CUSTOM DIGITAL FABRICATION IN INDUSTRIAL DESIGN

BY

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THESIS

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Abstract

Customization is a large field of business, ranging from low-cost custom designed t-shirts to the customizable interior of a luxury car. Even though designers are trained to develop aesthetically and functionally satisfying products, the sector of customizable products is growing with every new product that is released by large companies. The release of the iPad has fueled the development of many accessories that customize the iPad. The level of technology in digital fabrication is becoming more and more sophisticated and the price of the equipment keeps dropping. Since the first commercially available 3D printer was released in 1988 by 3D Systems, the technology has advanced and it is possible to by a DIY 3D printer kit for under $1000 from MakerBot Industries. The term digital fabrication is publicized as the next step towards fabricating your own products in your home and customizing them to fit your own needs. This new technology could change the whole way in which products are designed, manufactured and sold. Eventually, digital fabrication might change the way we consume products in the future as well as change the way designers work.

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Chapter 1: CUSTOM DIGITAL FABRICATION IN INDUSTRIAL DESIGN

Customization is a large field of business, ranging from low-cost custom designed t-shirts to the customizable interior of a luxury car. Even though designers are trained to develop aesthetically and functionally satisfying products, the sector of customizable products is growing with every new product that is released by large companies. The release of the iPad has fueled the development of many accessories that customize the iPad. The level of technology in digital fabrication is becoming more and more sophisticated and the price of the equipment keeps dropping. Since the first commercially available 3D printer was released in 1988 by 3D Systems, the technology has advanced and it is possible to by a DIY 3D printer kit for under $1000 from MakerBot Industries. The term digital fabrication is publicized as the next step towards fabricating your own products in your home and customizing them to fit your own needs. This new technology could change the whole way in which products are designed, manufactured and sold. Eventually, digital fabrication might change the way we consume products in the future as well as change the way designers work.

I will examine the current state for custom design and fabrication technology. What are the possibilities and what are the limitations? How can we integrate design capabilities into the process of digital fabrication and thus shift the position of the designer to be the architect of a digital fabrication process? Does the digital fabrication technology have the potential to disrupt the traditional constellation of consumer, designer, distributor and manufacturer? Following this idea, I will look at examples and ways which could alter the current model of business practice of designers.

The term digital fabrication is broadly used in a lot of disciplines, like architecture and design schools, as well as in community-based movements like the Fab Lab concept. My thesis is taking the perspective of an industrial designer and focusing on aspects which influence the role of the designer in the future. The main goal of this thesis is to grasp the complex influence digital fabrication will have on the profession of an industrial designer alone but also in connection with the surrounding society.

Chapter 2: DEFINING DESIGN AND DIGITAL FABRICATION

2.1. The designer

The profession of the designer originates in the industrialization of consumer products when manufacturing of products changed from craft based workshops to industrial mass manufacturing. The craftsman in his workshop would teach his apprentice the skills of his trade and if he failed to pass it on, his knowledge and experience would die with him. With the rise of large manufacturers, the knowledge and expertise had to be preserved in a common curriculum which would be render the manufacturer independent from the individual worker. The industrial designer became the person responsible for planning the product while the work was purely executing the instructions. The entire fabrication process which was originally handled by one individual was structured into different standardized steps which were handled each by a different worker. This process proved to be more efficient and it required less expertise from the individual worker. In a fabrication process where each step or part is made by a different individual, it is essential to make sure parts are interchangeable. When Henry Ford introduced the moving assembly line in the production of the automobile Ford Model T, he was able to reduce price and improve productivity. Nevertheless, the available color palette of the Model T which contained in the beginning the colors red, grey, green and blue, was from that point reduced to the color black due to manufacturing cost. The designer was now responsible for the development of the product which had to be constructed out of standardized parts. Over time these factories became increasingly efficient since they were able to focus mainly on optimizing their established fabrication process.

The designer's role is to develop new products which can be fabricated using established means of manufacturing. That means that every product has appeal to a larger audience since mass production encourages the fabrication of large numbers of one product. The designer is required to work towards eliminating the need for a custom fit product and instead develop products which ergonomically and functionally can be used by the largest possible consumer percentage. One step in doing so is the empirical acquirement of human factor data which helps to design products that can be used by many users which have different body conditions similar to military outfitting.

According to John Heskett, current Chair Professor at the School of Design at the Hong Kong Polytechnic University, "design, stripped to its essence, can be defined as the human nature to shape and make our environment in ways without precedent in nature, to serve our needs and give meaning to our lives." (Heskett, 2002, p. 1) This is a very technical and fundamental description of design, which acknowledges the intuitive desire of every individual to shape their environment. For this reason, the profession of a designer has only limited legal protection compared to the regulation and licensure procedure which is in place for professional engineers and architects. Everybody is free to use the term design for products as well as call him/herself a designer. This challenges designers to continuously advocate themselves through differentiation and personality. It is integral to every designer's career that they define design as well as the role they see themselves playing in the field of design. Like Hari Koskinen, a designer from Finland is stating:"The Fundamental purpose of design is to either answer or formulate essential questions." (Koskinen, 2005, p. 154) Every designer's definition or philosophy is in way unique to his/her field of work.

The design process is structured to create a lot of options at the beginning and step by step synthesizing them into one final design. By researching the market, gathering user feedback and consumer insight, he/she tries to predict what the consumer wants to buy/needs and makes his/her decisions based on the gathered information.

2.2. Technology

2.2.1. What is digital fabrication?

Digital - representing data as a series of numerical values; fabrication – the act or process of fabricating, making or constructing; this term describes the process of fabricating physical objects based on a digital set of data. This process is repeatable and if the digital data changes, the physical output changes. The factor which differentiates this process from existing fabrication processes is the possibility of changing the digital data from one fabricated product to the next. Therefore the physical results can vary in various factors and specifically changed according to the individual consumer desire.

2.2.2. Parametric Model

The word parametric is derived from the noun parameter, which is a variable in an equation or system. By changing the numeric value of a single parameter, the product of the equation can be changed. In the field of digital modeling, the term parametric model refers to a digital model which is based on a set of variables, where the resulting three dimensional digital shapes or patterns can change. This means that the digital final model is not necessarily completely developed by the designer but more a result of an equation which the designer establishes. In 1977, the French airplane developer Dassault Aviation, started to develop the first 3D CAD/CAM software which used one set of parametric data to design, engineer, analyze and manufacture the parts for an airplane. By using one data set that can be shared by several applications, the possibility of human error during translation of 2D drawings was greatly reduced and productivity was increased. Today, the software is known as CATIA and is the standard for complex product development in the aerospace, car and ship industry.

2.2.3. Cartesian coordinate system

The Cartesian coordinate system is a geometric principle which is used to describe digital shapes very precisely in a virtual three dimensional space. The system is based on three axes: x, y, z and negative and positive values on these axes. Each axis starts with zero in its center and runs infinitely into the negative and positive numeral space. All three axes meet at the zero point which is also defined as the origin. Value of origin is x0, y0, z0 which is written as (0,0,0). Model is used to define one or more points and their relation to each other. Digital models can consist of an infinite number of points.

2.2.4. Additive Manufacturing

This is a process in which products are created by adding material in layers on to each other to create the final result. This process is more efficient than traditional manufacturing techniques which use a subtractive manufacturing approach. The term additive manufacturing has been established with the development of the 3D printing process and is used today as a general term to group those different processes.

2.2.5. Subtractive Manufacturing

This is a process in which material is removed from a natural or industrial shaped raw material to create a product. Most of the current manufacturing processes use this approach. It is less efficient then additive manufacturing techniques because it can create as much as 90% waste during the process compared to the additive manufacturing process of a 3D printer that hardly generates that much waste.

2.2.6. Digital fabrication via Internet

The internet as a medium for communication and a channel for distribution is a fundamental element for the success of digital fabrication. Since images, CAD drawings, 3D models, 3D print files and CNC tool paths are predominantly used to fabricate objects, they can be widely distributed through the internet. The internet is not only a medium which traditional business forms of business like retail stores and service providers use as an addition to other means of communication but it becomes a means to do business by itself: small and medium companies that purely interact with the consumer over the internet or sell specific services/products that only exist within the world wide web are gaining more ground. Good examples are printing companies for business cards, photo books or t-shirts. Customers are designing the products themselves, often with the help of a web interface and can order them without leaving their home. Products can be designed remotely and shipped to every place in the world or fabricated locally just-in-time. When the design of a product is done digitally, prototypes can be done as needed through locally available rapid prototyping equipment and talented personal from all over the world can be employed without being tied to a local job market.

2.2.7. Electronic Commerce

The term electronic commerce describes the exchange of goods and service over computer networks primarily the internet. While this service is used by a lot of traditional retail stores and service providers, companies that operate purely within the digital realm of the World Wide Web are growing. Selling a

product over the internet through web platforms like Etsy.com can be the first step of passionate individuals to become a business. Since the financial overhead of purely electronic commerce is relatively low compared to the high cost of retail space, it is a perfect for products that have only a niche market.

2.2.8. Crowd sourcing

The term crowd sourcing describes the outsourcing of a task to a larger audience outside the realm of the entity which is posing the task. This audience can consist of amateurs or professionals which can contribute different amounts of work and are not necessarily financially rewarded. The method of crowd sourcing has been successfully used by scientific projects as well as commercial projects. Often, the method of crowd sourcing is used by open-source software developers who use the expertise of the programmer community to develop software that is available for free while their business model is focused entirely on the support of the software. One of the most influential crowd sourced projects is the web encyclopedia Wikipedia which uses the internet community to create content for an open source web encyclopedia. Another, example is the social networking website Facebook, which used its global community to create a culturally authentic translation of its website for different countries all over the world. Two examples which are becoming increasingly relevant for designers are the companies Quirky and Kickstarter.

Chapter 3: RESEARCH

3.1. Digital fabrication technology

This chapter will give an overview over the different principles of digital fabrication. Similar technological principles are grouped together and high-end as well as low-end solutions are described.

3.1.1. 3D printing technologies

The term 3D printing is grouping a lot of different additive manufacturing technologies which build three dimensional objects using a similar building approach. They are constructing the object through creating thin layers of solid material. In the process of 3D printing either a raw material is extruded through a nozzle or a liquid binding agent is sprayed onto thin layers of powder. The process is called 3D printing since the technology was adapted from the regular desktop printer which uses a movable print head to apply ink onto print media. The process of stereolithography creates objects in layers but does that by using a UV laser to partially solidify a liquid UV-curable photopolymer resin. Both technologies require the preparation of a 3D model in order to create a physical output. The common used file type for these processes is the STL[1] file format. Once the file is created, it is loaded into proprietary software which operates the specific machine. It allows to position the model in the build space and to set further parameters like printing resolution[2], scale and supporting material structure. Once the build process is started, it can run relatively unsupervised. Depending on the volume of the object and the printing resolution or the machine, the finished object can be received after a couple of hours.

Depending on the specific process used, the printed object may require additional surface finishing or hardening. The company Stratasys Inc. (Stratasys.com) offers a 3D printer which extrudes thin lines of thermoformed ABS plastic which create a very durable object. During the build process, the machine also uses a support material which helps to retain the shape of the object while it is printing. A

[1] STL: stereolithography format, common used for rapid prototyping technologies. It describes three-dimensional objects through triangulating the surface area.
[2] Printing resolution: 3D printing resolution, objects can be printed out with different lay thicknesses, the thickness of the individual layers can range from 1mm to 0.05mm.

different approach is used by the company ZCorp Inc. (zcorp.com) which sprays a liquid binder into several layers of a powder. In this case the build space is completely filled with powder which also supports the object during the printing process. The company Objet developed a 3D printer which uses a variety of material components which can be mixed in different ways to create objects with different material properties. It allows for example to create objects which are partly stiff, transparent, soft, opaque or flexible.

Another 3D printer for a specific use is manufactured by the company Solidscape Inc. and prints objects in wax. These wax models are then used by jewelers to fabricate custom jewelry using the lost wax casting technique[3]. But there is also technology available to directly infuse the 3D print with liquid bronze or to glaze and fire it in a kiln. This allows people to design and fabricate e.g. their own Oscar statuette or their own personal dish washer proof table ware. The only factor which currently prohibits the extensive use of this technology for the hobbyists is the relative high price for the material and fabrication. At the company Shapeways.com, a 3D printed ceramic coffee mug which is glazed and fired in a kiln costs about $50-$70 depending on specific size and volume. Another company which is taking a different approach on the material cost is MCor Technologies that manufactures and sells the Matrix 300 3D printer which uses standard office paper to create objects. The advantage of this system is that the building material cost only about $ 0.10 per cubic inch and the models are recyclable since the machine uses a water based adhesive. The office paper is loaded into the machine and uses a carbide cutting blade to cut every layer of paper individually. But there are several companies and individuals who are experimenting with different materials and the 3D printing process. Successful experiments include 3D printing with chocolate or cake frosting. Additionally to constantly improving materials and developing new printing materials, the build space is also increasing. The Italian inventor Enrico Dini constructed a 3D printer, called D-Shape that uses primarily sand and an inorganic magnesium-base binder and has a maximum build space of 6 x 6 x 9 meters. The resulting structures are hard as sandstone and up to two stories tall. On the other end of the spectrum, we find desktop

[3] Lost wax casting technique: used for casting objects out of metal, the wax model is enclosed in a plaster mould and evaporates when it comes in contact with liquid hot metal.

sized 3D printers like the MakerBot Inc. 3D printer or the RepRap 3D printer. Both of them were developed by an open-source community and cost less than $1000 to build. The concept behind the RepRap 3D printer is to create a low-cost machine which can be replicated using a 3D printer. This approach has created a growing community of 3D printer builders. It is expected that 3D printing will grow into a large industry which will change the way products are manufactured in the future. The company Airbus is planning to fabricate the first entire airplane wing in 2020 through the use of an additive manufacturing technique and already uses 3D printing today to build full scale prototypes of aircraft engines.

3.1.2. CNC controlled milling, routing, turning

The term CNC is a short form for computer numerical controlled and describes manufacturing technologies directly controlled by computer through coding language. The computer file is usually written in G-Code[4] or in a modified version. The G-Code is often programmed using CAM[5] software but can also be written through a text editor. The G-Code contains information like machine speed, cutting tool type and it describes the path in which the machine is moving the tool. There are numerous types of machines which are numerical controlled. The most common are table routers, milling machines and lathes in the field of metal and wood working. Machines working with CNC interface are mostly using a subtractive process for removing material. They use a cutting bit to carve material away from a solid piece of raw material. This process is usually done in several stages which involve different cutting bits and tool path commands.

Using CNC fabrication equipment requires the designer to work very closely with the person who is programming the tool path and fabricating the object to ensure manufacturability. The fabrication process requires careful planning because the block of material often has to be repositioned several times until each of the sides has been machined. For this process, it can be necessary to create additional jigs which hold the work piece in place. Another limitation for all the CNC operated

[4] G-code: computer programming language for CNC operated fabrication equipment; called because main commands are use the letter G e.g. G01 Z-1 is the command for a linear cut to Z(-1)
[5] CAM: Computer Aided Manufacturing: *description*

equipment is that it is very difficult to create cavities in objects since the cutting tool with the spindle motor attached is very large. That means that objects with cavities usually have to be split into several sections which will be joined again after the fabrication. There are three general types of CNC operated machinery: the table router, the mill and the lathe. The table router is usually used to work with flat sheet material and its size is oriented towards the standard material sizes e.g. the four feet by eight feet sheet of plywood for the construction industry. There are numerous variations in size, a table router like the Shopbot PRSalpha geared for the hobbyist might work only with a maximum material size of four feet by eight feet and a maximum height of six inches while a large industrial version like the Titan CNC router works with material sizes up to 50 feet by 20 feet and a material height of 10 feet. Although different in size, the basic principle is similar; a gantry is travelling over a table or specified area and carries a spindle which holds the tool bit. This setup is able to move the cutting tool in three different axes over the material. For more industrial application, additional axes can be added which tilt the tool in different angles to machine areas which cannot be reached otherwise. The CNC operated mill is a based on the traditional manual mill and is used primarily for machining metal parts. In this category the machine types can vary from a small table-top CNC mill to an enclosed high-speed CNC milling center which has a footprint of 10 feet by 10 feet.

The CNC lathe is based on the traditional lathe and has also evolved into many different machine types to turn parts from the size of pen to a one foot by 20 feet large feeding screw for a manufacturing plant. Although table router, mill and lathe originated in different fields and were meant for specific purposes, it possible to adapt current CNC operated machinery in different ways e.g. a rotational horizontal chuck to turn objects on a table router or mill. This blurs the distinctions between the different areas. But the market is not only dominated by industrial machines, a growing number of hobbyists and individuals are building their own CNC operated machines and offering their building plans on the internet. One of the entrepreneurs who offer CNC router kits for sale is the company BuildYourCNC.com which sells plans, kits and parts to build your own customized CNC

routers. The material of choice is MDF[6] board or similar material which provides a sturdy and very affordable structure for the motors and the spindle. The company offers machines in different sizes, a desktop CNC router costs about $2000 and they also offer advice on how to build CNC routers in custom sizes. Of course, these machines are not comparable in precision and longevity with industrial grade machines but they are appealing to the hobbyist customer. They are creating a simple and easy option for people who want to run CNC cutting operations to fabricate low volume runs of parts or products. They are giving amateurs the possibility of using CAD programs to create sophisticated and complex objects with a level of precision which is usually only achieved by dedicated woodworkers.

The field of CNC operated fabrication equipment and its use is growing in all areas. More and more designers are using CNC table routers to create furniture which they designed to be cut out very efficiently from plywood. The company Apple Inc. is taking a very innovative approach by using nine different CNC machining operations to create a seamless case for their MacBook Pro which they call a unibody. One very sophisticated part replaces a large number of parts usually used in notebook fabrication. While this requires a lot of effort to develop, the visual and tactile result is clearly the reason for their success.

3.1.3. CNC Laser-, Plasma-, and Water cutting

This chapter describes the technologies of Laser cutting, plasma cutting and Water Jet cutting. They are grouped together since they process primarily sheet material in a similar way. While they are also classified as a subtractive manufacturing process, they are mostly used to cut flat sheet material or to engrave surfaces. They are not suitable to shape three dimensional surfaces as well as for example a CNC controlled router. All the machines are commonly used industrial environments like factories or machine shops, but laser and plasma cutters have become more affordable with prices starting at around $ 10,000. At the price level, the quality of the machines cannot be compared with industrial manufacturing versions but the work well for the hobby user. The cutting process for a lot of the low-

[6] MDF: Medium density fiber board; describes a specific timber product which is made of small compressed wood fibers and adhesives.

end machines is very simple compared to 3D printers or CNC table routers, since they only require a 2D drawing and no specific tool path programming or the calibration of the cutting tool. A small table-top Laser Engraver can be used almost everywhere as long as the fumes can be ventilated outside. More expensive in use are Water Jet Cutters that use a high pressure water stream which contains abrasive particles to cut through materials of up to 13" thick. This process requires very precise parts that wear out over time and a substantial amount of abrasive particles which makes it an expensive machine and costly to maintain. The plasma cutter uses a high electric current to cut through sheet metal and is also available as a handheld device. It does not deliver such a good edge quality compared to the one which can be achieved by cutting materials with the laser or water. Of these three different technologies, Laser Cutters have the largest user group among hobbyists since they are generally smaller, operate cleaner and can be used with a common electrical outlet.

3.2. Business models for rapid custom fabrication

This chapter is looking at several business models which using either one or several technologies from or related to the area of digital fabrication. The primary goal of the businesses listed, is to provide value to the consumer through custom fabricated or custom fit products.

3.2.1. Fluid Forms – Design Your Own

The company Fluidforms Walter & Williams OG is based in Austria and sells products like lamps, jewelry, clocks, bowls and side tables. Every product is fabricated using a different digital fabrication technology. The customer uses a browser based software application to manipulate a digital model. Starting with a digital raw model, the customer can either sculpt the shape to his desire using simple digital brushes. The company also offers to customize products with a specific landscape using elevation and contour data from Google Earth.

The company offers different product which use different fabrication process and different approaches to create a product. Every product is connected to one specific fabrication process, this makes it easier for the company to handle the process and it becomes more cost-effective since each

product can be manufactured from a different company. The fabrication process is also specifically chosen to support the product idea. A lamp shade is fabricated with a 3D printer out of translucent white polyamide which aids in light distribution. The surface of a fruit bowl is milled with a CNC router out of maple/walnut plywood which adds depth to variations in elevation.

3.2.2. Ponoko – the world most easiest making system

The Company Ponoko is an online retail platform which offers different services around selling and buying products made by digital fabrication technology.

It offers digital showrooms to individuals who are designers, craftsmen or hobbyists who can display products and offer them for sale through this platform. The company also offers the service to fabricate digital designs using digital fabrication technology like a laser cutter, CNC router or 3D printer. This website offers interesting opportunities for a variety of customers. On the one hand it attracts consumers who are looking for products which are unique and cannot be found in large retail stores. On the other hand it is a channel for people who would like to sell a self designed and self made product, but also an opportunity for people who always considered developing their own products but did not have the access to fabrication technology. By being able to design, fabricate and sell products using all services from Ponoko, individual members keep their financial overhead low and their daily business flexible. Ponoko is actively seeking to become a hub for digital fabrication and a support for anything that helps users to make a business from their creations. This attracts a lot of hobbyists and inventors which offer products like a shelf for cats to sleep on or other gimmicks.

3.2.3. Shapeways – passionate about creating

The company Shapeways is an online store and 3D printing service for professionals and hobbyists. It offers 3D printing services for a wide range of materials and sizes. The company also offers customers to create a web store where other customers can browse through the digital 3D files and order physical 3D prints. In order to purchase a 3D print it is necessary to submit a digital file which adheres to the requirements of the chosen material. The possible materials are steel, aluminum, silver, sandstone,

glass, ceramic, ABS and further plastics. The prices for the material are calculated in cubic centimeter and range from $1 to $20. Once a 3D model has been optimized for a specific printing material, the user can display it with a rendering in his personal web store and offer it for sale. The retail price is determined by the user, it includes the fabrication cost charged by Shapeways which also takes care of fabrication and shipping. The money is paid to the user via a PayPal account. While their services are used to fabricate a wide range of objects, the most popular objects are customizable household items like napkin holders and candle lights.

3.2.4. Unique Solutions – Intellifit Virtual Fitting Room

The company Unique Solutions has developed a full size body scanner which can be installed in shopping malls or retail stores. The body scanner is attached to a kiosk where consumers can search for clothes which fit their unique body specifications. The scanner is using radio signal which are reflected by the human skin and create a digital three dimensional scan of the body. The consumer does not have to take his clothes off in order to use the machine. After scanning, the kiosk prints out a unique identification number which consumers can use to review their data, match it with existing fashion lines from different stores or order their own custom make shirts, suits or wedding dresses. If the kiosk is installed in a shopping mall, it can serve a large number of stores. The data helps consumers to identify the right sizes of clothes much easier since it translates their sizes into the different brand sizes. This business model is very relevant for digital fabrication process, since only objects which are available in form of digital data can be fabricated. If this business model keeps growing, it could potentially fuel a large number of startups that use the digital body data to custom fabricate apparel over the internet for customer across the world. If personal digital body measurements can be accessed and managed by the customers and they can distribute them to their favorite brands or tailors, clothes can be ordered remotely and it is guaranteed that they will always fit once they arrive.

3.2.5. The Left Shoe Company – Made to measure

The Left Shoe Company is a company which specializes in custom made shoe by combining traditional craftsmanship with modern 3D scanning technology. The company offers custom fit shoes with customizable details. The company has several flag ship stores mainly in Europe which are equipped with 3D scanners. After scanning their feet, customers can choose a specific shoe model from the collection which can be customized with different materials. Customers are assigned an identification number which allows them to order new shoes anytime in the future without having to visit the store again. The prices for a pair of shoes start at around $290.

3.3. Product design for digital fabrication

This chapter describes several conceptual approaches of customizable product design. While some are unique in the way they engage the customer, others a carving out a niche for products that push the boundaries in terms of using 3D printing as a manufacturing technology.

3.3.1. FreshFiber: Custom iPad Case

The goal of the company FreshFiber is to design and fabricate accessories for hand held device from Apple like the iPad and the iPhone. The guiding principle is to offer opportunities for customization through a software interface and fabricate the products with a 3D printer out of a grey nylon material. The company works in collaboration with the established company Freedom of Creation and is currently developing their services. After presenting their business plan to the community at the crowd funding platform Kickstarter, they failed to raise enough money for their project but they have continued development of their project.

3.3.2. Fluid Forms: Cassius Lamp

The company FluidForms is selling customized home accessories and jewelry. One of their products is a customizable lamp shade which is fabricated by a 3D printer. Unique about this product, is the way how the customer can shape it to his/her desire. At the beginning, the shape of the lamp is cylindrical

and resembles a punch bag. The customer can interact with the shape using virtual boxing gloves and form the shape. The resulting shape may have holes to let light through and different wall thicknesses which create different light intensities. While the creation of a 3D model usually requires skill and time, this approach uses the simple analogy to a punch bag in order to simplify the complex process of 3D modeling. Since customers might not be able to spend a long time on customizing a product, this is a fun and effective approach.

3.3.3. Droog: Design for Download

For the Salone de Mobile 2011, the conceptual Dutch design company Droog started an investigation in exploring the possibilities custom design solutions for consumers using parametric design tools. The result was an exhibition, featuring different approaches towards customizable design ranging from small to large, from 3D printed electrical outlets to CNC cut furniture. According to Droog, the results will be used to develop a platform which allows consumers to use easy-to-use parametric design tools to modify open-source content and design it according to their desires. The software generates blueprints that can be fabricated in various ways, either locally by existing manufacturers or through an international network of digital fabrication companies. While this service is not available yet, Droog hopes to bring the platform online before the end of 2011.

3.3.4. Freedom of Creation

The company Freedom of Creation is a pioneer in the field of designing objects that use the advantages of the 3D printing fabrication process. The products they design are unique in terms of shape since they are designed free from all traditional limitations of fabrication. While the company was founded in 2000, they became quite popular in the last three years and their creations are already exhibited in internationally recognized museums like the MoMA in New York City, NY, USA. The founder of FOC, Janne Kyttanen describes the goal of the company to design products which are only fabricated when somebody decides to buy it, therefore reducing unnecessary manufacturing waste and

obsolete products. Although, FOC does not customize products per se, they develop custom objects for clients.

3.3.5. Dirk vander Kooij: Endless Chair

This project was initiated by Dirk vander Kooij who turned a used Fanuc industrial assembly robot into a large scale 3D printer, capable of producing large, low resolution 3D prints at an industrial speed. The robot arm has a tank for granulated plastic and an extruder mounted to it and it is used to lay a continuous line of molten plastic on the floor which eventually became a chair, hence the name "endless chair". The extruder uses granulate from shredded plastic parts from fridges. Unique about this project is how the fabrication directly influences the visual quality of the chair and how practical it is for the designer:"... by combining different techniques, I was able to design an automated but very flexible process … this opened the possibility for me to design in the good old-fashioned way, making a chair, evaluating, refining, making a chair, evaluating, refining and making a chair. or developing an infinitely large collection of variations. Endlessly." (Kooij, 10) Even though, it might now have been his original intention, Kooij used digital fabrication technology as means to design but also to fabricate a product which can be sold as is.

3.3.6. Sketchchair by Diatom Studio

SketchChair is open-source software by the design firm diatom studio which helps people to design, evaluate and fabricate their own furniture.

The software allows people to design a chair through using simple digital drawing tools. The drawings can be evaluated using an anatomically correct digital mannequin which virtually takes a seat on the desired design. After the design is completed, the drawing is turned into a set of two dimensional drawings which can be turned into a tool path for a CNC router.

3.3.7. Magic Box by Studio Ludens

The software Magic Box is an online parametric vector drawing program which allows you to either customize pre-existing templates or create your own personal parametric drawings. Created by the Dutch design firm studio Ludens, it encourages users to create their own two-dimensional designs and share them with the online community. Every file can be saved as an SVG[7] file and cut out of cardboard, acrylic or plywood using digital fabrication technology. The templates are based on algorithms which can be changed by entering different values. The simplest object is a box where the sides are connected through finger joints. The design is set up to be modified in height, depth and width, but also in the number and size of the finger joints[8]. The software also allows to account for manufacturing tolerances as well as the material thickness. Currently the available templates include a cardboard milk carton, a pair of acrylic glasses, a plywood box and a paper basket. Theoretically there is no limitation to a specific material though it is preferable to use the recommended material because of practical reasons.

3.3.8. Autodesk 123D

The program 123D is a free solid modeling[9] program which has been released from the software company Autodesk. The company Autodesk is a developing 3D modeling and rendering applications for design and engineering firms. The program 123D is combining precision modeling with an easy interface. The target groups for this software are semi-professionals and hobbyists who want to create files for digital fabrication. This program is a direct competitor to Google SketchUp, which is free as well but less suited for digital fabrication because it uses a surface modeling[10] approach since it was developed for building architecture models.

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[7] SVG: scalable vector graphic, common used file format for digital drawings made in layout programs. Vector drawings can be scaled in size and modified without loss of quality.

[8] Finger joint: also known as a comb joint, a series of complementary rectangular cuts which connect two pieces of material in an angle. The joint can be glued but fabricated with small tolerances also holds through friction.

[9] Solid modeling: describes a principle for the digital modeling of three dimensional objects in a physically correct way. Software based on this system is mainly used in engineering applications.

[10] Surface modeling: describes a principle for the digital modeling of three dimensional surfaces using curves. Software using this system is mainly used for manipulating the skin of objects since it can be shaped more freely.

Autodesk is working in partnership with the online platform Ponoko, the 3D printer manufacturer 3DSystems and the workshop community TechShop to help people to fabricate objects using digital fabrication technology. The software has an easier interface than the professional counterparts from Autodesk like Inventor and the free version has more options for the import and export of different file formats compared to the free version of Google SketchUp. This program was released by Autodesk specifically targeted at the hobbyist and it shows that the field of digital fabrication is anticipated to grow among amateurs and might become a large market for established software companies.

3.3.9. Google SketchUp

Google SketchUp is software designed to easily build three dimensional objects and architectural designs. Primarily acquired by Google as a tool to build 3D architecture models for the software Google Earth, it became popular among architecture students and has been very useful to the community of hobbyists and makers.

While a version, which is limited in the use of common file formats, is available for free, the fully functional professional version can be acquired for about $500. Some 3D printing services like iMaterialize also accept the proprietary SketchUp file format for fabricating architecture models on their ZCorp 3D printers.

3.3.10. Autodesk Photofly 2.0

The software Photofly is developed by Autodesk as alternative to 3D scanning or 3D modeling. It creates digital 3D models through a process called photogrammetry[11] which essentially analyses digital photos of an object to calculate the three dimensional shape of it. This approach requires the user to take several pictures of every vantage point of the object without flash or other way of altering the light source. The software analyzes the shadow and textures in the image to connect them. Processing the images and creating a 3D model usually requires large computing power but Autodesk developed

[11] Photogrammetry: method of evaluating the three-dimensional shape of objects through photographs

a way to offset these operations through cloud computing[12]. The software can be used to record objects from the size of a cell phone to complete room interiors. Currently the software does not work with objects that have reflective surfaces, which is a common problem for laser-based 3D scanners. Using this software, hobbyists can create 3D models from existing objects in a simple and affordable way. It is also an opportunity for interior designers and architects to create 3D models from locations without using a portable 3D scanner. This software opens up opportunities especially for small and medium business which cannot afford large expenses for technology.

3.4. Culture of personal fabrication

3.4.1. Make: technology on your time

The Make magazine reports on unique Do-It-Yourself projects and distributes the step-by-step instructions to build these projects on your own. The magazine has grown into to include a variety of channels, events and products and attracts a growing community. The guiding principle "All of us are makers" (Dougherty, 2011) connects a broad range of people and encourages them to make and modify objects – to make them their own. The highlight of the community is the MakerFair, which is organized as a gathering for everybody who is making something by herself and includes the hobbyist as well as the professional craftsman.

3.4.2. Fab Lab

A short form for Fabrication Laboratory, community fab labs are in countries all over the world. They provide a range of different rapid manufacturing equipment like e.g. a laser cutter, CNC table router, vinyl cutter, 3D printer and CNC mill. Originally developed at the MIT they are the result of a class which was called:"How to make (almost) anything," taught by Neil Gershenfeld. Soon after that fab labs were opened in remote areas in India, Afghanistan and Norway as a means to enable local and remote communities to solve local problems with the help of digital fabrication equipment. This idea proved to be quite successfully. The fab lab in Afghanistan developed their own wireless

[12] Cloud computing: connected network of individual computers that can be used as one.

communication structure by using standard WLAN routers and signal amplifiers made from metal scraps. Local community members in a fab lab in India developed a device to measure the amount of water in milk and therefore determine its quality. After their international success, the fab lab concept was quickly adopted by schools and communities in the United States. While every fab lab is unique in terms of serving the needs of its local community, fab labs in the United States have been primarily targeting young kids and high school students to introduce them to digital fabrication. The user group of fab labs in remote areas like in Lyngen, Norway seems to include a more diverse user group and develop into community centers. An important reason for the global success of fab labs lies in the communication link in form of a web conference system which links all fab labs worldwide together and allows exchanging ideas, collaborating on projects and is a resource for all sorts of technical problems.

Many fab labs in the United States have been opened in high schools or universities. The Champaign Urbana Community Fab Lab, located 1301 South Goodwin Avenue
Urbana, IL 61801 has officially opened its doors on 11.11.2010 and is funded by the University of Illinois at Urbana-Champaign. It is open about three times a week and a handful of volunteers introduce community members to software and hardware. Personally, I have been involved in the organization and daily business of this fab lab since the end of 2009. The whole space includes a conference room, a computer area, fabrication are with laser cutter, vinyl cutter, CNC router as well as a dedicated electronics lab. During spring semester of 2011, I was employed as a student assistant and helped to conduct workshops and manage the facilities. Through being directly involved with people who have never been in touch with a 3D printer, a CNC router or a laser cutter, I was able to first hand observe their reaction with digital fabrication technology. What I observed was that there was an inherent fascination for the technology from the visitors once they saw them running. This helped especially in learning the software to operate them; it was a motivation that kept even kids focused and eager to accomplish their project. A major hurdle for many was to practice their imaginative abilities to visualize what they wanted to create. My conclusion from my observations is; people and especially kids like to fabricate or simply said: make things. Many do not have the opportunity to

practice this desire and therefore cannot teach it to their kids. They seem to be quite emotionally disconnected from the process of making an object, planning and prototyping the parts and enjoying the final result. As a designer, I tend to look at the fabrication process like a challenge, a mind-boggling three-dimensional puzzle which has to be solved in a precise order of steps. It was surprising when regular visitors of the fab lab started to pick up experience in the use of the machines and started to develop more complex though out projects.

3.4.3. Etsy

The website Etsy is a platform which allows people to sell and buy products. While this is generally possible through a lot of channels, Etsy is tailored specifically to individuals who produce and sell products which are handmade or self designed. Users are able to set up a digital storefront for their own brand and market to large online community which is interested in unique products. The price of the products sold ranges mostly from a few dollars up to eighty dollars and only seldom exceeds a hundred dollars. One way how Etsy manages to keep the majority of the advertised products unique and of high quality is through customer reviews but also by letting users create groups and connect with each other. This helps sellers to provide credibility through gathering a group of followers who vouch for his/her services.

3.4.4. 100K garages

The website www.100kgarages.com is building a network of 100.000 garages or shops that have digital fabrication equipment available. The goal is to connect individuals who need rapid prototyping equipment in order to fabricate a project with individuals or shops that have this equipment available. The name is derived from the notion that a lot of companies have initially started in a garage. So far, the network includes roughly 200 places in different locations worldwide but mainly in the United States. Every participating garage or shop describes itself shortly. Although the project is supported by ShopBot Tools Inc and Ponoko and was started in 2009, it has remained quite static since then.

3.4.5. Thingiverse

The website Thingiverse is a community based platform to share digital files, designed specifically to be fabricated using a 3D printer. Users can upload any project, as long as they were responsible for the creation. The simple interface and principle has attracted a large group of active users. The website is created and supported by MakerBot Inc, which is a popular manufacturer of DIY 3D printer kits. Most of the active users seem to be owner of a MakerBot and they use this website to distribute useful add-ons which increase the functionality and usability of their 3D printer. The objects which are shared range from small toys over usable products like a watering spout for a standard plastic bottle. A large number of these products solve very specific and unique needs, like for example a special building block which connect the popular LEGO toys system with a wooden toy train set or a special clip holds an insulin pen and attaches it to the A/C vent of a car. Although this website is clearly open source focused, it is an example on how 3D printers can become part of everybody's daily life.

3.4.6. The NeuroMaker Project

The project was initiated by me for the 10 to watch [13]series at the Figure One[14] exhibition space. It was scheduled to be on display from January 31st, 2011 to February 17th, 2011 with the opening reception on February 11th, 6-8pm.

In the early stages of this project, it became clear that the venue and the 10 to Watch series required developing a project which would be different from other exhibitions I have taken part in before. The venue is a long space with a separate space of about 15 by 15 feet which was reserved for the 10 to watch series. The goal of the 10 to watch series is to give students the opportunity to use this space for a specific period of time to "bring relevant and engaging ideas from the School of Art + Design's classrooms to a public forum." (Luu, 2011) As the only student chosen from the field of Industrial Design, my interest became to design and build a system which would visitors allow being involved in the design and fabrication of an object. Due to the venue and the how it would be

[13] 10 to watch: a year-long exhibition series which features 10 students from different fields of the School of Art and Design, UIUC. It is curated by Jorge Lucero, Jimmy Luu and Tumelo Mosaka.
[14] Figure One: exhibition and event space for student from the University of Illinois, School of Art and Design.

accessed by people, the involvement of the visitor with the process had to be focused on one aspect of the whole product.

This project was initiated and executed with the help of Robert E McGrath and Alan B Craig from the National Center for Supercomputing Applications at the University of Illinois at Urbana-Champaign. Financial and organizational support came from the Champaign Urbana Community Fab Lab.

Initially the project was started with the goal to explore alternative input methods for object customization through digital fabrication technology. During the initial feasibility research, two specific items were chosen to be included in this experiment: a small CNC table router with a cutting area of 12" by 36" as the output device and a NeuroSky MindSet EEG brainwave sensor as the input device. Both items were chosen based on their physical robustness, large option for modification and suitable employment in an exhibition environment. Another option for the output device was a 3D printer but that was rejected later due to the longer turnaround time for a fabricated object. While the fabrication process was largely a technical issue, the software and the resulting product proved to be the larger and complex issues. Since the human brain is a very complex and powerful organ, it is not possible to interpret the electric impulses received via the MindSet because they represent only a small fraction of the neural activity. In order to build a functional system in time for the exhibition, we limited the amount of data we collected to only a few numbers. These numbers are directly taken from the neural activity of the user's brain in the very moment when he presses the record button. The problem which we faced now was that these numbers could not directly be integrated into a g-code which can be executed by the CNC router. The solution to this problem was an intermediate software routine that would use an algorithm to which distributes the input within boundaries. To make this process easier, we limited the result to only two axes of the Cartesian coordinate system: x and y which limits the result to a two-dimensional artifact. The possibility of consciously and intentionally designing an object through your thoughts cannot be realized yet with current technology. With the goal to transfer the abstract data from a person's brain into a more tangible and meaningful state, an object had to be designed that would carry this meaning but would not necessarily be desirable without it. Finally I

decided on using the router to either engrave or plot a custom image onto an object. Different materials were tested in terms of cutting or scoring ability. My idea was to develop a product which would gain substantial value through customization and could be fabricated from a flat sheet of material. By scoring the material, it could be folded into a three-dimensional object. Unfortunately, the testing eliminated this possibility because it proved to be complicated and visually undesirable. Another factor which had a large impact on the final outcome presented itself during the use of a cutting bit. It was not possible to keep the noise level at an acceptable point in the exhibition space since it had very bad acoustic qualities. Due to additional safety concerns which could not be resolved in time, we had to primarily use the router as a plotter. One of the main goals during the development process was to streamline the fabrication process towards a point where it would be simple and clear to operate with as little variables for failure as possible.

Due to many factors which influenced this project up to the last minute, the complete interaction process between the user and the software was finalized shortly before the opening. The software frontend which collected data from the user and guided through the process was realized through the software Powerpoint. The java applications for the backend of the software: the data collection from the MindSet and the tool path generation were implemented in between the slides. The process of use starts by entering a name or descriptive word which names the file and therefore makes it identifiable later. The user then is presented with a screen which allows him to record data from his brain, in the moment when he presses the designated button; a short section of the continuous data stream from the MindSet is saved. The data can be visualized in two ways through an intermediate algorithm which either displays the data in a continuous curve or in a series of rectangles. These two ways produce different images which are based on the same data and represent the two major trends of shape within the field of designed objects: either an object tends towards a curved shape or towards a rectangular shape. Once the user has completed the recording process, an assistant stepped in and loaded their file into the CAM software. The user was then asked to choose one of several different colored square sheets of museum board with an approximate size of six by six inches. After placing the desired

material on the table the process was started and the visitor was able to receive the finished result after a plotting time of approximately two minutes.

The exhibition was set up with a clear focus on the machine itself; descriptions in large letters on the wall gave visitors an insight into the context of the work. During the opening reception, approximately 40 visitors were able to use the machine.

Figure 1: Visitor using MindSet to record data

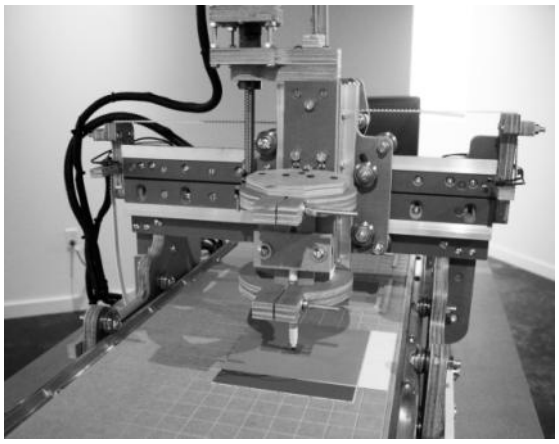

Figure 2: Machine plotting data on medium

The feedback of the visitors who experienced the machine by using it or just observed it was generally positive. Watching the CNC router to move across the table and draw curved or rectangular shapes at a constant speed had for some visitors a spiritual notion. The changing, low pitch noise of the motors which move the axis was associated by some visitors as a melody. From the many visitors who used the MindSet to create an image of their thoughts, a large portion where fascinated by the result and were feeling connected to it.

3.5. Designer as entrepreneur

3.5.1. Kickstarter

The website Kickstarter is a platform which helps people to raise funding for projects of all kind. Individuals or groups can present their idea with a video and can set a specific they need in order to bring this idea to reality. The videos can be viewed by everyone and people are able to support their favorite projects through donations starting with as little as one dollar. Once a project has reached its desired goal, the money is collected and the website Kickstarter keeps a percentage of the money.

This website has accumulated a large number of followers which support projects ranging from music albums over documentaries to product concepts and architectural projects like building a public pool in the bay area in New York City. It also becomes a growing alternative for designers to seek funding for projects which have been initially rejected by established companies. A unique example for this is give by Scott Wilson, a designer who created two unique product ideas called TikTok and LunaTik, which transform the current iPod Nano into a wristwatch. Originally seeking only $15.000 in funding, he ended up receiving about $941,000 in funding. This did not only help him develop and manufacture his product but it guaranteed him a large number of customers upfront without spending any money on marketing or advertising. Not only did Kickstarter help him to bring a product to the customer but the principle of Kickstarter also ensures that only projects or products which seem reasonable or desirable are funded. Screening the vast majority of product design projects presented on the website, successful ones are usually responsible, useful and well designed like the Tembo Trunks, a set of collapsible ear bud speakers which are made from silicone rubber and clip onto ear buds to amplify their sound. Developed was the idea by Scott Norrie, an Industrial Designer who initially was seeking only $10,000 in funding but at the end received $88,000 total. These examples show, that a smart idea paired with good design make their way to the market without the support of large investments firms or financial institutions but only with the help of the consumer. Surprisingly, the projects are looking mostly for relatively small sums of money which are usually dedicated to cover the first production run of a project. These sums are too large to be handled by one person but can be easily distributed within even a small group of followers. The universal smart phone stand: Gripzila has successfully reached the funding goal of $ 5,700 with only 286 individual supporters which equals to an average investment of about $20 per person. Looking at the listed supporters for each project, it quickly becomes clear that Kickstarter has built a community of followers who each support several projects. Not all projects have a commercial purpose and many successfully funded projects are benefiting a larger community or market.

3.5.2. Quirky

The company Quirky combines' different aspects of web based communication, social networking, product development and business together. The result is a unique social product design firm which develops and sells ideas which are submitted by the web community. But not only can everybody submit a new product idea, the community can also actively engage in the product design process which rewards them in return with a small percentage of the sales and the proud feeling of being able to claim ownership. New members start by submitting an idea supported through images or video which is voted by the other members of the community. Once an idea has passed the initial voting phase, it is reviewed by Quirky's product development team which analyzes the product in terms of design potential, marketing potential and viability. After deciding to move forward, the design team develops the idea further by including feedback of the community. While Quirky continues through traditional product development steps, it does not manufacture a product if it has not reached a certain number of pre-orders. This threshold is the last barrier before a product is available for sale, it assures the manufacturer to have customer for the product as well as it sorts out products which are not able to reach enough customer interest.

3.5.3. The Designer Fund

The Designer Fund is a recently established network of professional designer and angel investors which has the goal to support entrepreneurial attempts and business ideas from designers. Recognizing that a majority of his effort went towards helping start ups to learn creative thinking, start up mentor Enrique Allen: "… realized I should be helping designers become more startup-ey," (Allen, 2011). This resulted in a network that primarily offers mentorship from a large group of designers to help start ups to develop their business model. Although the network recognizes the important and unique role designers can play in the process of forming a company, their primary goal is to connect the designer on eyelevel with engineers, programmers and business administrators in order to build teams rather than support individuals who want to do everything themselves. While a lot of start ups are focusing

on building web based business, the mentor network includes designers from established design companies like IDEO and Frog design.

Chapter 4: FINDINGS

4.1. Technology

The biggest trends in the field of digital fabrication technology are the increasing level of functionality, the decreasing price for equipment and the growing interest from amateur users. The quality of the printed object has been improving and more material options are becoming available. The price and the running cost of 3D printing equipment are declining. They are available for about $3000 and one cubic inch of printed volume costs less than one dollar. This makes them more affordable for smaller businesses and individuals. Additionally, the growing interest and engagement by people from different areas in 3D printing technology has created a unique movement and a strong technical support community. While the first two trends are logical and easy to explain: the continuous development and improved production have made 3D printers more versatile and reduced the price, the international fascination for 3D printing is unique. When ink jet printers where becoming more affordable and where sitting in everybody's home office, they did not provoke the same reaction. Even though an inkjet printer might not be as groundbreaking as a 3D printer, it offered a similar advantage by giving people the opportunity to print anything at their home without going to a specialized store. Ink jet printing now has become a daily routine and there has been only one documented attempt to design and build a DIY ink jet printer kit. Compared with the amount of 3D printer kits and CNC router kits that are available or in development phase, it is obvious that there is more to the growing interest for digital fabrication than just a fascination for the technology. Judging from the activity and variety of objects on the website Thingiverse, individuals are investing a lot of time and effort into designing and fabricating objects which improve their daily life by either adding functionality to existing products or by creating completely new products. A particular nice examples for this are custom printed LEGO bricks which can be used with the original building blocks or a 3D printed clip for an insulin pen which attaches directly to the air vents in a car and help to keep the medication cool. While the prediction that in the future there will be a 3D printer in every home seems to be at first farfetched, I think that through a low price and ease-of-use technology, it will definitely become popular among the whole population.

4.2. Business models

During the research, it was still difficult to find store and web based business models which create custom fabricated products using digital fabrication technology. Digital fabrication technology services definitely seem to have a large potential in the hobby market. The possibility of designing objects, models or miniatures on the computer and outsourcing the fabrication to Shapeways certainly has its advantages. Especially since Shapeways offers high quality, detailed 3D prints which are comparable in quality to injection molded plastic. The only prohibiting factor for a widespread use of such services seems to be the rather high upfront learning curve and modeling time which has to be invested into using modeling programs to generate the necessary digital models. Offering customizable products that are fabricated to order like from the company FluidForms seems to be more suitable for the average consumer which would have no 3D modeling experience. While this company certainly has developed interesting ways to engage the consumer, the products price point seems prohibitive for a larger audience. Another issue is that a consumer might be willing to pay more money for an object designed by a professional and famous designer like Philippe Starck rather than paying several hundred dollars for an object that has been more or less designed by deforming a cylinder. The extra value which is added through shaping your personal lamp shade by punching holes through it or creating a fruit bowl from the topography of the Midwest United States might not create enough meaning for the customer. The process for the customization of these products is designed to work within specific boundaries that do not necessarily leave room for recognizable customization but are merely mass-produced custom designs. A real benefit could be achieved by pairing the digital fabrication technology with 3D scanning technology which allows creating custom fit clothing, accessories and products in the field of disability assistive devices. In this product category, the customer recognizes a clear value which is a product that perfectly fits his ergonomic needs and is therefore truly unique.

4.3. Design for digital fabrication

To design products which specifically make use of digital fabrication technology while being competitive with mass-manufactured products is quite difficult. Since the products are not manufactured by hand and do not intrigue the consumer with a story about tradition, they might be initially perceived equal to mass-manufactured goods. Now it is up to the degree of customization to make a difference in value to the customer. This might be easier in some field where customization is important for an ergonomically correct use of a product, where customization can be seen as a factor of differentiation towards other consumer or where customization has not been profitable before. The iPhone and iPad covers of the company FreshFiber can be seen as a possibility to differentiate you from somebody else. Using a personalized iPad cover compared to using the standard ipad cover that comes with the purchase, sets you apart from the mass. While this idea is not new, the company claims to develop software which will make the process of designing your own ipad cover easier. This could certainly be the important aspect which the consumer convinces to choose this product. Although they offer customization, the products of FreshFiber have the same visual quality like other traditionally injection molded plastic objects which does not help to increase the perceived value. While this is no reason to abandon digital fabrication technology per se, it is certainly an important aspect which needs to be considered by the designer. Judging from numerous plans and attempts by designers and software firms to lower the barriers to custom fabricated goods, there is a large interest to push this trend forward. By releasing 123D, Autodesk recognizes the need for simple and easy-to-use beginner software for 3D modeling. Comparing the different approaches of SketchChair, MagicBox and Droog's Design for Download, it seems that the idea of including the consumer in the design process through a software interface is just getting momentum. While the company Fluid Forms exposed the consumer to a rather fool proof software, the other attempts put a lot more freedom into the user's hands.

4.4. Culture

Similar to the DIY culture which has a strong community of followers who like to build all kind of objects themselves, the digital fabrication community is enthusiastically exploring the possibilities of software and hardware. They not only modify the hardware, but also design products for their personal use. Typical is a carrot holder which attaches carrots to the cages of small pets. The file can be downloaded from Thingiverse and printed on any 3D printer. Surprisingly the original design has been redesigned and improved already by another member of the sharing platform. This illustrates, in my opinion, very well how amateurs and hobbyists are exploring the possibilities of this technology, and by a process of trial and error, are contributing to the long term success of the technology. In a way, this is also the way how the company MakerBot started to design their first 3D printer. Starting with a working prototype and enough parts to build 20 individual products, they sold it to interested individuals and opened their product up to improvement; several iterations later the quality of the product has been significantly improved and MakerBot has sold around 5000 3D printers. Looking at the growing number of Fab Labs, MakerFairs and projects on websites like Thingiverse, it seems possible that 3D fabrication technology will take a similar path to the personal computer. Bill Gates and Paul Allen envisioned a personal computer in every home which seemed to be a daring projection at that time but now many people in the US and Europe own several computers today. Through my experience in the Champaign Urbana Community Fab Lab I got in contact with people who are fascinated by this technology and have few reservations playing around with it. Although, being able to master the software is a major hurdle towards making effective use of any 3D printer, CNC router or laser cutter, it does not stop them from trying.

4.5. Designer as entrepreneur

The common role of a designer is to work for a client or with a distributor or manufacturer and it has been also possible for some to elevate this role, which is usually situated more in the background of a company, into a strong, international brand like Philippe Starck or Karim Rashid have. This career is not an option for every designer because it requires a lot of time, money and persuasion. A designer has to bring a product to market in order to be recognized. Without public recognition, nobody would like to invest upfront in the design cost for new products. Today, designers get the opportunity to create designs, test and evaluate them with the support of easily accessible digital fabrication techniques and pitch them to an internet audience of a many thousands of people. This is an opportunity which several design start ups have taken like Studio Neat. Consisting of two designers, they prototyped a new accessory for the iPhone called the glif, they successfully raised funding through Kickstarter and are now releasing their second product. Without digital fabrication technology, they would probably not develop their design to the point where they could demonstrate it and it was ready for manufacturing. Another possibility of how designers can carve out their own niche is the approach of Janne Kyttanen and FOC, in his own words at a Pecha Kucha presentation: "… we don't have any money to invest; we just sit on the couch and make some 3D files …. " (Kyttanen, 2010) His approach is basically to create whatever product he can think of, present it to the consumer through his website and if a customer would like to buy it, it will be fabricated. This approach is very suitable for his products since they are expensive to fabricate and he can keep the price low if he only fabricates them to order. In these two ways and many more variations thereof, designers could actually achieve being an entrepreneur, creating their own brand as well as being recognized internationally.

Chapter 5: CONCLUSION

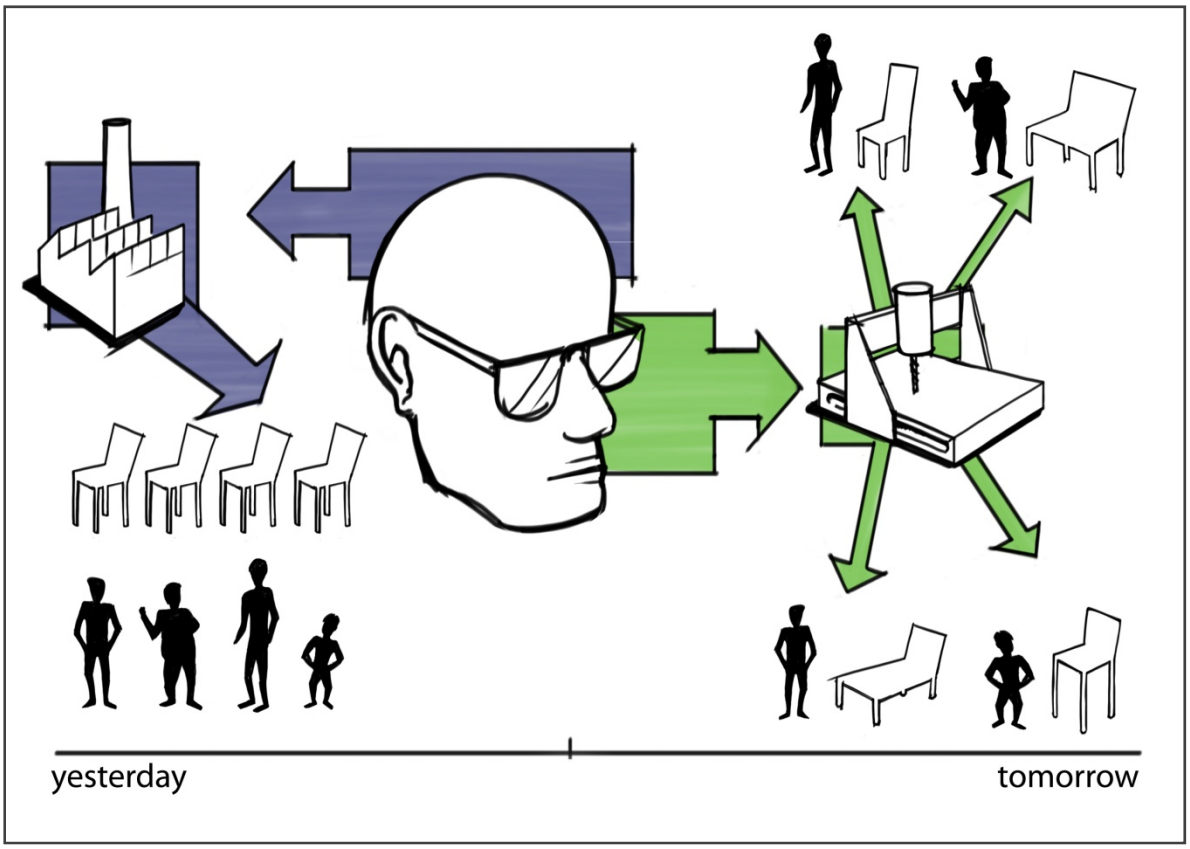

Figure 3: Diagram showing the transition of the designer from the traditional practice to a new practice of design. While the traditional approach consisted of fabrication one design which would fit everybody, the new approach uses digital fabrication technology to fabricate custom products that fit the specific customer.

5.1. Design and Digital Fabrication

Based on the research, we can predict that the role of the designer is changing. But has the role of the designer ever been constant? The profession of the designer has probably the least defined career path compared to similar disciplines like engineering or architecture. Designers work in various areas and ways constantly adapting to the needs of society.

Nevertheless, if personal fabrication is the next revolution that will impact our lives, like Neil Gershenfeld proposes in his book, it will drastically change the role of the designer. Originating in the Industrial revolution, designers have come a long way since then, always working in partnership with

the manufacturing industry. Digital fabrication already has its impact on manufacturing and if it is continuously advances at its current rate, it will change the manufacturing landscape. Maybe it will be just because additive manufacturing is more material effective than subtractive manufacturing or because it offers more flexibility in production. Looking at the relationship of manufacturing and design, it is inevitable that designers have to rethink their role. This might not apply to all, more traditional ways of product development might still continue but it is certain that young designers, recently graduated from a design school have to face this question. And it is up to the universities to prepare them for this. Educators have to face the fact that a certain part of product design has to move to China in the future which changes the job market for designers in the United States. If students are not prepared to redefine their role as a designer, they are facing challenging times. Designers acquire a lot of skills during the education but they are only trained to execute them in the current setting of client-designer-manufacturer. I must admit, this is a complex issue in itself goes further than the scope of this thesis. Nonetheless, designers are exploring new ways of designing a product and bringing it to market, direct and on their own initiative as Droog and several designers demonstrate through Kickstarter. Here might also be an opportunity for design education, usually always eager to expose students to real life design challenges, tools like Kickstarter are openly available and projects for it can be developed within the academic environment.

5.2. Supporting digital fabrication

There are numerous projections into the future that paint a picture where digital fabrication technology is available and used in every household. While this is a projection which is certainly questionable and promising at the same time, designers have to work with the tools they have available at this point in time. If designer can take close looks at current digital fabrication technology which is readily available, they might be able to find opportunities to make use of the current possibilities in technology to describe the future possibilities in digital fabrication. Based on their education in traditional craft or established industrial manufacturing techniques, designers envision new products which sometimes

challenge the techniques. They cannot wait until digital fabrication technology is well-established as is taught on the sophomore level in design schools as part of manufacturing processes. Today, designers can support and influence the future use of digital fabrication technology by treating it like a relevant manufacturing technique. By envisioning its potential relevance for the design, fabrication and distribution of consumer goods, they not only show an example to the industry but also to the consumer which is essential.

Being a student on a large and diverse university campus like at the UIUC has the advantage of being exposed to different kinds of technologies which are not accessible for everyone. While I am personally very familiar with digital fabrication technology, large parts of the society are unfamiliar with their technical possibilities. If digital fabrication can be employed in consumer goods and potentially change the way consumers purchase a product, it is necessary to expose the mass of consumers to the idea of customized fabrication and to highlight the value that it has for the consumer. If consumers recognize the value custom digital fabrication can offer them in specific product categories they are more likely to demand it from the industry. And if the demand is visible to entrepreneurs and businesses, it is very likely that profit oriented business plans will be developed to satisfy it. As part of a design project, designers are building models to visualize the potential finished result. By building a tangible model that visualizes the idea of custom digital fabrication today, we help to create it in the future. When Charles and Ray Eames designed furniture, they pioneered the use of technologies like fiberglass in industrial furniture fabrication. Today they are well respected for their achievements and their original chairs are high-priced commodities. Designers need to explore the opportunities of custom digital fabrication by experimenting without any hesitations. Since the beginning of their profession, designers have been going back and forth between working within manufacturing limitations as well as challenging them. Digital fabrication technologies are not new anymore, it is time for designers to challenge them and put their promises to the test.

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