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A Contribution toward a Research Agenda: Identifying Impact Factors of Mass Customization on Environmental Sustainability

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Abstract

Mass customization (MC) has been broadly discussed as a potential business model for heterogeneous markets in the management literature. In market settings that are characterized by high levels of customer need heterogeneity, MC has to be considered as an economically viable strategy. However, it might not be sufficient to assess business models solely on the basis of economic indicators. Environmental problems and the exacerbating climate change have sparked a global debate about ecological thinking and sustainability. In this context, existing literature describes the need for strategies that are sustainable in terms of economic, social and environmental aspects. In accordance with this aspect, more and more authors claim that MC – besides being an economically attractive business approach – also carries the potential to be an environmentally and socially beneficial business model. This paper aims to identify potential impact factors of MC on sustainability in order to establish a research agenda concerning the role of MC for sustainability.

Key words: *About Mass Customization, Sustainability, Research agenda*

1. INTRODUCTION

Mass customization (MC) is a strategic approach that is developed to cope with high levels of heterogeneity among the needs of customers in a given market. The basic idea is well explained by Davis [1]: MC aims at serving customers individually through a high-variety product offering, whilst broadly retaining the same overall sales volume as a comparable mass production strategy [1]. Thus, from a strategic management perspective, MC is a hybrid competition strategy that attempts to master the simultaneous realization of product differentiation and cost efficiency.

The concept is based on the idea that every customer envisions an "ideal product", which will be used as a benchmark for all products that are available in the respective market, comparable to the well-established expectancy disconfirmation model [2, 3]. Following the concept of Chamberlin's [4] theory of monopolistic competition, customers gain the increment of utility of a customized good that better fits their needs than the most suitable standardized product that is available. Subsequently, the better a product fits the customer's needs, the higher will be the customer's willingness to pay [5], and the higher the level of customer needs heterogeneity in a given domain, the larger will be this gain in utility [6]. Following this rational, a MC strategy holds the potential to increase revenues by turning heterogeneities in customer needs into an opportunity to create value. That way, the implementation of MC has to be considered as an economically viable business model pattern: on the one hand, firms can charge higher prices for customized goods because of the increased customers' willingness to pay for individualized goods. On the other hand, the realization of flexible manufacturing processes and suitable customer interaction tools allows providing these customized goods at cost levels that are comparable to those of mass produced goods. Subsequently, profit margins may be higher compared to those of standardized products under such heterogeneous market conditions.

However, in view of the challenges that the global community faces today, it might not be sufficient to assess business models solely on the basis of economic indicators. Environmental problems and the exacerbating climate change have sparked a global debate about ecological thinking and sustainability. We are very well aware of the fact that there still is no general academic consensus with regard to the definitions of the terms "environment" and "sustainability". In fact, the most popular and frequently used definition of sustainability is the one proposed by the World Commission on Environment and Development (WCED) in 1987 where sustainability is defined as a goal to "meet the needs of the present generation without compromising the ability of future generations to meet their own needs" [7].However, it can be observed that in many markets the customer demand for more environmentally friendly products has increased and that more and more political decision makers strive for the implementation of stricter governmental regulations for social and environmental issues. Subsequently, the general concept of sustainability has come to the attention of many companies. In this context, Elkington [8] claims that companies need to develop so called "Win-Win-Win"-strategies, which are sustainable in terms of economic, social and environmental aspects. In accordance with this aspect, more and more authors claim that MC – besides being an economically attractive business approach – also carries the potential to be an environmentally and socially beneficial business model. For example, literature sees MC as a mean to reduce overproduction and waste of resources [9], claims that customized products have a longer life span [10] and allow better reuse and recycling possibilities [11].

Nevertheless, there are only very few studies that support these hypotheses concerning the role of MC for environmental sustainability; especially beyond conceptual research. Thereby, the existing trade-off of considering MC and sustainability simultaneously can trigger a new research stream for academia. Research initiatives need to support companies in implementing MC in a more sustainable manner. Therefore, in a first step, this paper aims at identifying general impact factors of MC on environmental sustainability primarily based on the existing literature and inspired by the results of the special session on MC and sustainability at the MCPC 2014 conference in Aalborg. In a second step, the paper will then provide a research agenda including the above-mentioned aspects of the MC-sustainability-relationship that need to be addressed by future studies.

2. THE CONCEPT OF MASS CUSTOMIZATION

The concept of MC is not new to the field of strategic management. It has been discussed in the respective management literature for approximately 30 years and today there is a multitude of MC business cases in all kinds of product domains. Still, it is rather difficult to provide a precise definition for the phenomenon. A first attempt to describe the idea was made by Davis [1, p.169], who defines MC as "[reaching] the same large number of customers […] as in mass markets of the industrial economy, and simultaneously [treating the customers] individually as in the customized markets of pre-industrial economies." Similar to this description, most definitions of MC agree that the term refers to the efficient mass production of customized goods [e.g. 12, 13, 14]. Nevertheless, beyond this rather fuzzy definition, Piller [15, p.314] claims "the term [MC] is used today for all kind of strategies connected with high variety, personalization, and flexible production." Moreover, research has failed to establish threshold values – e.g. for the degree of customization or a minimum sales volume – beyond which a strategic approach may be recognized as a valid implementation of MC. In response to this dilemma, we suggest to no longer regard MC as a stand-alone business model or strategy, but rather as a so-called business model pattern. Such business model patterns are archetypal and reusable descriptions of business approaches with similar characteristics, behaviors or building blocks [16]. Patterns can be retrieved from existing business cases and can then serve as blueprints for the development of business model innovations. Following this logic, Gassmann et al. [17] have identified 55 business patterns, one of them being MC.

In this context, the pattern of MC merely describes the idea of profiting from heterogeneous markets by offering customized products or services according to the individual needs of the customers. At this stage, it is irrelevant how this customization is achieved and how the realization of this MC pattern affects, for instance, the existing manufacturing processes or distribution channels of a company. These issues need to be solved only if a company decides to make use of the MC business model pattern in its specific product domain and market. In this case, it has to develop a full business model in accordance with the general idea of the pattern and under consideration of the specific context of the firm. Thereby, the concept of MC is merely used as a starting point, as its idea describes a customer value proposition, but it cannot provide answers with regard to the resources and processes that are needed for realizing this proposition [18]. Consequently, as the pattern only serves as a blueprint or impulse for the development of the respective business model, the resulting business approach might be very different from other business models that are based on the same MC pattern [17]. Thus, it becomes apparent that the development of a MC based business model is strongly context dependent and that there is no completely standardized approach to MC [19, 20].

Even though MC-based business models strongly depend on the specific product domain or market setting in which a firm operates, management research tries to provide generic guidelines to help firms with their transition towards MC. Following the argumentation of the resource-based view of the firm, these studies argue that the implementation of MC demands profound organizational change [15, 21] and that companies need to acquire a distinct set of strategic capabilities for this endeavor [22, 23]. Salvador et al. [20] propose a well-established framework of three strategic MC capabilities: solution space development (SSD), robust process design (RPD) and choice navigation (CN) [20]. Thereby, SSD is concerned with the definition of a firm`s product offering. As offering unlimited choice is economically unfeasible, companies need to identify those product attributes for which the customers require variety and that provide additional value for the customers [24, 25]. Secondly, RPD describes the capability of a company to ensure that the increasing product variety of a MC offering does not impair the firm's manufacturing and distribution processes. Therefore, a flexible and efficient production has to be realized [26, 27]. The third capability – called CN – is concerned with managing the communication and interaction processes between firms and their customers. This capability is needed, so that the increased complexity of the firm-customer-interaction in MC does not lead to a disproportionately strong growth in transaction costs [28, 29, 30]. However, managers have to keep in mind that these strategic capabilities have to be understood as generic guidelines. Not all of the above-mentioned aspects will be relevant for a specific MC-based business model. Instead, it can be expected that each individual approach to MC requires its specific pattern of strategic capabilities and organizational resources [31].

3. MASS CUSTOMIZATION AND SUSTAINABILITY: STATE-OF-THE-ART

As the concept of MC has been subject of scientific research for nearly three decades, today, there are already several available studies in management literature that scrutinize the interrelation of MC and sustainability. However, for this literature review, two groups of publications have to be distinguished. On the one hand, there are studies that mention MC as a potential driver of sustainability. For example, Piller [32] states that a consequent implementation of research insights on MC will lead to "more sustainable mass customization applications in industry".

However, this argumentation is based on a definition of sustainability, which purely takes the perspective of long-term persistent economic success. Similarly, Kotha [33] compares mass production and MC in the context of a company-specific case and concludes that MC can enhance a firm's ability to maintain a sustainable competitive advantage, especially in rapidly changing environments. Shahzad and Hadj-Hamou [34] run a simulation and show that MC efforts can help companies to become more robust against unpredictable fluctuations of demand or shortened product life cycles. In all these examples, sustainability is not understood in the sense of the concept of the triple-bottom-line [8] and, subsequently, social or environmental aspects are not taken into consideration at all.

Therefore, these studies cannot be considered as related research in the context of this paper.

On the other hand, there are studies that indeed investigate the interrelation of MC and the sustainability concept from a triple-bottom-line perspective. Hereby, it can be noted, that almost all available studies either focus on an individual aspect of MC and its sustainability impacts or on a specific business case in a given product domain. Jovane et al. [35], for example, claim that MC has a beneficial impact on environmental sustainability, but their study exclusively focuses on the make-to-order principle of MC and its ability to reduce overproduction. Badurdeen and Liyanage[36] also acknowledge this aspect of MC, but mainly discuss the sustainability impact of co-creation, which often plays an important role during product design in MC-based business models. Beyond these investigations of individual aspects of MC and their sustainability impact, there are several studies that attempt to compare MC and mass production in a specific product domain via an assessment of the respective carbon footprints of each approach. For example, Chin and Smithwick [37] examine the product life-cycle of a men's dress shirt, whereasKleer and Steiner [10] provide a similar assessment for the product domain of shoes.

Nevertheless, all these analyses fail to provide a universal proposition on the overall impact of MC on sustainability. However, this issue is not surprising at all, if MC is understood as a business model pattern as described in section 2 of this paper. As such a pattern, MC only makes up one part of the overall business model and the processes for designing, manufacturing and distributing products differ strongly from one application to another. Subsequently, it is simply not possible to generally state whether MC has a beneficial or harmful sustainability performance, but the impact of MC depends on the specific context of a product domain or manufacturer. For this reason, in this paper, we provide a first step towards the individual sustainability assessment of MC-based business models by identifying several impact factors of MC on environmental sustainability.

4. A PRODUCT LIFECYCLE APPROACH

"In essence, sustainability is an enlarged framework through which to view the making and selling of products and services" [38, p. 52]. In this light, the realization of sustainable development requires a reduction of wasteful and environmentally and/or societally harmful practices in all stages that are relevant for the making and selling goods and services [38]. Subsequently, our considerations on potential impact factors of MC on sustainability need to employ a total product life-cycle approach, which considers all the stages of a product's life.

In this context, Jawahit et al. [39] suggest a framework of four separate stages: pre-manufacturing, manufacturing, use and post-use [39]. However, as we believe that this approach does not provide sufficient detail with regard to the early phases of the product life-cycle, we go beyond the suggested four stages by splitting the manufacturing phase into two different phases namely manufacturing and distribution. Hence, for this paper, the product life-cycle contains five phases. Thereby, the life of a product is initiated in a design phase.

Afterwards, the product is manufactured and distributed, before it enters its actual usage phase in the customer domain. After usage, the product ideally proceeds to an end-of-life phase, where proper waste management strategies should be implemented. One important aspect of such waste management strategies is the implementation of innovative approaches that enable a transformation from open-loop material flows of single product life-cycles to closed-loop material flows across multiple product life-cycles in which the components and parts can be reused several times before disposal [38]. Figure 1 illustrates the life-cycle loop and its five phases as employed in this paper.

Figure 1. Close loop product life-cycle

In the following parts of the paper, various impact factors of MC on sustainability will be identified. For this purpose, each stage of the proposed product life-cycle will be analyzed from the perspective of a MC business model in order to understand the importance of certain MC characteristics and their impact on sustainability. Thereby, it has to be considered that the potential impact factors are not necessarily beneficial for sustainability. It is conceivable that certain aspects of an MC business model show negative impacts on certain environmental indicators. In the following analysis, it will be attempted to include all potential impact factors – both positive and negative.

4.1 **Impact factors in the design phase**

Throughout the overall product life-cycle, the design phase is considered a very critical stage. The decisions that are made during the design phase significantly affect the final performance of the product [36]. Moreover, design is not only the initial stage of a product life-cycle, but also an essential step to close the life-cycle loop through merging the beginning-of-life with the end-of-life of a product. In this regard, sustainable design is widely known as an eco-design concept that includes environmental, social and economic concerns during the design phase of a product [40].

MC is a business approach that is fundamentally based on firm-customer-interaction and joint collaboration during the design phase. The process of co-design allows customers to articulate their requirements of a product and configure their desired product within a finite solution space and consequently be involved in the process of value creation [15]. Involving the customer in the design phase of the product can not only enhance the social aspect of sustainability, due to higher customer satisfaction, but also the environmental aspect. The co-design process should enable products that are much more aligned with the customers' needs and desires compared with standardized offerings. In other words, this specific design mode enables MC companies to produces only those products that is needed and requested by the customers. Accordingly the amount of waste will be decreased, as less unwanted products are produced [36].

Beside the co-design process itself, the implementation of a configurator tool during this design process can act as an impact factor for sustainability as well. A configurator is an essential resource to implement MC and is widely applied by MC companies to enable their customers to design a product according to their needs and desires. Configuration of an MC product takes place in several steps and considering different aspects of customization defined by the company such as appearance, fit, and performance [15]. Extending the configuration choices by giving information about the environmental impacts of the selected features increases the customer awareness [36]. Consequently, providing customers with information about potential environmental impacts of each selected feature and likewise of the whole sustainability impact of the final product during the co-design process can get them to choose and design a more eco-friendly product.

In addition to co-design, a MC product is usually characterized by its modular architecture. Modularity is regarded as one of the main operational enablers for MC. A modular architecture gives the manufacturer the possibility to produce a large number of product variants using standard components. Each module represents one or more functions of the product and is available with several options that result in different performances of the product. In fact, modularity could lead to advantages in terms of economies of scale and further reduction in lead-time if well-defined [41]. Thanks to its modular architecture, a MC product usually can be decomposed in an easier and more sustainable manner at the end of its life. However, it should be noticed that modular products cannot be optimized with the same efficiency as integrative solutions with regard to weight and performance. Hence, more material resources are required for MC products than for mass-produced ones [42].

4.2 **Impact factors in the manufacturing phase**

During the emergence of the concept of sustainability, manufacturing companies that intended to pursue sustainability started to focus on waste reduction during the production phase and later on reduction of resource and energy consumption. According to the National Council of Advanced Manufacturing [43] sustainable manufacturing refers to the "creation of manufactured products that use processes that are non-polluting, con-serve energy and natural resources, and are economically sound and safe for employees, communities, and consumers" [43].

The MC practices which are deployed during the manufacturing phase, have controversial effects in terms of environmental sustainability. In most cases, an MC product is only produced after receiving an order from the customer. This make-to-order or assemble-to-order nature of MC products prevents production of unwanted products and hence avoids overproduction. This results not only in a notable decrease in the level of waste of final products, but also in a lower level of energy and resource consumption for production. According to an estimation in 2009, 300 million pairs of shoes are overproduced annually. Considering the energy required to produce each pair of shoes, the total energy consumption to manufacture all the unsold shoes equals 14% of the energy consumption in Switzerland in one year [44].

Such information highlights how MC can be a positive driver for sustainability in terms of manufacturing. Nevertheless, the negative side of MC during the manufacturing phase should not be neglected neither. It can be argued that producing customized goods results in a higher amount of waste of raw materials in comparison with mass-produced products.

Coming back to the example of shoes, every customized pair of shoes requires a different type and cut of the leather, while for a standard pair of shoes the same type and cut of leather is used. Therefore the optimization of raw material usage in mass production leads to a lower consumption of raw materials. The same argument is valid regarding energy consumption. In order to produce customized products, different and more complex manufacturing processes are necessary compared to standard products. Therefore the optimization of these processes in terms of material and energy consumption is more complicated [45]. Hence, a higher level of production process variety in a MC environment usually causes negative environmental impacts.

On the other hand, the type of production system applied by an enterprise can be a source of sustainability performance improvement. In order to be successful, a MC firm requires robust production processes in order to deal with increased process complexity and lower batch sizes [20]. Heterogeneity in customers' needs generates additional costs for production systems, as this heterogeneity requires firms to recombine or reconfigure production resources in order to increase the flexibility of the manufacturing system and respond to diverse orders of customers within a reasonable period of time [12, 20].

In this context, robustness of production processes refers to the capacity to reuse or re-merge the existing manufacturing resources to satisfy a diverse range of the customers' needs and requirements [46]. Having robust processes, a company can deliver customized products with near mass production efficiency.

Accordingly, a successful MC business model should aim at creating stable, but still responsive and flexible, processes to manage the dynamic nature of orders and eventually products [12, 20, 47]. A multitude of approaches that can help companies to increase the flexibility and robustness of their manufacturing capacities are available. For example, firms could employ Flexible Manufacturing Systems (FMS), Reconfigurable Manufacturing Systems (RMS) or Rapid Manufacturing Technologies (e.g. 3D printing). Thereby, it is difficult to foresee, whether these robust production systems may consume additional energy and resources, or whether they are even more energy-efficient and are thus capable of enhancing the sustainability performance of a MC company.

4.3 **Impact factors in the distribution phase**

In the context of environmental sustainability, the distribution phase of the product life-cycle is always considered a critical stage with respect to the amount of energy consumption and emissions. The environmental impacts of this phase are not only related to the distribution strategies, but also to the type of distribution channel that a firm uses to reach its customers. In terms of distribution channels, the majority of mass customizers choose to directly deliver the customized products to the end customers. In such a scenario, customers place the order and receive the final product at home without having to visit a physical store. However, at the same time, this distribution channel necessitates individual shipments of the products. Obviously, this distribution approach requires more resources for packaging and results in higher energy consumption for transport than the delivery of large batches to retail stores [45, 48]. Moreover a single batch delivery (compared to several batch deliveries in the case of standard products) requires a higher number of delivery transports and hence creates a higher level of emissions as a negative impact. Nonetheless, the fact that customers do not have to travel to a store for placing the order and for the pick up the final product suggests a reduction in the amount of consumed energy as well as emissions. Furthermore, it can be argued that in a MC environment the product does not travel through several tiers of suppliers and therefore might also positively affect the level of energy consumption and emissions [45].

In this discussion of distribution channels, the impact of reverse logistics is a critical point. Generally speaking, MC companies enjoy a less complicated distribution system in terms of reverse logistics. The fact that the customized product is produced to satisfy the individual needs of a specific customer makes it quite impossible to apply a return policy for the products. Naturally, having no return policy has its own controversial impacts in terms of environmental sustainability. On the one hand, the absence of reverse logistics and re-shipments in MC environments leads to significant reductions in the level of energy consumption and emissions. On the other hand, a lack of return policies can result in an increase of waste since the customized products (in case of not being compatible with the customers' desires) can be rarely used by another person due to its personalized features and thus will be disposed without being used.

Apart from the above discussed impact factors; there are some future trends in MC, which could play a significant role in the conversion of MC into a more eco-friendly business model. For instance, the increasing popularity of micro-manufacturing and mini-factories might have a major impact on MC production in the near future. Mini-factories are small-size manufacturing systems with downsized production processes, which consequently result in reduced resource consumption. In addition to their reduced dimensions, mini-factories are usually characterized by their extreme precision and efficiency in different machining processes. Such a manufacturing paradigm can lead to multiple benefits for mass customizers, such as space reduction, shorter process chains, increased flexibility, improved response times, modularity of production processes and eventually cost reductions [49]. Beside these benefits of increased efficiency and flexibility, mini-factories can also strongly enhance the level of environmental sustainability. As these small-size factories are usually located in close proximity to the respective markets, the distribution route from the manufacturing site to the customer would be significantly reduced through the implementation of micro-factory-manufacturing. This impact factor becomes even more crucial, when considering that manufacturing for mass production is oftentimes outsourced to countries with low labor cost, which are typically far away from the targeted markets. The resulting proximity of manufacturing and target markets, thus, has to be regarded as a positive impact factor that is capable of lowering energy consumption and emissions during the distribution phase [50].

4.4 **Impact factors in the customer/usage phase**

The usage phase of a product life-cycle refers to the time span in which the product is delivered to the customer and is applied by him/her to satisfy his/her needs. Based on the life span of the product the environmental impacts of the usage phase might vary. However, it is commonly believed that the usage phase is usually the longest stage of the product life-cycle and thus can have significant impacts on sustainability. In terms of MC products, the life span is usually considered to be longer due to the fact that a customer might be more attached to customized products. In the case of standard products, the purchase price for a certain group of products might be so low that consumers do not hesitate to dispose a nearly unused product if it does not meet their needs anymore and purchase a replacement product [48, 51]. This scenario is less likely in the case of a customized product, as an individualized product should have a high compatibility with the customer's needs and it also carries a premium price. Subsequently, it should be less likely that the consumer will replace the customized product with another product and therefore might use the product for a longer period of time compared to a standard product. This eventually enhances the environmental sustainability since less waste is produced.

Furthermore, the modular nature of an MC product facilitates upgrading of the product and consequently extending its life-cycle [45]. Having a modular architecture, a product can be easily re-configured through changing or replacing one or more modules and hence it can be used for a longer time. Moreover, modularity facilitates the maintenance of the product during its usage phase since any defective module can be simply replaced by a new one [52]; whereas in products with an integrated architecture the defective parts cannot be disassembled and therefore the product cannot be used any longer. On the other hand, taking into account the necessity of efficient production in a MC environment, most of the MC companies try to develop standard modules which can be used in multiple products. As a consequence, the company can invest more in optimizing these modules to make them more energy-efficient. Considering the high volume of these modules, due to their application in several products, the level of energy consumption in the MC products can be significantly lowered compared to mass-produced products [45].

4.5 **Impact factors in the end of life phase**

Decisions that are made at end-of-life phase significantly influence the environmental sustainability impact of the product. In this regard, several methodologies have been proposed in order to pursue a closed-loop life-cycle including the 3R concept (reduce, reuse, recycle) [53] and the 6R methodology which is an extension of the 3R concept. The 6R methodology considers six main strategies (reduce, reuse, recover, redesign, remanufacture, recycle) for a sustainable treatment of a product at the end of its life-cycle[38]. While the main focus of "reduce" is on the prior phases of the life-cycle (design, manufacturing, distribution, and use) by emphasizing the reduction of energy and raw material consumption, the other strategies mainly refer to actions during the end-of-life phase.

In the case of customized products, the "reuse" strategy might seem challenging, considering the fact that MC products are tailored to the individual needs of the respective customers. Hence, it seems very unlikely that the product and its attributes fit an entirely different consumer and can thus be re-used[43]. From this perspective an MC product seems quite non-reusable; however it can be argued that if a product contains the possibility to adapt / reconfigure a product after purchase, the likelihood of re-use increases [54].

The two strategies of re-design and re-manufacturing emphasize on creating multiple life-cycles for a single product. In the words, the life of the product would be extended by re-designing or re-configuring some parts of it and creating multiple usage phases for the product. In the case of re-manufacturing the product would be disassembled, cleaned, inspected, repaired, replaced and finally reassembled so that it would be revived as an entirely new product in terms of performance and durability [55, 56]. Considering the characteristics of products within the MC strategy, re-designing and re-manufacturing seem to be applicable and realistic strategies for waste management. In fact, the modular architecture of MC products makes them a proper choice for disassembling and re-assembling. In this regard, re-manufacturing of an MC product would be much more cost-efficient compared to a product with integrated product architecture. Moreover, the redesign process can enable consumers to assess the impact of each customized alternative with regards to resource consumption and environmental benefits during the co-design process [36]. The same argument could be made for recycling. The initial step of recycling of every product is disassembling and separating the recyclable parts from those that are non-recyclable. MC products again, thanks to their modular architecture, can be disassembled very easily and quickly.

5. CONCLUSION

From its emergence as a trend, MC has been extensively discussed as a proper business model to satisfy the individual needs of customers. However, the increasing importance of sustainability in the last decades has pinpointed it as a crucial point of attention for manufacturing companies. This paper tries to have a closer look at the concept of MC from the perspective of environmental sustainability. It discovers potential interdependencies in order to explore the impact factors of MC on environmental sustainability. To this end, a product life-cycle approach was considered including five separate phases of a product's life.

The analysis of each product life-cycle phase reveals that in some aspects MC products can enhance the environmental sustainability thanks to the employment of specific practices and capabilities, which are required for successful implementation of MC. For instance the modular architecture that is typically used in many MC products can have a positive impact on environmental sustainability. It facilitates disassembling of the product at the end of its life as well as re-designing or re-manufacturing to extend the product life-cycle and decrease waste production. Customer involvement in the co-design process (during the design phase), make-to-order nature of MC and robust production processes used to produce MC products (during the manufacturing phase) are other examples of MC practices which might result in lower environmental impacts.

Nevertheless, beside their positive impacts, MC practices can also negatively affect sustainability. Taking into account the necessity for individual shipments during the delivery of MC products, the level of energy consumption and emissions could increase significantly. Moreover, the customized features of an MC product make implementation of re-use policy quite impossible at the end-of-life of the product. Considering all the above mentioned points, It can be observed that MC is a strategy which can both benefit and harm the environmental sustainability through various impact factors. The final influence of MC on sustainability, however, is a trade-off which should be managed by MC firms to reach the desired level of sustainability performance. In other words, the main challenge of MC enterprises, in terms of sustainability, would be the implementation of MC in a more eco-friendly manner.

While the current paper brings into light some potential interrelations between MC and Sustainability, it's still soon to conclude about the real impact of MC practices on sustainability. In fact, the open research streams in the field of Mass Customization and Sustainability bring into lightthe necessity of defining a research agenda targeting at exploring the potential interdependencies between the two concepts from different perspectives. From a general perspective, the issue of externalities is always a challenge: How shall we measure and what shall we measure? How many of the indirectly used products, services and processes shall be incorporate in order to discuss if or if not the MC industrial process is sustainable? And how do we ensure that we have been mapping the cost and benefit right? From a practical perspective, firms would have to evaluate how the different impact factors are related to their specific MC business model. Certain mapping methodologies such as the Business Models Canvas [16] could lead them to solve this assignment. Also, the Business Model Cube could be a useful mapping tool [57]. This tool helps to link the identified impact factors to seven different dimensions of the business model. Doing so, an MC firm will get a detailed picture of the interrelation with the relevant impact factors. As in each case some impact factors may be regarded as more important than others a ranking of impact factors could be a useful next step.

An additional research stream relates to analysis of social effectsof MC beside its environmental impacts. MC products can be extremely socially sustainable during the usage phase due to their customized features and attributes (e.g. in the case of people with special needs or disabled people). Moreover MC can be seen as a driver to create local jobs and protect local labor thanks to the use of mini-factories and decentralized production systems. Consequently, the future research directions should be focused not only on the environmental dimension of sustainability, but also on the concept of sustainability as described in the concept of the triple bottom line [8]. In addition, the increasing interest and involvement of MC companies in sustainability might make it feasible for future researchers to extend the qualitative research into a quantitative phase by measuring the impact of MC on sustainability through quantitative key performance indicators. The "MC assessment and measurement framework for industrial applications" [58] could be used as a reference for such a quantitative assessment.

Eventually, as described in the introduction, this paper tried to take an initial step toward definition of a research agenda in terms of Mass Customization and Sustainability. The proposed approach of analyzing the potential impacts of MC on environmental sustainability considering different phases of a product life-cycle is an initial step toward cause-effect analysis of MC and sustainability and definition of a structure for a research agenda. Hence, the above mentioned research streams along with the findings of future works can be used to map the open issues and build an extensive research agenda.

6. REFERENCES

[1] Davis, S. M. (1987), *Future Perfect*. Addison-Wesley, Reading, USA

[2] Oliver, R. L. (1980), "A Cognitive Model of the Antecedents and Consequences of Satisfaction Decisions", *Journal of Marketing Research (JMR),* Vol. 17,No. 4, pp. 460-469.

[3] Oliver, R. L. and DeSarbo, W. S. (1988), "Response Determinants in Satisfaction Judgments", *Journal of Consumer Research,* Vol. 14,No. 4, pp. 495-507.

[4] Chamberlin, E. H. (1962), *The Theory of Monopolistic Competition: a Re-orientation of the Theory of Value*, 8 ed. Harvard University Press, Cambridge

[5] Franke, N. and Piller, F. (2004), "Value Creation by Toolkits for User Innovation and Design: The Case of the Watch Market", *Journal of Product Innovation Management,* Vol. 21,No. 6, pp. 401-415.

[6] Kaplan, A. M., Schoder, D., and Haenlein, M. (2007), "Factors Influencing the Adoption of Mass Customization: The Impact of Base Category Consumption Frequency and Need Satisfaction", *Journal of Product Innovation Management,* Vol. 24,No. 2, pp. 101-116.

[7] World Commission on Environment and Development (WCED) (1987), "Our Common Future," Oxford University Press, Oxford

[8] Elkington, J. (1994), "Towards the Sustainable Corporation: Win-Win-Win Business Strategies for Sustainable Development", *California Management Review,* Vol. 36,No. 2, Winter94, pp. 90-100.

[9] Pollard, D., Chuo, S., and Lee, B. (2008), "Strategies For Mass Customization", *Journal of Business & Economics Research,* Vol. 6,No. 7, pp. 77-86.

[10] Kleer, R. and Steiner, F., "Mass Customization: Bridging Customer Integration and Sustainability? (Working Paper)", Available at SSRN: http://ssrn.com/abstract=2245622.

[11] Boër, C. R., Pedrazzoli, P., Bettoni, A., and Sorlini, M. (2013), *Mass customization and sustainability: an assessment framework and industrial implementation*. Springer, London, UK

[12] Pine, B. J. (1993), *Mass customization: the new frontier in business competition*. Harvard Business School Press, Boston, USA
[13] Tseng, M. M., Jiao, J., and Merchant, M. E. (1996), "Design for Mass Customization", *CIRP Annals - Manufacturing Technology,* Vol. 45,No. 1, pp. 153-156.
[14] Zhang, M. and Tseng, M. M. (2007), "A Product and Process Modeling Based Approach to Study Cost Implications of Product Variety in Mass Customization", *IEEE Transactions on Engineering Management,* Vol. 54,No. 1, pp. 130-144.
[15] Piller, F. T. (2004), "Mass customization: reflections on the state of the concept", *International Journal of Flexible Manufacturing Systems,* Vol. 16,No. 4, pp. 313-334.
[16] Osterwalder, A. and Pigneur, Y. (2010), *Business Model Generation: A Handbook for Visionaries, Game Changers, and Challengers*. John Wiley & Sons, Hoboken, USA.
[17] Gassmann, O., Frankenberger, K., and Csik, M. (2014), *The business model navigator: 55 models that will revolutionise your business*. Pearson, London, UK
[18] Johnson, M. W., Christensen, C. M., and Kagermann, H. (2008), "Reinventing Your Business Model", *Harvard Business Review,* Vol. 86,No. 12, pp. 50-59.
[19] Lampel, J. and Mintzberg, H. (1996), "Customizing Customization", *Sloan Management Review,* Vol. 38,No. 1, Fall96, pp. 21-30.
[20] Salvador, F., De Holan, P. M., and Piller, F. (2009), "Cracking the Code of Mass Customization", *MIT Sloan Management Review,* Vol. 50,No. 3, pp. 71-78.
[21] Rungtusanatham, M. J. and Salvador, F. (2008), "From Mass Production to Mass Customization: Hindrance Factors, Structural Inertia, and Transition Hazard", *Production & Operations Management,* Vol. 17,No. 3, pp. 385-396.
[22] Fogliatto, F. S., da Silveira, G. J. C., and Borenstein, D. (2012), "The mass customization decade: An updated review of the literature", *International Journal of Production Economics,* Vol. 138,No. 1, pp. 14-25.
[23] Huang, X., Kristal, M. M., and Schroeder, R. G. (2010), "The Impact of Organizational Structure on Mass Customization Capability: A Contingency View", *Production & Operations Management,* Vol. 19,No. 5, pp. 515-530.
[24] Liechty, J., Ramaswamy, V., and Cohen, S. H. (2001), "Choice Menus for Mass Customization: An Experimental Approach for Analyzing Customer Demand with an Application to a Web-Based Information Service", *Journal of Marketing Research (JMR),* Vol. 38,No. 2, pp. 183-196.
[25] MacCarthy, B. L., Brabazon, P. G., and Bramham, J. (2002), "Key value attributes in mass customization", in *Moving into Mass Customization: Information Systems and Management Principles.*, C. Rautenstrauch, R. Seelmann-Eggebert, and K. Turowski, Eds., ed Berlin: Springer, pp. 71-89.
[26] Åhlström, P. and Westbrook, R. (1999), "Implications of mass customization for operations management", *International Journal of Operations & Production Management,* Vol. 19,No. 3/4, pp. 262-274.
[27] Tu, Q., Vonderembse, M. A., and Ragu-Nathan, T. S. (2001), "The impact of time-based manufacturing practices on mass customization and value to customer", *Journal of Operations Management,* Vol. 19,No. 2, pp. 201-217.
[28] Broekhuizen, T. L. J. and Alsem, K. J. (2002), "Success Factors for Mass Customization: A Conceptual Model", *Journal of Market-Focused Management,* Vol. 5,No. 4, 2002/12/01, pp. 309-330.
[29] Dellaert, B. G. C. and Stremersch, S. (2005), "Marketing Mass-Customized Products: Striking a Balance Between Utility and Complexity", *Journal of Marketing Research (JMR),* Vol. 42,No. 2, pp. 219-227.
[30] Schreier, M. (2006), "The value increment of mass-customized products: an empirical assessment", *Journal of Consumer Behaviour,* Vol. 5,No. 4, pp. 317-327.
[31] Wellige, M. and Steiner, F. (2014), "Measuring Firm Capabilities for Mass Customization: Construction of a Formative Measurement Index", *Best Paper Proceedings of the 74th Annual Meeting of the Academy of Management, Operations Management (OM) Division, Philadelphia, USA, August 1st - 5th, 2014.,*
[32] Piller, F. (2007), "Observations on the present and future of mass customization", *International Journal of Flexible Manufacturing Systems,* Vol. 19,No. 4, pp. 630-636.
[33] Kotha, S., "Mass Customization: Implementing the Emerging Paradigm for Competitive Advantage", *Strategic Management Journal,* Vol. 16,No. S1, 1995, pp. 21-42.
[34] Shahzad, K. and Hadj-Hamou, K. (2013), "Integrated supply chain and product family architecture under highly customized demand", *Journal of Intelligent Manufacturing,* Vol. 24,No. 5, pp. 1005-1018.
[35] Jovane, F., Yoshikawa, H., Alting, L., Boër, C. R., Westkamper, E., Williams, D., Tseng, M., Seliger, G., and Paci, A. M. (2008), "The incoming global technological and industrial revolution towards competitive sustainable manufacturing", *CIRP Annals - Manufacturing Technology,* Vol. 57,No. 2, pp. 641-659.
[36] Badurdeen, F. and Liyanage, J. P. (2011), "Sustainable value co-creation through mass customisation: a framework", *International Journal of Sustainable Manufacturing,* Vol. 2,No. 2/3, pp. 180-203.
[37] Chin, R. and Smithwick, D. (2009), "Environmental Impacts of Utilizing Mass Customization: Energy and Material Use of Mass Customization vs .Mass Production", in *5th World Conference on Mass Customization & Personalization (MCPC 2009)*, Helsinki 2009
[38] Badurdeen, F., Iyengar, D., Goldsby, T. J., Metta, H., Gupta, S., and Jawahir, I. S. (2009), "Extending total life-cycle thinking to sustainable supply chain design", *International Journal of Product Lifecycle Management,* Vol. 4,No. 1, pp. 49-67.
[39] Jawahir, I. S., Rouch, K. E., Dillon Jr., O. W., Joshi, K. J., Venkatachalam, A., and Jaafar, I. H. (2006), "Total life-cycle considerations in product design for manufacture: a framework for comprehensive evaluation", in *10th International Research/Expert Conference "Trends in the Development of Machinery and Associated Technology" TMT 2006*, Barcelona / Lloret de Mar, 2006, pp. 1-10.
[40] Ardito, C., Barricelli, B. R., Buono, P., Costabile, M. F., Lanzilotti, R., Piccinno, A., and Valtolina, S. (2011), "An ontology-based approach to product customization", in *End-User Development*, M. F. Costabile, Y. Dittrich, G. Fischer, and A. Piccinno, Eds., ed Berlin: Springer, pp. 92-106.
[41] Blecker, T. and Friedrich, G. (2006), *Mass Customization: Challenges and Solutions*. Springer, Boston, USA
[42] Ulrich, K. T. and Eppinger, S. D. (2004), *Product design and development*. McGraw-Hill, Boston, USA
[43] National Council for Advanced Manufacturing. (30.07.2014). *Sustainable Manufacturing*. Available: http://www.nacfam.org/PolicyInitiatives/SustainableManufacturing/tabid/64/Default.aspx
[44] Boër, C. R. (2009), "International cooperation on sustainable manufacturing", in *ICT for Energy Efficiency Conference*, Brussels, 2009
[45] Brunø, T. D., Nielsen, K., Taps, S. B., and Jørgensen, K. A. (2013), "Sustainability Evaluation of Mass Customization", in *Advances in Production Management Systems - Sustainable Production and Service Supply Chains*, ed Berlin: Springer, pp. 175-182.
[46] Walcher, D. and Piller, F. T. (2012), *The Customization 500: An International Benchmark Study on Mass Customization and Personalization in Consumer E-Commerce*. Lulu Press, Raleigh, USA
[47] Tu, Y. L., Xie, S. Q., and Fung, R. Y. K. (2007), "Product Development Cost Estimation in Mass Customization", *IEEE Transactions on Engineering Management,* Vol. 54,No. 1, pp. 29-40.
[48] Petersen, T. D., Jørgensen, K. A., Nielsen, K., and Taps, S. B. (2011), "Is Mass Customization Sustainable?", in *World Conference on Mass Customization and Personalization MCPC 2011* San Francisco, 2011.
[49] Pourabdollahian, G., Taisch, M., and Tepe, G. (2013), "Exploring Different Faces of Mass Customization in Manufacturing", in *Advances in Production Management Systems. Sustainable Production and Service Supply Chains*, V. Prabhu, M. Taisch, and D. Kiritsis, Eds., ed Berlin: Springer, pp. 13-20.
[50] Reichwald, R., Stotko, C. M., and Piller, F. T. (2005), "Distributed mini-factory networks as a form of real-time enterprise: concept, flexibility potential and case studies", in *The Practical Real-Time Enterprise*, B. Kuhlin and H. Thielmann, Eds., ed Berlin: Springer, pp. 403-434.
[51] Hethorn, J. and Ulasewicz, C. (2008), *Sustainable fashion: Why now?: A conversation exploring issues, practices, and possibilities.* Fairchild Books, New York, USA
[52] Nielsen, K. and Brunø, T. D. (2013), "Closed Loop Supply Chains for Sustainable Mass Customization", in *Advances in Production Management Systems. Sustainable Production and Service Supply Chains*, V. Prabhu, M. Taisch, and D. Kiritsis, Eds., ed Berlin: Springer, pp. 425-432.
[53] Joshi, K., Venkatachalam, A., and Jawahir, I. (2006), "A new methodology for transforming 3R concept into 6R concept for improved product sustainability", in *Proceedings of the Global Conference on Sustainable Product Development and Life Cycle Engineering*, Sao Paolo, pp. 3-6.
[54] Rijsdijk, S. A. and Hultink, E. J. (2009), "How Today's Consumers Perceive Tomorrow's Smart Products", *Journal of Product Innovation Management,* Vol. 26,No. 1, pp. 24-42.

[55] Nasr, N., Hilton, B., and German, R. (2011), "A framework for sustainable production and a strategic approach to a key enabler: remanufacturing", in *Advances in Sustainable Manufacturing*, ed Berlin: Springer, pp. 191-196.
[56] Seliger, G., Kim, H. J., Kernbaum, S., and Zettl, M. (2008), "Approaches to sustainable manufacturing", *International Journal of Sustainable Manufacturing,* Vol. 1,No. 1/2, pp. 58-77.
[57] Lindgren, P. and Horn Rasmussen, O. (2013), "The Business Model Cube", *Journal of Multi Business Model Innovation and Technology,* Vol. 1,No. 3, pp. 135-182.
[58] Nielsen, K. (2014), "Mass Customization Assessment and Measurement Framework for Industrial Applications", Ph.D. thesis, Department of Production, Aalborg University, Aalborg, Denmark

A Contribution toward a Research Agenda: Identifying Impact Factors of Mass Customization on Environmental Sustainability

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Rezime

O kastomizovanoj industrijskoj proizvodnji (KIP) se veoma mnogo diskutuje u menadžerskoj literaturi kao o potencijalnom poslovnom modelu namenjenom za heterogena tržišta. U tržišnim uslovima koje karakteriše visok nivo heterogenosti potreba kupaca, KIP mora biti uzeta u obzir kao validna strategija. Međutim, moguće je da je pristup poslovnim modelima samo na bazi ekonomskih indikatora nedovoljan. Problemi životne sredine i pogoršavanja u pogledu klimatskih promena su podstakli globalnu debatu o ekološkom razmišljanju i održivosti. U ovom kontekstu, postojeća literatura opisuje potrebu za strategijama koje su pogodne u pogledu ekonomskih, socijalnih i ekoloških aspekata. U skladu sa ovim gledištem, sve više autora tvrdi da KIP – pored toga što je ekonomski privlačan poslovni prilaz – takođe sa sobom nosi potencijal da bude ekološki i socijalno koristan poslovni model. Ovaj rad ima za cilj da identifikuje potencijalne faktore uticaja KIP-a na održivost kako bi se ustanovila istraživačka agenda koja se tiče uloge KIP-a u održivosti.

Ključne reči: *O kastomizovanoj industrijskoj proizvodnji, Održivost, Istraživačka agenda*