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Exploring Parametric Design: Consumer customization of an everyday object

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Abstract
Toolkits for mass customization can be seen as a link between a consumer and a solution space and enable the user to customize a design to their own needs and desires. The development and increasing availability of additive manufacturing which enables customization and the growing amount of businesses developing mass customization services will direct industrial designers to rethink their role and their tasks in the design process. Customization through digital fabrication technologies is an emerging field where industrial designers have to be aware of and able to design for. There is an ongoing shift from standardization and mass production towards individualization, markets of one and customization. The aim of this exploratory study is to get a better understanding of toolkits for mass customization in order to develop a method for designing customizable products. The experiment conducted in this study invited participants to customize, use and evaluate a kitchen product. We present five core findings from this experiment. This study has identified several issues that play a role when consumers take on the task of customizing a consumer product. The study has also shown potential future areas when it comes to parametric design.

Keywords: mass customization, additive manufacturing, toolkits, co-creation, parametric design, consumer involvement

Introduction

Toolkits for mass customization (Tseng & Jiao, 2001) can be seen as a link between a consumer and a solution space (Berger & Piller, 2003). Such a toolkit can enable the user to customize a design to their own needs, wants and desires. A *configurator* or *toolkit* (Franke & Piller, 2002, Von Hippel, 2001) is often a software program dedicated at one specific product. Mass customization is a strategy which is used to produce individual products with near mass production efficiency (Tseng & Jiao, 2001). In co-creating a product the designer has the task to design a *solution space* and the task of the user is to, within that space, customize a particular design. This task can range from the simple picking and choosing of a color to more advanced tasks like selecting a material, changing material properties, adjusting features of a design or the shape of an object. Von Hippel has argued that a toolkit typically possesses five characteristics: the user is able to learn through trail-and-error, it comprises an appropriate solution space, the toolkit is user-friendly which means that the skill level of the toolkit corresponds with the skill level of the user, it is built upon module libraries and the outcomes are producible by the intended manufacturing system (Von Hippel, 2006). However, there are various forms of toolkits. In this study the focus is on *parametric design*. With parametric design is meant that the design changes in accordance with different forms of input data. In the case of mass customization the data is provided by the end consumer. There are already a few toolkit concepts waiting to be commercialized that would allow consumers to parametrically customize a product. These toolkits use rapid manufacturing technologies such as laser cutting (Droog, 2011) or 3D printing (Digital Forming, 2011). This is an emerging field where new steps are constantly taken when it comes to customization combined with digital fabrication technologies.

The introduction of parametric customization is promising but also leads to many interesting questions. For instance, what is the role of the designer in relation to the consumer, what are the degrees of freedom that are best suited for parametrical approaches and how will the consumer handle his new active role in the design process. In this paper we will primarily focus on aspects related to what happens when a consumer is customizing an everyday object.

This paper is structured in the following way. We will discuss the background and briefly highlight what is the current research focus in mass customization. We will also present a study where we focus on the consumer engaged in parametric customization of an object. At the end we will discuss the issues we identified and interesting areas to focus on in future research.

Background

The rapid development and increasing availability of additive manufacturing (Wohlers, Bourell, Leu, and Rosen, 2009) on one hand and the growing amount of businesses developing mass customization services (cyLEDGE Media, 2011) on the other hand enable new possibilities for mass customization of products. Bespoke consumer products are malleable by consumers themselves to fit individual needs and wishes. This development creates challenges to the traditional way of understanding the design process and will direct industrial designers to rethink their role and their tasks in that process. In the traditional product development process the professional designer has the task to find out the needs of the consumer and according to these needs a product is designed. Through the use of focus groups, interviews and observation the need information is acquired. In the co-creation process the acquisition of *sticky information* (Von Hippel, 1994) is no longer only the task of the industrial designer. The consumer is now concretely involved in the design process just for that reason, transferring at least some of the need-related information. According to Zipkin (2001) expressing the needs by a consumer is, together with process flexibility and logistics, one of the three main aspects of mass customization.

The consumer who customizes a design performs a creative task. Any creative activity can be characterized by two variables, the extent to which the target outcome is defined and the amount of instructions provided (Dahl & Moreau, 2007). A mass customization toolkit is product-specific; it has a fixed target outcome while maintaining a certain degree of freedom for the consumer. A full step-by-step set of instructions is not necessarily provided in the toolkit, consumers can explore through trail-and-error within the boundaries of the toolkit. Often the user is guided through the process of customization by sequential steps that show the different options in the toolkit. When you place the mass customization toolkit in Dahl and Moreau's graph (2007) of experiential creation (Figure 1) it fits in the upper region of the fourth quarter: 'fixed target outcome' and 'set of instructions'. Consumers have different motivations for carrying out a creative task, competence and autonomy, are the two main reasons according to Dahl & Moreau (2007). The freedom of the consumer in a mass customization toolkit has an optimum. When consumers have too little freedom, they feel they did not contribute to the design and when they have too much freedom and options, the consumers could be overwhelmed by the amount of choice and complexity (Schwartz, 2004). The constraints of a toolkit for consumers have several advantages including ease of use, low skill requirements, certainty of the outcome and learning opportunities. The drawbacks of constraints are uniformity of the outcome, decrease of process enjoyment and a potential mismatch between the challenge of the creative task and the user's skill level (Dahl & Moreau, 2007).

In society at large there is a shift from standardization (de Rijk, 2010) and mass production towards *individualization*, *markets of one* (Pine II, Peppers, & Rogers, 2000) and *mass customization* (McKenna, 2000). In the mass production paradigm industrial designers define the product and optimize the design for lean production in mass quantities. Uniformity has made complex, technological products affordable to the masses. The nature of these manufacturing technologies dictates large quantities of a product in order to redeem the expensive investments in design, preparation, molds, and production planning. Instead of a designer that develops an optimal design, in mass customization the designer develops a solution space which encloses many different possible designs. Furthermore, the designer is also involved in developing the toolkit that the consumer will use to customize the design.

Mass customization has been around for a few decades since it was first introduced by Davis in his book *Future Perfect* (1987). Most existing research about mass customization is either done from a business perspective and includes work that is concerned with the benefit for companies, value creation and willingness to pay for customized products (Franke & Piller, 2004). Or it is done from a consumer behavior point of view where perceived uniqueness plays a role (Schreier, 2006). There is also research done from a manufacturing point of view, focusing on lean production, modularity and supply chain management (Anderson, 2008) or from an engineering perspective that focuses on Design for Mass Customization (DFMC) through a product family architecture (PFA) (Tseng & Jiao, 1996). This paper will take a *design perspective* and look at the *consumer's role* in mass customizing products.

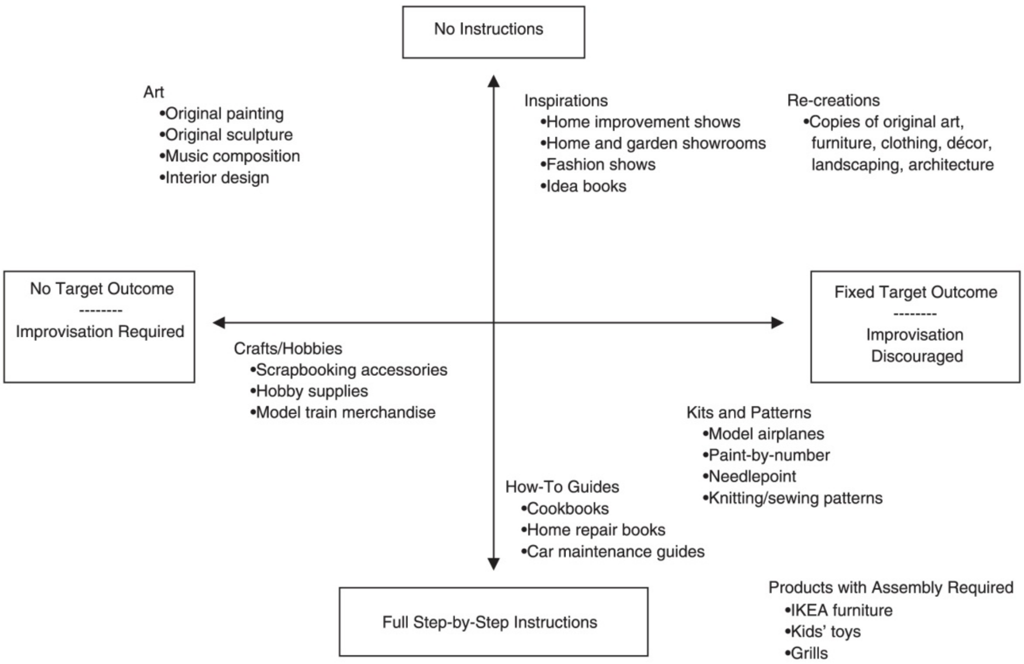

Figure 1 Experiential creation

Source: Dahl, D.W., & Moreau, C.P. (2007)

Methodology

The aim of this exploratory study is to get a better understanding of toolkits for mass customization and the consumer's role in order to develop a method for designing customizable products. Understanding the co-creation of products can be reached by looking at the three main parties involved, the toolkit, the designer and the consumer. In this study the focus was on the consumer and his involvement in the design process. This study tried to identify the issues that play an important role in mass customization when it comes to the consumer. The involvement of the consumer was studied through an experiment where they were asked to customize, use and evaluate an everyday kitchen object.

This study has been designed as an experiment rather than using existing toolkits for mass customization. The commercial availability of parametric toolkits for consumer products is limited and therefore we have developed a simple toolkit suitable for our experiment. Customization can be done on different levels, such as, functional, ergonomic and aesthetic (Berger & Piller, 2003). Within each of these levels different product attributes exist including function, features, topology, shape, material, construction, dimensions, surface texture, color, engraving and print. Any attribute can be used for customization on any levels. For instance, the shape influences the aesthetics of the product, but it could as well influence the functionality. The attributes are not necessarily mutual exclusive, for instance, the color might be determined by the attribute material or exist independently of the material. In our study, we have focused only on customization of the *shape* of the object. Shape was chosen for two reasons. First of all, the intention of this study was to go beyond aesthetic customization as seen in commercially available toolkits. Secondly, although shape giving is not necessarily an easy to master skill, the idea of altering a shape is fairly easy to grasp for non-designers.

The experiment consisted of four steps, namely
(1) the development of the solution space,
(2) the customization of the object by the consumer

(3) the production of the customized design, and
(4) the use and evaluation of the customized object by the consumer.

The solution space consisted of a design template with eight parameters that controlled the shape of the object and this was modeled in Autodesk 3D Studio Max 2011[1] (Figure 2). Besides the 3D model and a reference object, the interface contained eight sliders on the left side of the screen (Figure 3). Four parameters controlled the shape of the bowl and another four controlled the press of the lime squeezer (Table 1). The range of the parameters was restricted by the size of the production tool, a MakerBot Thing-O-Matic[2] 3D printer, used for this experiment. The maximum print size of this 3D printer was (w) 100 x (d) 100 x (l) 100 mm. ABS plastic was used for producing the prototypes. The reference object was the university's entry card, a familiar item to all participants.

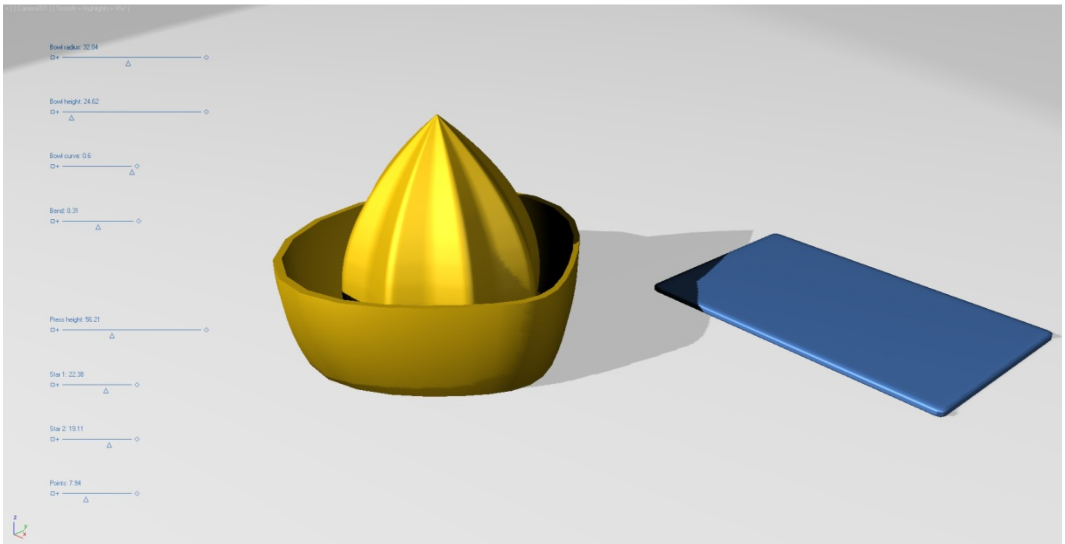

Figure 2 Screen shot of the interface

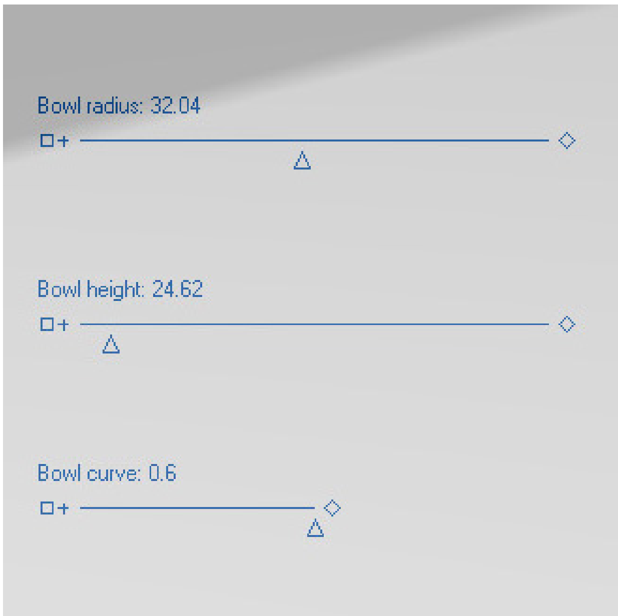

Figure 3 Screen shot of 3 sliders

[1] Autodesk http://usa.autodesk.com/3ds-max/
[2] Makerbot http://store.makerbot.com/thing-o-matic-kit-mk7.html

Parameter	Range
Radius of bowl	25-40 mm.
Height of bowl	20-95 mm.
Curve of bowl	-0.6 – 0.6
Angle of bowl’s top surface	-40 – 40
Height of press	35-95 mm.
Inner radius of star press	10-30 mm.
Outer radius of star press	5-26 mm.
Number of star points of press	0-24 points

Table 1 Description of the parameters and their range

The second step of the experiment was the involvement of the consumer in the design process. The *first task* of the consumer was to play around, explore the toolkit and find a shape that one satisfies. A prototype of the customized object has been produced by additive manufacturing afterward. The *second task* for the participant was to use and evaluate their customized object. After the first and second task of the consumer questions were asked about their experiences and expectations. We selected a lime squeezer for customization since it is an everyday object and it could be made of one material, one part and it does not contain any mechanical or electronic parts. The setup consisted of a laptop computer with mouse, a reference object and some limes. The interface was a color 3D CAD model with eight parametric sliders. By dragging a slider up and down the shape of the model changed in real-time. There was no time restriction for the participants in this experiment. The consumer was represented by a small group of seven participants; none of them had formal design education or professional design experience. The group was a mix of different ages, genders and levels of education. Ages ranged between 20 and 40 years, 3 male and 4 female participants, 3 employees and 4 students of the local university. All participants were familiar with performing basic tasks on a computer. The interviews conducted after each step of the experiment have been transcribed and analyzed through coding the text manually and then identifying relevant themes. All participants were able to interact with the interface, customize a design and after producing a prototype they were able to use their customized design.

Results

The outcomes of this study are both the *prototypes* themselves of the customized objects and the *evaluations* of the participants. We have chosen to present five core findings that emerged in the process of interpreting both the produced objects and the interviews. We believe that these findings capture some of what we saw as the more interesting results. The five findings are: F1 lack of variation, F2 responsibility shift from designer towards consumer, F3 understanding 3D models, F4 priority of parameters and F5 control over product attributes. Before we discuss the findings we will briefly comment more generally on the prototypes and the interviews.

Prototypes

In Figure 4 an overview of the produced prototypes can be found. The first design (4-a) differs from the template design in two aspects, the height and sharpness of the press. Design 4-b has a smaller bowl diameter and a less pointy press. The third design (4-c) has a press which is more sharp and slim. The bowl is quiet the same as the design template. Design 4-d has a lower number of ribs on the press and also the angle of the top surface has been changed. The fifth design (4-e) is lower and wider than the template. Design 4-f is the most distinct design in this experiment, it is the one that most differs from the initial starting point. The bowl is higher and slim and the press has many ribs. The last design (4-g) mainly differs in the angle of the top surface of the bowl, it is more tilted. Overall, the customized objects all fall into the boundaries set in the solution space. *All of the customized designs explore a rather limited area of the available solution space* (F1). The amount of change compared to the initial template given to the participants is relative small. The designs look similar to the design given at the start of the customization task.

Interviews

From the interviews, conducted after the two tasks, several general themes were identified. The concept of an 'ideal design' was mentioned and "*the fact that you are yourself responsible for the decisions made in the design"* (F2). A question was asked: "What is the ideal design of the lime squeezer?" and one participant noted that "You can't say why didn't they think of this? It's you now". We found *a discrepancy in understanding of the virtual model on the screen and the physical prototype* (F3). General comments after seeing the prototype was that the participants expected that the model would have been bigger. Participants pointed out several aspects such as the scale of the model on the screen, the ability to relate to the overall size or parts of the object and keeping track of the proportions of the design. Furthermore, a participant noted *"the difficulty of prioritizing what parameters are important for the design*" (F4). The last theme we deducted is control over the product attributes. *Several participants wanted to have more control over the design* (F5). They wanted to be able to have control over parts or product attributes that were not malleable in this toolkit.

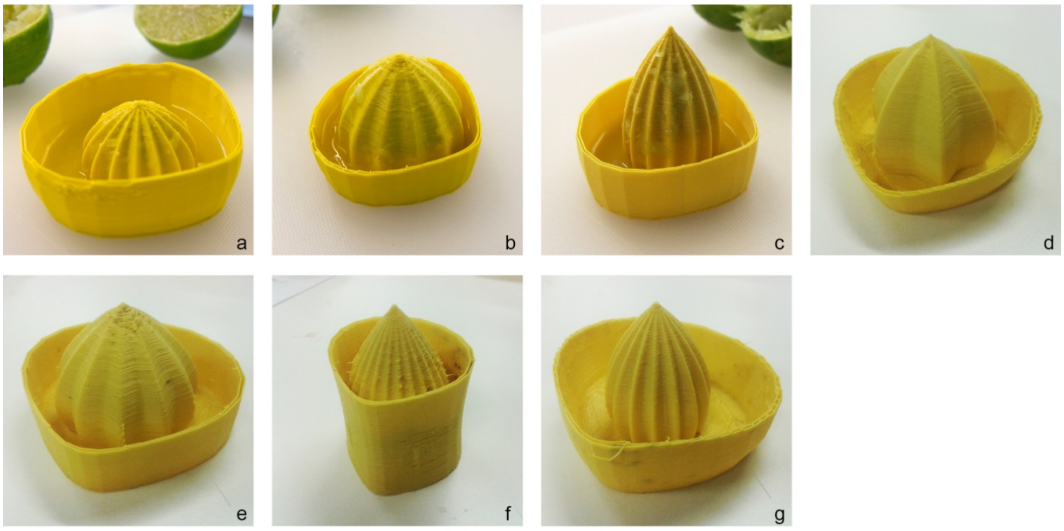

Figure 4 Prototypes (a-g) of the customized designs

Findings

The five findings pointed out in the results of this study will be explained in order of importance.

Lack of variation (F1)

The lack of variation in customized designs (F1) was the most interesting finding from this experiment. The participants were given a solution space in which they can freely move and design their own object. The notion of a *solution space* is a familiar and understood term among industrial designers, programmers and other professionals. However, do consumers equally understand this concept? Consumers are used to have a solution space which is a discrete range of products types and variations. For instance, a product family consists of three types of products, within one type there are five variations which differ among each other in, for example, color. This array of 15 products is all they can choose from, for this particular brand. The competitors have also different types and variations. In the end, the whole range of products one can choose from is limited and more importantly they are all individually defined. A solution space in mass customization is a dynamic and partly undefined area, or space, where the consumer has to define certain aspects of the product. In this case, the space is a three dimensional one, which is probably new to many consumers. Unfamiliarity and uncertainty play a role here. The participants did not know what to expect from the toolkit. No examples of produced lime squeezers were given to them in advance, the only example they have seen was the template which was there starting point for customization. Consumers search for products that meet their needs and wishes, it is a passive activity based on acceptation or rejection of proposed solutions. In customization the consumer has to have an active attitude and make decisions about the design itself, instead of making decisions whether or not to accept a design. What does this active role exactly mean? How are non-designers looking at this new role? What are their expectations? Two motivations for participating in a creative task, for example customizing a product, are competence and autonomy (Dahl & Moreau, 2007). How active is the user in this particular task of customization? Even if the user of the toolkit does not do anything, one will still end up with a design, of course similar to the design template. And if they change only a little bit, as seen with some of the participants, do they still feel they contributed to the design? On the other end of the spectrum are some interesting issues as well. What happens when they run into the boundaries of the solution space? Will their satisfaction of customizing decrease because they feel constrained in their creative expression?

Responsibility shift (F2)

The most interesting finding that came forward in the interviews was the responsibility shift from the designer towards the user (F2). In mass production all the responsibility of the design lies with the designer. The consumer has a passive role. In customization, the active role of the consumer brings a certain amount of responsibility with it and responsibility is a determinant of regret (Schwartz, 2004). When a user would make a bad decision in the customization process, he could regret this later when having the actual product. Because he was actively involved, he might feel responsible, and to a certain extent is responsible, and feel even more regret compared to buying a product which is entirely designed by a professional. Even though the idea of a solution space is that all the customizations are producible and functional, the user cannot make something that malfunctions, he might still end up with something he does not want. The 'ideal design' which was mentioned refers to the expert who knows what is best. Customization has an 'ideal space' in which all variations work well, it depends on one's preferences what fits best. A way to make people take the responsibility for their design might be engagement. If people are engaged in the design process, because they feel the customization of this particular product fits them or it could be the method of customization that is entertaining or interesting, they might not be afraid to make decisions and come up with experimental and truly customized designs.

Understanding 3D models (F3)

The finding F3 is concerned with the ability to understand 3D models in CAD and their physical counterparts. Even though the interface had a reference object which was also physical present while customizing, experience is needed to overcome this discrepancy. Industrial design students gain this experience already in their education where they have to work with sketches and 3D CAD models on one hand and foam models and prototypes on the other hand. Consumers who might never have been exposed to this have to learn to interpret virtual models when engaged in customization.

Priority of parameters (F4)

The fourth finding concerns the priority of parameters (F4). Are some parameters more important for the design than others? In this experiment the parameters were represented by sliders. Each slider had the same size and they were presented underneath each other. There was no visual hierarchy. Due to the design of the toolkit there was no difference between them. The question is if a hierarchy is needed, depending on the product, the type of parameters and maybe the anticipated users. If so, it could be solved by putting more emphasis, visually, on some aspect and thereby guiding the user towards the more important parameters first.

Control over product attributes (F5)

The last theme identified had to do with what product attributes of the design can be controlled in the toolkit (F5). The industrial designer decides which parts of the products are malleable for the user when designing the solution space. This is a very important step in satisfying the consumer needs and choosing the relevant parameters to customize with the relevant range for each parameter. This is where the overall design space is defined. How this is done determines what the user can do and what potential product can be designed with the toolkit.

Discussion and conclusion

In this study we have identified several issues that play a role when consumers take on the task of customizing a consumer product. The study showed that when developing a mass customization toolkit these issues have to be considered. It is also clear from our study that the findings we have extracted are mostly in the form of questions. This means that what the study has done is opened up for more research.

We are convinced that the new responsibility facing a consumer when involved in the design process is part of a larger paradigm shift. It requires a different mind set and different approach towards selection, choice and purchase of physical goods. Even if it is difficult to predict how this paradigm shift will develop in practice, we would argue that a professional designer needs to know what a consumer *wants* to customize. As seen in the experiment, even though the users had several options, they wanted to have other options as well, and they were searching for support when they had to make their decisions. The design of a toolkit is therefore not a simple and straightforward design. For instance, it is not necessarily the case that more user freedom, that is, a larger design space, is what a user wants or needs. There is a tradeoff between giving the user *freedom* in customization and setting up *constraints.* Too much freedom can lead to the user being overwhelmed and feeling lost. This is referred to in literature as *mass confusion* (Huffman & Kahn, 1998). Too many constraints on the other hand, may give the user a sense of being restricted.

Apart from the final result, the customized design, contributing in the design process itself could, if done in a way that correspond to users' desires, lead to consumer satisfaction. It may give the consumer a sense of accomplishment and autonomy. The experience of purchasing and using a product as a passive activity is expanded with customizing the product where the consumer has to take on an active role. From knowing what a consumer would like to have, acquiring need related information, towards knowing what a consumer would like to customize is an unfamiliar activity to most professional designers.

It is important to state that our study has not addressed differences in customer views in general when it comes to the question if it is desirable to be involved in the design process or not.

The experiment in this study has of course several limitations. First of all, the sample size was rather limited. The toolkit developed for this experiment was also simple and only allows for customization of one product attribute, namely shape. A more extensive toolkit would include other product attributes. Another limitation of this experiment was the prototypes which were produced on a small, desktop 3D printer. The printer limited the size and quality of the prototypes and for more realistic prototypes a professional 3D printer should be used. Probably the initial engagement of the participants towards customizing a lime squeezer was also lacking. Since customization requires an active role of the consumer where one has to make decisions about the design a certain amount of commitment is necessary.

In future research the customizable attributes should be explored in a broader perspective such as material and its properties, function and features to name a few. Furthermore, this study focuses solely on the consumer. Other stakeholders, to begin with the product designer, interaction designer, but also product engineers, marketers and manufacturers could be taken into consideration. The issues identified here still constitute a first step in understanding mass customization of consumer products and this study can contribute in developing a methodology for designing customizable products.

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