mass customization through a standard product with distributed manufacturing using Industry 4.0 tools in SMEs in the manufacturing sector.

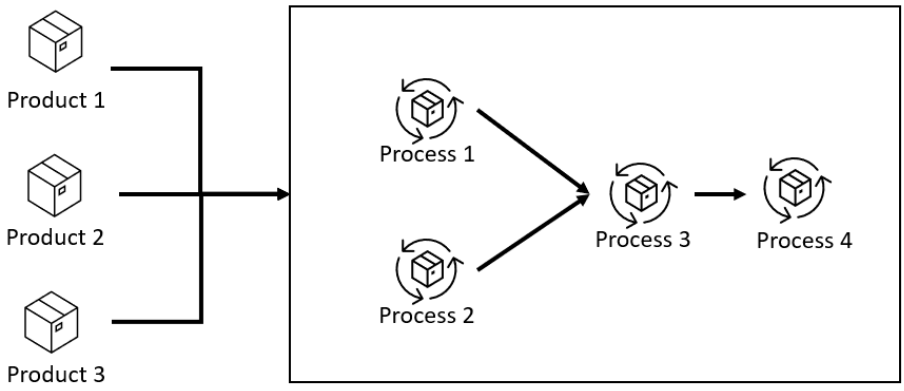

Figure 9. Distributed manufacturing adapted from Kusiak [74].

As an important element in the migration to mass customization, product decomposition is a much-researched topic in the literature. The concept of product families has been explored, as it relates to obtaining an agile and easily reconfigurable product that meets customer requirements. In their research, based on an approach analyzing the sales data of configurable products, Kusiak, Smith, and Song [71] emphasized the importance of product families in meeting diverse needs. By working with product families in a just-in-time environment, it is possible to provide subassemblies that meet the customer's product specifications within a targeted timeframe. However, companies often grapple with how to reduce the complexity of a product without impacting the range of options available to customers [75]. Koppenhagen and Held [75] proposed products with a modular architecture to meet this demand. Modular products make it possible to standardize the creation process by limiting part variability without reducing customer choice. Figure 10 illustrates this principle through a modular architecture with a hierarchical concept. Indeed, the decomposition of a product into modular systems and subsystems makes it possible to respect the principles of modularization.

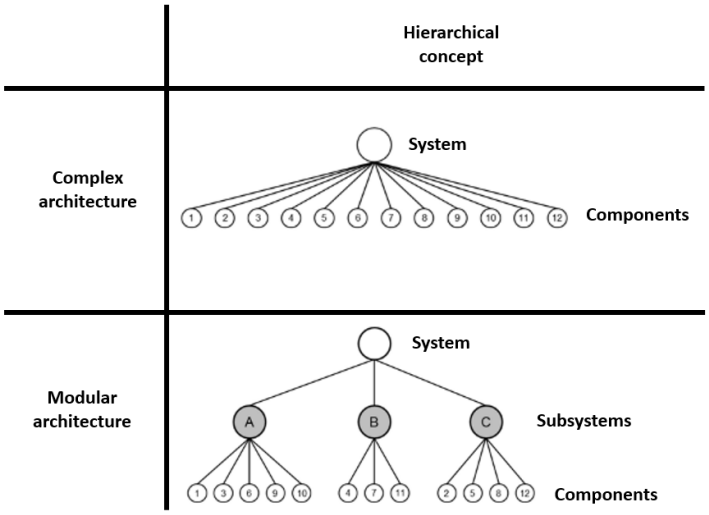

Figure 10. Basic principle of modularization from a general systems perspective adapted from Koppenhagen and Held [75].

Since the advent of mass customization at the expense of mass production and the paradigm shift in manufacturing strategies, product configuration has been at the heart of many research projects [76]. Indeed, product configuration is especially complex when a mass customization strategy is targeted at the design level [77]. In their work, Bruun, Mortensen, and Harlou [77] used a practical implementation to present a visual design tool, the interface diagram, to support the development of complex system modularity by a

product family. Figure 11 shows a generic symbolic representation of the interface diagram. This tool makes it easier to manage the interfaces between modules, thereby facilitating the implementation of modular design.

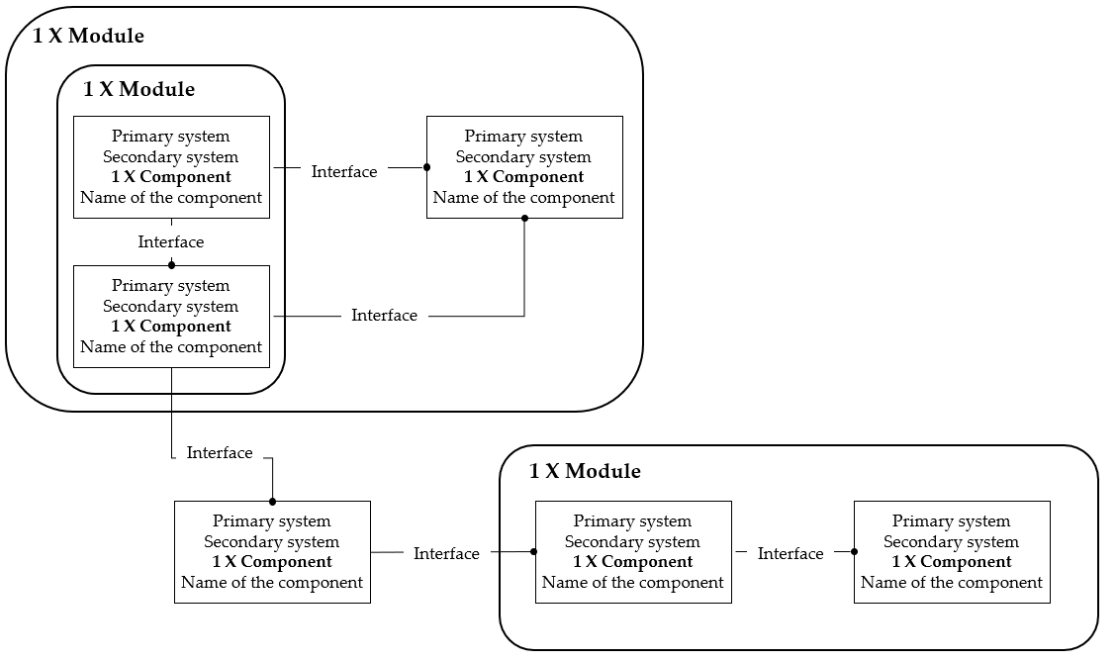

Figure 11. Symbolic representation of the interface diagram adapted from Bruun et al. [77].

The strength of this design tool is that it can be implemented and used in companies with complex diversified products to simplify modular product design [77]. It would therefore be interesting to explore how this modular configuration tool could facilitate the implementation of principles promoting mass customization in the context of Industry 4.0 in SMEs in the manufacturing sector. Moreover, although the integration of new technologies and new strategies focused on agile products and production systems is at the heart of SME concerns in the context of Industry 4.0, mass customization is also changing the portrait of the manufacturing activities of various SMEs in the manufacturing sector [5]. As noted by the authors in Table 4, customer proximity is an increasingly important variable. Customer orientation leads to a migration towards mass customization, which is now more focused on meeting specific customer needs [3]. Aheleroff et al. [78] stated that, as it is increasingly stimulated by individualization and operationalized due to increasing digitalization, mass customization can generate benefits beyond the current configuration [78,79]. In their work, the authors used case studies as they sought to present mass customization as a service to meet unique and specific requirements using Industry 4.0 technologies. The various technologies included the Internet of Things, additive manufacturing, big data, cloud fabrication, and blockchain [78,80].

At the end of their research, based on a review of the literature related to the implications of modularization, Dutta, Kumar, Sindhwani, and Singh [3] showed that the digital shift facilitates the integration of customer requirements in both design and manufacturing. The authors concluded by revealing that although technology is necessary for the digital shift, it is not necessarily a guarantee of success. Technology use must be supported by work methods and organization, in addition to human resources focused on this change. The digital shift offers a clear opportunity for SMEs in the manufacturing sector to transform and compete by offering greater agility through increased responsiveness to specific customer requirements [3]. A body of research argues that mass customization, with the help of Industry 4.0 technologies, can increase manufacturing SME agility, making it possible to compete in the context of market globalization [54]. However, while scientific research on mass customization is well underway, there is less research exploring how to

implement it [81,82]. Suzic and Forza [81] used a design science research strategy, along with three years of observation in two SMEs, to examine the guidelines for implementing mass customization. First, the authors developed a maturity grid to evaluate the SME maturity level regarding mass customization [81–83]. This maturity grid is based on the characteristics of the mass customization implementation guidelines and a list of eight characteristics that support mass customization [81]. Maturity levels are determined according to whether it will be easy (maturity level 3) or difficult (maturity level 1) to implement the criterion promoting mass customization in an enterprise [81]. The initial proposed maturity grid, includes the eight characteristics that support the implementation of mass customization: product platform development, product modularization, IT-based product configuration, part standardization, group technology, form postponement, process modularity, and concurrent product–process–supply chain engineering.

The study assessing SME maturity using eight criteria favouring mass customization also argued that, in the same vein as Hernandez et al. [84], there is no logical sequence for implementing these criteria [81]. In addition, by consulting various mass customization experts in their research, Suzic and Forza [81] developed, in parallel, a procedure for using and evaluating the maturity grid. A case study with two SMEs was then conducted. This study revealed problems limiting mass customization that included rushing to satisfy customer requests without taking into account the production organization and supply delays as well as the growing variety of products over time [81]. However, characteristics favouring mass customization were also noted, including the presence of experienced engineers who know the products within the SME as well as the presence of a manager who shares the vision of mass customization [81]. Ultimately [81], this research did not address prioritizing certain characteristics over others. Indeed, although the authors argued that there is no set sequence, it would be instructive to analyze whether some of these factors have greater impacts on mass customization.

4. Discussion

The literature review highlighted the importance of the link between agility and Industry 4.0, the importance of mass customization in a context of increasing customer demands, and the need to implement an agile collaboration network between the different actors in the chain. Furthermore, the literature highlighted the need to implement Industry 4.0 to maintain or create a competitive advantage in a competitive environment. The literature also highlighted the importance of exploring how to set up an agile network to operationalize mass customization through a standard product using distributed manufacturing and modular design tools.

The transition to Industry 4.0 creates the need to increase the agility of distributed networked companies to operationalize mass customization more easily. The need for agile products, processes, and technologies is even more significant. Several factors favouring the implementation of Industry 4.0 technologies were discussed in the literature, as were factors for assessing a company's maturity level regarding mass customization.

However, the literature did not offer any prioritization or inter-relationships between these factors in the context of mass customization in industry. The review of the literature highlighted six factors that have considerable impacts on operationalizing mass customization in SMEs in the manufacturing sector: product modularity, collaboration networks, business agility, the use of technologies, the digital supply chain, and process modularity. Figure 12 shows the six factors to be studied to analyze how these factors impact the operationalization of mass customization.

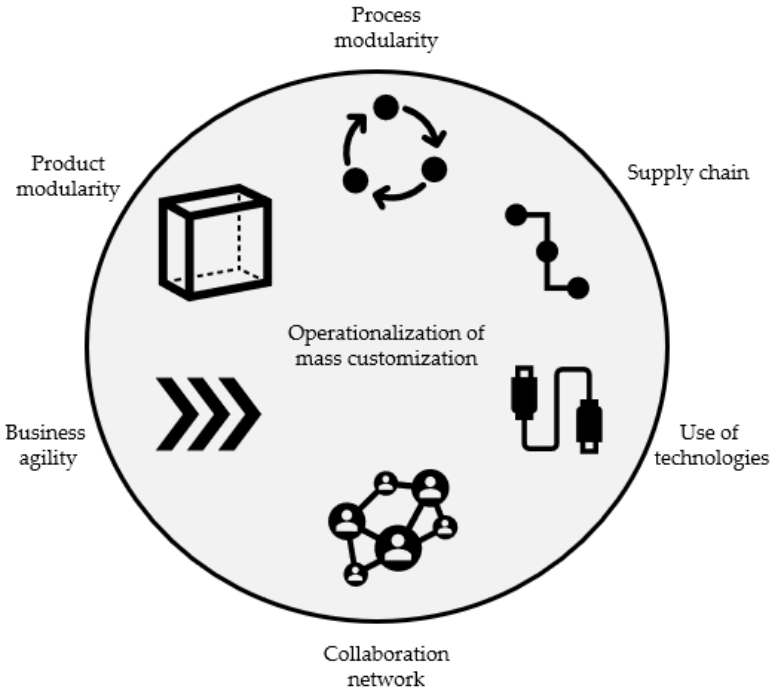

Figure 12. Inter-relationships of factors to be studied in relation to mass customization.

Modularity is a key success factor in the migration to mass customization [62,85]. Modularity makes it possible to reduce costs and engineering time while being able to meet the specificity of customer demand [85]. On several occasions in the literature, the importance of product modularity was advanced as a way to reduce the complexity of making an assembled product [75]. Furthermore, while agility is essential in the context of Industry 4.0, it extends to many other concepts. Indeed, agility can be extended to the supply chain, the workforce, industrial processes, business strategies, information systems, and facilities [60]. The more agility extends to the different dimensions of an enterprise, the easier it is to adopt Industry 4.0 technologies [3]. Moreover, the digital shift facilitates the integration of customer requirements at both the design and manufacturing levels. [3]. Finally, collaboration with a network of partners is a factor that was often identified as favourable for implementing mass customization in the context of Industry 4.0 [16,17,22].

However, although the literature pointed to factors that impact the operationalization of mass customization, the literature does not currently contain the tools that flow from these factors or a strategy for prioritizing these factors. Therefore, there is currently a lack of clarity on the tools, strategy, level of maturity, and sequence for implementing the six factors in Figure 12.

Mass customization should therefore be operationalized sequentially by developing and implementing the tools resulting from the six factors shown in Figure 12. Mass customization is a way of thinking that must be included in each stage: design, manufacturing, logistics, and sales [86]. However, the current lack of understanding and knowledge related to personalization and how to implement it is one of the biggest barriers for SMEs [87]. Thus, the need to develop a strategy adapted to the reality of SMEs in the manufacturing sector is all the more crucial to be able to stand out from the competition [86].

However, to put in place the various factors put forward in this article to operationalize mass customization, it is important to have access to funding. The issue of financing is not addressed in this research. However, SMEs often face restricted access to external financing due to the lack of financial history and their inability to guarantee results [88]. Since they are often faced with funding refusals due to the risk of carrying out such a project, it is all the more relevant to offer a validated operationalization strategy that allows SMEs to build on successful implementations [88].

5. Conclusions

The purpose of this study was to conduct a systematic review of the literature to highlight the need to establish an implementation strategy detailing the process for operationalizing mass customization and increasing the agility of SMEs in the manufacturing sector. The scientific contribution of this research reveals the growing need for companies to migrate to mass customization since they are faced with dynamic demand and greater requirements from customers.

However, although some strategies for implementing mass customization currently exist in the literature, the factors to implement have not been prioritized. Indeed, no study has prioritized or offered an ideal implementation sequence for successfully implementing mass customization in SMEs in the manufacturing sector. Furthermore, the tools and their levels of maturity resulting from the factors to be implemented were not detailed in the literature.

This research establishes that the literature offers several possible solutions for developing such a strategy. Indeed, the practical contribution of this research argues that companies' products, manufacturing processes, and IT infrastructure as well as business plans will have to be adapted to create an agile network between partners, companies, and customers. This process will involve increasing agility and implementing Industry 4.0 tools within SMEs. Lastly, the involvement of actors from SMEs in the manufacturing sector in the shift towards mass customization will be crucial to successfully maintain competitive advantages and offer a sustainable product in the Industry 4.0 era.

This study has some limitations. Mass customization was studied only in the context of SMEs in the manufacturing sector. Furthermore, this study was limited to the articles that were covered in this literature review with the inclusion and exclusion criteria in place.

Future research should prioritize and explore the factors that make mass customization more easily understood by SMEs. Working in conjunction with a larger research program and collaborators in the same research area, exploring and developing the tools needed to enable the implementation of factors could also be part of future research. Future research could also explore how to build an agile network using distributed manufacturing and modular design tools. Lastly, future research could address the financing mechanisms available to SMEs to acquire technological tools and collaborative networks and to enable the globalization of their market in a context of mass customization.

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