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MASS CUSTOMIZATION DESIGN, BETWEEN CUSTOMERS AND SUSTAINABILITY

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Abstract: *Today, humanity's greatest challenge is to reduce its environmental impact. In a world where the desire for customization and personalization is increasingly present among consumers, it is crucial to minimize the harmful effects of human activity in the customizable product sector in order to make it sustainable. This paper proposes a sustainable design method for mass customization, helping designers to choose customization options based on their environmental impact and customer preferences. A case study for bathroom vanity is presented to validate the proposed method.*
Key Words: ***Mass Customization, Lifecycle analysis, Product configuration, Sustainability, modular design.***

1. INTRODUCTION

Today, humanity's greatest challenge is to reduce its environmental impact. Many scientists have proven that climate change has been caused mainly by human actions. In response to that, the international community has reacted and tried to reduce carbon emissions. With agreements, such as COP 21, states commit themselves to efforts towards environmental sustainability. Nowadays, a main part of carbon emission is related to the industrial production of consumer goods. Therefore, it is a necessity that manufacturers of consumer goods add measures to reduce their gas emissions.

In a world where the desire for customization and personalization is increasingly present among consumers, it is crucial to minimize the harmful effects of human activity in the customizable product sector to make it sustainable. Mass customization (MC) aims to deliver products that best meet individual customers' needs with near mass production efficiency. Thus, from a strategic production perspective, MC is a hybrid strategy that attempts to master the simultaneous achievement of product differentiation and cost efficiency [1]. MC's greatest strength is to fit with customer needs and many studies have proven that the better a product fits customer needs, the longer it will be used, which reduces overconsumption. It is important to benefit from the advantages offered by MC to reduce environmental impact, by offering more ecological MC products. Yet, there are still very rare works aiding designers in developing more ecological MC products.

Sustainability is defined by the United Nations as a universal call as meeting the needs of the present without compromising the ability of the future generations to meet their own needs [2]. Sustainability includes environmental, economic, and social dimensions. Nevertheless, this study focuses mainly on the environmental part of sustainability.

To quantify all impacts of a consumer product, it is necessary to adopt a life cycle approach. It identifies both opportunities and risks of a product, all the way from raw materials to disposal. The product lifecycle is divided into five parts: Design, Manufacturing, Transportation, Usage, and the end of life [3].

Impact factors in the design phase: The decisions that are made during this phase affect the final performance of the product [4]. Firstly, it raises awareness of how design choices can affect a product's final efficiency [5]. Secondly, customer involvement increases the perceived value.

Impact factors in the manufacturing phase: MC allows companies to produce only goods that consumers need. Thus, it allows a reduction of unused components, and also a reduction in energy consumption for the production of unneeded products.

According to an estimation in 2009, 300 million pairs of shoes are overproduced annually. If we made up the total amount of energy that is needed to manufacture all the unsold shoes, it is possible to supply 14 % of the energy that Switzerland is consuming each year [6].

Impact factors in the distribution phase: Most of MC product distributions are directly delivered to the client. Individual delivery has the consequence of consuming a greater quantity of resources unlike classical delivery in stores [7][8]. On the other hand, since customers don't go to a store, this represents energy efficiency. It prevents the artificialization of the soil [9].

Impact factors in the usage phase: It should be noted that the environmental impact of this phase corresponds to the life span of products. An MC product has a longer life than a mass-produced product for several reasons. Firstly, the prices of MC products are slightly higher than MP products. Higher prices constitute a barrier to purchasing what is needed. It is a barrier to compulsive buying [10]. Secondly, customization helps to meet customer expectations. Thus, it is likely to use the product longer since it fits the customer's needs [9]. Thirdly, the modular aspect of MC products facilitates its improvement over time and it makes it easier to repair.

Impact in the end-of-life phase: There are several methodologies for closing the product life cycle. The 6R (Reduce, Reuse, Recover, Redesign, Remanufacture, Recycle) is one of them. Reuse's strategy is one of MC's weaknesses since due to high customization, it is complex to find a second life for the product. However, redesign and remanufacture are the strengths of MC. Indeed, due to their modular architecture, MC products are way easier to upgrade or repair. On top of that, the modular architecture makes it easier to split recyclable from non-recyclable parts [11].

There are four variations of the MC approach [12] where the customization could take place in the distribution, assembly, manufacturing, or design phase. This paper aims to develop a methodology that can be generalized to any mass customization modular product to minimize the environmental impact of its commercialization while maintaining the customizable aspect that will meet the customer's expectations.

Section 2 presents the state of the art of previous studies on the subject of sustainability of mass customization. Section 3 aims to explain the methodology used. Section 4 presents a case study modeled using SimaPro software. Finally, Section 5 concludes the study and its limitations.

2. BACKGROUND AND RELATED WORKS

Many works discussed the concept of sustainable mass customization. A framework using digital twins is prosed in [13], but it focuses on analyzing the relations between sustainability and MC. [14] presented a new product design approach based on a unified set of Design for eXcellence (DFX) guidelines applied to the design of sustainable mass-customized products. these guidelines are a "process guideline" by which products can be designed based on sustainability and mass-customization requirements in mind but do not provide the tools required for sustainable MC design. [15] presented as well a set of guidelines for implementing MC in affordable house-building projects, considering the constraints of using traditional building technologies. Again, these are guidelines lacking the tools and methods to support them. This paper tries to cover this gap by proposing a method for designing sustainable MC products using a lifecycle assessment tool. Even though many works have shown the link between mass customization and sustainability [16, 17, 18], there are still rare works proposing a design method for sustainable MC. [19] proposes the use of SESA (SMC Excel Sustainability Approach), which is an approximated sustainable approach based on delta LCA evaluation. It is used to offer realistic information about product environmental sustainability to consumers involved in the codesign process of MC products. This research tries to propose a method applicable to all types of MC.

3. MODEL DESCRIPTION

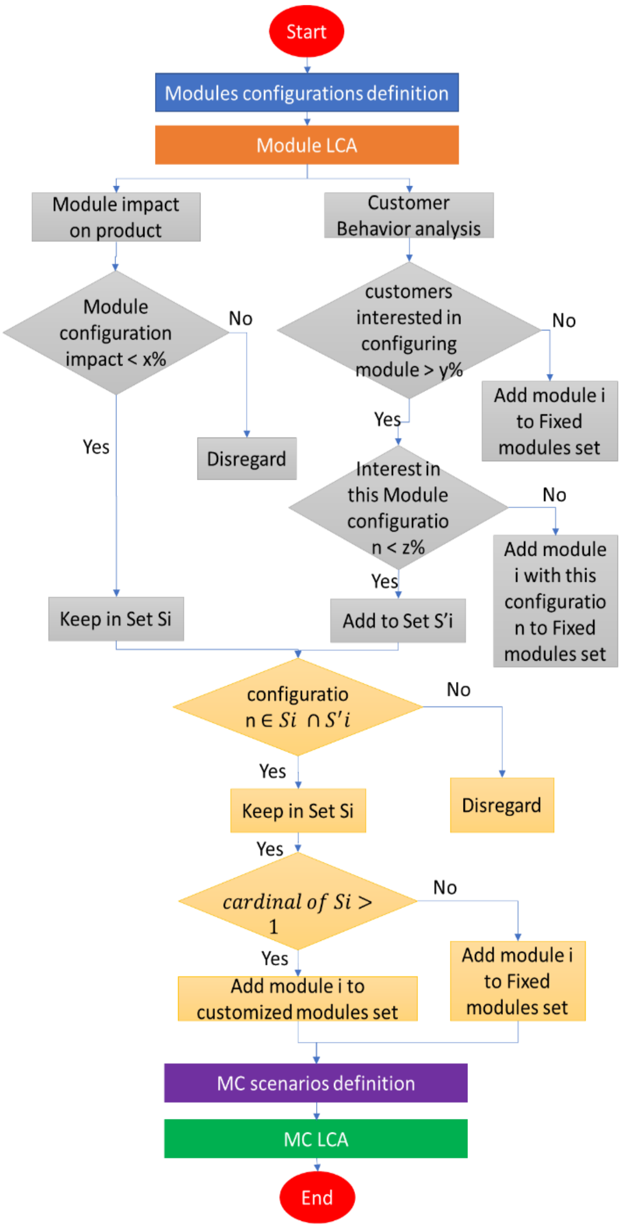

Fig. 1. *Methodology for sustainable MC design*

Figure 1 summarizes the proposed methodology that should occur after the detailed design phase of a mass customization product. At this point, the main modular design of the product is done. Hence, the different product modules are known. This method aims to choose for each module the customization options offered to the customer, by following seven main steps. The idea is also to define which modules of the product should not be customized and hence will have their configuration fixed by the design team.

Step 1: Product Modules configurations definition

The purpose of this step is to define all the possible configurations of the studied object, focusing on its modules. This means listing all the possible different characteristics of each module. These could be related to the material choice, the form, etc. Every possible configuration of module i is added to a set Si.

Step 2: Module's lifecycle assessment

In the second step, the modules are each studied. A life cycle assessment (LCA) of all possible configurations per module is done, and this is for all modules. Fifteen environmental indicators are compared, including the impact on ozone depletion and the impact on water pollution. To reduce this environmental impact the comparison of material life cycles is crucial, conclusions can be drawn on the worst and best configurations which together with the following studies will determine the chosen customization options.

Step 3: Module's impact on the whole product

In this step, an LCA is realized on the complete product, with each configuration of module i. The goal is to derive the impact of each module on the whole product and conclude with a quantification of the significance of the impacts of the modules on the whole product performance. The results of steps 2 and 3 are simultaneously analyzed. If a configuration of a module does not meet the maximum allowed environmental impact (X%), it is disregarded. If not, it is kept in S_i.

Step 4: Customer behavior analysis

This step is done in parallel with step 3. It is a customer behavior analysis to identify the desires and needs of customers and therefore the demand for customization. They can express their advice on the importance of customization on each module, and their favorite configurations. In this case, a value of Y% of the least accepted interest in customizing a module is set. If the number of customers interested in customizing module i is larger than Y% (a predefined value) and if at least Z% of them are interested in a specific configuration of this module, it can be kept in Si. If the number of customers interested in customizing module i is less than Y%, the module is added to the set of fixed modules.

Step 5: Fixed and customized modules definition

Considering the results of the two previous analyses: this step fixes modules and configurations by making a compromise between the different criteria: environmental impact, customer demand, price…

Step 6: Definition of mass customization scenarios

The aim of step 6 is to define all possible MC scenarios for this product:

- **Distribution scenario:** product already assembled, with all possible configurations;
- **Assembly scenario:** product ready to be assembled, modules already produced;
- **Production scenario:** the product is only produced after order placement.

For each scenario, the type and the frequency of transportation, and the number of waste materials are determined.

Step 7: Mass customization lifecycle analysis

Step 7 carries out a life cycle analysis for each type of mass customization desired and draws conclusions from the results on the suitability of each.

4. CASE STUDY

According to ADEME (Agence de l'Environnement et de la Maîtrise de l'Energie / Agency for the Environment and Energy Management), consumer products are responsible for 45% of the carbon emissions of a French person per year. The impact of the furniture sector is not negligible. Therefore, the product selected for a case study, is a bathroom vanity unit sold at Leroy Merlin, a French retailer specializing in home improvement. This product is an MC product, which proposes variations of materials, colors, and different configurations.

4.1. Step 1: Product *Modules configurations definition*

The purpose of this step is to define all the dimensional information and possible configurations for each module of the vanity (materials, masses, volumes, manufacturing method...) which will be useful for the life cycle analysis. The product bill of materials (BOM) is presented in **Error! Reference source not found.**.

Table 1. *Product BOM*

Modules	Material
1 - Washbasin	Ceramics Resin Glass
2 - Worktop	Laminate Teckwood
3-4-5-6-7-7bis-Facades	Laminate Pine tree
6 - Drawer bottom	Counter-plated Laminate
9 - Handles	Stainless steel chrome ABS
10 - Legs	Solid ash ABS

4.2. Step 2: Module's lifecycle assessment

To identify which material has the biggest environmental print, it was necessary to make a full life cycle study. For each component, a life cycle study has been made with every different configuration. In this case, the difference between the configurations was mainly the choice of materials.

For the LCA, SimaPro is used. It is the world's leading life cycle assessment.

The first step is to do an LCA for each configuration per module, then the second step is to do a comparative study between all configurations of the same module to identify the best and worst configuration from environmental impact point of view. Table 2 summarizes the results of these analyses.

Table 2. *Best and worst materials for each module*

Modules	TOP Materials	WORST Materials
Whashbasin	Glass	Ceramics
Worktop	Laminate	Teckwood
Facades	Laminate	Pine tree
Drawer bottom	Laminate	Counter-plated
Handles	ABS	Stainless steel
Legs	Solid ash	ABS

4.3. Step 3: Module's impact on the whole product

Once having identified the environmental impact regarding the choice of material, it is now important to figure out which modules have the highest environmental impact.

To this end, it is necessary to identify all possible combinations of the bathroom vanity unit. For instance, one of them is the combination of every component with the material who is the most environmentally friendly.

At this step, it is noted that the bowl made out of ceramic or resin and door handle made out of Inox have the biggest impact.

According to the results, a particular attention should be paid to material's selection for the door handle and the bowl.

4.4. Step 4: Customer behavior analysis

To choose what module would be fixed or customizable, it is important to consider the customer desires. The customer behavior analysis is realized with an online survey. The main objective is to identify if some modules aren't important for the customers to customize so that they could be added to the fixed modules set.

This survey is realized on Google Forms and published on social networks and via e-mails, mainly with students and staff at UTC, during one week in November 2021. 537 responds were collected. This study isn't representative of the entire population but represents a sample that will be used as a basis for the rest of the study.

Three areas of questions were asked:

- Importance given to customization;
- Material preferences;
- Customization VS price VS environment;

First, respondents gave a moderate importance for the customization of the bathroom vanity unit: half of them gave a score between two and three out of five.

They gave more importance for choosing washbasin and worktop than handles and legs. The principal and most visible modules are the most important to customize. For example, for furniture legs, only 38% of responses are above 2 out of 5.

For the next step, customers need to choose their favorite material for each module. Each time, the choice "I don't know" was also proposed. To make the choice, customers didn't have information about colors, prices or environmental issues about materials, they only had their own knowledge.

Here, customers have a very precise choice for handles: they prefer inox at 83.8%. However, 35.7%t chose "I don't know" for the facades and 43.4% for the legs, that would mean that is not important for them, or they don't know what to choose (**Error! Reference source not found.**).

Table 3. *Results of customer preferences for each module*

	Ceramics (%)	Resin (%)	Glass (%)	Laminate (%)	Teckwood (%)	Pine tree (%)	Stainless steel chrome (%)	ABS (%)	Solid ash (%)	Doesn't know (%)
Washbasin	62,5	11,8	9,2							16,5
Worktop				21,5	52,6					25,9
Facades				21,5		42,8				35,7
Handles							83,8	4,5		11,7
Legs								15,5	41	43,5

To conclude this survey, customers had to quantify customization importance opposed to price, price opposed to environmental impact and environmental impact opposed to customization. Customers prefer environmental impact to customization, although opinions are nuanced. 82.6% are ready to pay at least 5% more for a better environmental impact, and 44% of them are ready to pay more than 10%. Customers are also interested to pay more for customization: 76.8% could pay more than 5%, and only 25 of those 76.8% should pay more than 10%.

According to this study, the ideal bathroom vanity unit for customers is composed of a washbasin made of ceramics, a worktop in teakwood, facades in pine tree, handles in stainless steel chrome and legs in solid ash.

4.5. Step 5: Fixed and customizable modules definition

According to the methodology presented above, legs are already fixed with solid ash because it is the material with smaller environmental impact, and people are not interested in customization for this module. Handles are also fixed with stainless steel chrome, because the majority of consumers are interested in this material.

With those data, configurations were made to study the environmental impact of mass customization in the next step. The configurations are summarized in **Error! Reference source not found.**.

Table 4. *Considered configurations*

	Configuration N°1	Configuration N°2	Configuration N°3
Washbasin	Ceramics	Ceramics	Glass
Worktop	Teckwood	Laminate	Teckwood
Facades	Pine tree	Laminate	Laminate
Handles	Stainless steel chrome	Stainless steel chrome	Stainless steel chrome
Legs	Solid ash	Solid ash	Solid ash

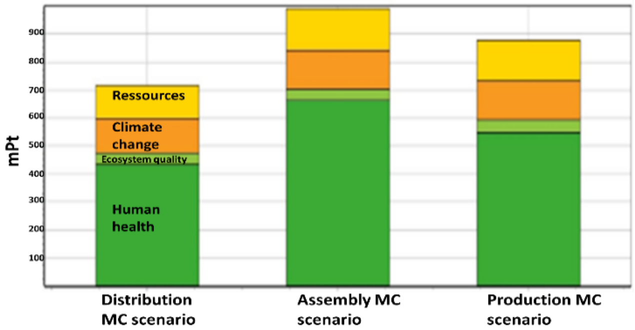

Fig. 2. *Comparaison of MC scenarios for product configuration 2*

4.6. Step 6: Definition of mass customization scenarios

Three main product configurations were identified with configuration 1 combining most required module configurations by customers. Also, three MC scenarios were defined.

Distribution scenario

For this scenario, the bathroom vanity unit is mass-produced, and the customization choice is only about the washbasin: ice or ceramic. It means that for ten products, seven ceramics washbasins and six ice washbasins are produced to anticipate the fluctuation of the orders. The quantity of each is based on the customer behavior analysis.

An estimate of 10% is provided by Leroy Merlin for the scraps of mass-produced modules and 30% for mass-customized ones. About the transport, there is one trip per week, with twenty bathroom vanity units transported.

Assembly scenario

Here, the configurations made above are studied. All modules are prefabricated. Only assembly takes place after a customer order. 10% scrap is considered for fixed modules and 30% for customized ones.

About the transport, it is also one trip per week with 20 bathroom vanity units.

Production scenario

For the last scenario chosen, each customizable module is produced after the order. No scraps and unsold goods are considered for these modules whereas 10% scrap is considered for fixed modules. For the transport, there are three trips per week because it is not possible to anticipate orders.

4.7. Step 7: Mass customization lifecycle analysis

The results of the LCA of the different MC scenarios are presented hereafter. Two analyses are made: comparing all scenarios for the same whole product configuration. Then these scenarios are compared to the best product configuration from an environmental performance point of view.

As shown in Figure 2, for product configuration 2 - Ceramics, laminate, stainless steel for the handles, and solid ash for the legs - a lower impact is obtained for the distribution MC, it remains close to the production MC. The assembly phase has a higher impact. The results for the other configurations are summarized in **Error! Reference source not found.**. Depending on the configuration, the same scenarios are not the best.

Table 5. *Comparison of MC scenarios per product configuration (green is best and orange worst performing)*

	Best	→	Worst
Configuration N°1	Distribution	Production	Assembly
Configuration N°2	Distribution	Production	Assembly
Configuration N°3	Production	Assembly	Distribution

By comparing the three configurations with an "ecological" configuration - consisting of the least impacting materials - within the assembly and production scenarios, it is easy to see that correctly choosing a configuration can reduce the environmental impact. If only the customers' opinion is taken into account (configuration N°1), the impact is important, if the configurations are well chosen, the impact decreases and is placed between that of the customer configuration and the "ecological" configuration (Figures 3 and 4).

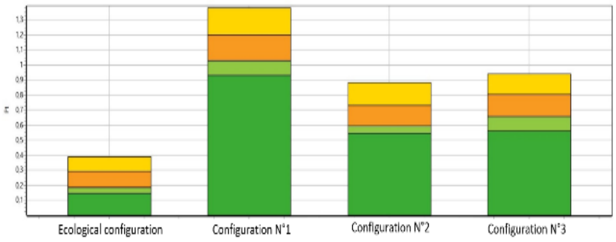

Fig. 3. *Comparaison of proposed product configurations with most ecological one for production MC scenario*

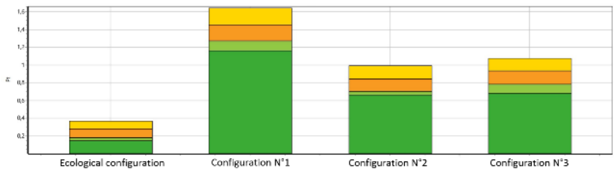

Fig. 4. *Comparaison of proposed product configurations with most ecological one for assembly MC scenario*

Based on this study, only customization options and modules configuration compatibility leading to configuration 2 or 3 will be proposed for the customer with either production or assembly MC scenario.

5. DISCUSSION AND CONCLUSION

This paper presented a methodology for modular MC products design focusing on which customization options to offer to the customer based on simultaneous analysis of customer behavior and environmental impact using a lifecycle assessment. A case study is presented and shows that depending on the parameters chosen the environmental impact can be considerably minimized. It has also shown the simplicity of its application and the adhesion of potential customers to it. The methodology developed can be generalized to any product if it has a modular design.

Concerning the limits of this work, this method is only applicable for modular products, and the end of life was humbly considered. Too little information about recycling and waste recovery was found to have accurate data. Future work should include a full study focusing on more real end-of-life modeling of a product. Also, the methodology should be included or integrated into a full design method. Moreover, at this point, only the environmental impact was considered. For future works, the social impact should be considered as well. Future research will concentrate first on comparing this method to other methods in a real case study.

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