11th International Conference on Customization and Personalization MCP 2024
The Power of Customization and Personalization in the Digital Age
September 25-26, 2024, Novi Sad, Serbia

DESIGNING FOR CIRCULARITY: CHARACTERIZING CIRCULAR, GREEN, AND SUSTAINABLE PRODUCTS IN THE CONTEXT OF MASS CUSTOMIZATION

Silvia Colabianchi[1] [ORCID 0000-0002-1811-8619], Chiara Grosso[1] [ORCID 0009-0008-2691-3947], Claudia Monzi[1], Luca Fraccascia[1,2] [ORCID 0000-0002-6841-9823], Fabio Nonino[1] [ORCID 0000-0002-0552-6031]
[1]Department of Computer, Control and Management Engineering "Antonio Ruberti", University of Rome La Sapienza, Rome, Italy
[2]Department of High-Tech Business and Entrepreneurship, University of Twente, Enschede, the Netherlands

Abstract. *In the looming paradigm shift from linear to circular economy (CE) the road map for companies is fraught with challenges to integrate circular targets into business strategy. The transition to a circular model requires the company to upskill and/or reskill additional capabilities for transiting to a production model able to close the loop. Research on CE agrees that the functionality of circular models can be effective only if the products and services are designed for circularity. The transition to circularity is especially challenging for those companies that combine high performance in product customization with high performance in cost, delivery, and quality (mass customization) while integrating sustainability principles into businesses (green management) in looming circular targets. The present study addresses circular targets with attention to product design to support mass customizers in dealing with the challenges of combining MC with CE models. More concretely, the study focuses on the characteristics of circular products while providing discernment into green versus sustainable product characteristics. The discernment of characteristics for each product type can support companies that adopt MC in identifying what characteristics are required for taking a product to full circularity and those products from their offering (if any) that are the likeliest candidates for moving from green and/or sustainable to circular to prioritize product (re) design accordingly.*

Key Words: ***Product Design, Circular Target, Sustainable Drivers, Customization, Twin Transition, Circular Economy***

1. INTRODUCTION

In the looming paradigm shift from linear to circular models of production and consumption, as outlined in the new EU action plan, companies face significant challenges in transitioning their capabilities to meet circular economy (CE) targets (Morseletto, 2020; Potting et al., 2017). Companies must adjust or even rethink their business strategies to align with CE requirements.

Research on drivers and barriers for transitioning to full circularity addressed CE per industry sector (Acerbi & Taisch, 2020), reviewed CE across decades (Ranjbari et al., 2021) research on how to achieve product-level CE (den Hollander et al., 2017; Lofthouse & Prendeville, 2018) multiple loops of circular design (Mestre & Cooper, 2017) and possible approaches (Sassanelli et al., 2020).

The literature on CE concurs that the effectiveness of circular models of production and consumption hinges on designing products and services for circularity. Within this context, the intersection of mass customization (MC), sustainability, and the CE presents a promising pathway to achieve both economic and environmental goals. MC refers to the production of goods tailored to individual customer needs while maintaining the efficiency of mass production (Da Silveira et al., 2001). This approach not only enhances customer satisfaction but also aligns with sustainability principles by reducing waste and resource consumption.

The synergy between MC and CE enables the efficient production of customized products designed with their entire lifecycle in mind, facilitating easier disassembly, reuse, and recycling (Bertassini et al., 2023). Moreover, co-creation and communication, design strategies, and material and energy efficiency are identified as key levers for diffusing circular principles in MC (Bertassini et al., 2023).

However, the shift towards integrating CE principles in MC is accompanied by several challenges related to industrial systems engineering. These challenges include the need for financial support, effective circular supply chains,

and addressing barriers in product redesign (Jaeger & Upadhyay, 2020; Roy et al., 2022).

The present study aims to contribute to research on mass customization strategy and CE with attention to product design to move a step forward in overcoming barriers in product (re)design for circularity. More concretely, the study focuses on the characteristics of circular products while providing discernment into green versus sustainable product characteristics.

The discernment for each product type would support companies that adopt MC in identifying what characteristics are required for taking a product to full circularity and detect those products (if any) from their offering that are the likeliest candidates for moving from linear, green and/or sustainable to circular to prioritize processes of product (re)design accordingly. Prioritizing product design intervention (hopefully) could hasten the process of integrating CE approaches in MC.

Empirically the present study systematically reviews 68 researches on product designs. Initial findings serve to detect the main characteristics and discernment between green, sustainable, and circular products. This study is part of an ongoing research project that will in the future culminate in the development of a circular product matrix.

The remainder of the paper is organized as follows. Section 2 presents the theoretical background that underlines the research. Section 3 introduces the research design and methodology applied to the scope of the present study. Section 4 presents a synthesis of the main interpretative findings, where articles are described according to the approaches used to describe circular products. Sections 5 discuss the research outcomes. The contribution of the study, limits, and open research questions on possible further research are described in the conclusive section.

2. THEORETICAL BACKGROUND

1.1. Circular product design

As reported by the European Commission, the design phase determines approximately 80% of the environmental impact of products (European Court of Auditors (ECA), 2023). The role of product design in the transition from linear to circular is crucial in promoting the design of products with circular characteristics free from planned obsolescence (London, 1932), but more durable and with repairable components. Planned obsolescence refers to products designed to quickly become obsolete, encouraging consumers to replace them frequently, while increasing companies' profits (London, 1932). The design approach detected by (den Hollander et al., 2017) aimed at reversing obsolescence level by declining product integrity. In their study (den Hollander et al., 2017) highlighted that circular product design should be consistent with two approaches, namely: (a) design for recycling and (b) design for product integrity. Concerning the former approach, the recycling process involves the dismantling and disintegration of a product and its constituent components and the subsequent reprocessing of the product's materials. Literature proposed several design strategies aimed at closing resource loops via recovering, refurbishing, and remanufacturing (Bocken et al., 2016; Hapuatte, 2021).

Concerning the latter approach, product integrity refers to maintaining the product in its original state, or in a condition as close as possible to its original state, for the longest possible duration. To achieve the longest possible duration a typology for design for product integrity is based on three strategies:

- Resisting obsolescence as a product design strategy that aims at designing products for physical and emotional durability;
- Postponing obsolescence as a product design strategy that aims at designing products for maintenance and upgrading;
- Reversing obsolescence as a product design strategy that aim at recontextualizing, repair, refurbishing, and remanufacturing.

1.2. Challenges for mass customizers

Mass customization has been defined as the organization's capability to produce differentiated products without sacrificing manufacturing costs and delivery lead times (Tu et al., 2001). MC is conceptualized as a competitive performance, rather than as a combination of routines and related inputs that enable such a performance.

A growing number of firms nowadays need to combine MC with green management. As a result, companies adopting a mass customization strategy have to deal with the twofold challenge of combining high performance in product customization with high performance in cost, delivery, and quality (mass customization) while integrating green management into their business models (Trentin et al., 2015).

Research on the synergies or trade-offs between MC and GM provides findings partly conflicting (Naldi et al., 2023): some studies suggest that MC and green management may be synergistic, while others raise concerns about the environmental sustainability of MC). Previous research (Trentin et al., 2015) pointed out that MC product modularity has been recognize to reduce the life-cycle environmental impact of customized goods (Brunø et al., 2013), while the postponing of product differentiation until customer order engenders environmental benefits (Badurdeen & Liyanage, 2011). Instead, (Petersen et al., 2011) argue that MC enablers may have both positive and negative effects on a firm's environmental performance, depending on the specific type of product. Based on product type (Boer et al., 2013) detect that MC enablers such as direct delivery reduce overall consumption of energy and resources in the specific case of customized footwear.

Technological advancements such as IoT, advanced manufacturing techniques, and redistributed manufacturing are essential for enabling highly flexible production systems that can quickly adapt to produce customized products while optimizing resource use and minimizing waste (Rocca et al., 2020). Product configurator systems play an essential role in supporting the design of new product variants or modular organization, and assembly in the industrial chain resources (Antonelli & Bruno, 2017). Moreover, MC poses significant challenges in production systems design, particularly in

transitioning from mass production and dealing with high variety and low volume production adopting new manufacturing environments, and stressing a modular design that allows for the easy disassembly, repair, and reuse of product components (Chen et al., 2021; Mikkola, 2007).

Challenges and opportunities of integrating CE targets claim for research to delve in synergies or trade-off of integrating circular approaches within any type of business model.

Despite numerous studies addressing the challenges and barriers of integrating MC and the CE, a clear characterization of circular product characteristics to support Mass customizers integrating CE approaches in product design is still missing

The present paper addresses the gap providing a distinction between circular, green, and sustainable product characteristics to support Mass customizers in detecting synergies or trade-offs between mass customization strategies and integration of circular approaches in product design.

3. METHODOLOGY

1.1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA)

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) method (Moher et al., 2009) was employed to conduct a systematic mapping study. The PRISMA guidelines provide a structured approach for the identification, screening, eligibility, and inclusion of studies.

Identification

The review involved searching the Scopus database for papers indexed up until January 31, 2024. Scopus was selected for its academic relevance, containing over 90 million records from 29,000 journals published by more than 7,000 publishers. The first step was to define the scope of the search query. To achieve this, an interdisciplinary team of four experts with diverse backgrounds was assembled: one specializing in mass customization and product configurators, another in sustainable project management, a third in the circular economy, green products, and the fashion industry, and the fourth in sustainable industrial systems. The selected query looked for every article using either "sustainable product", "sustainable design", "green design", "green product", "circular design" or "circular product" along with “conceptual model” or framework to broadly collect all the articles describing the characteristics of these products.

The scope of the research was limited to articles published in English. The query is structured to align with the objectives of the study, which seeks to identify essential elements that contribute to the design of sustainable, green, and circular products. The aim is to pinpoint those elements that can facilitate the integration of mass customization within a framework of circular design logic. In summary, the search query for the database was:

(TITLE-ABS (("sustainable product" OR "green design" OR "green product" OR "sustainable design" OR "circular design" OR "circular product") AND ("conceptual model" OR "framework"))) AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (LANGUAGE , "English"))

As a result, 1061 articles were identified through this search query. 97 articles were excluded because they were duplicates or their full text was not available.

Screening

During the screening phase, each article's title, abstract, and keywords were examined to determine if its research aligned with the review's objectives. Among 964, 702 articles were excluded since they did not focus on product models and/or processes and/or supply chains for the design, development, production, and recycling of green, sustainable, and circular products.

Eligibility

During this phase, 330 articles were analyzed. The team reviewed the full text and 262 articles were excluded as they did not meet the inclusion criteria.

Inclusion

A total of 68 articles were included for further analysis. The research team thoroughly reviewed these documents to extract data and synthesize relevant information. This process enabled a deeper understanding of the contributions of previous studies and helped identify gaps in the existing research.

The detailed process is illustrated in the workflow shown in Figure 1.

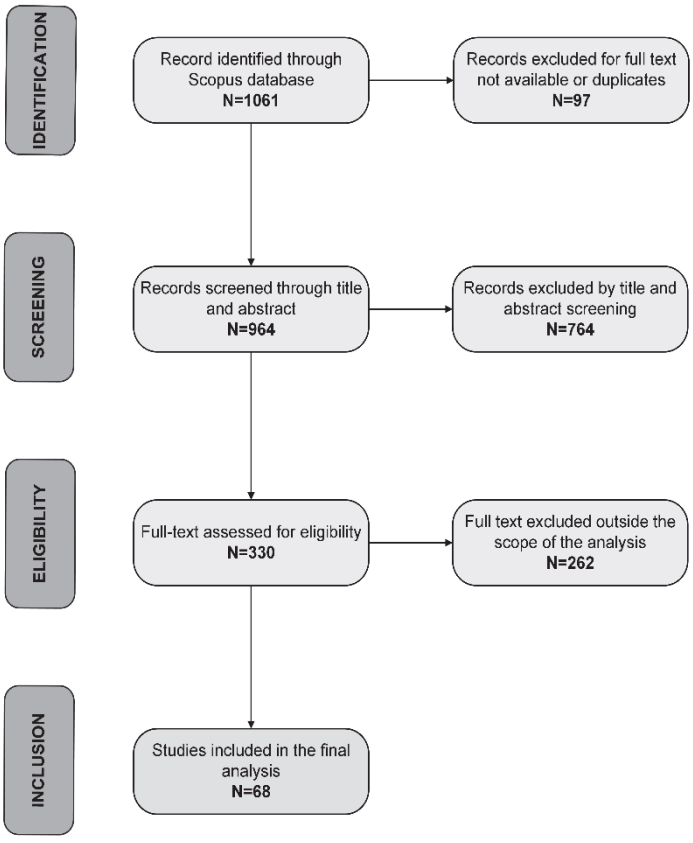

Fig. 1. *Prisma flowchart*

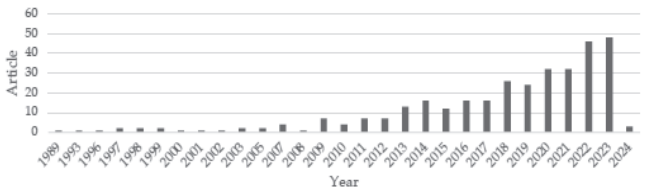

Fig. 4. *Evolution of documents over years*

4. FINDINGS

4.1. Bibliometric analysis

Regarding the evolution of publications over time, Figure 2 illustrates a growing trend in the number of documents. This increase is likely due to the spread of the topic and rising interest in CE. In particular, articles from the 1970s and 1980s predominantly used the term "green." In the 1980s and 1990s, the focus shifted toward sustainable production, and it was only from the 2000s onwards, that publications began referencing the term "circular economy."

The entire initial dataset was divided into three categories: Green Product, Sustainable Product, and Circular Product or “not specified”: The pie chart in Figure 3 shows the percentages obtained. Notably, the Sustainable Product category is the most prevalent. This is partly due to the sometimes generic use of the term, which does not specifically describe defining characteristics. Additionally, the construct of sustainability refers to at least three dimensions: economic, social, and environmental sustainability. The concepts of Green and Circular Products are more specific and can be considered subcategories of sustainability. These concepts have gained more interest recently with the growing emphasis on the CE.

4.2. Descriptive findings

Product life cycle

In the classification of articles by dimensions related to the product life cycle, it emerges that 64% placed greater emphasis on impacts before the product's use (Figure 4). This indicates a growing awareness of the importance of considering environmental and social impacts from the earliest stages of the design process. However, 22% of the articles focused on impacts after the product's usage, highlighting the importance of considering the final destiny of products, which is very important for circular design (Wang et al., 2021). Finally, the remaining 14% of the articles analyzed the impacts during the product's use, also considering dimensions such as energy consumption and pollution related to the product's use. It is interesting to note that most of the articles with a focus on before usage classified their products as green, meaning products that have an orientation towards a circular economy paradigm from their inception.

Business models, certifications, and standards

The results highlighted a broad overview of business and

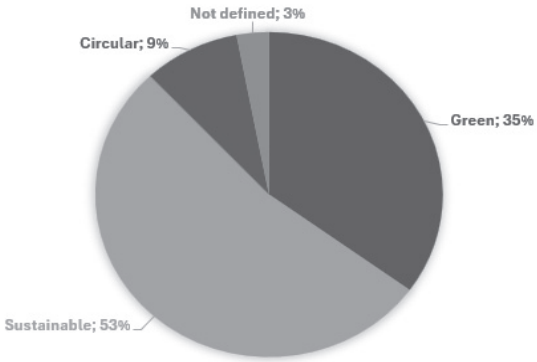

Fig. 2. *Product categories*

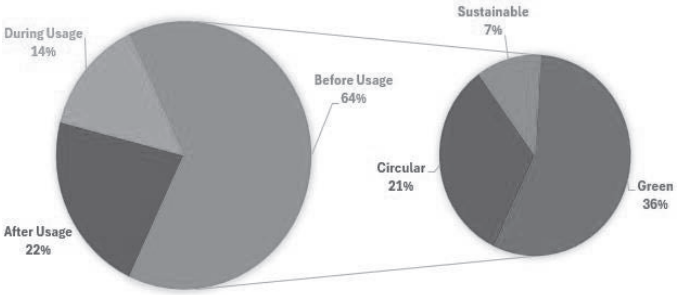

Fig. 3. *Product life cycle*

organizational models within the fashion sector. The analysis revealed various areas of focus within these models, with particular attention given to sustainable business models, the circular economy, and green marketing practices. A wide range of studies also emerged, examining the importance of certifications and standards in the fashion industry to promote sustainable and circular practices.

Certifications and standards, such as ISO14001 and Nutri-Score (Hankammer et al., 2021), were cited as crucial tools to ensure companies adopt eco-sustainable practices throughout the supply chain and production process. Furthermore, the role of certification organizations, such as Fair Trade America and the National Council of Textiles Organization (Bick et al., 2018), was recognized in evaluating and monitoring fair trade and production standards in the textile sector.

Some articles also emphasized the importance of resource efficiency metrics and standards to support eco-design and circularity in products, highlighting the need for internationally recognized certification criteria to promote eco-sustainable and responsible practices (Bick et al., 2018; Kirchherr et al., 2017). However, not all articles specified which certifications or standards were considered in their studies, although there is a general consensus on the importance of these tools to ensure sustainability and transparency in the fashion sector.

Reduce, reuse, and recycle

The documents were then analyzed according to the 3R framework: Reduce, Reuse, Recycle. The framework summarizes the objectives of the circular model as follows:

- Promotes the reduction of resource use and minimization of waste (Reduce).

- Promotes the reuse of existing materials and products to extend their useful life and avoid the need for new resources (Reuse).
- Promotes the recycling of materials and waste to create new resources and reduce environmental impact (Recycle).

Although there are revised versions of the framework, such as the 4R framework which also includes the dimension of Recovery (Kirchherr et al., 2017) or the 10 targets proposed by Potting et al., (2017), this initial phase adhered to a classification based on the 3Rs. Table 1 presents the key elements that emerged in the description of the characteristics of these products derived from the literature review as reported by the articles.

5. DISCUSSION

5.1. Product characterization and implication for Mass customization strategy and Circular design

Green Product

Definition. Findings from the literature review concur in defining a green product as a product designed, created, and marketed to reduce negative environmental impact throughout the product's life cycle (United Nations Environment Programme, 2011)

Materials. Green products are made using eco-friendly materials, and eco-friendly manufacturing processes and are designed to be biodegradable, recyclable or compostable.

Main goal. To minimize the environmental impact and promote sustainability through conscious choices throughout the product development and use process.

Implication for design. Design for green products has to minimize environmental impact in terms of optimization of production processes and waste reduction without compromising the functionality and attractiveness of the product. Green design is achieved by using recycled or recyclable materials, and eco-sustainable packaging practices.

Sustainable Product

Definition. Findings from the literature review concur in defining a sustainable product, a product designed to satisfy current needs without compromising the resources needed to satisfy the needs of future generations (World Commission on Environment and Development, 1987)

Materials. Eco-friendly and recyclable materials

Main goal. To ensure a balance between current needs without compromising the quality of life and preserving resources for the future

Implication for design. Design for sustainable products has to ensure durability and repairability and minimize environmental impact in terms of waste reduction, of energy efficiency. At the social level product design has to care of the safety and well-being of workers.

Circular Product

Definition. Findings from the literature review concur in defining a circular product as a product designed to maximize the use of resources and minimize waste while enabling repairability, reuse, and recycling (Ellen MacArthur Foundation, 2017)

Materials. Biodegradable or easily recyclable materials

Main goal. To reduce environmental impact and promote a sustainable and resource-efficient economy by creating products that can be reintegrated into the production cycle without loss of quality or value.

Implication for design. Design for circular products has to be in accordance with circular principles, which include (i) design for recycling, (ii) design for product integrity, (iii) modularity to encourage easy disassembly and remanufacturing. Furthermore, circular design has to engage all actors involved in the value chain to engender connections that can facilitate the transition towards a sustainable and resource-efficient model of production and consumption.

Table 1. *Summary of the 3R Targets in Green, Sustainable, and Circular Products*

Target	Green Product	Sustainable Product	Circular Product
Reduce	Limited use of non-renewable resources	Minimization of non-renewable resource use	Design for maximum resource-use efficiency
Reuse	Limited reuse or repurposing	Design for reuse or repurposing	Products designed for reuse and repurposing
Recycle	Limited recyclability	Recyclable materials	Products designed for recycling

Table 2. *Product categories definition*

Green Product	Sustainable Product	Circular Product
A product designed, manufactured, and used with materials and processes that minimize environmental impact throughout its entire life cycle.	A product designed and manufactured with consideration for environmental, social, and economic impacts throughout its entire life cycle.	A product designed and manufactured to be easily repaired, recycled, and reused at the end of its life cycle, to minimize waste.

Preliminary findings on the characterization of green, sustainable, and circular products pointed out that Mass Customizer which integrated green product design is required to put less effort into implementing circular principles than those who don't implement any green or sustainable principles in product design. Instead, MCs that integrated sustainable principles in product design are even closer to transiting to CE approaches than MCs that are only adopting green product design.

Consumers play a crucial role in the transition to a circular production model, as they are increasingly willing to reduce environmental impacts and enhance sustainability through CE initiatives (Alves et al., 2022). The discernment pointed out that MC customizers that have not implemented any green nor sustainable principle for product design, can achieve circular approach of product integrity with a design

strategy of resisting obsolescence. For example, by enhancing the degree of benefits that customers can derive from product customization to feel emotionally engaged to them.

Based on the preliminary findings of the present study, to achieve continuous improvement and circularity of the product Mass customizers have to prioritize at least two trends in product design processes (i) slowing down and (ii) closing the resource cycle loop.

To slow down the cycle, to prioritize design of long-lasting products, extending their useful life by increasing consumers' emotional attachment to the products themselves so that they are kept for longer. This trend can be facilitated by a degree of product personalization that provides customers with the benefits of possessing a customized product (i.e. self-expressiveness, uniqueness) or derived by product customization itself (i.e. pride of authorship, hedonic benefits) (Sandrin et al., 2017), as well as product directly linked to consumers' preference (Trentin et al., 2015).

To close the resource cycle, to prioritize the design of products partially or (better) fully recyclable to cite an example by including the adoption of bio-based options for product components or include in their offering components made with recycled materials; and to prioritize modular design that enables ease disassembly processes for upgrading and repair of the components. Instead, the reusability of a customized product would depend on the degree of personalization.

Table 3. *Product characteristics*

Characteristics	Green Product	Sustainable Product	Circular Product
Materials Used	Eco-friendly materials	Ecological and recyclable materials	Biodegradable or easily recyclable materials
Durability	Attention to durability	Design for durability	Modular design for repairability
Packaging	Eco-sustainable packaging	Reduced or recyclable packaging	Reduced and recyclable packaging
Environmental Impact	Reduced environmental impact throughout the life cycle	Minimized environmental impact with sustainable production practices	Elimination of waste and reduction of environmental impact through circular design
Social Impact	Limited attention to social aspects	Consideration of human rights, worker safety, and well-being	Promotion of social responsibility through production policies that value workers' and local community rights
3R Practices	Minimal application of the 3R	Implementation of the 3Rs	Advanced practices of the 3Rs and 10Rs

6. CONCLUSIONS

The role of product design in the transition from linear to the circular model is crucial to the success of an effective transition. This success lies in the adoption product design strategies, consistent at least with two approaches: design for recycling and (2) design for product integrity.

The present study addresses circular product design in the domain of Mass Customization strategies to support companies that adopt MC strategies in dealing with the challenges of combining MC with CE approaches for product design. This study forms a component of an ongoing research project that aims to develop a matrix detailing the characteristics of circular, green, and sustainable products. This matrix will assist companies in crafting a roadmap for transitioning their business models to embrace circularity. In fact, the study represents an initial step toward creating a comprehensive guide. This guide will identify key elements that facilitate mass customization within the context of sustainability.

Previous research on sustainable product design identified product characteristics for each product type separately to cite a few: on green product design (Dangelico & Pontrandolfo, 2010), sustainable product design (Mengistu et al., 2024).

At theoretical implication level the study moves a step forward in providing preliminary finding that would culminate on a map of product characteristics which encloses green, sustainable and circular product types.

At managerial implication level, by discerning product characteristics, preliminary findings of the present study offers practitioners with an overview of product characteristics (green, sustainable, circular) that serve as a compass to identify what characteristics are required for taking a product to full circularity and those products from their offering (if any) that are the likeliest candidates for moving from green and/or sustainable to circular so as to prioritize product (re) design strategy accordingly. To prioritize designs strategy could hasten company transition to CE approaches. To hasten the transition, it's a quite urgent issue considering the short term required to companies to adapt their business model to more sustainable targets. More concretely, starting from July 2024 all EU country members has to be aware of the new EU directive on Corporate Sustainability Reporting (CSR) that will be active from January 2025 for all companies in EU. As a consequence, companies are called to rapidly standardize their CSR to EU standard.

Limits of the present study rely to its initial phase, and will be address in the ongoing research project. Further research could address how to integrate CE approaches into to create interconnection with all actors involved in the value chain. At MC supply chain level, further research could investigate how to engage providers and stakeholders to foster the design of circular products. At MC customers' level further research could investigate how to empower customers' awareness on the sustainability of their choice while customizing a product.

7. REFERENCES

Acerbi, F., & Taisch, M. (2020). A literature review on circular economy adoption in the manufacturing sector. Journal of Cleaner Production, 273, 123086. https://doi.org/10.1016/j.jclepro.2020.123086

Alves, W., Silva, A., & Rodrigues, H. S. (2022). Circular Economy and Consumer's Engagement: An Exploratory Study on Higher Education. Business Systems Research, 13(3), 84–99. Scopus. https://doi.org/10.2478/bsrj-2022-0026

Antonelli, D., & Bruno, G. (2017). Product configuration for order acquisition and fulfillment. In Mass Customized Manufacturing: Theoretical Concepts and Practical Approaches (pp. 167–192). Scopus. https://doi.org/10.1201/9781315398983

Badurdeen, F., & Liyanage, J. P. (2011). Sustainable value co-creation through mass customisation: A framework. International Journal of Sustainable Manufacturing, 2(2–3), 180–203. https://doi.org/10.1504/IJSM.2011.042151

Bertassini, A. C., Piller, F. T., & Gerolamo, M. C. (2023). Opportunities and Challenges of Mass Customization for Circular Economy: A Literature-Based Analysis. Lecture Notes in Mechanical Engineering, 24–32. Scopus. https://doi.org/10.1007/978-3-031-34821-1_3

Bick, R., Halsey, E., & Ekenga, C. C. (2018). The global environmental injustice of fast fashion. Environmental Health, 17(1), 92. https://doi.org/10.1186/s12940-018-0433-7

Bocken, N. M. P., de Pauw, I., Bakker, C., & van der Grinten, B. (2016). Product design and business model strategies for a circular economy. Journal of Industrial and Production Engineering, 33(5), 308–320. https://doi.org/10.1080/21681015.2016.1172124

Boer, C., Pedrazzoli, P., Bettoni, A., & Sorlini, M. (2013). Mass Customization and Sustainability. https://doi.org/10.1007/978-1-4471-5116-6

Brunø, T. D., Nielsen, K., Taps, S. B., & Jørgensen, K. A. (2013). Sustainability Evaluation of Mass Customization. In V. Prabhu, M. Taisch, & D. Kiritsis (A c. Di), Advances in Production Management Systems. Sustainable Production and Service Supply Chains (pp. 175–182). Springer. https://doi.org/10.1007/978-3-642-41266-0_22

Chen, G., Liu, X., & Zhao, W. (2021). Mass customization based on generic technology and modular production method. 235. Scopus. https://doi.org/10.1051/e3sconf/202123501057

Da Silveira, G., Borenstein, D., & Fogliatto, F. S. (2001). Mass customization: Literature review and research directions. International Journal of Production Economics, 72(1), 1–13. Scopus. https://doi.org/10.1016/S0925-5273(00)00079-7

Dangelico, R. M., & Pontrandolfo, P. (2010). From green product definitions and classifications to the Green Option Matrix. Journal of Cleaner Production, 18(16), 1608–1628. https://doi.org/10.1016/j.jclepro.2010.07.007

den Hollander, M. C., Bakker, C. A., & Hultink, E. J. (2017). Product Design in a Circular Economy: Development of a Typology of Key Concepts and Terms. Journal of Industrial Ecology, 21(3), 517–525. https://doi.org/10.1111/jiec.12610

European Court of Auditors (ECA). (2023). NEWS-AAR-2023. http://www.eca.europa.eu/en/news/news-aar-2023

Hankammer, S., Kleer, R., Mühl, L., & Euler, J. (2021). Principles for organizations approaching sustainable degrowth: Framework development and application to four B Corps. Journal of Cleaner Production, 300, 126818. https://doi.org/10.1016/j.jclepro.2021.126818

Hapuatte, B. M. (2021). Closed-loop sustainable product design for circular economy. Journal of Industrial Ecology. https://onlinelibrary.wiley.com/doi/abs/10.1111/jiec.13154

Jaeger, B., & Upadhyay, A. (2020). Understanding barriers to circular economy: Cases from the manufacturing industry. Journal of Enterprise Information Management, 33(4), 729–745. Scopus. https://doi.org/10.1108/JEIM-02-2019-0047

Kirchherr, J., Reike, D., & Hekkert, M. P. (2017). Conceptualizing the Circular Economy: An Analysis of 114 Definitions. Resources, Conservation & Recycling, 127, 221–232. https://doi.org/10.2139/ssrn.3037579

Lofthouse, V., & Prendeville, S. (2018). Human-Centred Design of Products And Services for the Circular Economy – A Review. The Design Journal, 21(4), 451–476. https://doi.org/10.1080/14606925.2018.1468169

London, B. (1932). Ending the depression through planned obsolescence. https://hdl.handle.net/2027/wu.89097035273?urlappend=%3Bseq=5

Mengistu, A. T., Dieste, M., Panizzolo, R., & Biazzo, S. (2024). Sustainable product design factors: A comprehensive analysis. Journal of Cleaner Production, 463, 142260. https://doi.org/10.1016/j.jclepro.2024.142260

Mestre, A., & Cooper, T. (2017). Circular Product Design. A Multiple Loops Life Cycle Design Approach for the Circular Economy. The Design Journal, 20(sup1), S1620–S1635. https://doi.org/10.1080/14606925.2017.1352686

Mikkola, J. H. (2007). Management of Product Architecture Modularity for Mass Customization: Modeling and Theoretical Considerations. IEEE Transactions on Engineering Management, 54(1), 57–69. https://doi.org/10.1109/TEM.2006.889067

Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G., & the PRISMA Group. (2009). Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. Annals of Internal Medicine, 151(4), 264–269. https://doi.org/10.7326/0003-4819-151-4-200908180-00135

Morseletto, P. (2020). Targets for a circular economy. Resources, Conservation and Recycling, 153, 104553. https://doi.org/10.1016/j.resconrec.2019.104553

Naldi, L. D., Galizia, F. G., & Bortolini, M. (2023). Is Mass Customisation Sustainable? A Literature-Based Analysis. In F. G. Galizia & M. Bortolini (A c. Di), Production Processes and Product Evolution in the Age of Disruption (pp. 15–23). Springer International Publishing. https://doi.org/10.1007/978-3-031-34821-1_2

Petersen, J., Thorborg, K., Nielsen, M. B., Budtz-Jørgensen, E., & Hölmich, P. (2011). Preventive effect of eccentric training on acute hamstring injuries in men's soccer: A cluster-randomized controlled trial. The American Journal of Sports Medicine, 39(11), 2296–2303. https://doi.org/10.1177/0363546511419277

Potting, J., Hekkert, M. P., Worrell, E., & Hanemaaijer, A. (2017). Circular Economy: Measuring innovation in the product chain.

Ranjbari, M., Saidani, M., Shams Esfandabadi, Z., Peng, W., Lam, S. S., Aghbashlo, M., Quatraro, F., & Tabatabaei, M. (2021). Two decades of research on waste management in the circular economy: Insights from bibliometric, text mining, and content analyses. Journal of Cleaner Production, 314, 128009. https://doi.org/10.1016/j.jclepro.2021.128009

Rocca, R., Rosa, P., Sassanelli, C., Fumagalli, L., & Terzi, S. (2020). Industry 4.0 solutions supporting Circular Economy. 2020 IEEE International Conference on Engineering, Technology and Innovation (ICE/ITMC), 1–8. https://doi.org/10.1109/ICE/ITMC49519.2020.9198517

Roy, T., Garza-Reyes, J. A., Kumar, V., Kumar, A., & Agrawal, R. (2022). Redesigning traditional linear supply chains into circular supply chains–A study into its challenges. Sustainable Production and Consumption, 31, 113–126. Scopus. https://doi.org/10.1016/j.spc.2022.02.004

Sandrin, E., Trentin, A., Grosso, C., & Forza, C. (2017). Enhancing the consumer-perceived benefits of a mass-customized product through its online sales configurator. An empirical examination. https://doi.org/10.1108/imds-05-2016-0185

Sassanelli, C., Urbinati, A., Rosa, P., Chiaroni, D., & Terzi, S. (2020). Addressing circular economy through design for X approaches: A systematic literature review. Computers in Industry, 120, 103245. https://doi.org/10.1016/j.compind.2020.103245

Trentin, A., Forza, C., & Perin, E. (2015). Embeddedness and path dependence of organizational capabilities for mass customization and green management: A longitudinal case study in the machinery industry. International Journal of Production Economics, 169, 253–276. https://doi.org/10.1016/j.ijpe.2015.08.011

Tu, Q., Vonderembse, M. A., & Ragu-Nathan, T. S. (2001). The impact of time-based manufacturing practices on mass customization and value to customer. Journal of Operations Management, 19(2), 201–217. https://doi.org/10.1016/S0272-6963(00)00056-5

Wang, J., Burke, H., & Zhang, A. (2021). Overcoming barriers to circular product design. International Journal of Production Economics, 243, 108346. https://doi.org/10.1016/j.ijpe.2021.108346

CORRESPONDENCE:

Dr Silvia Colabianchi,
Assistant Prof.
University of Rome La Sapienza
Department of Computer, Control and Management Engineering "Antonio Ruberti", Via Ariosto 25, 00185, Rome, Italy silvia.colabianchi@uniroma1.it

Dr Chiara Grosso, Assistant Prof.
University of Rome La Sapienza
Department of Computer,
Control and Management Engineering
"Antonio Ruberti", Via Ariosto 25,
00185, Rome, Italy,
chiara.grosso@uniroma1.it

Dr Luca Fraccascia, Prof. University of Rome La Sapienza Department of Computer, Control and Management Engineering "Antonio Ruberti", Via Ariosto 25, 00185, Rome, Italy
University of Twente, Department of Industrial Engineering and Business Information Systems, Enschede, the Netherlands luca.fraccascia@uniroma1.it

Claudia Monzi, University of Rome La Sapienza Department of Computer, Control and Management Engineering "Antonio Ruberti", Via Ariosto 25, 00185, Rome, Italy,
monzi.1813833@studenti.uniroma1.it

Dr Fabio Nonino, Prof. University of Rome La Sapienza Department of Computer, Control and Management Engineering "Antonio Ruberti", Via Ariosto 25, 00185, Rome, Italy,
fabio.nonino@uniroma1.it

ACKNOWLEDGMENTS

This study was carried out within the MICS (Made in Italy – Circular and Sustainable) Extended Partnership and received funding from the European Union Next-Generation EU (PIANO NAZIONALE DI RIPRESA E RESILIENZA (PNRR) – MISSIONE 4 COMPONENTE 2, INVESTIMENTO 1.3 – D.D. 1551.11-10-2022, PE00000004). This manuscript reflects only the authors' views and opinions, neither the European Union nor the European Commission can be considered responsible for them.