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Configurators as a means to Leverage Customer-Centric Sustainable Systems – Evidence from the 3D-Printing Domain

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Abstract

Customer-centric strategies such as mass-customisation rely heavily on customer involvement such as co-designing products and services. In this sense, companies struggle to provide a better shopping experience by enabling technologies and Industry 4.0 practices. Online configurators are an example of these technologies that exist since decades but whose role in increasing value for the customer and the company is growing. This paper addresses the integration of sustainability preferences into configurators, with a focus on the 3D-printing domain. The basic ideas of this research work are, on one hand, that configurators can be enriched with readable and meaningful environmental indicators to increase customers environmental awareness based on the measurement of the impact of their choices, and on the other hand, such historical data about customer choices and orders available within configurators databases could support a more sustainable management of products and services portfolios. A case study-based research was developed in the 3D-printing domain exhibiting a high potential to support the rapid prototyping of customised products and thus helping to speed-up production ramp-up and time-to-market. The main findings include an initial proof-of-concept and several opportunities to further develop the configurator.

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Keywords: Configurators; 3D printing; Customisation; Costing; 3DBenchy.

1. Introduction

Mass-customisation paradigm supports the development of business agility by combining the advantages of customisation and mass-production, resulting in a cost-effective and customer-driven industrial system [1]. One of the biggest advantages of this concept is that it is useful not only for large companies but also for small entrepreneurs, who can provide their customers with a unique customisation experience, which is often more difficult to achieve for large manufacturing players because of their more rigid production systems [2].

The market trend indicates a growth in the desire to purchase customised products, which is reflected in the customers' willingness to buy [3]. 25-30% of customers have a high interest in buying such products, making customisation a huge market for a potential new customer base. This trend has been empirically confirmed by the Consumer Barometer survey conducted by KPMG and IFH Cologne [4], based on a panel of 500 consumers interested in customised products.

The findings indicate that three out of ten consumers have already prepared a product design that corresponds to their personal preferences. The survey also estimates that even

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customers who have not yet taken the step of customising a product will probably do so in the near future. Of those surveyed, 43% expect to see more customisation offers and 55% of experienced customers are willing, but above all able, to spend more on these type of products [5].

This idea of "Create Your Own" [6] is very popular with consumers today, as it offers them the opportunity to create unique products while reducing inventory and improving the ability of brands to meet customer needs.

Louis Vuitton [7], for example, is one of the companies in the luxury goods sector that is attempting to innovate and broaden their product portfolio through mass-customisation. The brand allows its customers to customise products on their site with their famous monogram or Damier fabric. Once the configuration is validated, the products are hand-made in France and delivered to the customer within eight weeks. Louis Vuitton sees this approach as an effective way to improve customer interaction by investing emotionally in the shopping experience. At the heart of this process are *online product configurators* enabling the scalability of the process.

A *configurator* is a tool that enables users to adapt the components and properties of a product so that the finished product meets the user's expectation as far as possible, thereby optimally covering their needs and requirements. When we talk about product configurators today, most certainly we mean digital applications that can be used on websites by a very large number of users at the same time to configure the respective "perfect" product.

A *product configuration* is a knowledge-based system that supports the user in creating customized products by specifying modules and options. The conceptualisations of the configuration knowledge can be classified to (a) rule-based, (b) model-based, and (c) case-based approaches. Each approach relies on a different ontology that is required to represent the domain knowledge and describe the object types (classes) and the relations among object instances. In 2013, the Austrian media specialist *CyLEDGE* published an analysis [8] based on more than 800 online configurators worldwide. This report has shown that configurators are present in all the different areas of the industry, particularly in the development of non-perishable products.

In addition to the benefits mentioned above, configurators help companies to limit risks by ruling out potentially unpopular products in the early stages of their creation. Using mass data or initial customer feedback gathered during the customisation process, brands can now apply any necessary changes at the initial level by adapting to the market in real-time, saving time and money.

Proposition: Configurators can be used to implement a customer-driven sustainability improvement process.

Configurators provide valuable input to the continuous improvement of a company offering, yet from an economic perspective. However augmenting configurators functionalities with environmental impact assessment showing the potential impact of customer choices would be of much interest in two ways: (i) increasing customer awareness of sustainability stakes, and (ii) supporting the management of offering variety towards sustainability (i.e., portfolio management depends not only on cost and profit indicators but also on environmental indicators [9]). This is likely to mitigate the risk undertaking for the company since it is a "customer-driven strategy".

To this end, this paper addresses the integration of sustainability into configurators, with a focus on the 3D-printing domain. This research is being developed within the framework of the Franco-American project SUSTAIN. The remainder of the paper is organised as follows: Section 2 describes the research methodology, Section 3 provides an overview of 3D-printing with a focus on economic and environmental perspectives, Section 4 elaborates on the development of a configurator, Section 5 discusses the results and perspectives, and finally, Section 5 concludes the paper.

2. Research Methodology

A case study-based research is conducted in order to answer the following question: *How to implement a customer-driven sustainability improvement strategy?* The basic idea of this research is that configurators can be enriched with readable and meaningful environmental indicators to support two objectives: (i) to increase customers' awareness of the environmental impact of their choices, and, ultimately, (ii) to improve products and services portfolio management based on historical data about customer choices and orders available within configurators databases. The case study was developed in the 3D-printing area and specifically for the *3DBenchy* model. *3D-printing* has been put forth as a key driver of customisation and mass-customisation. Furthermore, it exhibits a high potential to support rapid prototyping of customised products and thus helps to speed-up production ramp-up and time-to-market. The assumption is that users of the configurators represent the customers and have a background in 3D printing.

3. 3D-Printing: Insights into Economic and Environmental Sustainability Perspectives

Since its launch in the 1980s, 3D-printing has become a production method in its own right, challenging traditional manufacturing methods. Small series, unique objects, or functional prototypes benefit from this new manufacturing technology capable of reducing production costs and time. As a result, many online 3D-printing services are now available.

3.1. 3D-Printing Materials and Technologies

Among the most common materials used for 3D-printing is *PLA*, which refers to *polylactic acid* [10]. *PLA* is a bioplastic, generally derived from corn starch, but also from sugar cane, beet, etc. It is fully biodegradable under industrial conditions. PLA is particularly popular in the field of food packaging, plastic bags, etc. In 3D-printing, PLA quickly became the most widely used filament. Its biodegradable character enters perfectly in the movement of the three-dimensional printing: production of the strictly necessary, on-demand, and relocated. The PLA filament is also the easiest plastic to print. Indeed, it melts at low temperatures (generally between 190 and 220°C) and is not very prone to peeling. Post-treatment of PLA printed parts is very easy. PLA is also inexpensive, the average price of a spool of PLA filament is around 20€. PLA filament reels are available in a wide variety of colours and packaging. It is the reference plastic for 3D-printing. Given this high potential, *PLA* will be focused upon in the case study. Complementarily several additive manufacturing technologies are used for 3D-printing and which are summarised in Table 1.

Table 1. 3D-Printing Technologies [11]

Technology	*Overview*
Fused Filament Deposition (FDM/FFF)	30-year old by S. Scott Crump. Mostly used for personal 3D-printers.
Stereolithography (SLA)	First 3D-printing technology (1986) by 3D Systems. For polymer. Restricted to prototyping rather than object production.
Selective Laser Sintering (SLS)	As SLA but the material in powder form (SLA in liquid form). Possible materials: plastic, ceramic, glass, metal (DMLS). The advantage of this technology is that there is very little waste, and the unmelted powder can be reused afterwards.
Polyjet process	Dated 1999 by the company Objet. Principle of *photopolymerisation* as SLA. A certain advantage of this technology is that it does not require any post-treatment, such as sanding or rinsing. It is also possible to add a second carrier material to the printing material which dissolves in water.
Digital Light Processing (DLP)	A similar principle to SLA. For high-precision jewellery or prosthesis manufacture. The advantage of the DLP process over *stereolithography* is the speed. Indeed, a layer can be solidified with each light projection. Only a vertical displacement of the platform is necessary.

3.2. The Economic Perspective of 3D-Printing

Among the most impacting parameters on the comparative costs of 3D-printing processes is used material [12]. In this sense, both filament coils and resins have a price that varies depending on the material chosen and the manufacturer. From flexible filament material through metal to traditional *PLA*, the price range is significant. The amount of raw material used depends on many printing parameters such as the percentage of filling, the thickness of the outer layer, etc.

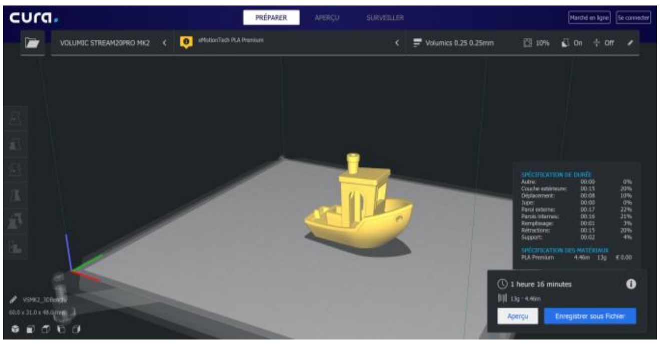

Fig. 1. Screenshot of Cura 4.0.0 Interface [13]

Fig. 1 shows a 3D-printing model on *Ultimaker Cura* 4.0.0 [13] software indicating material cost (e.g., with a required quantity of 13g of PLA; the material cost of the model is 0.26 €). However, to obtain the total cost it is also necessary to take into account the electricity consumed, the number of hours of machine usage, the manpower, the failure rate, the maintenance time of the machine, the realisation of the part in CAD, etc. An hourly rate or price per meter of filament must, therefore, be set. It is important to take these costs into account. Indeed, the material cost might be insignificant compared to these other costs (see Table 2).

Another relevant factor to 3D-printing costs is the equipment [14]. The 3D-printing market is vast and offers various 3D-printers at various prices [15]. It is difficult to give a general cost price since this depends on the technology of the 3D-printer, the material but also on the 3D-printer itself.

Regarding technology, it appears that the printers with fused wire deposition are globally more affordable than the 3D *Stereolithography* printers. While the *FDM* 3D printer itself has a lower purchase price, the surface finish of a 3D printout via a 3D *Stereolithography* (SLA) printer is incomparable. Depending on the customer's criteria, different types of printing can be considered. In any case, FDM or SLA, it will not cost more than 4,000€ to have an excellent office 3D-printer. A price that remains negligible compared to the prices of so-called industrial 3D-printers (> 100,000€).

Table 2. Cost Examples in 3D-Printing

Cost Category	*Overview*
Material cost	Meters of filament consumed or by weighing the piece and its possible supports.
Damping of 3D-printer	Depreciated over a fixed period-of-time (3 years) or for hours of use (5H/D). The time required to print a part in addition to the part volume depends on the selected print resolution and the internal filling of the part. In both cases, it is directly proportional.
Quality related cost	Failed printing.
Preparation & post-treatment cost	Lacquers (Media=0.5 cm3/print), anti-warping blades, lubricants, finishing products, post-treatment and supervision time (removing substrates, sanding, polishing, painting, etc.).
Electricity consumption	Electricity consumption depends on the type of printer, model and settings but is often higher than 225 W (0.225 KW) and the cost of electricity in France is 0.1450 €/KW (EDF - *Tarif Bleu* (regulated)).
Software (license) cost	There are many open-source programs, but this depends on the choice made by the decision-maker (design, slicer).
Operational cost	Part design time, equipment, transport of parts, rental of space, collection management, wages, and other contributions.

The profitability of the 3D-printer starts with its amortisation with regard to the frequency of printing. For example, if a 3D-printer costs 2,000€, the amortisation period is three years and you print about 200 pieces per year, this means that each print costs 3.33€ (only in terms of amortisation).

The use of external service providers may be considered. More and more online printing services are available. The majority of companies offering such services offer a free online quote. This offers the opportunity to print objects and access to a wide range of techniques and materials without investing.

Fig. 2 shows an example of the use of *CraftCloud*, currently listed as the cheapest 3D-printing service provider. It offers the printing of the model in various materials and offers different levels of services in terms of delivery. *CraftCloud* provides a basis for assessing the results from the case study developed in the current paper.

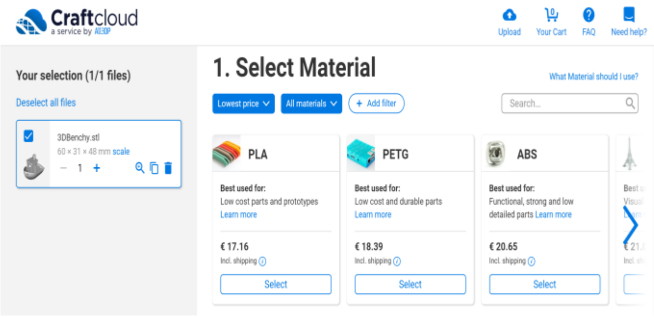

Fig. 2. Screenshot of CraftCould Interface [16]

3.3. The Environmental Impact Assessment and 3D-Printing

Life Cycle Assessment (LCA) [17], which appeared in the 1960s, makes it possible to quantify the impacts of a "product" (i.e., goods, service, or process), from the extraction of the raw materials that make it up to its safe disposal, including its distribution and use (see Fig. 3).

Fig. 3. Representation of Life Cycle Assessment [18]

The flows of materials and energy entering and leaving at each stage of the life cycle are inventoried, and an exhaustive balance is made of the consumption of energy, natural resources, and emissions into the environment. These balances of incoming and outgoing flows are called "Life Cycle Inventories (LCI)". These consumption and emission data are used to evaluate the potential environmental impacts of the product under study. *These depend in turn on the functional unit considered for the study***.** The principles of LCA are defined by the international standards of the ISO 14040 series [19].

The results of an LCA are presented in the form of indicators of potential impacts (e.g., "kg of CO2 equivalents for the greenhouse effect", "kg of H+ equivalents for acidification", etc.) and physical flows (e.g., "MJ of non-renewable energy", "kg of common waste", etc.). These potential impact indicators are calculated from the LCI data and characterisation models that allow the evaluation of these environmental impact indicators – from the LCI data. For example, the LCI data relevant to the calculation of the "global warming" impact indicator are the emissions of greenhouse gases (CO2, CH4, N2O, etc.) into the air. The characterisation model used for the potential impact indicator on global warming is generally that of the IPCC1, which associates a global warming potential (*GWP*) calculated in *kg CO2* equivalent with the emissions of each gas. When performing an LCA, certain assumptions must be considered to simplify the calculation (i.e., cut-off rules).

Regarding the 3D-printing context, most of the studies that exist are limited to FDM printing with PLA or ABS. In wire deposition printing (PLA and ABS) there are emissions of micro and nanoparticles. To a lesser extent, these emissions could concern polycyclic aromatic hydrocarbons (if ABS is used). Emission rates or measured concentrations rise sharply during printing and fall at the end of the printing process. Particles emissions in 3D [20] printing depend on factors such as:

- *Filament type*: the highest total PUF emission rate is observed using ABS filaments.
- *Process bed temperature*: the higher the temperature, the higher the emissions.
- *Addendum*.
- Presence of a *protective enclosure*.
- *Machine malfunction* rate.

Indicators exhibiting the potential to be integrated into other indicators should be meaningful for the customer, easy to implement, and significant to the decision-making process within the company.

4. *3DBenchy* Case Study Development

4.1. 3DBenchy Overview

3DBenchy [21] is designed to offer a wide range of challenging geometric features for 3D-printers and address various issues related to additive manufacturing. The 3D model is designed to print at 1:1 scale without carrier materials. This is a challenge for most 3D-printers, but the small volume (15.55 cm^3) typically prints in less than two hours and does not require a lot of hardware. The different surfaces of the *3DBenchy model* reveal typical problems with surface finish, model accuracy, warping, etc.

3DBenchy is designed to test and calibrate a 3D-printer by adjusting hardware and software settings for optimal results. The shape and size of this 3D-model are designed to challenge 3D-printers. The dimensions are easy to measure using a calliper and can be compared to references. These measurements can be used to check dimensional accuracy, tolerances, warping and deviations due to changes in printing parameters and material types (see Fig. 4).

Fig. 4. 3DBenchy Design

4.2. Configurator Development

The architecture of the configurator is described in Fig. 5. A Guided User Interface (GUI) supports the customer in configuring the *3DBenchy* model. Main options implemented so far include quality level and filling rate selection. The configuration is stored in a local modelling database with several attributes reflecting customer choices. The configuration GUI feeds a model to calculate the environmental and economic indicators. These are shown in a result GUI. The calculation of environmental indicators, *CO2* for instance, is supported by an extraction from an environmental database.

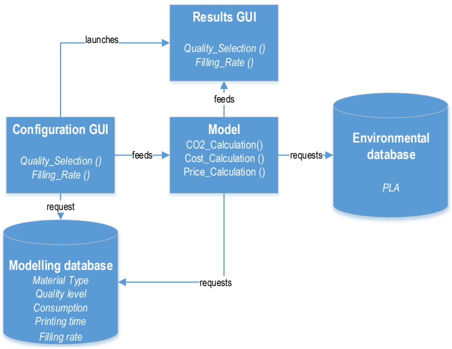

Fig. 5. Configurator Architecture

The development relies on EXCEL VBA which is a programming language that allows the use of Visual Basic code to execute the many features of the EXCEL Application (a set of macros). To make the configurator more user-friendly and to be able to illustrate the concepts, a set of forms were developed to support the configuration process by the user. A dialog box allows the user to enter his preferences in the configurator in an easy way.

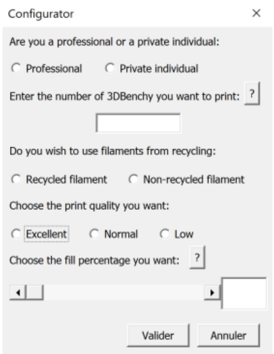

Fig. 6. Screenshot of the Configurator Interface

For example, as can be seen in Fig. 6, the user must indicate the desired number of pieces, whether he/she wishes to use recycled filament or not. By default, the configurator will use the data for the non-recycled filament. Then the user must choose the print quality he wants. This parameter is represented by the layer thickness. The thicker the layer thickness, the better the final quality of the part will be. Choosing an excellent quality instead of a low quality will result in a longer printing time. Finally, the user has to choose the filling rate of the part. The fill rate is the percentage at which the inside of the part will be filled. Its main influence is the overall strength of the part. But the fill rate will also be considered in the calculation of the printing time as well as in the final cost of the part. The higher the fill rate, the greater the amount of filament used. The fill rate will also affect the weight of the part. Help is available throughout the configurator to assist the user, who does not necessarily have any knowledge of 3D-printing, in his/her choice of the various parameters. These aids are symbolised by the question mark buttons.

The carbon emission assessment is based on the impact of electricity consumption and of plastic. *CarbonDB* data was used for assessing electricity consumption impact [22]. *CarbonDB* is an open collaborative LCA database (of activities, products and services) focused on climate and energy impacts. It is also an open-source tool for consulting these data. Depending on the time of use of the 3D-printer and the electrical consumption of the printer, the carbon impact of 3D-printing can be determined.

For assessing the plastic carbon impact, documentation of emission factors from the Carbon Base ® of the ADEME (French Environment and Energy Management Agency) product life cycle data have been extracted. For recycled plastics only aggregate data is available. Based on the amount of plastic used to print the model considered by the slicer, the carbon impact of the plastic is deduced. The value of the default plastic and the value of the default recycled plastic are retained. The carbon impact of printing at 20, 100, and 500 years is obtained by adding the carbon impact of energy production and the carbon impact of using plastics.

All the choices made by the user are stored using macros and compiled when he presses the validate button. Subsequently, the configurator displays a new dialog box containing the carbon impact of printing at 20, 100, and 500 years as well as economic indicators. Depending on whether the user is *professional* or *individual* either cost and unit cost or price including VAT are displayed, as shown in Fig. 7.

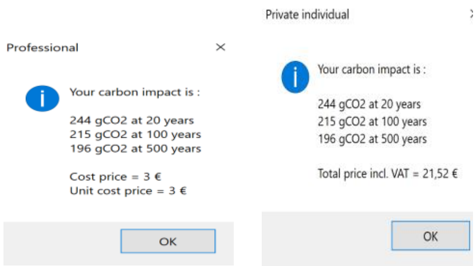

Fig. 7. Screenshot of the Professional Interface (left) and Private Individual Interface (right)

5. Discussion

To choose an online 3D-printing service for comparison with our configurator we used the *All3DP*® store's 2020 ranking of online 3D-printing services. *All3DP*® is a 3D-printing magazine for beginners and world-renowned professionals. We chose the *CraftCloud*® platform which is ranked first in this ranking. The *CraftCloud*® platform uses a configurator that allows customers to get an immediate quote. A relevant aspect introduced in the proposed model is considering the quality level of the 3D-printing. With regards to *CraftCloud*®, the price of the proposed model is comparable if we choose ABS (Acrylonitrile Butadiene Styrene), PLA and PETG (polyethylene terephthalate modified with glycol), with small variations. In order from lowest to highest, ABS is ABS, PLA is PETG. Thus, ABS, PLA, and PETG from *CraftCloud*® are respectively compared to low-quality, standard-quality, and high-quality levels in the proposed model. This witness the relevance and reliability of the results from the case study. Furthermore, the proposed model is also compatible with the technologies covered by

Ultimaker Cura software. *Ultimaker Cura* is a professional slicing software designed to take advantage of the full potential of the printers and provide a reliable and smooth printing experience. This software, once the slicing is done, returns the printing time and the quantity of raw material used. These two parameters are the two variables used in our configurator. Thanks to this slicer, as can be seen in Fig.8, we were able to show that on the printer used only 15 *3DBenchy* could be printed at the same time. This number is, therefore, the maximum size of our batches.

While the case study has shown the applicability and reliability of the economic and environmental assessment of customized solutions, several improvement avenues are still to be explored. For instance, it is also possible to analyze the carbon impact more exhaustive by integrating additional data such as the one related to transportation. Depending on the distance and transportation means the mass of CO2 emitted per kilometre can be determined more accurately. Similarly, the cost model implemented can be improved further by integrating other cost sources such as logistics.

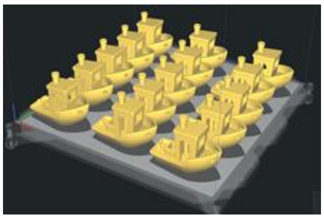

Fig. 8. Lot of 15 3DBENCHY on *Cura 4.0 Ultimaker* Software [10]

Since the model underpinning the configurator is only a prototype, it allows the user to control only one type of model, the *3DBenchy*. Pursuing the development will include expanding the configurator to support several 3D-models. One possible perspective involves an interface with the *Ultimaker Cura 4.0* slicer.

Further improvements should consider the rationale of configurators in the mass-customisation domain, keeping it consistent with a customer-centric tool [23]. Indeed, it is important not to lose the mass-customisation. Too many features will complicate the process and confuse the customer. Too few features will not necessarily satisfy the creative needs of the customer. The customisation process should be an easy, simple, fairly short and very visual experience. The customisation experience must also be interactive and immersive so that the user receives constant feedback on their actions while allowing them to visualise the changes they wish to make. Moreover, the connection between data from the configurators about customer orders and models for managing product and service portfolio should be well thought out to push forward sustainability while considering requirements.

6. Conclusion

Configurators provide customization possibilities limited to a handful of options that give the customer an impression of creativity while not unnecessarily inducing production and logistics costs. In this paper, a configurator for 3D-printing was built for demonstration purposes. It supports well-informed decisions on customer choices based on sustainability impact of 3D-printing, in the particular case of 3DBenchy model. Yet, the use of open-source slicer allows seeing many improvement perspectives for the developed configurator such as the interconnection with the slicer to obtain quotes for any model. Economic and environmental sustainability assessment can further be improved consistently with Life Cycle Thinking. These efforts are being conducted within the Franco-American project SUSTAIN.

Acknowledgements

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