Design Revolution in 3D Printing Processes

Pia Tamminen*, Jarkko Moilanen**

** Aalto University, Finland; pia.tamminen@aalto.fi*
*** University of Tampere, Finland; jarkko.moilanen@uta.fi*

Abstract: Purpose of this case study is to describe the evolution of design processes in 3D printing area, and compare similarities and differences in the ways of working between companies and 3D printing community. The study sheds light to the evolving process phases, the role of designers and customer involvement in the process. This is an inductive case study. Mainly qualitative research methods are used to gather and analyze the data. The study identifies three different design process modes in open design area. The results indicate that companies cannot ignore the development in the open communities because the new ways of working can bring additional benefits to the business. It seems that company driven design and customer driven open design are coming closer to each other in technology and design process perspectives. The study focuses on the fuzzy design area between companies and 3D printing community, which has not been researched much yet.

Key words: 3D printing, design, open community, peer production

1. Introduction

3D printing has created new ways to design, and this case study sheds light to the design processes as well as customer involvement and the role of the designers in the processes. The study focuses on the fuzzy design area between companies using 3D printing technology and 3D printing community, so the area combines semi-closed design processes of companies and open design processes.

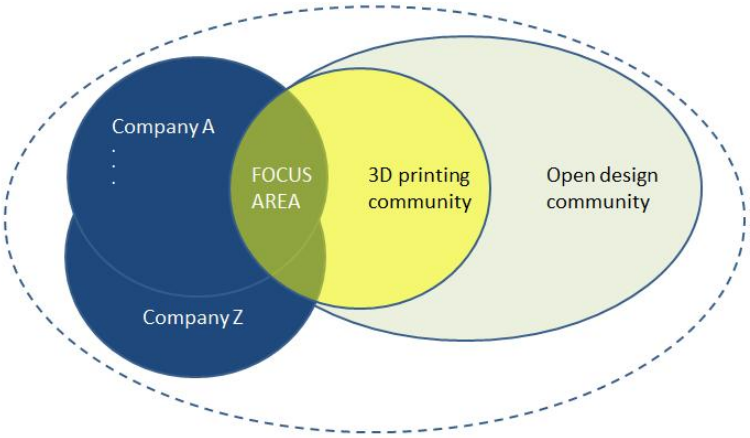

Figure 1. The focus of this study is on the common area between companies and 3D printing community.

3D printing has intrigued a growing group of theorists because it can be seen as one of the most promising phenomena of the predicted and emerging "revolution in manufacturing". Economists and theorists of innovation such as Jeremy Rifkin [29], Yochai Benkler [5], and Michel Bauwens [1, 2] have concluded that the Third Industrial Revolution is at hand. Peer production based 3D printing enables activities which can be labeled as ‘prosumerism’ defined by Alvin Toffler [31]. Prosumer is normally seen as a combination of professional and

consumer, but in this context producing consumer is more accurate since it refers to manufacturing enabled by 3D printing.

Victor Papanek claimed already in the beginning of 1970s that all men are designers, for design is basic for all human activity [23]. Design and design processes could be compared to early days of computing. Conventionally design is done in cathedrals; designers use expensive devices and software, and all design and knowledge is kept hidden from the public. Lately design has moved from cathedrals to bazaars. In bazaar model design is open (cathedral - bazaar analogy taken from Eric Raymond [25]), 3D models are shared publicly and derived work is a normal activity. Design activities have become possible for all. At the same time production of artifacts has changed. Although 3D printing has been around for over 30 years, acceleration in the development of features and usability of the software programs and applications started in 2007 [28]. The development has enabled evolution of new type of design processes, new business models and a new design community which is populated by new design generation people. Purpose of this case study is to describe the evolution of design processes through data collection of ways of working in jewelry companies and in a global 3D printing community. Aim of the article is twofold; we want to understand to what extent the traditional design processes describe the way of working in open design area. We also want to know, how the involvement of a customer has evolved in design processes. The goal of the study is to describe design processes within open design area, and link them with design processes of companies within 3D printing area.

2. Theoretical Approaches

2.1 Design Theories

Some research has been done in the area of product design in 3D printing [12], but they mainly focus on prototyping in the early phases of the product development or different technologies [8]. For the sake of clarity, the words “producing consumer”, “end-user” and “user” are grouped under one term, customer. In this paper, “peer” is understood as autonomous agent, an individual participating in a peer-to-peer network [1].

There are many perspectives to review and study product design processes and design theories. One of the most popular approaches is to focus on the *user-centered design* [22] where the aim is to understand the core needs of a user and convert them into an appropriate design of a product or a service *for* the customer. User-centered design can also be described as market oriented approach from a company perspective. The second approach focuses on *contextual design* [6] where the situational factors are taken into account in the product design. The third approach is more inclined towards service design, and it focuses on *experience design* [24] where the aim is to create an experience e.g. an emotional one, for the user through a certain type of design. Empathic design could be seen as being part of the experience design, since it tries to understand user experiences in the early phases of the design process [17]. The fourth approach is *participatory design* where the focus is on people participating in the design process as co-designers. Participatory design, also called cooperative design, has its roots in research of democracy forms [10] and in the 1970’s Scandinavia. It can be seen as a way to involve users in the design already in the designing phase of an artifact [26, 27]. It empowers people; those who are affected by design should also have the possibility to influence it. Participatory design joints the decision-making and work practices of users and designers, so the artifact is designed *with* the customer. The fifth approach is the *co-design*, which is built on a mindset of collaboration. Co-design is a process that has its origin in user-centered and emphatic design

approaches. Co-creation activities take place within co-design process focusing on the collective creativity of involved users and stakeholders [14, 30]. Co-design is about openness, collaboration and partnership with the customer. Designers' role is to facilitate creative processes among users who create the finished solution. The sixth and newest design theory is *open design* which can be seen as a continuation of the participatory design. However, the users produce the objects themselves [7], so the artifact design is done *by* the customer.

2.2 Design Processes

There are several different theoretical frameworks for design processes within the science of design [9, 12, 15, 17]. This study focuses on design processes with emphasis on the artifact design although there is a fine line between it and an engineering design. A design process of an artifact starts with an identification of a problem and ends with a ready product or a service. The design problem includes usually a goal, constraints and criteria by which the solution will be recognized [9]. In the beginning of the process, the designer does not necessarily know what the solution will be like. In the same spirit, customers might understand what they want after seeing the finished artifact.

The theoretical models of the processes are similar; the process includes from three to four phases: inspiration, ideation and implementation, and there can be many iteration rounds between the phases. The fourth phase is communication of the ready-for-manufacture-design. Furthermore, the process is divided into three broad phases: analytical, creative and executive. Interactions with the world outside of the design process are taken into account [9]. March developed a philosophical design model in 1984 [9, 15] based on philosophical thinking of Charles Sanders Peirce. Analytical and creative thinking are applied to evaluate and analyze design in the model. The act of synthesis, i.e. combining things together to create something new, is central. The hypothesizing of what may be as in abductive thinking is the third way of thinking in March's model. Design thinking is a concept that combines analytical thinking with intuitive i.e. creative thinking [16].

2.3 Design in 3D Printing Community

According to Beek [4], open design is disruptive and embodies a paradigm shift in which design object in itself has no fixed identity, instead it is something which is an ongoing process, and the fixed identity of the consumer has changed to 'prosumer'. Therefore design in an open design process is found 'in-between', in the space between individuals. It is different from traditional design thinking where object and subject are clearly separated. Since 3D printing is also seen as disruptive, the combination of open design and 3D printing can be said to be double-disruptive; containing disruption in both design process and manufacturing.

Massimo Menichinelli [18], one of the long term open design researchers, has added a term peer-to-peer (P2P) into open design. Menichinelli uses the term open P2P design to stress the need to co-create a community that collaborates as a common activity. In other words, Menichinelli has added the aspects of with and for the community to open design, which can embody an act of designing, developing and managing participatory public services, creating businesses based on communities or managing interactions between business and communities. A preliminary model for "open/commons design economy" is under work [19, 20] with four interlinked layers in the model: individuals, tool/design layer, community and sharing platforms, and manufacturing/production.

3. Research Methods

This is an inductive case study and mainly qualitative methods are used to gather and analyze the data. The process of the study is illustrated in figure 2 below.

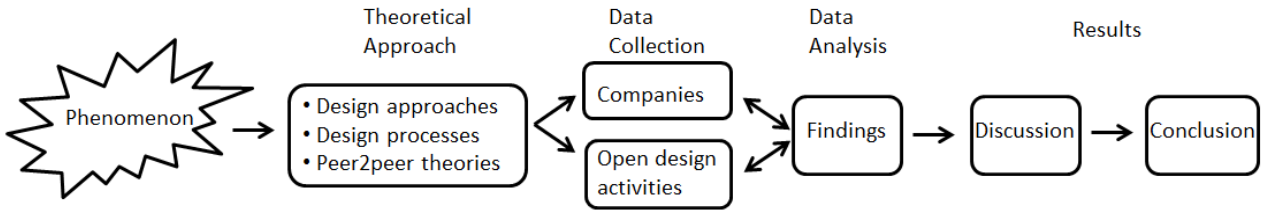

Figure 2. A simplified process flow of the methods used in the case study.

The first step was the identification and definition of the phenomenon described in the Introduction chapter of this conference paper. The second step was to study scientific theories related to design and peer to peer theories. The first research question related to the discontinuity between design processes and open design approach was developed. The third step was the data collection, which was divided into two separate paths; companies and 3D printing community.

Two Finnish jewelry companies were selected as polar cases; Kalevala Koru and Saarikorpi Design. Personnel working with design processes and 3D printing technology were interviewed. The interviews were recorded and the recordings were written down word by word. Observations were also done in the R&D and production areas of the companies. Descriptions of the design processes presented in this study have been verified by the interviewees.

Data collection within 3D printing community started with a pilot email survey. Piloting was done to verify the relevance of the questions. Feedback of the pilot indicated that the community members did not understand the questions or the aim of the survey so the format of the email survey was changed. The community members were asked to draw their design process. The final survey was sent to the people participating in an open design contest. Two polar cases, business and community oriented, emerged from the data. Interviews of other designers were continued until saturation point was found. Eight semi-structured interviews were conducted in total. Some of the interviewees provided sketches of their design process while others answered only briefly to the stated questions. Two interviews were conducted via Skype chat, one as Skype call, and the others were email interviews.

The fourth step was analysis of the data. While diving deeper into the data, the second research question related to the customer involvement in the process emerged. All the data was first analyzed within own paths and after that across the paths. The fifth step was drawing of the conclusions based on the findings, and pointing out topics that might provoke questions about the chosen research set up. Furthermore, creation of propositions in open design area revealed questions that need further research.

4. Design Processes in Practice

The main locus of this study is to describe different design processes when 3D printing technology is involved in the overall artifact design process. Diversity in ways of working, available services and variety of users makes the available data rich and compelling.

4.1 Product design process in 3D printing design community

Two cases within 3D printing community were selected to be studied in more detailed level because they represent opposite modes: one was business oriented and the other one community oriented. Sharing is one of the key values in open design community, thus sharing platforms are a fundamental element of the process. In this

paper sharing platforms such as Thingiverse.com, Github.com, Ponoko.com, i.Materialise.com, Shapeways.com and Cubehero.com are understood similar to Bauwens: "*Corporate platforms create the possibility for users to share their own creative work, or what they have found, but no common code or knowledge base is created. The platforms are owned by corporations, and the attention and behavioral data are sold to advertisers. Regulations over these platforms are established by the corporate owners." [3]*

4.1.1 There is an opportunity to do business

The interviewee had master's degree in architecture. He had been involved in 3D printing since 1999, and was business oriented. He mentioned that working alone is unusual because "*there's a team to work with*". Interviewee did not "*like the idea of having a fixed process for design*", but trusted in intuition and "*my experience and ability to learn new stuff*". His design approach could be described as a romantic "*feeling the way*" approach or trial and error approach. Yet interviewee was able to identify four stages in his design process (figure 3).

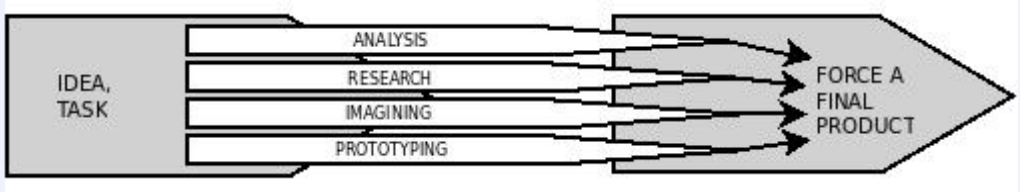

Figure 3. Design process of an open design community member. Source: interview with a designer.

The identified stages were: analysis, research, imagining and prototyping. Analysis is about identifying a problem to be solved. Research phase is about finding and selecting appropriate sources of information. Imagining phase is about interaction between others. He expressed it as "*talking, questioning, thinking, sketching, dreaming, modeling, …*" Prototyping is a trial and error process or "*[e]volution-like process of testing ideas; often a part of a design, sometimes the whole. Sometimes physical, sometimes simulated."* All the above phases run in parallel and when time, money or other resource run out, all the processes are gradually freezed. Interviewee labels this activity as "*force a 'final product'*". The interviewee emphasized that "*these are not successive stages but activities running parallel; it's about balancing attention between them along the way*".

4.1.2 It is All about Sharing

The interviewee was a designer focused on hardware development of an open source driven RepRap 3D printer [32]. The designer started the work since it was "*an interesting hobby, then finally modded the machine and finally designed a new one"*. The figure 4 describes his design process.

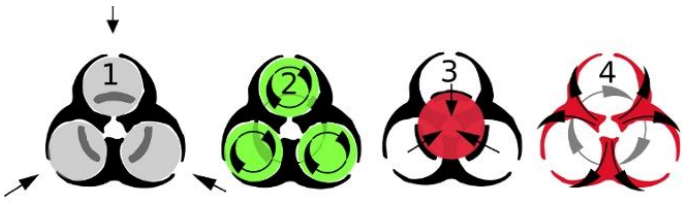

Figure 4. Design process of one Open Design community member. Source: interview with a designer. The interviewee provided the drawing.

The four 'cycles' are not separate chronological phases, but "*can repeat over and over or the four phase simultaneously*" and "*each small circle is at a different stage*". The process description reflects also the ideology and values of the designer; he sees "*design as a 'good viru' to spread change*", and therefore uses biohazard symbol as theme behind all thinking. The first (1) cycle "filling" is a process in which the designer collects ideas

and "*start by diving into a subject, learning more and more about it (or filling the tank in that analogy)*". The ideation phase can be part a co-creation process: *"Today I'd say that these ideas/concepts can be enriched by other people's view*", but the work is mostly done alone. Publishing results, e.g. sketches in the early phase allows others to join if they find it interesting. In the second (2) cycle designer "*tritture*" ideas and thoughts: *"[...] you start to mix the things that inspire you with your own ingredients*." In the third (3) cycle "*extracting*" excess is removed and "meme" is formed which "*describe[s] ... minimum component that compose a concept*". In the fourth (4) cycle the results are "shown" to gain e.g. more contributions and share knowledge of ongoing projects. The process is never-ending; it is "*always in evolution, but we have to make an iteration like a picture of a state of it sometimes*". Open source designers use similar methodology as in software development without knowing it until getting familiar with it, or as an interviewee put it "*later when I discovered agile methods they allowed me to put words on what I was trying to do*"

4.1.3 Open Design in 3D Printing Community

A preliminary open design process model was constructed based on the results of the interviews. Designers identified phases but stressed that they are not sequential but intertwined and parallel. Due to limitations of 2D images and for the sake of clarity, preliminary process model has been drawn to include distinct phases (figure 5). In the process model inner yellow ring is the core design process and the outer elements represent additional community-driven activities.

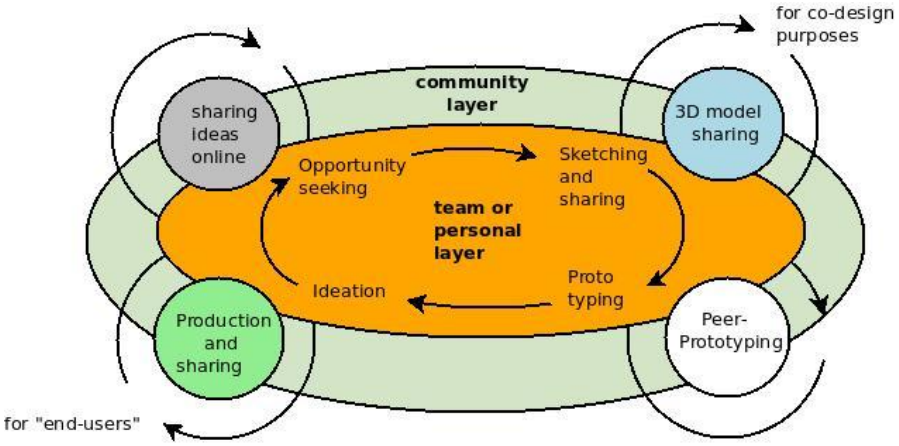

Figure 5. Preliminary process model of open design.

Ideation Phase

The sources of ideas can be categorized to three: 'scratch an itch', 'think outside the box' and derived work. 'Scratch an itch' refers to a personal need that does not have a solution developed by someone else [29]. Motivation to create an idea can be two-folded as an interviewee put it: "*I design for customers and for myself. But mostly the products I designed [...] I first designed it because I wanted to have it."* Willingness to think outside of the box enables innovation. An interviewee described the way of thinking as "*I look at everything as a possible brick that could be used in something else"*. One aspect of finding new ideas and solutions is ability to "*synthesize all the good ideas I [sic] seen in things around*". This refers to thinking in which "*we never start from scratch as we are inspired by all the thing we see*". Derived work refers to the use previous inventions and models; the designer begins with existing items and redesigns them. The need for modification might be personal, 'scratch an itch', or the designer wants to make the solution slightly different and more efficient. In the latter the

results are more often contributed back to community. "*You find many things that could fit, but not exactly the way you want, I import the .stl in sketch up and work beside it to make my version.*"

Opportunity Seeking

When the initial idea and goal of the design are clear, designers can have discussions about the topic with each other. An interviewee described the phase as "*filling the tank*". Reflections can take place in online asynchronous discussions in e.g. IRC channels or other technology related peer communities. While "*the IRC is the petri dish where you can observe the bleeding edge of the development*", it is also a place where design related issues, ideas, points of view, implementation techniques and development tools are discussed.

Sketching and sharing of working designs

Being an active member in an open design community requires that sketches, digital 3D models and related items are exposed to the community. There are several sharing platforms, and designers' have personal preferences: "*[...] with the GUI for windows it's easier to update the models, the thingiverse thing is more a link to the repo*".

Prototyping

Once the design has been created as a digital 3D model, it needs to be produced. A designer has at least four options to get an object printed out. 1) Designer can have an own low-cost 3D printer, and she can 3D print the object. 2) Designer can use a local DIY community if there is a 3D printer. This is natural evolution since open design community, 3D printing and local hackerspaces have a common history; the development of low-cost 3D printers started in hackerspaces. 3) Designer can use 3D printing services. Although the prices of 3D printing services are not high and there are many material options, it is still the most expensive option. The timespan between order and delivery can be weeks, while 3D printing in local DIY community can be done much faster. 4) Many members of the open design community can 3D print an object and even test it. This is labeled as a peer-prototyping.

4.2 Product Design Processes in Companies

Private companies have specified design processes and related roles and responsibilities with strict timetables. Costs, quality, customers and stakeholders are involved in the design processes either implicitly or explicitly. Designer's challenge is two-fold and both tracks need to be developed side-by-side; understand the problem and find the solution.

4.2.1 Focus in Mass Production

Kalevala Koru launches about 100 new models of jewelry into the markets each year, and 3D printing technology is used in the product development phase in 90 % of them. Mass production dictates the design of the artifacts; the design has to be manufacturable according to the requirements and conditions set by different production stages. Product development is a continuous process, as one of the interviewees stated: "*We try to develop the process and we do not believe that we are ever going to be in a state that everything is perfect, that would be a worrying point. We aim to look at it from left and right, and from up and down…*" Kalevala Koru uses investment casting process which is commonly used in jewelry industry. The company uses 3D printing technology in the beginning of the production to manufacture wax casts.

There are two distinctively different jewelry brands, Kalevala Koru and Lapponia Jewelry, within Kalevala Koru. The design process of Kalevala Koru is described in figure 6. The process starts with a brief of a certain task

or a theme. The form and content of the brief varies, and it can come from e.g. a customer, management of the company or designer herself. In the ideation phase the designer gathers information about the task, and tries to understand the context in which the jewelry will be worn as well as the preferences and needs of the end-user. The designer uses both analytical and creative thinking in the ideation phase; data gathering is analytical, and the activity of combining the data in a new way to create a design that is functional, esthetic and ergonomic, is creative. Abductive thinking takes place in the ideation and sketching phase. The designer creates the first visuals of the artifact in the sketching phase, and the discussions with goldsmiths, product development team and production start. A goldsmith specialized in 3D printing technology creates a 3D figure of the artifact and once the features and dimensions of it are ready and accepted by the designer, a wax cast is 3D printed. There can be numerous iteration rounds in the process, and the image of the artifact can change along the way.

Knowledge, skills and experience are needed when creating a design that can mass produced. 3D technology decreases the product development time six months. 3D printed model of the design enables a more efficient dialogue between the designer, product development team, production teams and the company management, too.

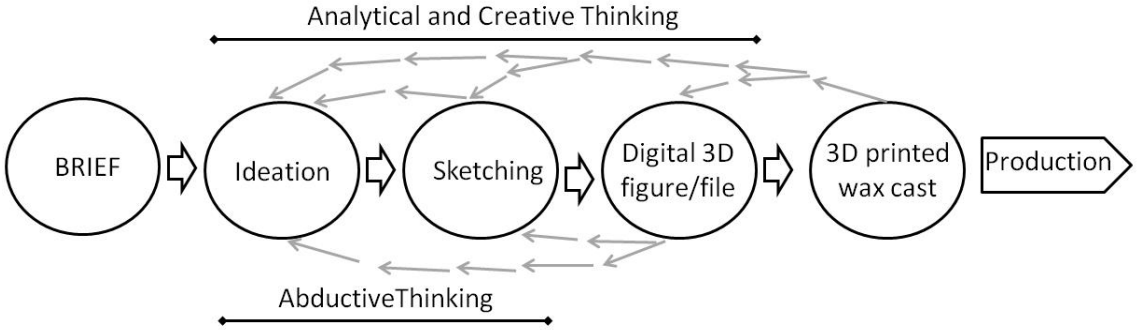

Figure 6. Design process of an artifact in Kalevala Koru collection.

Collections of Lapponia Jewelry focus on the high-end jewelry, and the designs are created by internal or internationally well-known designers. Brief and ideation phases can be similar to the ones used in Kalevala Koru collection. However, the famous designers have a privilege to create prototypes the way they want so the design process can vary depending on the designers' preferences (figure 7). If a designer creates a prototype manually, a digital picture of it is taken with a 3D scanning machine. The scanning enables a fast configuration of the design into a format suitable for 3D printing.

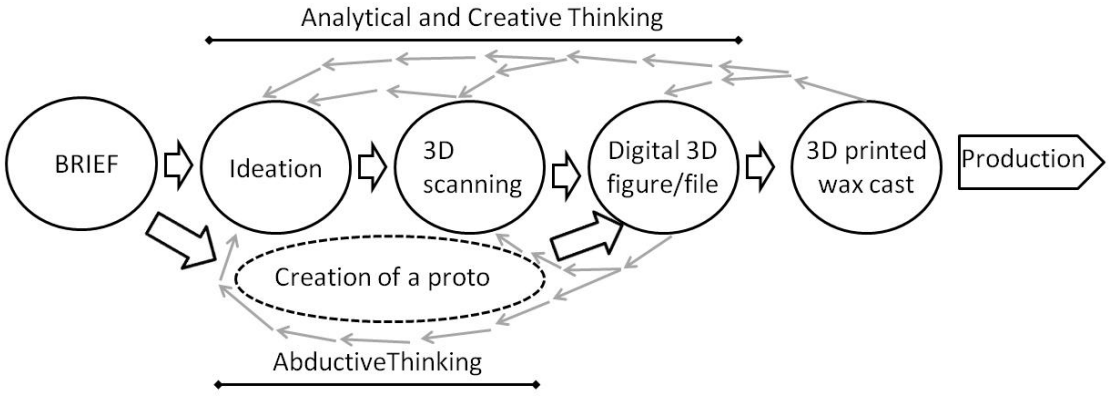

Figure 7. Design process of an artifact in Lapponia Jewelry collection.

4.2.2 Focus on finding a solution for a problem

Saarikorpi Design designs tailor made pieces of jewelry to customers according to their needs and wishes. "*I solve customers' problems*" stated Mr. Saarikorpi, the master goldsmith and designer of the company. Saarikorpi Design uses milling machines and 3D printing technology to manufacture the artifacts. 3D printing is used to print out 3D wax casts, which are sent to another company to make the metal castings. Casted pieces of jewelry are sent back to Saarikorpi Design for further manufacturing, e.g. polishing and adding of precious stones.

The design process has three main phases (figure 8): ideation, creation of a digital 3D figure and 3D print of an object. The ideation phase starts when the customer tells about her needs to the designer. The designer uses computer to sketch and design of the artifact. There might be a need for several iteration rounds before both the customer and the designer are satisfied with the design. The designer uses analytical and creative approaches when working with the design; analytical thinking enables use of 3D software programs and taking into account manufacturing criteria and conditions that 3D printer and the casting phase set. Creative thinking with a twist of abductive thinking enables the actual creation of unique pieces of jewelry. The designer describes the process in the following way: *"… You should trust strongly in what you do, and make independent solutions… and make them based on your own intuition...not let too many things influence. You have to of course follow the trends somehow to be able to know what is happening in the world but…"* Once a piece of jewelry looks good in the computer screen and the technical details of it are suitable for a 3D printer, the artifact is printed out as a physical three dimensional wax cast.

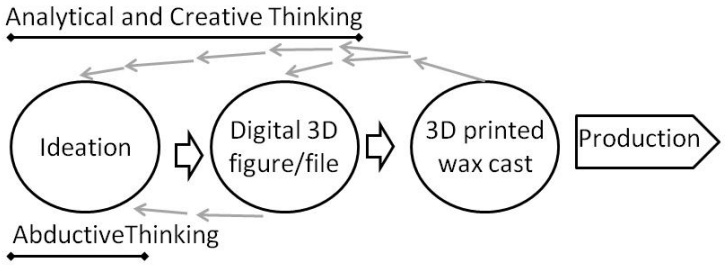

Figure 8. Design process of an artifact in Saarikorpi Design.

4.2.3 Design process and the role of a designer

Archer's and March's design processes [9] include both analytical and creative phases, which could be identified in the cases. One of the interviewees described how abductive thinking happens during the design process: "*Sometimes things just turn out to go that way, you just do it and it is good, and sometimes you redo it 10 or 20 times. But you still have a feeling of whether it was any good but it turns out that the sales of it is going well and that is a good thing. But...don't know, on the other hand, if you like something and you yourself are happy with it at some level, so how many billions of people are there… so somebody else likes it too."*

All design processes emphasize the importance of communication to support the manufacturing of the designed artifacts, but experience and knowledge of 3D technology play a vital role, too. Role of a designer is undisputable; designer seeks opportunities and leads within big data, trends and consumer behavior in the market, and connects the ideas in an unconventional way to create a functional and beautiful artifact. Both companies can make customizations to the products; Kalevala Koru makes corporate gifts to other companies based on the given specifications of the customer company and Saarikorpi Design creates artifacts based on customers' requirements.

4.3 Customer involvement in product design processes

Kalevala Koru applies user-centered and Saarikorpi Design participatory design approaches (figure 9). 3D printing community is more inclined towards co-design processes and open design. However, business oriented mode of the open design community can be seen to apply both participatory and user-centered design approaches.

Accountability for the quality of the end-products is different in private companies from the open design community. Quality is essential for the companies but there is no guarantee that a design created within the community can be manufactured with 3D printers or that the design works as intended. The use of third party 3D printing services and wide variety of 3D printers can increase variation of the product quality, too. So end-users of an open design community are expected to have higher evaluation skills for the design and product quality than an average end-user of commercial products.

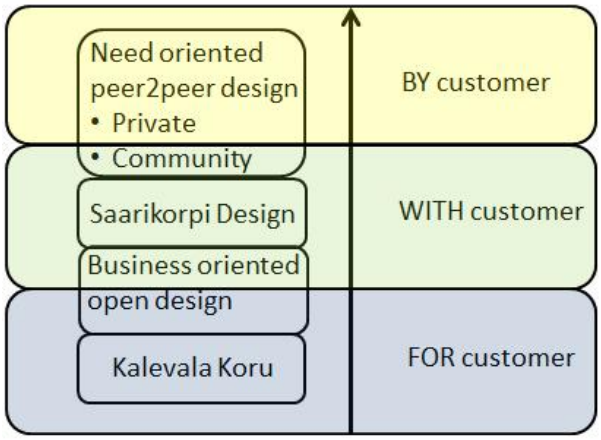

Figure 9. Customer involvement in design processes of the cases.

5. Discussion

The amount of interviews within open design community was rather limited, so the described open design process model (figure 5) might lack some elements. Yet the model offers an interpretation of open design process and it is a starting point for further research. The case companies are based in Finland although they have international markets and connections. Open design and 3D printing communities are not bound to any country borders. However, the researchers are based in Finland so there might be an explicit impact on chosen research methods and interpretation of the data.

The findings suggest that the open design community is looking for widely accepted forms and applied processes. The community is still immature, but there are indications for more coherent practices and shared understanding of what open design is and how it works. Building on the strengths of the open design processes, companies have possibilities in the area. Due to the early adopter phase of the 3D printing technology, services and applications, there is still plenty of room for further research.

6. Conclusions

Design processes of the companies are better defined than in open design area although Kalevala Koru and Saarikorpi Design seek information and ideas both internally and outside of the company. The companies follow up the technological development, use high-end technology and methods, cooperate with various educational institutions, and follow the global development of the markets. The companies cannot ignore the development in the open design community if it can bring additional benefits to the business.

Design processes are presented in the figure 10 with company-driven design processes in one end and open design in the other end of the horizontal axis. Production modes are presented in the same figure with customization in one end and mass production in the other end of the vertical axis. Customization refers to the use of design to accommodate the needs of individuals. Mass customization is in the middle of the axis.

Individual-driven open design illustrates the mode where artifact is customized for own use. In *Customer-driven open design* the given design fulfills customers' needs, and it can be mass customized. Mass production in *community-driven open design* refers to distribution of the designed model to local manufacturing units which can be companies, community labs and end-users. The volume of manufactured objects in distributed open design can be similar to the amounts of products that are manufactured in traditional mass production lines. Community driven open designs are contributed back to the community, often under some commons licenses for others to use and modify. The designs in distributed manufacturing might differ slightly from each other, since users can modify given models. It seems that company driven design and customer driven open design are approaching each other within technology and design process perspectives.

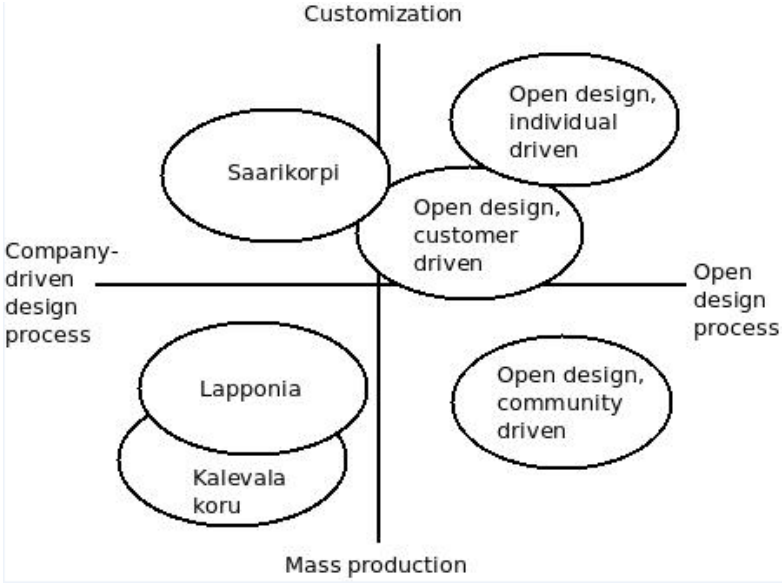

Figure 10. Mapping of design processes of the studied cases.

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