NordDesign 2016
August 10 – 12, 2016
Trondheim, Norway

Personal 3D-Printing: A Remapping of the Relationship between Product Designers, Products and Users

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Abstract

The prime motivation of this study was driven from the need to understand the full potential of the practical interactions between desktop 3D Printers (3DP) and home users. Nowadays, rapid advancements of 3D Printing Technologies (3DPT) create new unexplored opportunities and challenges. 'Like the swallow heralds the spring', the desktop Fused Deposition Modeling (FDM) and Stereolithography (SLA) 3DP, which recently started to be marketed for home use, herald new times, when users will be able to manufacture their products in their homes. This paper will refer to a context of reality in which, desktop 3DP will be integrated in home environment, and will be affordable enough, so many users will be able to afford one. In such a reality, new design values will arise and the interaction with the user will be more direct and flexible. The attempt to understand the potential was made by analyzing paradigms and methodologies from the fields of Mass-Customization (MC), user involvement, 3DPT and by reviewing the current situation. By analyzing the abilities of the 3DPT and by adding the factor of the presence of such a technology to home environment, products might be defined by 4 categories: Flexible Democratic Product (FDP) - a product that can be fully 3D printed and be customized by the user; Flexible Semi-Democratic Product (FSDP) – a product in which only certain parts of it can be 3D printed and can be customized by the user; Rigid Democratic Product (RDP) – a product that can be fully 3D printed without the ability to be customized by the user; Rigid Semi-Democratic Product (RSDP) – a product in which only certain parts of it can be 3D printed without the ability to be customized by the user. This article will discuss and present a new mapping that includes the links of the value chain according to these 4 categories.

Keywords: ***Mass Customization, User Involvement, 3D-Printing, Indie***

1 Introduction

The natural course of industries shows that there are two main phases: the initial centered-power phase and the secondary democratic phase. The transformation from the initial to the secondary phase takes usually more than a lifetime. It's a long continuous process that relies mostly on technological developments and the time that it takes the society to adopt those changes. "Transformative change happens when industries democratize, when they're ripped from the sole domain of companies, governments, and other institutions and handed over regular folks" (Anderson, 2012). This aspiration for equality can be observed along the human culture history, e.g. the Neolithic Revolution (≈8,000 BCE) that democratized food, the Printing Revolution (15th Century) that democratized knowledge and the Industrial Revolution (19th Century) that democratized all kinds of goods and products. The "democracy" sense does not represent an ownership of something by everyone, but rather the level of the affordability and accessibility of something to everyone. The present ongoing Digital Revolution, or the Information Technologies Revolution, which we are now experiencing, was evolving thanks to the inventions of the personal computer (1984) and the internet. The influence of this revolution cannot be summarized yet, however evidence show that it increased the level of democracy in many industries. Additive instruments and tools like the personal digital printer increased the level of democracy as it relates to printing, and expanded the market, contrary to the concerns of the industrialists of the printing market, which have been proven wrong. Anderson refers to the music industry, as an industry that has undergone a most significant change. Today, a musician can produce a musical composition, or a song, all by himself with a computer and with/without other complementary instruments. Once the musician decides to share the creation, it can be done immediately through designated distributive platforms e.g. YouTube, Vimeo, SoundCloud, etc. In the initial stage, the virtual audience can choose to listen, or not, to the musical composition, without any human intermediaries. The artist can gain his/her popularity purely from the common people, without any assistance from a marketing department of a records label. The relationship between the artist and the audience became more direct. Instead of reality, when the artist had to beg the records labels to take responsibility and sponsorship over him, records labels are now "begging" successful artists to sign with their label. This transformative change along with the fact that listeners can consume the artist's product selectively and freely, can demonstrate a completion of a positive democratic change. In the same year (1984), when the first personal computer was presented by Steve Jobs, the first stereolithography (SLA) 3D Printing Technology (3DPT) was presented by Chuck Hull. It took approximately 30 years until this concept became accessible and affordable for home use. Many writers and scholars refer to the invention of the 3D printer (3DP) as the mean that herald the next industrial revolution, out of the democratic move that it embodies. The Fused Deposition Modeling (FDM) and SLA 3DP, which recently started to be marketed for home use, represent the transformative change, that need to be examined, when users will be able to manufacture their products in their homes.

2 The new products market

2.1 The "Indie" market

One of the consequences of the industrial revolution was the shift of the dominancy from the craftsmen to the factories. The motorized machines, enabled production of parts in high volumes and in lower costs per unit, which lead to the birth of the mass production system. The necessity to sell many products to many consumers increased the level of democracy in the products market. The development of the marketing and distribution industries increased the accessibility aspect, and the supply of a variety of cheap products increased the level of the affordability factor. Now, for the first time, a manufacturing tool which is the home use 3DP will enable the expansion of the manufacturing process in the user's home environment. This expansion will not eliminate the factories, same as factories did not eliminate craftsmen, but it will increase the level of democracy in the products market by increasing the accessibility aspect and by reducing the costs of certain types of products, hence increasing the affordability aspect. "In an industrial economy, goods are produced in the physical space of the manufacturer. From there they are distributed, often through intermediaries, into the hands of the consumers. In the new economy, the end of the manufacturing chain of goods and services increasingly will be produced by customers, in their own physical space" (Davis, 1987). Even though Davis's statement predicted the partial shift of the market from the public physical space to the user's private physical space, it did not predict the possibility of such a manufacturing tool as the 3DP to be in the hands of the users. From the industry perspective, levels of Mass Customization (MC), like "Tailored Customization" and "Pure Customization" (Lampel & Mintzberg, 1996) will become more feasible for every user in a personal 3DP reality, and thus the level of competitive advantage factor will expand. From the perspective of both the users and the designers, the level of the user's involvement in the final design can be more significant, and thus it will increase the value of the product for each user. The opportunities that the digital revolution opened enabled the "Indie" (Independence) industries to flourish. As previously mentioned the Indie-musician produces his/her musical, and by distributing it through designated websites and social cyberspace networks, consumers can listen to it almost anytime and anywhere. A simplification of the levels of the value chain that links a product to a customer (figure 1) presents a dramatic elimination and / or reduction of the significance of certain levels, e.g. packaging, marketing, physical distribution, ordering, and other additional services (partially adopted from Da Silveira et.al., 2001).

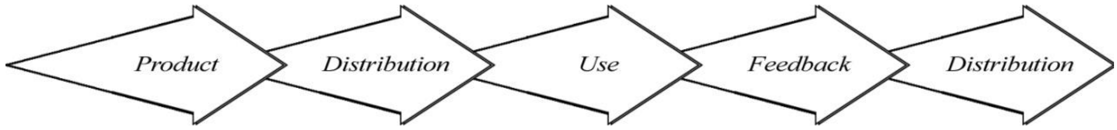

Figure 1. A simplification of the levels of the value chain that links a product to a customer in an "Indie" market.

Accordingly, a comparison (table 1) between 3 "Indie" industries: music, graphic design and the newborn "Indie" product design industry, shows a real similarity in the process that makes products more accessible to customers. As can be seen, the obvious differences are in the tools that are being used by the designer / artist as complementary means for the final production of the product, and by the complementary means that enable the product to be tangible for the user. There are other "Indie" industries that are surfing on the digital revolution waves such as the creative writing, cinematography, teaching, and more, and each one behaves generally the same, i.e. according to the process that was presented in figure 1. The elimination of the human intermediaries by the computer and the internet created an almost direct contact between the designer / artist and the customer (divided by the cyberspace only). The customer that uses the product is acting also as a potential marketer and distributor, as a result of the cyber feedback system that enables to share and spread contents by pressing of a virtual button.

Table 1 – Comparison of "Indie" music, graphics and products markets.

		Music	*Graphics*	*Products*
Designer / Artist	***Production means***	Software	Software	Software
	Complementary means	Microphone, Speakers, Headphones, Mixers, etc.	2D Digital Printer	3D Printer
	Marketer / Distributor	Designated websites, Social networks	Designated websites, Social networks	Designated websites, Social networks
User	***Consumption means***	Computer + Internet	Computer + Internet	Computer + Internet
	Complementary means	Speakers, Earphones, etc.	2D Digital Printer	3D Printer
	Marketer / Distributor	Play, Cyberspace: Share, Like, Rate, Comment, etc.	2D Print, Cyberspace: Share, Like, Rate, Comment, etc.	3D Print, Cyberspace: Share, Like, Rate, Comment, etc.

2.2 Mass Production & Mass Customization

Despite the flourishing of the "Indie" industries, it's still a branch in the products market, where the mass production system is the main trunk. The main purpose of the 3DPT is mostly by producing prototypes during the product development process, but in recent years it was starting to be used as an additive manufacturing tool in the mass production system, or as a leading technology in tailor made industries e.g. the medical implants field. There are two main reasons why companies are using 3DPT as an additive manufacturing tool. First, to produce parts with geometry that cannot be reached by using traditional technologies, or relatively expensive to produce e.g. "Boeing" company that integrated housing for a compressor inlet temperature sensor that was manufactured by Selective Laser Sintering (SLS) printer in its jet engines. Second, more consumers oriented, and more aligned with the MC approaches. The term MC that was coined by Davis in 1987 was defined as an ideal in which "the same number of customers can be reached as in mass markets of the industrial economy, and simultaneously treated individually as in the customized market of pre-industrial economies". Since that definition was stated, many scholars were trying to interpret and categorize this term, relying on the mass production system (Pine, 1993; Ross, 1996; Lampel & Mintzberg, 1996; Pine & Gilmore, 1999; Duray et al., 2000; Piller, 2000; Da Silveira et al., 2001; MacCarthy et al., 2003; Hu, 2013; Kull, 2015). Pine refers to the term MC, as an operation that gives advantage in a competitive market. "While the practitioners of Mass Production share the common goal of developing, producing, marketing, and delivering goods and services at price low enough that nearly everyone can afford them, practitioners of Mass Customization share the goal of developing, producing, marketing, and delivering affordable goods and services with enough variety and customization that nearly everyone find exactly what they want" (pine II, 1993). Because of the reason that mass production systems are relying mostly on molds, the most challenging thing is to flex the manufacturing system. Therefore, the most common customization act that is offered to customers is an offering of a variety of the same solution in different scales, colors and cosmetic graphics. A reality in which 3DP will be integrated in home environment, and will be more significantly integrated in factories as an additive manufacturing tool, might overcome this challenge, and will enable to fulfill Davis's and Pine's ideals. The American jewelry studio **Nervous System** (n-e-r-v-o-u-s.com) recently launched a website which offers a variety of on-demand jewelry designs. The studio presents few flexible / open architecture jewelries that enable the user / customer to be involved in the determination of the final design. A dynamic platform enables customization in three levels. 1. The design of the shape (under considered conditions); 2. Physical customization, according to the physical dimensions of the user; 3. Personal customization, according to the personal taste of the user (color and type of material). Once the customer places the order, the studio is 3D printing the required design and delivering it to the customer. This kind of website can clearly demonstrate the advantage of the computer-internet-3D printer potential, and its ability to deliver a pure customized product. A simplification of the described interactive process (Figure 2) demonstrates a mass personalized production system that combined from "Open Architecture Products, Personalization Design, On-demand Manufacturing System and a Cyber-Physical System" (Hu, 2013). The "Open Architecture Products" is represented by the "Meta Design" link which presents a general design, ready to be customized by the customer. The "Personalization Design" is represented by the "User Involvement" and the "Definitive Design" links, by the ability of the system to enable adjustments and customization according to the customer personal taste. The "On-demand Manufacturing System" is represented by the "Manufacturing" link (based on 3DPT) which enables production of the required design without any special preparations, beside the need to generate a suitable file for 3DP. The "Cyber-physical System" is represented by the "Dynamic Platform" and the "Order" links which enable implementation of the whole process.

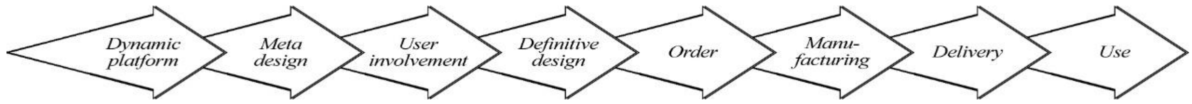

Figure 2. A simplification of a fully 3D printable "Industrial Personalized Design and Manufacturing System" process.

The only link that remained unassociated is the "Delivery" link. A situation in which products are offered to customers through a similar interactive system, but the manufacturing process will be held by the customer (using a personal 3DP) can eliminate the necessity of the delivery stage (Figure 3). The process's inner changes will occur in the "Order" and the "Manufacturing" processes, by the need to get a suitable 3DP file from the "Design Source", and by the fact the customer is manufacturing the products by himself. In such a case, the value chain can be implemented as a whole in the customers' home environment, and thus implement Davis's and Pine's ideals. Such a process can truly represent a fully democratic product.

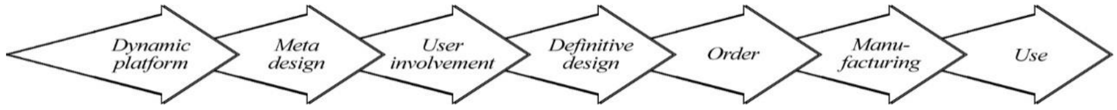

Figure 3. A simplification of a fully 3D printable "Personalized Design and Manufacturing System" process.

Another American company calls **normal** (newnrml.com) used to offer through an interactive app customized earphones. The company decodes the shape of the external space of each user, and 3D prints the intermedia part so the earphones will fit exactly to each user's ear shape. The rest of the product is assembled mostly from standard parts, and there is a fusion between 3D printed and mass produces parts. Unlike a standalone jewelry that can be 3D printed as whole, without any need of a complementary part to complete the assembly of the product, the earphones depend on complementary unprintable electronic components, and other parts. A simplification of the described process (Figure 4) shows that the dependency on complementary parts and components prevents from the product to be 3D printed by a personal 3DP in a case when the user owns one. Another difference is in the level of the involvement of the user. While in the previous case, the user was involved in the design and thus become kind of a designer, in this case, the user is only suppling required information (imaging of the shape of the ear) while the rest of the process is being managed and done by the company.

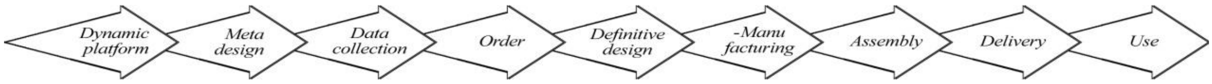

Figure 4. A simplification of a partially 3D printable "Industrial Personalized Design and Manufacturing" process.

In such a case, when a product depends on unprintable parts or components, even an existence of a personal 3DP will not create a fully democratic move. As can be seen in Figure 5, in case of an existence of a personal 3DP and a suitable interactive cyber system for such a product, the changes in the process occur in the replacement of the "Definitive Design" and the "Order" stages. The "Order" stage, with relevancy to this discussion, represents the need to get a 3DP suitable file. The "Delivery" stage becomes more fluid and it represent the need to get complementary parts / components in order to assemble the final product and then use it.

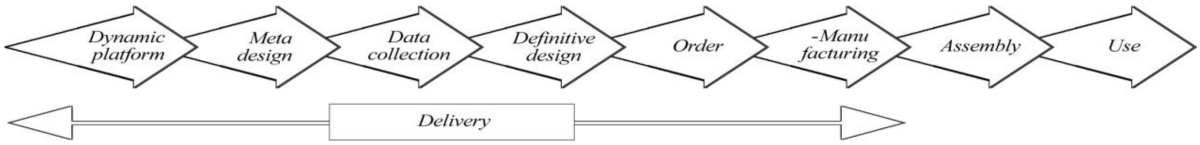

Figure 5. A simplification of a partially 3D printable "Personalized Design and Manufacturing" process.

Duray et.al (2000) suggest a taxonomy of types of users, according to four stages (Design, Fabrication, Assembly, Use), and the point where the customer is being involved. According to the personal 3DP described reality, in a case of a fully 3D printable product the user can play simultaneously all the roles (Fabricator, Involver, Modularizer and Assembler), and thus cover all the MC approaches at once. In a case when a product is dependent on complementary parts / components, the user can act as an involver and as assembler (despite the fact of the existence of a personal 3DP).

2.3 A futuristic scenario

The reviewed cases reflect the current possibilities that were mostly influenced by the abilities and the limitations of the existing 3DPT. Even if most of the limitations which were described in previous researches (Berman, 2012; Weller et.al, 2015) will be solved, the designer will have to take in consideration one external aspect that determines whether the product is 3D printable or not. This aspect is the size of the personal 3DP which influences directly on the size of the parts, and thus the designer will have to set a decision for which minimum size of a 3DP the product fits (relates to the volume). For a one-part product this decision can be easily made, but in a case of a multi parts product that need to be assembled, an understanding of fact that the biggest part will determine the minimal 3DP size that is required for the ability to fully produce the part by the user. In a case when a product is fully, or partially 3D printable, a generic dynamic physical-cyber platform such as Nervous System platform will be needed if the offered design is flexible architecturally for customization by the user. Such a platform will also have to include a feature that prevents engineering failures in the product while the customer is doing manipulations on the design. In a case of a rigid architecture of the design such a platform will not be required. Once the customer will find, or design exactly what he / she wants, the following steps will include an order (downloading a suitable file), manufacture (using the personal 3DP), assembly (in a case of a multi parts product) and use. Dependency on non-3D-printable components e.g. batteries, processors etc. will require the user to get / purchase those complementary parts in order to complete the assembly of the product. As can be studied from the 2D digital printing market, there is a certain maximum size of printers that fit to home environment. Not likely that people will own a size of a 3DP that enables to print a car, but there is a possibility that people will own a kind of a 3DP that will enable to print complementary personalized and customized parts e.g. the steering wheel, buttons, handles, etc. A simplification of a possible process in such a futuristic scenario (Figure 6) describes a process of fusing Nervous System and Normal systems, but in consideration of a reality with more sophisticated 3D printers, that can produce multi-material parts, with better properties, surface finish and with the ability to produce colored parts.

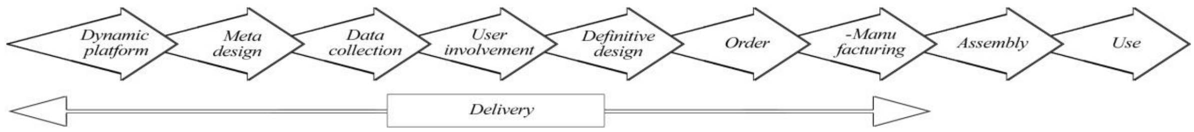

Figure 6. A simplification of a partially 3D printable "Personalized Design and Manufacturing" potential futuristic process.

3 Product Designer – Product – User

3.1 Character of products

Out of understanding of the potential possibilities in an era in which personal 3D printers will be widely integrated in home environment, two main factors will define the character of the products: 1) Whether the architecture of the design is open or closed for customization by the user 2) Whether the product is fully or partially 3D printable. A taxonomy matrix (Figure 7) shows that by combining those factors, four characters of products may exist: a) Flexible Democratic Product (FDP): similarly to Nervous System case; b) Flexible Semi Democratic Product (FSDP): similarly to Normal case; c) Rigid Democratic Product (RDP): close architecture 3D printable product, like widely offered today by companies and "Indie" designers in designated websites and cyberspace social networks; d) Rigid Semi Democratic Product (RSDP): can be less found today relates to products, but widely in use by product designers and mechanical engineers for prototypes. The flexibility and the rigidity of the product relates to the type of the architecture of the product, and its ability to enable customization by the user. The democratic aspect relates to the dependency of the user on intermediaries which comes down to the dependency on a complementary part / component.

		Product dependency On complementary parts / components	
		Dependent	**Independent**
User involvement in the product design	**Involved**	Flexible Semi Democratic Product	Flexible Democratic Product
	Uninvolved	Rigid Semi Democratic Product	Rigid Democratic Product

Figure 7. Personal 3D-Printer: Character of products matrix

3.2 Product Designer-User Relationship Mapping

The involved factors that assemble the continuous interactive process between to the product designer and the user, and the four characters of products that were classified and presented in Figure 7, formulates a matrix map (Figure 8). The map relates to a situation in which the user owns a 3DP and can fully or partially 3D prints the desired product. In a case when a product is 3D printable, but the user owns a kind of a 3DP that cannot produce the parts because of not having the proper raw material, or the volume of the 3DP is too small, then this kind of case will be classified under the semi-democratic products columns, depending on the type of the customization factor. A flexible design that enables customization through an interactive physical-cyber platform, but the user cannot 3D print it using his/hers 3DP will be characterize as a FSDP, while a rigid one that cannot be manipulated will be characterize as a RSDP. The factors that assemble the value chain relate to the flexibility / rigidity of the design architecture and thus to the ability to do manipulations in the design in favor of the customization act, the type of the intermediary platform, the ownership transfer phase (order & delivery), and the common independent phases that supposed to be made by the user only. In reference to the factors that assemble the value chain, the design architecture that can be open or closed should be implemented under many considerations. In a case of a closed architecture, then following design methodologies of MC for mass production systems can be much useful. In a case of an open architecture product, those methodologies can assist to form the Meta design, but there are missing methodologies that direct designers how to design such a product. According to an ongoing research that will be presented in the future, a methodology for an open product design will be offered, and it will refer to three sub-factors: 1) Modularization – the ability to customize the functional shape; 2) Customization – the ability to customize the product according to the user's dimensions and physical data; 3) Personalization – the ability to enable customization according to the personal taste of the user e.g. colors, graphics and textures. The intermediary platform of the flexible products, which can be Nervous System alike, with more consideration regarding to the types of personal 3DP, should support the design by preventing conflicts between factors and by preventing engineering failure in the product. The ownership transfer phase should embody in it a business plan which needs to be competitive relatively to mass produced products, and should embody profit for the designer / studio / company etc. Completion of the ownership transfer phase, transfer the process to the independent phase where the user has to complete the manufacturing and the assembly (if necessary) by him/her self. In some cases, additional services from the designer might be needed, e.g. supplying manuals for an assembly of complicated products, enabling access to spare parts files, user manual etc. The feedback phase which obviously can enable the users to comment and rate the process and the product can also be useful for data collection in order to improve them. It can act also as a platform that enables further distribution of the product, by the users.

	Flexible Democratic Product	***Flexible Semi-Democratic Product***	***Rigid Democratic Product***	***Rigid Semi-Democratic Product***
Design architecture	*Open*	*Open*	*Close*	*Close*
Platform	*Interactive Physical-Cyber System*	*Interactive Physical-Cyber System*	*Website*	*Website*
Type of customization	*Pure*	*Pure*	*Standard*	*Standard*
Definitive design	*Determined by the user*	*Determined by the user*	*Choosing from a variety of options*	*Choosing from a variety of options*
Order	*3DP file*	*3DP file + Coplementary Part / component*	*3DP file*	*3DP file + Coplementary Part / component*
Delivery	—	*Coplementary Part / component*	—	*Coplementary Part / component*
	3D Printing			
	Assembly			
	Use			
	Feedback			

Figure 8. A mapping of relevant factors according to character of products

4 Summary

The current FDM and SLA 3DP that recently started to be marketed for home use embody new conceptual and practical opportunities. Even though this personal 3DP market is not mature enough to lead, it can start a psychological move that will ease the adoption of this technology by the common people and by certain industries. The reviewed subjects can be already implemented by using FDM and SLA 3DP as long as the design of the relevant products will take in consideration the suitable polymeric raw material. Once this market will be mature enough, and multi materials 3DP will be available and affordable for home use, along with the willingness of consumers to adopt the technology, a new industrial revolution will arise and create a transformative change. One of the many results of a reality in which users will own a personal 3DP will be the redefinition of the term mass production. It will include the traditional definition that describes the ability to produce high volume parts in short time, and additionally by the number of parts that were 3D printed by users, using theirs personal 3DP.

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