International Journal of Industrial Engineering and Management (IJIEM), Vol. 3 No 4, 2012, pp. 205-214
Available online at www.iim.ftn.uns.ac.rs/ijiem_journal.php
ISSN 2217-2661

UDK: 005:001.895

A Model for Evaluating the Solution Space of Mass Customization Toolkits

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Received (19 November 2012); Revised (02 December 2012); Accepted (06 December 2012)

Abstract

Mass customization involves consumers in the design process by enabling them to customize a product through the use of a toolkit. The aim of this paper is to develop a profound understanding of constructing a solution space of mass customization toolkits and to examine the autonomy of the user in relation to the solution space. In this study a model is proposed that can be used to evaluate the solution space of mass customization toolkits. The model is based on target outcome and guidance and analyses toolkits by examining product attributes, mechanisms and choice in the solution space and guidance throughout the process of customization. The three main findings presented concern the emphasis of existing toolkits on customizing 'hard' product attributes, a strong focus on 'lower-level' product attributes, and the lack of uniqueness in the outcomes from current toolkits.

Key words: *Mass Customization, Product Design, Solution Space Development, Toolkits*

1. INTRODUCTION

A well-known mass customization toolkit is NikeID [12] which offers consumers the possibility to customize a pair of shoes. When entering the website one can select a shoe based on gender, sport or collection and for each shoe one can customize the colour and material. The number of sneakers this website can produce is vastly while at the same time maintaining Nike's brand identity. A solution space [1] encompasses all the possible designs a toolkit, in this case the NikeID's website, can produce. It is mediating between the *authority* of the designer and the *autonomy* of the user. A toolkit gives the user access to a solution space filled with designs that might suit the user. The designer defines the boundaries of this solution space by setting which parts of a product can be designed by the user and which parts are determined. The creative task of adapting a product to one's preferences can be constrained for several reasons, i.e. maintaining a brand identity, making it easy for non-designers to engage in customization or technological constraints might dictate certain boundaries. In conventional product design the designer completely defines a product as in contrast to mass customization where a certain amount of control is given to the consumer.

The aim of this study is to propose a model for evaluating the solution spaces of mass customization toolkits focusing on the autonomy of the user in relation to this space. When one is developing a toolkit, it is important to understand the creative freedom a solution space offers to the user. The purpose of this paper is to develop a profound understanding of toolkits that enable consumer involvement in the design process. In order to reach this goal, a qualitative analysis of toolkits is performed. The richness of the toolkits is preserved and the analysis has been used to evaluate and refine the proposed model.

The paper is structured as follows, in the background section mass customization and existing relevant studies are discussed. A previous empirical study where consumers used a toolkit to design an everyday product is introduced as a case study. In the next section a model is introduced for evaluating toolkits, this is followed by the analysis of 12 toolkits. The paper ends by pointing out the three main findings and discussing the implications for industrial designers as well as other professionals who are involved in developing customizable products and their toolkits.

2. BACKGROUND

Mass customization is a strategy concerned with offering products that meet individual's needs and preferences while these offerings are produced with near-mass production efficiency [18]. One way of obtaining one's preferences is done through direct consumer involvement, also referred to as collaborative customization [14] which is of interest in this study. The transfer of need-related information from the user, or the so-called *sticky information* [19], is typically done through a toolkit or configurator. This is usually software that lets the user configures a product, for instance a pair of shoes, a vase or jewellery. A toolkit encompasses a solution space [1] where the designer has determined what the consumer is able to customize. A solution space is constrained, whereas a design space is seen as an infinite one. Von Hippel defines a toolkit by five characteristics [20]: trial-and-error learning, appropriate solution space, user friendly, libraries of modules and producible by intended manufacturer.

A toolkit allows the user to engage in three types of customization, these are based on the three functions a product can possess; i.e. utilitarian, kinaesthetic or visual [13]. Berger & Piller offer a similar definition of the types of customization into functionality, fit (ergonomic) and style (aesthetic) [1]. When one customizes a product, the three types of customization can be reached in different ways. Let us customize a juicer squeezer. The user is able to alter the colour, the material and the shape of the juicer. When he changes the colour, the aesthetics change, but the functionality and ergonomics are not influenced. When he changes the shape of the juicer, not only does the aesthetics change, but it also influences the ergonomics; it might be easier to hold during usage for instance. This example shows that by changing one product attribute, one or more types of customization can be realized.

Configuring a product through a toolkit can become problematic when the amount of attributes is overwhelming to the user. A large number of options can make the user uncertain and confused and can ultimately lead to postponing decisions [17]. Approaches have been developed to organize and select the usefulness of each attribute. Adaptive attribute selection is based on the assumption that through customization *"product design is reduced to a series of selections of attribute values"* [22]. We will, however, approach customization as a creative task. A creative task is defined as *any activity in which one produces an outcome* [5] and consists of target outcome and guidance. In the case of mass customization, the outcome is a digital design for producing a physical product and guidance is provided to the user in the toolkit. To offer a customizable product, there are three capabilities that are important; these are solution space development, robust process design and choice navigation [15, 21]. In other literature these capabilities are defined as elicitation, process flexibility and logistics [24]. Process flexibility is particularly interesting now that additive manufacturing is advancing and becoming more and more accessible and affordable.

There is an extensive overview of available toolkits. The Customization 500 [21] is a benchmark study which examines 500 mass customization companies. The offerings are evaluated on visual realism, usability, creativity, enjoyment, uniqueness and number of given choice options and are based on expert ratings. A qualitative study has been comparing five toolkits that use digital fabrication as a production technology [anonymised reference]. The main recommendation from this analysis was to further investigate the solution space and the freedom users have in it. Furthermore, there are two online databases which give an overview of available mass customization toolkits, the Configurator Database [4] and Milk or Sugar [6]. The literature gives a broad overview of the available mass customization toolkits. However, a deeper understanding of constructing a solution space and the autonomy of the user in relation to the solution space is lacking. What constitutes the freedom a user has in a solution space of a mass customization toolkit? To answer this question, existing toolkits and their solution spaces are analysed with a model proposed on target outcome and guidance. To clarify the concept of a mass customization toolkit combined with the possibilities of digital fabrication, a case study is presented and discussed.

3. PARAMETRIC CUSTOMIZATION: THE JUICE SQUEEZER CASE

In our previous experiment parametric customization of a consumer product by non-designers has been explored [anonymised reference]. The aim of this experiment was to get a better understanding of the role of the consumer in a constrained creative task and to find issues that might arise from involving consumers in the design process.

3.1 **The Study**

An experiment was conducted that invited participants to customize, use and evaluate a juice squeezer (Figure 1). The experiment consisted of four steps: the development of the solution space, the customization of the object by the participants, the production of the object by additive manufacturing and the use and evaluation of the object by the participants. A parametric approach has been used in order to enable the shape of the object to be customized. A simple toolkit has been developed consisting of a 3D CAD model with eight parametric sliders (Figure 2) that controlled different parts of the shape. By changing the values of the sliders, the 3D model on the screen changed in real-time. The participants could experiment and change the shape until they were satisfied with the result. Hereafter, the designs have been 3D printed in ABS plastic by a desktop 3D printer. The final stage of the experiment consisted of the use and evaluation of the prototype by the participants. They evaluated their design through semi-structured personal interviews. The results of this study are both the prototypes as well as the evaluations of the participants.

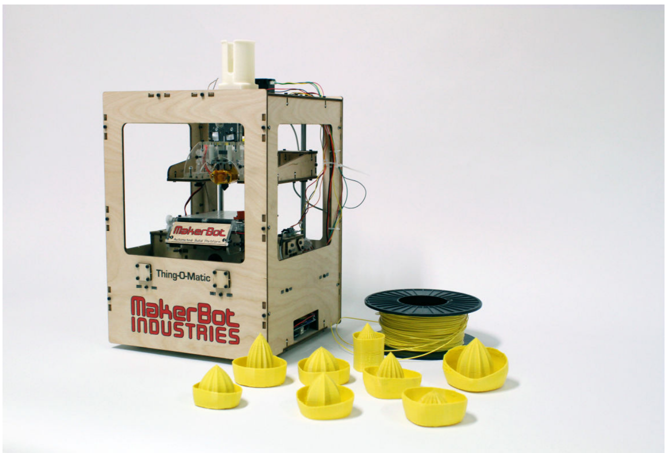

Figure 1. The customized designs with the desktop 3D printer that produced them.

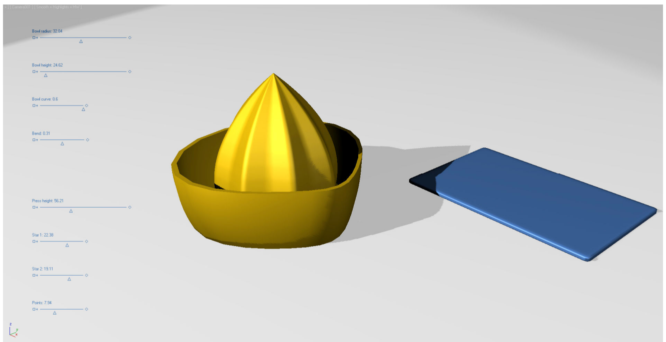

Figure 2. Screen shot of the interface with sliders (left), the design (middle) and reference object

3.2 **Findings**

The three main findings from this study are presented and discussed shortly. First of all, there was a lack of variation (1) between the customized designs produced in this study. The participants were given a solution space in which they were able to design their own object. The notion of a solution space is well understood among designers and other professionals, but do consumers equally understand this concept? Typically, consumers deal with a defined and concrete array of solutions, i.e. products, to choose from. Their decision making is based upon acceptation or rejection of proposed solution. In mass customization however, the consumer is faced with making decisions about certain aspects of a product. They are defining parts of a design in an undefined and dynamic. From our study, it became clear that uncertainty and unfamiliarity play an important role. Secondly, participants noticed a responsibility shift from designer towards consumer. Before, the designer would take all the responsibility for a product and the consumer had a passive role. Some participants referred to an ‘ideal design’ and were uncertain what decision to take and might regret whatever decision they would take about the design. Thirdly, the difficulty of understanding a 3D virtual model was expressed as a concern. Furthermore, prioritizing what can be customized and having the right amount of control over the customizable product attributes have been pointed out by participants.

3.3 **Discussion**

This study has identified several issues when a consumer takes on the task of customizing a design. The findings are mostly in the form of questions and open up new spaces for research. The design of a solution space and toolkit is not a straightforward task; too much design freedom will overwhelm the user; too little design freedom will not lead to a sense of competence and autonomy. There is a trade-off between giving the user enough freedom and setting up constraints by the designer. The new responsibility of the consumer requires a different mind-set. Before, in the mass production era, consumer had a passive role of consumption, whereas in mass customization, the role of the consumer becomes one of active participation and a creative mind set is needed to fully benefit from the potential of designing your own product through the use of toolkits.

4. INTRODUCING A MODEL FOR EVALUATING THE SOLUTION SPACE OF MASS CUSTOMIZATION TOOLKITS

In a mass customization setting, a consumer has an active role in the design of a product and interacts with that design through a toolkit. In trying to understand the construction of a solution space and the role of the consumer in it one can examine the toolkit itself. To compare and evaluate mass customization toolkits with each other, an analytical model is proposed. In every toolkit, there is a trade-off between the *autonomy* of the user and the *authority* of the designer both over the product as well as the process. The autonomy of the user in a toolkit can be seen as the creative space one has to design the product to his or her own needs. This freedom is not only concerned with the outcome of the toolkit, but also with the freedom one has to decide on the process. The authority of the designer on the other hand is concerned with the control the designer has over the design. What parts of the design can be customized and what needs to be determined in order to keep the design intention alive.

This model interprets customization as a creative task and adopts a pragmatic interpretation of experiential creation, as defined by Dahl & Moreau. This definition consists of the factors: (1) the level to which the target outcome is dictated and (2) the amount of guidance provided when creating an outcome [5]. This model also builds on the definition by Walcher & Piller [21] who define creativity in a similar way: (3) the amount of freedom the toolkit offers to the user and (4) the ability to let one's creativity reign free. Target outcome and guidance will be used as the two factors describing experiential creation in mass customization toolkits. The model proposed takes the two criteria and divides them into more detailed questions.

Target outcome

- Product attributes: Which hard and soft product attributes can be customized with the toolkit?
- Mechanisms: Which mechanism enables the user to customize the product? In other words: what enables the high process flexibility required for mass customization?
- Choice: How much options are offered to the user for customization in terms of the *number* and the *variety*?

Guidance

- Start point: How does the user begin the customization process? This can be done by offering a blank canvas or one or more design templates.
- Guiding method: How is the user guided through the customization process? This can be done through sequential or a-sequential steps.
- Instructions: What type and amount of instructions are provided to the user when engaged in the customization task?
- Feedback: What type of feedback is provided to the user and when is this feedback delivered? It could

be visual, audible or other forms of feedback. The time frame in which it is delivered can be real-time or post-customization.

In the following sections, the seven questions that form the basis for the model are discussed in detail.

4.1 **Target Outcome**

Target outcome is characterized by three aspects, i.e. product attributes, mechanisms and choice.

4.1.1 Product attributes

A toolkit enables the user to customize a product to one’s own preferences by altering one or more product attributes. One can for instance pick the colour of a smart phone case, determine the size and fit of a shirt or choose to material of a piece of furniture. In all these cases the user is making decisions about product attributes, i.e. colour, dimensions and materials. Therefore, customization can be seen as defining the characteristics and qualities of a product.

Product attributes can be divided into hard and soft [9] or physical and appearance properties [2]. The hard attributes make up the physical product, e.g. colour, texture, material. The soft attribute is the meaning derived from the physical product. In this paper, hard product attributes are regarded as layers of a product, ranging from core -the function- to skin -the surface-. A range of product attributes is derived from existing toolkits: function, features, structure or arrangement of components, material and its properties e.g. colour, strength, stiffness, texture, conductivity, transparency, shape, dimensions and surface including colour, engraving, etching, embroidery, graphical prints. A product attribute can either be customized in a discreet or continuous way. Discreet is meant that there are a limited number of options, for example the attribute colour has 10 instances. Whereas continuous is used as that it varies over a range; colour on a screen consists of the three components red, green and blue that each range from 0 to 255. Soft product attributes on the other hand are a combination of physical properties that give a product a certain meaning. They can be divided into sensory, symbolic and stylistic attributes [7, 9]. Sensory attributes are aesthetic properties such as feel, texture and form. Symbolic attributes are verbalized by words like aggressive, cheap, trendy or exclusive. Stylistic refers to the different stylistic movements such as Art Nouveau, Modernism or Retro.

4.1.2 Mechanisms

Mass customization deals with offering unique products to consumers. In the definition from Tseng & Jiao it states that mass customization does this with near-mass production efficiency [18]. In order to offer unique products at large scale efficiency is reached by highly flexible systems. A mechanism is an enabling technique to gain the high level process flexibility needed for offering mass customization.

The model proposes four different mechanisms that were derived from existing toolkits. Veneer (A) is a mechanism for customizing products by adding a visual, decorative layer to a mass produced product. This method is a common way of offering mass customization in today's market. Companies like Zazzle [23] use it by printing custom texts and graphics on a large variety of mass produced products, ranging from coffee cups, T-shirts to smart phone cases. Besides printing graphics on products, methods like engraving, etching and embroidery are often used. Modularity (B) is another way of obtaining high process flexibility by combining and assembling mass produced modules or components to form a customized design [8]. Von Hippel states that a mass customization toolkit consists of modules [20]. The total number of designs in a modular toolkit is limited by the number of combinations formed from the modules. Although limited, in reality however, this number is often extremely high. Parametric customization (C) is based on a 3D model which can be modified by changing parameter values. The model consists of parts or features that are interrelated, by changing one parameter the dependent features change dynamically in a specified manner [11]. For example, a model of a tube can be modified by a parameter “radius” and a parameter “height” and these two parameters can be related to each other in any way. Rather than veneer or modularity, the manufacturing stage is postponed in its entirety until after the customization stage. An example of parametric customization is the case of the juice squeezer where consumers were given a 3D model on a computer and were asked to customize the juicer by manipulating sliders that controlled different shape parameters [anonymised reference]. The fourth mechanism generative customization (D) is an approach based on using code and scripting to synthesize two or three dimensional form [10]. An example of generative customization is used in the D.dress [3] toolkit where the toolkit generates the dress by triangulation of a user-designed shape. The production of the design is in generative customization also postponed till after the customization phase.

4.1.3 Choice

A toolkit allows the user to customize certain product attributes and a mechanism is used to realize high process flexibility. Every toolkit has its own solution space; some toolkits are very restrictive where as other toolkits are open and support a large number of different products. The size of the solution space is an indicator when determining how much the target outcome is dictated by the toolkit. The size is determined by two factors: the number of options (1) and the variety of these options (2). Variety can be established by having different customizable attributes and offering variety within one attribute. The wider the solution space the more freedom a user has in creating its own design.

4.2 **Guidance**

Guidance is the second factor that defines experiential creation. Target outcome is concerned with the result of a mass customization toolkit whereas guidance is concerned with the process of the customization task. The designer of a toolkit is not only able to control the product but also the process of customization. The process is defined by the start point, guiding method, provided instructions and feedback that the user receives along the way.

4.2.1 Start point

Toolkits could direct the user from the start of the customization process. The user either starts with a blank canvas or with one or more design templates. Design templates are used to inspire and jump start the process, for example, when one enters the NikeID website a large variety of customizable shoes are presented to the user to choose from.

4.2.2 Guiding method

After decided on the start point, the user is guided through the customization in one way or the other. The most restricted toolkits use sequential steps that will take the user by hand and walk them through all the different steps. Another possibility is that the options of the toolkit are presented without a clear path to follow; in this case it is up to the user to explore and find his way in the solution space.

4.2.3 Instructions

The customization task can be supported by providing instructions along the way. This can be done in several ways, providing instructions upfront, during the process or being able to unlock additional information about a specific step or option. One of the characteristics of mass customization toolkits is learning by trial-and-error [17], therefore the toolkit should allow the user to experiment and go-back-and-forth during the customization process. Instructions are passive support from the toolkit whereas feedback is the active version.

4.2.4 Feedback

The last aspect of guidance is the feedback the user receives from the toolkit. Feedback can be given in different forms, e.g. visual, audible and in different time frames, i.e. real-time or post-customization.

The proposed model for evaluating the solution space of mass customization toolkits is based on target outcome and guidance. It provides a way to frame different solution spaces and provides a vocabulary for talking about them.

4.3 **Visualization of the model**

The model is visualized for clarity and to easily communicate it among toolkit developers, designers and engineers, it has been visualized in a diagram (Figure 3). The circle is divided in four quarter that represents the four mechanisms and seven layers that represent the product attributes. The layers are -from inside to outside- function, features, structure, material, shape, dimensions and finally the skin of the product. Besides the physical product attributes and the mechanisms that are visualized in the circular graph, the choice is depicted as the number of options that the toolkit offers.

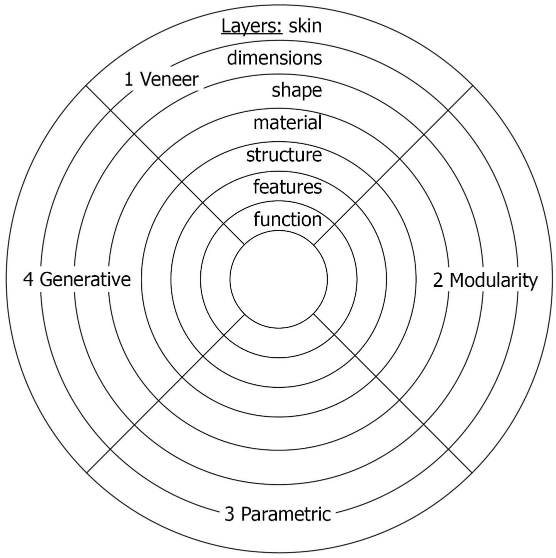

Figure 3. Visualization of target outcome with its four quadrants and seven layers

5. METHOD

The proposed model for evaluating solution spaces of toolkits is being applied to examine current mass customization toolkits on seven aspects. These aspects have been discussed, i.e. customizable product attributes, mechanisms, choice, and start point, guiding method, instructions and feedback.

A number of mass customization toolkits have been selected (Table 1) according to three criteria: the toolkit focuses on consumer products, the toolkit enables customization through a web-based interface, and the toolkit enables online ordering of the product. Furthermore, the selection of toolkits has to cover a wide variety of product categories and all four identified mechanisms are represented equally.

Table 1. Selected toolkits

	Company	**Type**	**Category**
A Veneer			
1	Oakley [I]	Radar	Sunglasses
2	NikeID [II]	Dunk high iD	Shoes
3	CaseMate [III]	(n.a.)	Accessories
B Modularity			
4	Blancier [IV]	(n.a.)	Watches
5	Suzuki [V]	Swift	Car
6	Dell [VI]	Desktop	Computers
C Parametric			
7	CYW [VII]	Cupboard without slope	Furniture
8	Bivolino [VIII]	Mens, business shirts	Clothing
9	Nervous System [IX]	Cell Cycle	Jewellery
D Generative			
10	Continuum Fashion [X]	D.dress	Clothing
11	Supabold [XI]	FluidVase	Interior
12	DiatomStudio [XII]	SketchChair	Furniture

This selection of toolkits is only a small sample from the commercially available toolkits. However, the aim of this analysis is to show that the model is an effective pragmatic tool for understanding the solution space of a mass customization toolkit. The focus is on the particular toolkit and the understanding of its characteristics and features, rather than providing a benchmark study of the whole market.

6. ANALYSIS

The analysis consisted of applying the proposed model for evaluating the solution space of mass customization toolkits to a selected number of toolkits. The results of the analysis are presented by mechanism and a number of the toolkits have been visualized.

6.1 **Mechanism 1 Veneer**

Three toolkits, sunglasses by Oakley, shoes by Nike and smart phone cases by CaseMate, are analysed by applying the proposed model. Oakley (Figure 4, left) offers a toolkit that allows the user to customize sunglasses in an aesthetic way. The toolkit offers 25 different types of sunglasses in four categories named sports, active, lifestyle and women. For this analysis we focus on the type Radar from the Sports category. The user is able to customize the hard product attributes colour and shape and the surface of the product can be decorated by custom etching. The attribute colour has many options, the frame and lens have 15 colours, the ear socks 14 and the logo can be customized in 24 colours. The shape of the lens has three variations and the option for etching can either apply to custom text or one can choose from a set of predefined logos. The toolkit uses the veneer mechanism, since it allows users to change the external layer of the sunglasses. The shape variations use the modularity mechanism, but by changing the shape only the aesthetics of the sunglasses change. The choice a user has in this toolkit is high, 211.680 possible designs plus the possibility to have etching of custom text or a logo. However the variety is low since one can only customize two different product attributes. Regarding the guidance that is provided to the user, the toolkit offers only one design template. The user is not explicitly guided through the customization process in a step-by-step manner; rather the interface shows several options where the user can work with. No additional instructions are provided and feedback is given in real-time.

NikeID and CaseMate offer similar toolkits (Figure 4, middle and right) to customize the aesthetics of sneakers and smart phone covers respectively. The visualizations show the customizable product attributes and mechanisms. The NikeID toolkit offers several design templates as well as a blank canvas to start designing from. The user is guided through the process by sequential numbered steps and no additional instructions are provided. When customizing a sneaker the feedback is real-time, selecting a new colour results directly in an updated design. The CaseMate toolkit offers a blank canvas. The user is guided to upload his or her picture to customize the case. Also this toolkit does not offer additional instructions and the feedback is real-time.

6.2 **Mechanism 2 Modularity**

The Blancier toolkit offers customization of wrist watches. As shown in Figure 5 the customizable product attributes are material, graphics for the clock-face and the possibility for an inscription on the back of the clockwork. The mechanisms modularity and veneer are used by this toolkit to obtain high process flexibility. The choice in numbers is very high -501.760 possible designs can be formed- and the variety is high as well since different product attributes can be customized. The guidance offered by the Blancier toolkit is minimal. The toolkit opens with a blank canvas, the user does not get guided through the process and there are also no further instructions. All the options are simply displayed around the blank canvas without any further instructions.

The Suzuki Swift toolkit allows one to customize a car to one’s own taste. Besides aesthetic customization of colour and graphics, it offers modular customization of several features including spoilers, side skirts, rims, and additional lights.

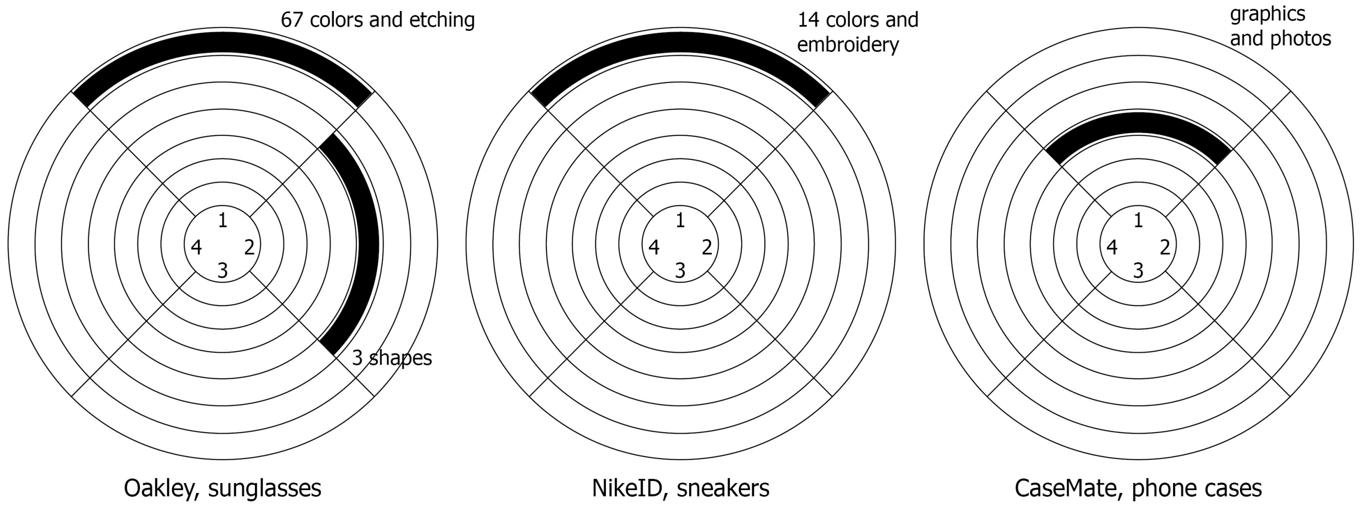

Figure 4. Visualization of three veneer toolkits

The toolkit opens with inspirational designs to choose from and the user is guided step-by-step through the process. There are no additional instructions, the toolkit speaks for itself and gives real-time feedback of the changes as well as the price.

Dell offers the customization of desktop computers by a modular system of selecting functional components of a pre-defined computer system. The product attributes features and functionality can be modified. The user is guided step-by-step through the process with additional information about the components and “help me choose” functionality. The feedback is only given in the price; the visual is not updated with the changes the user makes.

6.3 **Mechanism 3 Parametric**

Cupboard Your Way offers a toolkit for customizing cupboards and bookshelves (Figure 5, middle). There are eight basic types of furniture that can be customized by the user. This can be done through the product attributes features, materials and dimensions. Features list different elements such as shelves, drawers, rails, doors and handles whereas material has several body and door finishes and a number of knobs. The dimensions are determined by user input. The toolkit uses a combination of the parametric mechanism for the features and dimensions and the veneer mechanism for the materials. The choice in this toolkit is high in numbers as well as in variety. The user starts the customization process by choosing from one of the design templates and is then guided through a step-by-step process. The feedback is real-time and the design is visualized schematically.

Bivolino offers customization of shirts by enabling the user to define the dimensions, material, colour and personal embroidery. There are four categories of shirts and for each type the user can choose from different options. The choice is high in number as well as variation. The user is guided through a step-by-step process and additional information for each aspect is available by clicking on the information button. Feedback is given for material, colour and embroidery, but not for the size.

Nervous System offers a parametric toolkit that allows one to customize jewellery like bracelets, earrings, necklaces, rings and brooches. This analysis is focused on the custom cell cycle, a bracelet, which enables customization of dimensions, structure (i.e. shape) and material. The shape and dimensions of the bracelet can be customized by eight parametric sliders that influence the structure as well as the shape. For the dimension there are also a number of presets available. The choice is high in number but low in variety. The guidance in the toolkit is characterized by design presets and no particular order for customizing the product attributes. The user gets feedback in real-time by a 3D model that can be explored in 3D space and an optional two-dimensional model. There are no additional instructions offered.

6.4 **Mechanism 4 Generative**

In the D.dress toolkit from Continuum Fashion the user is able to create her own dress (Figure 5, right). The product attributes shape and dimensions can be defined by drawing in a front and back view with a mannequin as support. The toolkit uses the generative mechanism and calculates the triangular structure of the dress after the users has drawn a design. The toolkit starts with a blank canvas and it offers no further instructions.

The FluidVase toolkit allows the user to customize a vase that is produced by 3D printing. The user influences a virtual stream of liquid poured into a box that forms the vase. The user can also define the shape of the box, the position of the pour and the flow of the pour. The toolkit uses the generative mechanism since it uses an algorithm to determine the final design. The choice in number and variety is quiet limited. The user begins the customization process by selecting a preset and is then left to explore the different features of the toolkit without any additional instructions. The visual feedback is in the form of a real-time updated 3D model of the design.

SketchChair [16] -originally released as a web application, but now available for download- is a generative toolkit that enables the user to sketch the side view of a chair. The software extrudes the two-dimensional shape and generates a waffle structure that can be laser cutted in a range of materials including wood, cardboard and acrylic. The user can choose to draw what he likes and explore the solution space in his own way.

The analysis has used the seven aspects of the proposed model to examine the solution spaces of a number of mass customization toolkits. The result of this analysis gives an insight into the construction of the solution spaces by identifying the customizable product attributes, mechanisms, choice and the guidance offered to the user. One can notice that toolkits do not use one mechanism exclusively. In some cases, more than one mechanism is used in order to enable customization.

7. DISCUSSION

This study proposed a model for evaluating the solution space of mass customization toolkits focusing on the autonomy of the user. This qualitative analysis of toolkits is relevant for those who design and develop toolkits since a deeper understanding of constructing solution spaces and the autonomy of the user in relation to mass customization toolkits was lacking.

Three relevant issues that came up in the analysis of the toolkits are discussed. It concerns the strong focus on hard product attributes (F1), the emphasis of many toolkits on customizing 'lower-level' product attributes (F2) and finally the lack of uniqueness in the outcomes (F3). Each finding will be discussed in detail and will be clarified with an example.

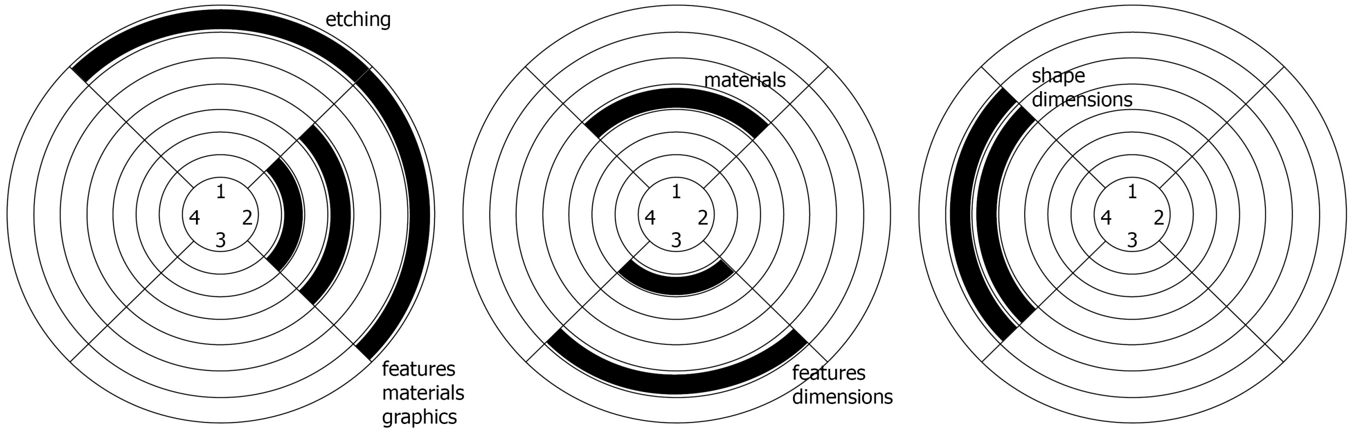

Figure 5. Visualization of modular (left), parametric (middle) and generative (right) toolkit

7.1 **Focus on hard product attributes**

The first finding concerns the strong focus in the analysed toolkits on customizing hard product attributes. Hard product attributes are the physical and tangible attributes such as colour, material, dimensions to name a few. Most toolkits present customization as a process of selecting from options or altering parameters or algorithms and primarily focus on the tangible aspects. The attention of the customization task is focused on selecting hard product attributes rather than on, equally important, intangible properties. Although, by altering the hard product attributes, one shapes the meaning of a product, the toolkit does not allow to 'select a meaning' which in turn defines the hard product attributes. The semantics of a product is an important factor for consumers to purchase or reject a certain product. The question is why the meaning is not directly and explicitly used as a customizable attribute. This particular focus is partly caused by the enabling mechanisms and production technologies. The mechanisms help to understand how toolkits work and why certain customization is possible. Most current toolkits use the veneer or modularity mechanism combined with conventional mass production techniques. The parametric and generative mechanisms are typically using digital fabrication technologies like laser cutting, CNC milling or additive manufacturing. The flexibility of these technologies in producing one-offs is far larger than conventional line production techniques and thus they open up possibilities that were previous unthinkable. The opportunities that these mechanisms bring along for customization have yet to be fully understood and explored.

7.2 **Emphasis on lower-level product attributes**

The second finding concerns the emphasis in many toolkits on 'lower-level' product attributes. In other words, many mass customization toolkits offer customization of product attributes such as colour and surface prints rather than shape, material properties or features. The focus of many toolkits is to add a decorative layer to an existing design rather than conceptualizing a new design. As demonstrated with the case study of parametric customization, it is possible to offer different, higher level product attributes to be customized. In that specific case, a parametric 3D model and digital fabrication were used to enable the required flexibility. Offering the consumer influence on 'higher-level' product attributes (towards the core of the product, i.e. the function) will lead to new possibilities for product offerings that can differentiate from current offerings.

7.3 **Lack of uniqueness in outcomes**

The third finding concerns the lack of uniqueness in the outcomes of a particular toolkit. The choice in a solution space can be defined by the number of options one has and the variety of options. The number of options in a toolkit is often very high, for instance the NikeID toolkit [12] offers a large amount of possible outcomes. However, the uniqueness of these outcomes is limited since one can only customize appearance attributes. Every sneaker that it produces is still recognizable as a Nike shoe. Although the uniqueness might not be significant, the perceived uniqueness by the consumer might be. Does the user have the feeling he has been tricked or do consumers -even though there is not much difference between the designs- still feel that they can create what they want? If more diversity in the outcomes is desirable, then this lack of uniqueness could be resolved by a toolkit that combines a range of diverse product attributes. For instance, allowing the user to alter material properties, features or shape might lead to more diversity and satisfaction.

The three findings pointed out are the result of the analysis with proposed model. The findings should be taken in consideration when developing mass customization toolkits and could inform designers and developers to better understand the autonomy of the user in creating their own products.

8. CONCLUSION

This study has shown that it is possible to study the solution spaces of mass customization toolkits and that there are differences between these spaces. A model for evaluating the solution space of mass customization toolkits is provided based on target outcome and guidance. The model depicts in what way a user can be autonomous and what this freedom of the user constitutes of. The autonomy of the user is not only concerning the outcome of the toolkit –the customized product-, but also the freedom in the process of customizing. This model is one approach to evaluate solution spaces and there are probably different approaches to evaluate and analyse the solution space which may reveal other aspects. The qualitative approach used in this paper is suitable for understanding toolkits and obtaining an insight in toolkits and maintaining all its richness. From this analysis, it is clear that the design of a solution space determines the autonomy of the user, in terms of the possible outcomes as well as the guidance throughout the customization task.

The limitations of this analysis concern the number of toolkits reviewed per mechanism. In this study an equal number of toolkits for each mechanism were taken which is not representative for today's offer in industry. The mechanisms *veneer* and *modularity* are far more common, developed and implemented. The definition of the latter two mechanisms, parametric and generative could be improved and grounded better. Furthermore, the guidance aspect has been paid less attention to in this analysis and it should be developed more in future research. The model and analysis presented are a first step in qualitatively evaluating the solution space of toolkits and moving towards a thorough understanding of the role of the consumer in constrained creative tasks.

To summarize, this study has shown that differences exist between solution spaces of mass customization toolkits and it has tried to explain how these differences are caused. Handing over control and enabling an autonomous user to design his own products has implications for the role of the professional designer. This model could inform practice in guiding and developing new toolkits for mass customization that offer the appropriate amount of autonomy for the user.

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Model za procenu prostora rešenja proizvoda za alate kastomizirane industrijske proizvodnje

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Primljeno (19. novembar 2012.); Recenzirano (2. decembar 2012.); Prihvaćeno (6. decembar 2012.)

Rezime

Kastomizirana industrijska proizvodnja (Mass Customization) uključuje korisnike u proces konstruisanja omogućavajući im da kastomiziraju dizajn kroz upotrebu alata. Cilj ovog rada je da se postigne dublje razumevanje konstruisanja prostora rešenja za alate kastomizirane industrijske proizvodnje. Model se zasniva na ciljnom ishodu, navođenju i analizi alata ispitivanjem atributa proizvoda, mehanizama i izbora u prostoru rešenja i smernice tokom procesa kastomiziranja. Tri glavna otkrića su predstavljena uzimajući u obzir naglasak postojećih alata za kastomiziranje atributa proizvoda, sa snažnim fokusom na ,,niže nivoe'' atributa proizvoda, kao i nedostatak jedinstvenih ishoda iz tekućih alata.

Ključne reči: *Kastomizirana industrijska proizvodnja, razvoj proizvoda, razvoj prostora rešenja, alati*