Investigating the Unexplored Possibilities of Digital–Physical Toolkits in Lay Design

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Digital–physical toolkits enable the layperson to design everyday consumer products. The aim of this paper is to identify and gain understanding of the unexplored possibilities of digital–physical toolkits. Looking at several different types of toolkits that enable novices to create, adapt or customize a design, we analyzed these toolkits and identified several characteristics and mechanisms that they share. We also investigated how people use toolkits through two usage experiments. In the first experiment, we identified several issues that arise when consumers use toolkits. In the second experiment, we developed a vocabulary for the exploration of the design space and we identified specific behaviors that laypersons enact when designing. The results of this paper are introduced through our lay design model, which deals with different types of layperson autonomy as well as with the unexplored possibilities of learning paths and iteration within digital–physical toolkits. If lay design becomes commonplace there will be an increasing need for understanding this practice. The unexplored possibilities discussed in this paper present opportunities for designers, and taking advantage of them will have far-reaching consequences for the whole product development cycle, from the way products are designed and developed to how they are distributed and sold.

Keyword – Consumer Participation, Lay Design, Mass Customization, Post-Industrial Design, Toolkits, 3D Printing.

Relevance to Design Practice – This paper exposes designers to the potential of involving laypersons as designers according to their own needs and preferences, constituting a shift from finished products to toolkits as the object of design. We introduce a lay design model that deals with different types of toolkits, learning paths and iterations.

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Introduction

Consumers adapt and modify products to their own preferences by expressing themselves through form, patterns and color, even though they are not trained as professional designers. Hot rods and custom-styled cars are examples of the dedication to customizing their possessions that novices can manifest. Consumers who make their own clothing are another example of laypersons designing. In this paper we are interested in the idea that the consumer becomes a designer of his or her physical environment with a focus on consumer products that are typically mass-produced. The advent of computers and the Internet has made it easier for consumers to create content, modify it, build upon others' work and share the results with anyone. In the mid-1990s the web hosting service GeoCities was one of the first to offer consumers the possibility to design their own HTML website. Involving the consumer in creating content has expanded to a broad range of media such as blogs, video, music and animation. *Time* Magazine named "You" person of the year in 2006. According to the magazine, the consumer had become the most influential person in making, adapting and sharing user-generated content (Cruickshank & Evans, 2008). In the physical world, mass customization (Tseng & Jiao, 2001) is a widely implemented approach that deals with an active consumer configuring a product to meet individual needs. In addition, digital fabrication technologies such as laser cutting and 3D printing are becoming more accessible through FabLabs (Mikhak et al., 2002), and these technologies make it increasingly easy to manipulate the physical world by turning digital designs into physical objects. Neil Gershenfeld, founder of the FabLab concept, wrote: "Consider what would happen if the physical world outside computers was as malleable as the digital world inside computers. If ordinary people could personalize not just the content of computation but also its physical form" (Gershenfeld, 2005, pp. 44-45).

Involving the consumer in the design of everyday products is an approach that is experiencing ongoing development. Open source was a concept formerly known only in software development, but it is increasingly being applied to product design (Avital, 2011). This conflicts with the prevalent focus of product design on developing *static artifacts* that meet consumers' needs and preferences. We use the term static artifacts here to characterize products that are fully defined by the professional designer and do not anticipate modification by the consumer. In contrast to conventional product design, the meta-design

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approach proposed by Fischer & Scharff "characterizes activities, processes, and objectives to create new media and environments that allow users to act as designers and be creative" (Fischer & Scharff, 2000). In this approach "a finished design is the result of the emergent properties of the interacting system" (McCormack, Dorin, & Innocent, 2004) rather than the work of one designer or design team. The questions that arise are, to what extent could a layperson be involved in product design, and how would their involvement affect the role of the professional designer?

The aim of this paper is to identify and gain understanding of the unexplored possibilities of *digital–physical toolkits* by means of which the consumer is able to design his or her own product. This conceptual paper is intended to open up an unexplored area and to identify and formulate interesting directions. The development of toolkits in product design is a relatively underexposed area since product design is mainly concerned with finished artifacts. In lay design, however, consumers are given a design space in which they find their own solutions. The design space consists of all imaginable designs, and the professional designer sets the boundaries of the design space. The two experiments that are presented in this paper serve the goal of exploring the area of lay design and in particular the tension between the consumer and the professional designer. We have investigated how novices explore a design space using toolkits, and we have identified several different ways of doing this. We formulate different lay designer characters that represent the different qualities that novices can express during their exploration of a constrained design space. We then introduce a model that we developed to help us frame the four different types of participation of the consumer that we observed in our experiments, and we bring into play the notion of learning paths to connect these types of participation. Learning paths are already present in digital toolkits and represent the ability of a toolkit to address the different skill levels of its users. Our empirical work helped us to make the argument of learning paths, iteration and varying degrees of involvement of the lay designer. By generating models of consumer behaviors and defining different types of layperson characters, we have been able to generate a deeper understanding of lay design and the potential of toolkit design.

This paper is structured as follows: first we give a brief overview of existing approaches and motivations for consumer participation in design. We then examine digital and digital–physical toolkits and identify their characteristics and mechanisms in order to get an understanding of the current situation. We identify the issues that arise when consumers use digital–physical toolkits to design everyday consumer products, derived from our two experiments with non-designers. In the last section, we discuss the unexplored possibilities of digital–physical toolkits. The paper ends with a discussion of the implications of these untapped possibilities for designers and reflects upon consumer participation in product design.

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Participation of the Layperson in Design

Design can be interpreted "as an activity undertaken by all humans, not just professional designers" (Simon, 1996, p. 215). Rittel argued in a similar way, stating that "design is not the monopoly of those who call themselves designers" (Rittel, 1974). If design is not solely the domain of the professional designer, the question arises how designer and novice would design together. The consumer, often portrayed as passive opposite to the designer, does not possess the knowledge, skills, sensitivity and experience a professional designer has when it comes to product design. Therefore, in this paper we use the adjective *lay,* meaning "not trained in a certain profession; not having a lot of knowledge about a certain thing" (Merriam-Webster, 2014), to refer to the consumer who participates in the design process, by using the term *lay designer*. We also make a distinction between involvement and participation, whereby the former concerns a passive stance, while the latter deals with an active attitude of the consumer. In participation, the consumer performs an activity, while involvement merely reflects the relevance of the consumer to the object (Barki & Hartwick, 1989).

In this section, we will provide a short overview of several different approaches that have been developed to enable the layperson to actively participate in the design process. Participatory design has a democratic foundation and aims to involve all stakeholders in the design process by empowering the user (Bødker, 1996). Co-design is a form of collective creativity that is based on the assumption that all people can be creative (Sanders & Stappers, 2008). Co-creation is a business strategy whereby the value of a product is created together with the consumer (Prahalad & Ramaswamy, 2004). Value, not only in the monetary sense, but also experiential and societal value, can be created through participation of the layperson (Sanders & Simons, 2009). Another approach has been to involve lead users in the design process with the idea that by using a select group of advanced users a company can gain new product ideas and concepts (Von Hippel, 2006).

One approach that is of particular relevance for this paper is mass customization. The term was first coined in the book *Future Perfect* by Stan Davis (1987, p. 272) and is an aggregation of mass production and customization. The aim of mass customization is to produce products that meet individuals' needs in an efficient way (Tseng & Jiao, 2001). Industrialization and mass production have distanced the consumer from the designer and manufacturer of products. To produce products that meet consumers' needs, designers typically try to identify a need at the beginning of a design project. This so-called sticky information (Von Hippel, 1994) is often difficult to extract from the consumer; therefore mass customization is adopted in order to let consumers configure a product themselves. This form of customization is called collaborative customization (Gilmore & Pine, 2000) since a dialogue is established with the individual customer.

Mass customization is an example of a top-down approach imposed by the designer. Besides these imposed approaches, consumers can also initiate their own customization through approaches such as do-it-yourself and hacking. Do-it-yourself refers to domestic activities in which a consumer is both producing and consuming (Edwards, 2006), whereas hacking is about repurposing objects or systems in ways the designer did not intend and does not necessarily agree with (Galloway, Brucker-Cohen, Gaye, Goodman, & Hill, 2004).

When novices are engaged in a design activity, they can be motivated for different reasons. Dahl and Moreau investigated "any activity in which an outcome is created" and generated a list of motivations for undertaking a creative task consisting of seven aspects: competence, autonomy, learning, engagement and relaxation, self-identity, public sense of accomplishment, and community (Dahl & Moreau, 2007). Alternatively, Gerber and Martin distinguished nine motivations of consumers, focusing on web-based self-services in particular (Gerber & Martin, 2012). In this paper we use the seven motivations depicted by Dahl & Moreau (2007) for evaluating existing toolkits, since they focus on creative tasks in a broad perspective. More specifically, this paper focuses on the active participation of the consumer in expressing their needs and desires in a constrained design space by using a toolkit.

Definition of Concepts

When the layperson becomes a designer, the novice is offered a *design space* or so-called *solution space* (Berger & Piller, 2003) containing all imaginable designs that fit the capabilities and degrees of freedom of a certain production system. Design is concerned with what ought to be (Simon, 1996) and deals with imagining a preferred state (Nelson & Stolterman, 2012, pp. 105, 127). This is in contrast to mass consumption, where the consumer does not require imagination since all solutions are defined and the consumer only has to accept or reject proposals. It is known from cognitive psychology that in creative tasks, people rely heavily on existing categories when creating a new object. This phenomenon is labeled as *structured imagination*, wherein "new entities consistently maintain properties of existing categories" (Ward, 1994). Designing by using a toolkit is concerned with the tradeoff between the designer's intent and the autonomy of the layperson. The degree of autonomy is related to the possibility of creating novel items with the toolkit. The designer influences the user by the design of the toolkit, and depending on the designer's intention it is either possible to create novel outcomes or not.

Figure 1 introduces a simplified version of the lay design model that is based on Dahl and Moreau's definition of *experiential creation*, which is "the universe of activities in which a consumer actively produces an outcome" (Dahl & Moreau, 2007, p. 358). It distinguishes creative activities by the variables *outcome* and *guidance*. To illustrate the model we include an example of a creative task in each quadrant. The first quadrant is characterized by no guidance and an undetermined outcome; making an original cabinet is an example of a creative task that fits this quadrant. Assembling a jigsaw puzzle is located in the second quadrant, with no guidance and a determined outcome, since the outcome is predetermined, but one has to figure out how to put the puzzle together. The third quadrant is defined by an undetermined outcome and step-by-step guidance. Following a sewing tutorial that provides a technique to make a piece of clothing is an example. Finally, building a model airplane, where a picture of the end result and a manual are provided, fits the fourth quadrant. We will use this model as a basis when examining design spaces and toolkits. Towards the end of this paper we will revisit this model, extend it and discuss it further in detail.

Within this model the layperson is given access to a design space by a *toolkit*. We define a toolkit as an assembly of tools aimed at a particular purpose, for instance a toolkit for designing jewelry or a toolkit for creating model airplanes. In the digital world there are toolkits that use code as material and programming as a means of obtaining adaptability. Since code is flexible, it is fairly easy to adapt and so create something unique (Reas & McWilliams, 2010, p. 176). In the physical world, toolkits use mechanisms such as modularity to obtain flexibility (Kratochvil & Carson,

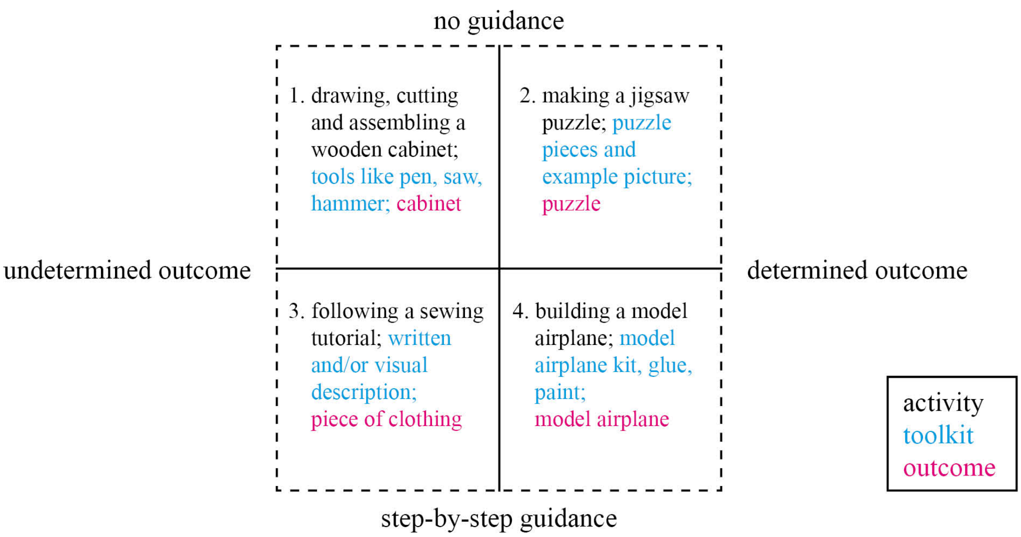

Figure 1. Simplified lay design model (adapted from Dahl & Moreau, 2007).

2005) and configurational toolkits are based on the concept of combining prefabricated modules. This is in contrast to the conventional built-to-forecast model where a prediction is made on the quantity that should be produced (Anderson, 2008). Von Hippel defined digital–physical toolkits by five characteristics: complete cycles of trial-and-error learning, appropriate solution space, user-friendliness, libraries of commonly used modules in order to let the user focus on the unique parts of the design, and producible outcomes for the intended manufacturer (Von Hippel, 2001). We use a model that has been developed as an analytical tool (Hermans, 2012) to gain an understanding of the design space of toolkits by breaking them down into the target outcome and the guidance given (Figure 1).

To describe the toolkits, we draw on only one aspect of this model, the *mechanism,* which is defined as "an enabling technique to gain the high-level process flexibility needed for offering mass customization" (Hermans, 2012). The model describes four mechanisms: veneer, modularity, parametric, and algorithmic. Veneer is a mechanism that adds a visual, decorative layer to a design. This mechanism is for instance used to personalize a portable mp3 player by engraving text onto it. Modularity is based on the concept of combining and assembling prefabricated modules to form a design. Desktop computers can be configured in this way, by combining modules, so that the computer meets the needs of the customer. The parametric mechanism is based on the concept of altering parameter values that influence one or more parts of the geometry. An example of the parametric mechanism is when the user can adjust the dimensions of the 3D design of a cabinet to fit a specific environment. The algorithmic mechanism uses an algorithm to synthesize a design; the user could influence this algorithm in one way or another. The algorithmic mechanism is applied in 3D printed jewelry design.

Analysis of Toolkits

In this section we examine existing toolkits that allow their users to engage in creating either digital content or a physical design. The purpose of this analysis is to get a better understanding of the role of the layperson in these toolkits. We examine two digital toolkits and two digital–physical toolkits to gain an understanding of the skill levels that are addressed. We achieve this goal primarily by analyzing the mechanisms used in the toolkits. In our analysis, we use the following four aspects derived from Von Hippel's toolkit definition:

1. Accessibility to laypersons (user-friendliness)
2. Possibility of learning and mastering the experience (learning)
3. Iteration (complete cycles of trial and error)
4. Tradeoff between authority and autonomy (appropriate solution space)

The selection of toolkits to assess was based on a mapping of an existing categorization of toolkits (Figure 2). The main interest of this paper is in consumers that design end-use products; therefore this categorization was useful. There are a vast number of examples of customization toolkits, including NikeID (www.nike.com/us/en_us/c/nikeid); an overview of these types of toolkits can be found in online databases (e.g., Configurator Database: www.configurator-database.com). The toolkits we did not consider in this study are toolkits meant for prototyping (e.g., Arduino: www.arduino.cc) and entertainment (e.g., LEGO Mindstorms: mindstorms.lego.com). Furthermore, consumer-oriented CAD software packages (e.g., Google Sketchup: www.sketchup.com; TinkerCAD: www.tinkercad.com) and professional CAD software (e.g., Solidworks: www.solidworks.com) were not considered since we approach lay participation from easy-to-use tools that do not require 3D modeling or design skills.

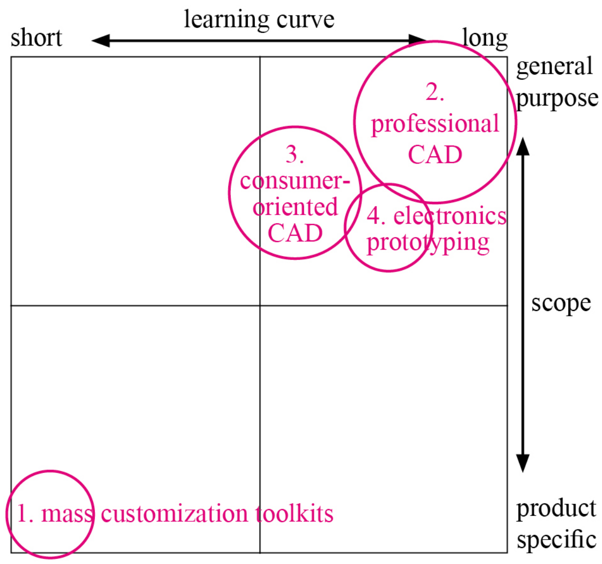

Figure 2. Mapping of existing categories of toolkits.

Digital Toolkits

We chose to compare two different toolkits in our first analysis: a content management system (CMS) and a music production toolkit (Figure 3). The content management system Wordpress (www.wordpressfoundation.org), used for setting up and managing web content, enables its users to design both the aesthetics and the functionality of a website. Wordpress was chosen as an example of a CMS since it is a widely implemented system. Maschine, a music production toolkit, consists of both software and hardware and enables its users to compose, arrange and produce electronic music (Native Instruments: www.native-instruments.com). The software encompasses a sequencer, a sampler and virtual instruments as well as effects, whereas the hardware allows the user to control the software. Maschine was chosen as an exemplar of music production since it consists of both hardware and software and therefore is not limited to the digital domain.

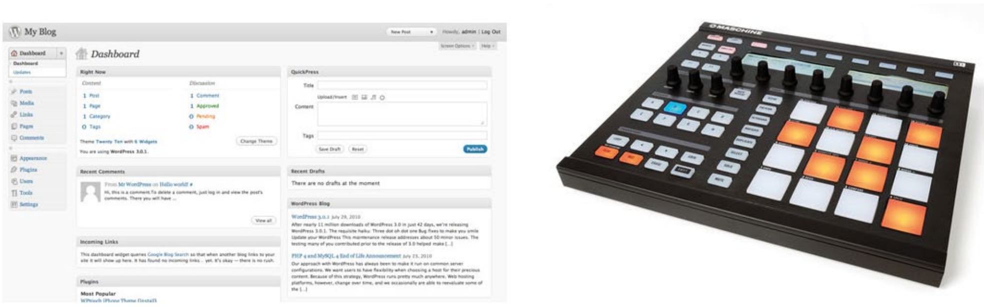

Figure 3. Interface of content management system Wordpress (left) **and music production controller Maschine.**

Wordpress

The Wordpress toolkit uses four mechanisms depending on the user's skill level, thereby opening up a field that was previously only accessible to the skilled expert. Programming knowledge was necessary in order to create and maintain a website; this toolkit, however, makes web design accessible for anyone. People with different skill levels use the Wordpress toolkit, and each skill level comes with a certain amount of autonomy and responsibility. Wordpress offers two basic versions, and we distinguished six different levels: simply choosing a ready-made theme (level 1), configuring this theme (level 2), manipulating by writing simple code (level 3), setting up a theme on one's own host (level 4), manipulating this theme by writing complex code (level 5), and designing a theme from scratch (level 6). The layperson is able to make iteration cycles before the code is published online and modify it over and over again. The amount of autonomy the layperson gains depends on his or her knowledge, skills and motivation. The toolkit allows for an increasing freedom if the novice is willing and able to learn the progressive steps.

Maschine

This toolkit employs the modularity mechanism (for setting up effect chains) and the parametric mechanism (for configuring virtual instruments and effects). Maschine is used by professional producers like Underworld and Flying Lotus as well as by amateur musicians, and it enables the consumer to access the world of music production in an affordable way. The music production toolkit has three skill levels: using stock loops, melodies and effects (level 1), using virtual instruments and composing from scratch (level 2), and developing the sound of virtual instruments and effects and/or sampling one's own instruments to compose from scratch (level 3). By offering different skill levels, the toolkit is suitable for the layperson as well as for the professional who has the skills and experience of composing music with high-end studio equipment. The user is able to create and modify their composition before exporting it as a final product. With this toolkit, the tradeoff between authority of the designer and autonomy of the layperson depends solely on the user's knowledge, skills and motivation.

The two digital toolkits analyzed are examples of creative rather than consumptive products. Autonomy and learning are particularly important motivations in these toolkits since both toolkits enable the user to take control of outcome as well as process.

Digital–Physical Toolkits

The two digital–physical toolkits (Figure 4) that were examined allow novices to design jewelry and furniture. We chose to examine two different product categories, since both these categories are popular products to customize and they use two

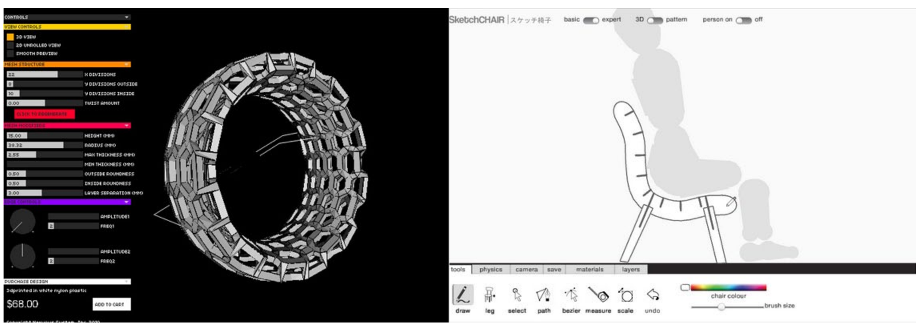

Figure 4. Interfaces of jewelry toolkit Cell Cycle (left) **and furniture toolkit SketchChair.**

different manufacturing processes. The digital–physical toolkit Cell Cycle enables the consumer to customize jewelry that can be produced by 3D printing (Nervous Systems: www.n-e-r-v-o-u-s.com). SketchChair enables the user to draw furniture (Saul, Lau, Mitani, & Igarashi, 2011); from the layperson's sketch the software generates a 3D model that can be produced by laser cutting.

Cell Cycle

This toolkit uses the veneer and parametric mechanisms for manipulating the function, shape, dimensions, color and material of the jewelry. The toolkit has a user-friendly interface that does not require any design skills and therefore it opens up an area that was previously only accessible to the professional. Contrary to the examples of digital toolkits, this toolkit does not accommodate different skill levels beyond the beginner's level. Cell Cycle is meant for laypersons without any skills or experience and therefore it is not possible to increase one's autonomy. The novice is able to create a design and modify it over and over again; however, the iteration cycles are within the digital domain and it is not possible to iterate between digital and physical without purchasing the design. The toolkit is product-specific and this makes it more constrained than the examples of digital toolkits. The layperson is able to adapt the design to his or her own preferences but the designer's intent is still strongly present in the final design. The tradeoff between authority of the designer and autonomy of the layperson is in favor of the designer.

SketchChair

The SketchChair toolkit uses the algorithmic mechanism since it automatically computes a 3D dimensional structure from a 2D sketch. Again, this toolkit opens up an area that was only accessible to professional designers by using a user-friendly interface. The drawing requires some skill and the layperson can improve this skill over time; however, once the novice has created the sketch the system generates the 3D model and the user has little control over the process. This toolkit is clearly meant for the layperson; a professional designer would not use it to design a chair. Iteration is only possible in the digital medium; however, it is possible to make a scale model of the design, for example by using an inkjet printer and some paper, and thereby make physical prototypes before producing a full-scale piece of furniture. This toolkit is also product-specific and the designer's intent is strongly represented in the designs. Compared to the jewelry toolkit this algorithmic toolkit needs user input to generate a design, which means more imagination and risk is needed from the user to create something from scratch.

Digital–physical toolkits do not address multiple skill levels in the way that digital toolkits do. Iteration is more difficult to establish since these toolkits have to bridge the digital and the physical worlds. It is inherently easier to manipulate bits than atoms; therefore digital toolkits have an advantage over digital–physical toolkits. The SketchChair toolkit tries to overcome this difficulty by being able to export scale models of the designs that can be easily fabricated from paper. We examined two types of toolkits and analyzed them according to four aspects. This analysis gave us insight into the characteristics of these toolkits. However, this analysis did not inform us as to how consumers will engage with these toolkits when designing an everyday object. To get an insight into how consumers appropriate digital–physical toolkits for creating their own product we present two experiments that we have conducted to explore the relation between laypersons and design spaces.

Two Experiments: *Understanding Lay Designers*

To gain an understanding of how novices use digital–physical toolkits and engage with the concept of a design space, we have to investigate the interaction of laypersons in an actual use scenario. How do consumers behave, relate to and engage with digital–physical toolkits to express their needs and preferences? How will they explore the design space they are offered?

The experiments serve the purpose of exploring the participation of laypersons in design and in particular the tension between the novice designer and the professional designer. The experiments are exploratory in nature and they lead to more questions rather than giving definitive answers. The way the experiments are presented in this paper is mainly for their outcomes. We do not intend to fully describe each experiment in detail and hence we refer to their individual publications for the complete background information. We simply want to give some context and background to the findings.

We performed two experiments that focused on design tasks in which laypersons were asked to customize an everyday object. For these experiments we developed two parametric toolkits, since the commercial availability of parametric toolkits is rather limited. The first exploratory experiment will be briefly described in order to highlight the issues that came up and that formed the basis for the second study, which identified specific behavior when novices explore a constrained design space.

Experiment 1: *Identifying Issues When Lay Designers Use Toolkits*

This experiment explored how laypersons use a toolkit to perform the design task of customizing the shape of a juice squeezer (Hermans & Stolterman, 2012). The aim was to identify issues when consumers are confronted with the task of adapting a design to their own preferences. The toolkit resembles today's mass customization offerings in terms of freedom, process and interface, and uses a parametric mechanism. In this experiment seven subjects participated, none of them with formal training or experience in the field of design. Through personal semi-structured interviews the participants were asked about their experience with, expectations of and satisfaction with their design and process. The interviews were recorded, transcribed and analyzed by coding the text manually to find relevant and similar themes. This exploratory study revealed issues that play a role when laypersons design a product by using a toolkit. The three main findings—exploration of design space, responsibility shift from designer towards layperson, and the tradeoff between designer authority and novice autonomy—are mostly in the form of questions and open up avenues for more research in this area. We discuss only the first finding, which led to the formulation of the second experiment.

The participants explored a limited area of the available design space. If one compares the final designs to the initial design template they were given, it is clear that the changes are relatively small. In contrast to today's market, where consumers search for products that meet their preferences, needs and desires, lay design challenges them with an active task of expressing their preferences and needs directly into the creation of an object. It is unclear how novices deal with the notion of a design space. The design space a consumer faces today is limited and defined. It is the collection of all products available in one category. For instance, when a consumer is looking to buy a new bicycle, there are a number of manufacturers (e.g., five) and each has a number of defined solutions (e.g., 10). The design space for this particular consumer consists of 50 bicycles. However, in lay design the design space is infinite, or at least could be perceived as such, and the boundary of the design space is set but the designs in it are undefined. This brings unfamiliarity and uncertainty along with it. Consumers, who are now dealing with a design space rather than a collection of solutions, may get confused and feel overwhelmed, which may lead to avoiding decisions (Schwartz, 2004).

Experiment 2: *Identifying Behavior of Lay Designers*

The second experiment was informed by the finding in experiment 1 of a lack of exploration of the design space. It focused more specifically on identifying the behaviors of the consumer when exploring the design space (Hermans, 2013). The participants were again given the task of designing an everyday object, a juice squeezer, by altering the shape, color and material. The toolkit resembled a typical mass customization offering as found in today's market; however, the tool was more developed and detailed than in the first experiment. In order to be able to analyze the subjects' behavior, we tracked their mouse movements. In this way, we were able to see what part of the design space was explored as well as how they explored the design space.

Experimental Setup

A group of 10 students from a local university participated, none of them with formal training or experience in the field of design. The experiment consisted of two stages, a design task in which the participants created a design, and a reflection part where they evaluated their process as well as the 3D-printed outcome. In the first part participants were able to choose a design preset and manipulate the preset by using eight parametric sliders. The object was produced by 3D printing and given to the participants. In the second stage of the experiment they reflected upon their process and design through a written survey. The survey consisted of 25 statements and open questions about the task and the design, and several general statements and questions about user participation in the design process. The subjects interacted with the object through an interface that consisted of a 3D model modeled in Autodesk 3D Studio Max 2012, and eight parametric sliders. Six sliders manipulated the shape and two sliders were for selecting the material and color. The designs were produced on professional additive manufacturing machines. The design task was captured on video and analyzed through visualizations that revealed behavior and were used to identify characters that would otherwise be invisible by simply observing the participants (Figures 6 and 7).

Results

The second study delivered 10 prototypes (Figure 5), surveys, and data from tracking each participant's process. The design task data have been visualized in two different ways (Figure 6): the graph on the left shows how the user navigates through the design space in terms of step size and scope, and the right graph shows the exploration of the space for participants that chose the same design preset. The participants reflected upon their process and design through a written survey. The topics exploration and imagination, iteration in a toolkit, and ownership of the design are discussed.

The first reflection concerns to what extent a consumer explores the design space and consequently whether or not one has the ability to imagine outcomes of the unexplored space. Some responsibility and freedom to define a design is shifted from designer to consumer, therefore this issue is at the core of lay design. The majority of the participants stated that they had

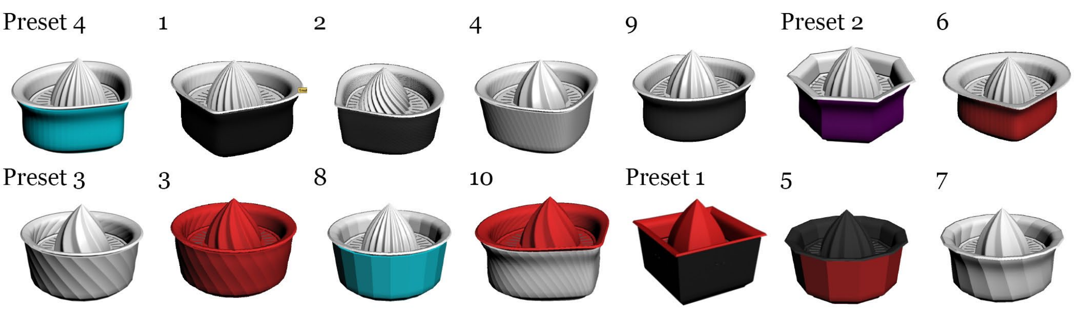

Figure 5. The four design presets and the designs made by the 10 participants.

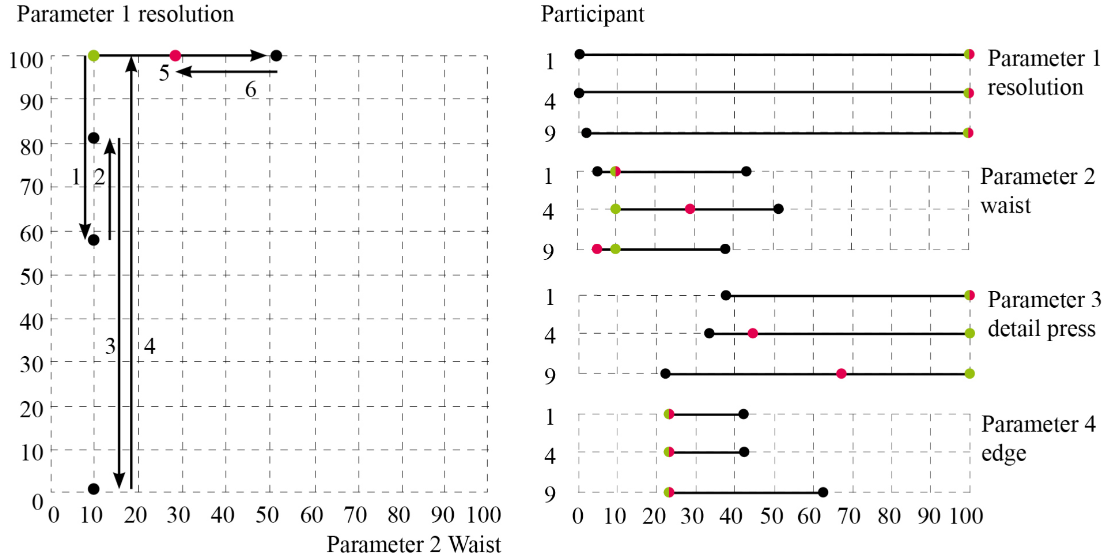

Figure 6. Visualization of design process; participant 4 with parameters 1 and 2 (left) and participants 1, 4 and 9 (right).

explored the toolkit to a large extent (8/10), and half of them assumed they could imagine what the unexplored part of the design space would look like. The toolkit offered in this study allowed for cycles of trail and error as suggested by Von Hippel (2001).

The second reflection acknowledged the importance of iteration in a design process; even though the toolkit in this experiment allowed the participants to make iterations, the majority of the participants (7/10) stated that they would like to design it again when they received their physical copy. Iteration is a fundamental aspect of the process of a professional industrial designer. Iterations in product development are "controlled, feedback-based redesigns" (Unger & Eppinger, 2011, p. 3). By iterating on a concept, the designer defines and refines a solution. This iteration goes from sketches, through mock-ups, prototypes and 3D CAD models.

The last reflection topic was around issues of ownership. When designer and consumer create a design together, the issue of ownership of the design will be raised. To what extent do users feel they contributed to the design and how do they value their participation in the design process? Seven out of the ten subjects felt that they had not created something new; however, they felt they had created something of their own. Furthermore, half the subjects would have been willing to spend more money on their design, because they had designed it themselves.

The Identified Issues

This experiment led to the formulation of three core findings, which are concerned with the behavior of the laypersons in the design space.

Lay Designer Characters

To identify and describe different lay designers in our experiment, we introduce the term *character*. A character is defined as "one of the attributes or features that make up and distinguish an individual" (Merriam-Webster, 2013). These characters are based on the design task visualizations (Figure 6) and represent different qualities of participants in this study. Four characters are identified (Figure 7). *Settler* and *Voyager* are derived from the design outcomes and *Stroller* and *Horseman* are derived from analyzing the design task on a detailed parameter level. Settlers explore the design space and end elsewhere in the space, with a different design. Voyagers move through the design space as well, but eventually return to their start point and thus they end with a similar design. When examining the process of the design task, we can make the distinction between two characters based on the scope, the extent of the exploration in the design space, namely Stroller and Horseman. The Stroller maps a small area of the design space in an intense way by going back and forth many times. The Horseman on the other hand travels through the design space at great speed, often from one end to the other. A layperson can employ any of these characters. For example, one could be a Settler by ending somewhere else in the design space and at the same time be a Horseman when one explores the design space with large strokes.

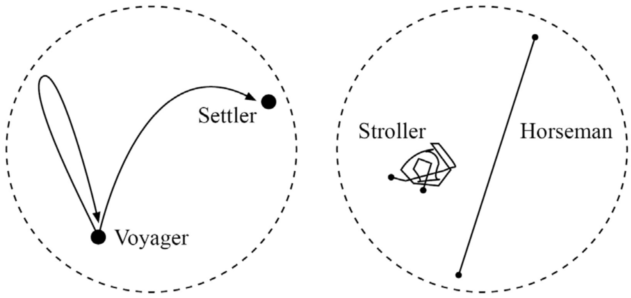

Figure 7. Lay designer characters focused on design outcome (left) **and the design process** (right). The dashed circle represents the design space.

Behavior of Lay Designers

The behavior of the participants was revealed through visualizations of the design task. The participants that chose the same initial design explored the design space, on a meta-level, in the same area and through the same path. This is especially visible for participants 1, 4 and 9 that chose preset 4 (Figure 6), participants 5 and 7 that chose preset 1, and for preset 3, which was chosen by participants 3, 8 and 10. The behavior is context specific and in toolkits that give more freedom to the consumer and concern other products and parameters different behavior might occur.

Predictability of Outcomes

The designer's intent is represented through the design of the toolkit. The designer defines the constraints of the design space and thereby directs the layperson. This toolkit gives autonomy to the layperson; however, as seen in this study the results are predictable to the designer of the toolkit. The size of the design space relates directly to the predictability of the outcomes. We assume that by broadening the possibilities of the toolkit, the outcomes become less predictable to the designer.

Discussion of the Experiments

Both studies investigated the relation between layperson and design space and gave us insight into what happens when the novice is put in a design situation. In the first study we saw that exploration of the design space is a central aspect. Consumers are not familiar with the possibility to extensively adapt or customize a product to their needs and preferences. Being able to explore a design space and converge on a suitable design is not a trivial task. The second study yielded insight into the behavior of lay designers in a constrained design space. We observed the different ways consumers explore a design space and hypothesized that this might be helpful in designing design spaces as well as toolkits. We have not seen literature specifying lay designer characters as a way to characterize design space exploration. These studies also revealed the limitations of the constrained design task, namely that it is configurational in nature. Both toolkits allowed their users to create designs by configuring, parametrically in this case, a template design. The designs created were not novel to the designer of the design space, and depending on the size of the design space, they may or may not have been novel to the user. However, a design space should allow its users to create something that is appropriate to them and that fits them.

The Unexplored Possibilities in Lay Design

In this section we present the overall findings of this paper in the form of unexplored possibilities of digital–physical toolkits. It ties together the literature review, the analysis of digital and digital–physical toolkits, and the exploratory experiments. In our two experiments we examined the relation between consumers and design spaces and we saw that moving from consumptive towards creative products requires a different mindset, a mindset that deals with imagining a preferred state and being accountable for the decisions one makes. Before discussing the unexplored possibilities, we introduce a lay design model that allows us to frame lay design activities from restrictive to open cases. The role of the lay designer is discussed as a continuum that connects the passive consumer with the professional designer.

Lay Design Model

The layperson can participate in design in a number of ways; a novice can configure a website through a content management system, arrange a piece of electronic music, or customize jewelry to 3D print. The lay design model (Figure 8) is built on the concept of experiential creation (Dahl & Moreau, 2007) and four levels of creativity (Sanders & Stappers, 2008). Experiential creation is defined as "the universe of activities in which a consumer actively produces an outcome" (Dahl & Moreau, 2007, p. 358). Creation is seen as an activity that has to be experienced first-hand and it can be anything from bringing something new into being, to hacking or remixing a thing that already exists. The second concept that is used as a basis for the model is the four levels of creativity. We use the four levels to describe what the layperson is doing in each quadrant, in the following way: from adapting, making, doing to creating, where adapting is the most restrictive form and creating is the most open one (Figure 8, gray labels). The model consists of the horizontal axis of undetermined to determined outcome and the vertical axis of no guidance to step-by-step guidance. The outcome axis is concerned with the degree to which the outcome is determined beforehand, while the guidance axis is concerned with the instructions provided for the user of the toolkit. The axes divide the model into four quadrants, namely *restrictive*, *open*, *technique* and *exploratory* (Figure 8, yellow labels). Diagonal arrows connect quadrants; one arrow is drawn between *technique* and *exploratory* and another between *restrictive* and *open*. The first arrow deals with the process of creation, from a rigid and well-defined process in the *technique* quadrant to an open and undefined process in the *exploratory* quadrant. The second arrow is concerned with the outcome of creation, where the *restrictive* quadrant is product-specific and the *open* quadrant has no determined outcome.

Four Quadrants: *Imagination and Responsibility*

Each quadrant requires a certain amount of imagination as well as a certain responsibility for the outcome. In Figure 8 (in pink) the horizontal axis also represents imagination, which increases from right to left. The vertical axis stands for responsibility, which increases going up. We will describe each quadrant and give a typical example to illustrate the increasing imagination and responsibility demanded of the layperson. The *restrictive* quadrant has been exemplified with the digital–physical toolkits of parametric jewelry and algorithmic furniture (Figure 4). This

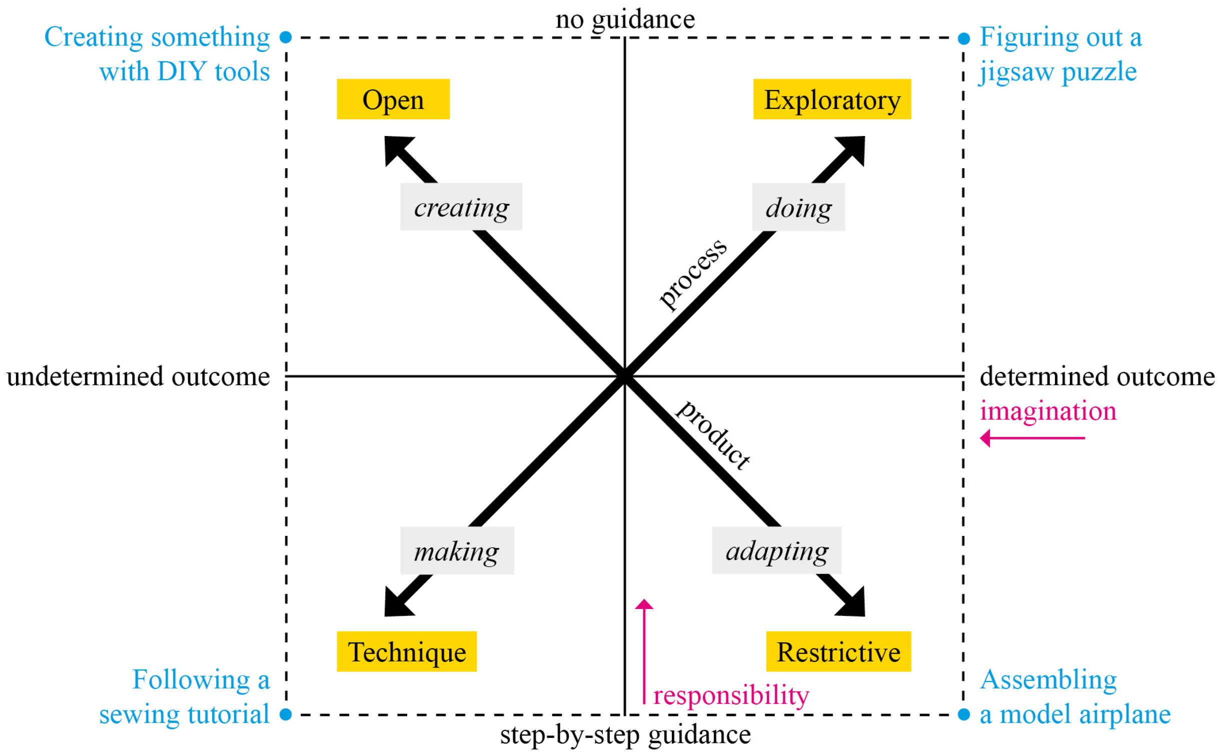

Figure 8. The lay design model with the four quadrants restrictive, open, technique and exploratory. Adapted from Dahl & Moreau (2007) and Sanders & Stappers (2008).

section is characterized by a determined outcome and a certain amount of guidance. The most restrictive example would be IKEA flat-packed furniture that has to be assembled. It is clear to the consumer what the outcome will be (no imagination needed) and a manual provides step-by-step guidance to assemble the item. The *restrictive* quadrant is mainly concerned with realizing a design rather than conceptualizing it, and therefore this section is dominated by toolkits with which laypersons can make designs of their own. Opposite to restrictive is the *open* quadrant where the outcome is undetermined and guidance is not provided. Open toolkits are concerned with conceptualizing as well as realizing a design; therefore this quadrant is labeled as creating. A typical example is a toolbox with a hammer, saw and screwdrivers. These tools can be used to make anything and the toolbox does not provide any guidance on how to do it. This quadrant, which is constrained by neither outcome nor guidance, is still constrained by the toolkit itself. The *technique* quadrant is characterized by precise step-by-step guidance without a determined outcome. Tutorials fit this quadrant since they impart a skill to the layperson without determining the outcome. An example is a sewing tutorial that teaches a particular stitch. Tutorials provide the necessary steps to work towards a skill that can be applied to many design situations. Technique is focused on learning a skill rather than on achieving a specific outcome. The fourth quadrant, *exploratory*, is best described as getting something done. It is characterized by a determined outcome without guidance or a specific plan on how to obtain the result. A jigsaw puzzle is a typical case since the outcome is determined, but there are no instructions provided, nor a detailed step-by-step plan that instructs the layperson how to assemble the puzzle.

The purpose of the lay design model is not only to categorize toolkits in a specific quadrant, but also to show that toolkits can be positioned in more than one quadrant in order to address multiple skill levels of the layperson. A box of LEGO bricks is an example of a toolkit that can be situated in all four quadrants. We will illustrate this by walking through each quadrant. When one follows the manual and builds the model as shown on the box, LEGO is positioned in the *restrictive* quadrant. When one learns a certain construction method, for example building an overarching bridge structure that can be applied to any design situation, then LEGO is positioned in the *technique* quadrant. LEGO is positioned in the *exploratory* quadrant when one remembers seeing a historic building and tries to replicate it. Finally, LEGO could also be positioned in the *open* quadrant when one is imagining a vehicle and builds it. In the LEGO example we show that it is possible to have one toolkit that addresses more than one skill level. Moving from one quadrant to another requires more imagination, skills and knowledge from the layperson; therefore we introduce the notion of learning paths to describe this phenomenon.

Moving Between Quadrants: *Learning Paths*

To become a lay designer, the consumer has to learn how to deal with increasing imagination and responsibility. This learning process should address the four competencies of mind, knowledge, skill and tool set in an integrated way (Nelson & Stolterman, 2012, p. 231). Existing digital–physical toolkits are primarily focused on the tool set. Mass customization toolkits have typically a user-friendly interface that does not require any design, modeling or programming skills, and which fits in the lower-right quadrant of Figure 9 (right). These toolkits enable unskilled access to adapt a design to one's preferences and this makes the toolkit accessible for beginners, but once one has explored the toolkit it is not possible to develop oneself further. In the two experiments presented we encountered the situation that participants wanted to go beyond the constraints of the configurational design space, which did not satisfy them.

From examining digital toolkits, we noticed that these toolkits address different skill levels. The Wordpress toolkit addresses the tool set as well as the skill, knowledge and mind set. In Figure 9 (left) a possible learning path is shown that addresses all six skill levels in the Wordpress toolkit. Becoming a lay designer is a process rather than a single isolated activity. The first level of the CMS toolkit is choosing a ready-made theme; by increasing imagination the layperson ends up at the last skill level, which is designing one's own theme from scratch. The music production toolkit (Figure 9, middle) also addresses multiple skill levels that can be captured in a learning path. One can start by following tutorials, then move to exploration and end up in the *open* quadrant and compose a song from scratch. In both cases, the imagination of the layperson is increasing as well as their responsibility. The toolkit does not guarantee a good outcome when one comes to the *open* quadrant. The price of being autonomous, being allowed to imagine a website design or songs, is that users are responsible for the outcomes themselves. This might seem trivial; however, when thinking about product design, it has serious consequences for the functioning of the design as well as for the manufacturing process.

Moving Within Quadrants: *Iteration*

The difference between a digital and a digital–physical toolkit that we extracted from the analysis as well as from the experiments is the lack of iteration in the latter toolkit. Digital toolkits allow the user to design, test and modify their design. In Wordpress, for example, when writing a blog post there is a "Preview" button that lets one preview the blog entry before publishing it. Through this functionality, users can easily prototype the code they write. With a digital–physical toolkit, due to the fact that it is concerned with a physical outcome, it becomes difficult to iterate since one has to go from digital to physical and back. The design has to go from one medium to another, whereas in digital toolkits the medium remains the same. In both experiments we noticed that the participants were dissatisfied by the lack of iteration. The toolkits allowed for "complete cycles of trial-and-error" (Von Hippel, 2001), which means that the user can manipulate the design over and over again; however, once the design is produced it is defined. This is in contrast with digital toolkits that allow for adaptation over and over again. Flexibility is mentioned as one of the seven dimensions of product personalization (Mugge, Schoormans, & Schifferstein, 2009), and is defined as the degree to which a product can be adapted repeatedly. Besides being able to adapt the product more than once and improve it, the benefit is that the perceived risk of making a wrong decision is reduced and hesitation is taken away by being able to iterate. Iteration is an important aspect of the process of any professional designer and we argue that it is likewise in the lay design process.

Continuum of Lay Designers

When the layperson engages in a design activity, whether it is adapting a pair of sneakers or configuring a kitchen, it is not about doing design, but rather about becoming a designer. Fischer has discussed the emergence of adaptive design (Fischer & Scharff, 2000) and argues for a scaling involvement of the consumer in the design process. The notion of a continuum is adopted and appropriate since the lay designer is neither a passive consumer nor a professional designer. The level of participation from adapting, making, and exploring to finally creating depends on the layperson's intention, motivation, knowledge and skills (Figure 10). Each increasing step of involvement requires more imagination and comes with more responsibility. The essential difference between a professional designer and a lay designer is that the latter is a personal designer who designs for his or her own context, whereas the industrial designer first and foremost serves others.

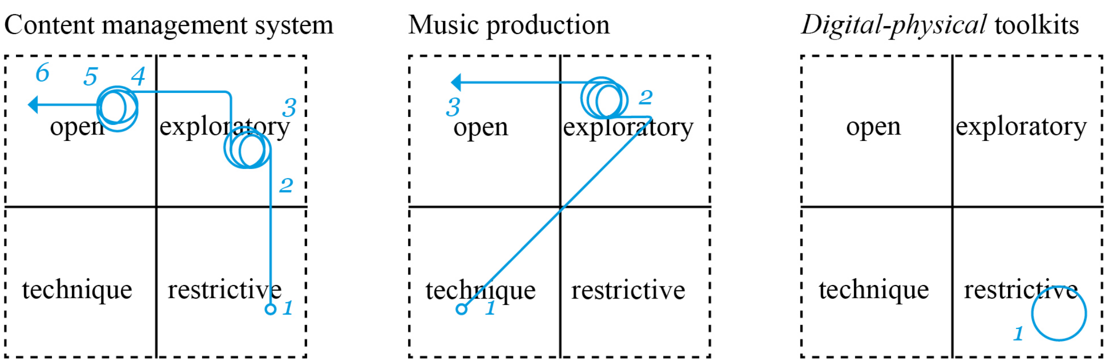

Figure 9. The lay design model with digital toolkits Wordpress (left) **and Maschine** (middle)**, and digital–physical toolkits** (right)**, and their skill levels.**

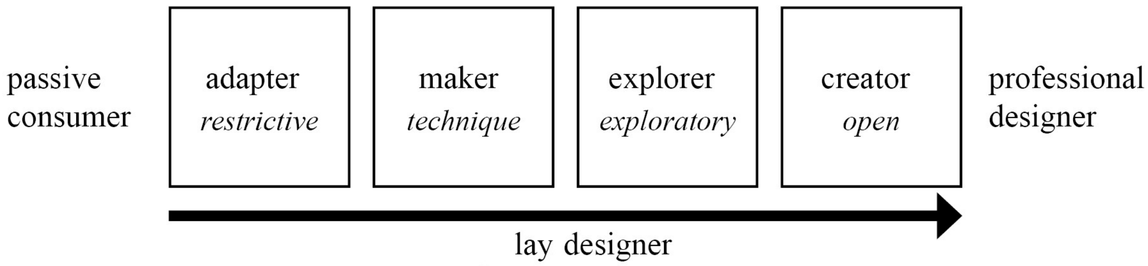

Figure 10. A continuum of lay design, from adapter, to maker, to explorer, to creator.

Discussion

Digital–physical toolkits engage the layperson in the design of everyday products. These toolkits consist of constrained design spaces within which the professional designer has almost full control over the design. Why are today's digital–physical toolkits this restrictive, such that they do not seem to benefit from the potential displayed by the lay design model? How could we engage future novice designers in imaginative design experiences in which a dynamic tradeoff is established between the authority of the designer and the autonomy of the layperson?

Digital toolkits offer a design challenge suitable for amateurs as well as professionals by addressing different motivations such as learning, engagement, competence and autonomy. Moving from the digital realm to the crossroads between digital and physical, there is a lack of toolkits that encompass this challenge. Here we will discuss three reasons that explain the unexplored possibilities of digital–physical toolkits. First of all, products are designed with the intention of them being consumed. That being so, consumer participation is often approached from a business perspective where the aim is to produce goods that meet consumers' needs and preferences in order to increase consumption. This is in contrast to addressing the intrinsic motivation of consumers as is done with toolkits in the digital realm, which are designed to facilitate a creative experience. We do not imply that digital–physical toolkits should entirely shift in this direction; what we do suggest is that digital–physical toolkits could benefit from addressing the intrinsic motivation of laypersons. Secondly, product design is focused on selling finished products that are produced in large quantities with exactly the same qualities and properties. As a result, manufacturing technologies have been focused on replicating exactly the same products in an efficient way. The third reason concerns the design intention. The majority of customizable products are designed for mass production and have been altered to make them adaptable. To enable customization of mass-produced products, a flexibility mechanism, for instance modularity, is often used. These products have been adapted to customization rather than being designed for customization.

To address the issue of engaging lay designers in imaginative design experiences, we have to return to the motivations for novices to be involved in a design activity in the first place. These motivations, including autonomy, learning and engagement, are addressed by several digital toolkits. The toolkits are open; they allow a mastery experience; they enable learning from beginner to expert level; and they are engaging as well as enabling self-identity. The user has the ability to create something unique that nobody has done before, and finally the toolkits enable sharing of the outcome with others in the community. Digital–physical toolkits have a different character and these toolkits are product-specific, which makes them inherently more closed. Mastery is usually not considered in these toolkits since they use an easy interface targeted at beginners. Engagement and self-identity are related to the amount of choice, or in other words the size of the design space. An increased freedom for the layperson increases autonomy as well as satisfaction.

The authority of the professional designer versus the autonomy of the layperson is the important tradeoff in lay design. The professional designer is not losing all control to the unskilled beginner, but rather both are performing parts of the process—parts that they are both capable of doing and willing to accept responsibility for. Control over the product is no longer solely that of the designer: "... the designer and the consumer share control over the product. Consequently, designers have to give up part of their authority..." (Mugge et al., 2009, p. 87). Unlocking the possibilities put forward in this article will have serious consequences for the way products are developed. Besides the changing role of the professional designer, many other aspects of product development will be affected. Brand identity, marketing and distribution, to name but a few aspects, will be influenced when lay people are involved in designing their own products. The unexplored possibilities that are discussed in this paper are opportunities for both designers and lay people. For designers it will bring a new perspective on how to design and how to deal with consumer needs and preferences, and a dialogue between designer and consumer will be established.

Conclusion

In this paper we have analyzed design spaces and toolkits that enable novices to create something of their own. Besides the analytical dissemination of toolkits and their design spaces, we investigated how people engage in creating a product by using a toolkit. We developed a vocabulary for the exploration of the design space and identified specific behaviors that laypersons have in those spaces. We also introduced a lay design model that deals with different types of toolkits, skill levels and learning paths. When the practice of the layperson participating in the design of everyday objects becomes commonplace, there will be an increasing need for the type of models developed in this work. Digital toolkits address different skill levels where consumers gain freedom, require more imagination and have to deal with increased responsibility. Digital–physical toolkits are narrower in scope and do not address multiple skill levels. Today's toolkits that engage consumers in design are a first step, and despite the difficulties pointed out in this paper there are huge opportunities when combining novice designers and digital fabrication technologies such as 3D printing.

For design researchers this paper opens new areas to investigate in order to increase understanding of lay design. Design research can focus on developing methods and tools that allow professional designers to design adaptable products and toolkits, taking advantage of digital fabrication technologies such as 3D printing as well as exploring meaningful adaptability in products. Design practice will shift its focus from designing static artifacts to developing unfinished designs. Designers will be more and more concerned with developing tools for lay people that allow them to appropriate such tools to their context and needs.

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