Mass Customization:

An Approach to Designing Product Platforms for Mass Customization

by

Marc LaPilusa

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Approved by

Jerrod Windham, Chair, Assistant Professor Industrial Design
Chris Arnold, Associate Professor Industrial Design
Tin-Man Lau, Professor Industrial Design

Abstract

Over the last several decades, the production industry has experienced a paradigm shift from traditional mass production processes toward mass customization processes; this enables consumers to become an integral part in customizing products. The ability for consumers to specify options that fit their needs has created a large demand for customized products. This segment of opportunity in the production industry has prompted companies to begin implementing strategies for "mass customization" that create customer-centric value in all of their products and services. Mass customization is an approach to mass production that offers the consumer the ability to input their options and specifications into a final product. While mass customization allows the consumer to become an integral part to the design process, designers are responsible for developing the guidelines for consumers to design within. This ensures desirable outcomes for both the consumer and the company providing the product platform for mass customization. Mass customization is still immature in its development, but companies with highly developed infrastructures, like Nike and Ford for example, are leveraging approaches to mass customization.

This study researches different approaches to designing product platforms for mass customization. Product platforms for mass customization, as referred to in this research, are the platforms created to allow consumers to customize a product. These platforms should be built and created by designers; it is the designer's responsibility to develop boundaries and rules to ensure that consumers customize desirable products. Developing standardized approaches to designing these platforms creates consistency, which increases production efficiency, consumer satisfaction, and value that companies are able to offer their consumers. This research focuses on combining traditional production strategies with developing strategies for mass customization and rule-based customization; these strategies use emerging technologies like digital fabrication, CAD/CAM, 3D printing/scanning, and CNC technologies. In addition, this research explores the ability to automate production processes, which ensures precise fabrication and can streamline the development of successful product platforms for "mass customized" products.

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Definition of Key Terms

3D Printing: fabrication process in which a machine prints layers, which produces three-dimensional parts from digital files.

3D Scanning: process that uses a device that analyses a real-world object or environment to collect data on its shape and possibly its appearance. The collected data can then be used to construct digital three-dimensional models ("Dictionary and Thesaurus | Merriam-Webster", 2016).

Computer aided design (CAD): is mainly used for detailed engineering of 3D models but it is also used throughout the engineering process from conceptual design to layout of products and manufacturing ("Dictionary and Thesaurus | Merriam-Webster", 2016).

Computer aided manufacturing (CAM): is the use of software to control machine tools and related ones in the manufacturing of work pieces ("Dictionary and Thesaurus | Merriam-Webster", 2016).

Computer Numeric Control (CNC): a computer converts the design produced by Computer Aided Design software (CAD), into numbers. The numbers can be considered to be the coordinates of a graph and they control the movement of a cutter ("Dictionary and Thesaurus | Merriam-Webster", 2016).

Consultations: a meeting with an expert or professional, such as a medical doctor, in order to seek advice ("Dictionary and Thesaurus | Merriam-Webster", 2016).

Consumers: a person who purchases goods and services for personal use ("Dictionary and Thesaurus | Merriam-Webster", 2016).

Customer-centric: A specific approach to doing business that focuses on the customer. Client centric businesses ensure that the customer is at the center of a business's philosophy, operations or ideas ("Dictionary and Thesaurus | Merriam-Webster", 2016).

Digital Fabrication: is a type of manufacturing process where the machine used is controlled by a computer. The most common forms of digital fabrication are: CNC Machining: where, typically, forms and shapes are cut out of different materials ("Dictionary and Thesaurus | Merriam-Webster", 2016).

Economies of scale: a proportionate saving in costs gained by an increased level of production ("Dictionary and Thesaurus | Merriam-Webster", 2016).

Engineering-to-order: is a manufacturing process defined by demand driven practices in which the component is designed, engineered, and built to specifications only after the order has been received ("Dictionary and Thesaurus | Merriam-Webster", 2016).

Ergonomics: a science that deals with designing and arranging things so that people can use them easily and safely ("Dictionary and Thesaurus | Merriam-Webster", 2016).

Generative design: is a technology that mimics nature's evolutionary approach to design. It starts with your design goals and then explores all of the possible permutations of a solution to find the best option ("Dictionary and Thesaurus | Merriam-Webster", 2016).

Interchangeable parts: components that are, for practical purposes, identical. They are made to specifications that ensure that they are so nearly identical that they will fit into any assembly of the same type. One such part can freely replace another, without any custom fitting ("Dictionary and Thesaurus | Merriam-Webster", 2016).

Just-in-time manufacturing: is an inventory strategy companies employ to increase efficiency and decrease waste by receiving goods only as they are needed in the production process, thereby reducing inventory costs. This method requires producers to forecast demand accurately ("Dictionary and Thesaurus | Merriam-Webster", 2016).

Lean manufacturing: production process using a systematic method for the elimination of waste within a manufacturing system. Lean also takes into account waste created through overburden ("Dictionary and Thesaurus | Merriam-Webster", 2016).

Mass customization: is a marketing and manufacturing technique that combines the flexibility and personalization of custom-made products with the low unit costs associated with mass production ("Dictionary and Thesaurus | Merriam-Webster", 2016).

Modularity: having parts that can be connected or combined in different ways ("Dictionary and Thesaurus | Merriam-Webster", 2016).

Modules: one of a set of parts that can be connected or combined to build or complete something ("Dictionary and Thesaurus | Merriam-Webster", 2016).

MRSA: any of several strains of a bacterium that are resistant to methicillin and related antibiotics and may cause usually mild infections of the skin or sometimes more severe infections especially in hospitalized or immunocompromised individuals ("Dictionary and Thesaurus | Merriam-Webster", 2016).

On-demand manufacturing is a manufacturing process wherein goods are produced when or as they are required. In traditional manufacturing, an assembly line works on standard shifts to produce large quantities of products, which are then kept in storage facilities until they are ready for shipping ("Dictionary and Thesaurus | Merriam-Webster", 2016).

Paradigm: a theory or a group of ideas about how something should be done, made, or thought about ("Dictionary and Thesaurus | Merriam-Webster", 2016).

Parametric: a rule or limit that controls what something is or how something should be done ("Dictionary and Thesaurus | Merriam-Webster", 2016).

Prostheses: an artificial device that replaces a missing or injured part of the body ("Dictionary and Thesaurus | Merriam-Webster", 2016).

Prosthetist: a specialist in prosthetics ("Dictionary and Thesaurus | Merriam-Webster", 2016).

Specifications: a detailed description of work to be done or materials to be used for a project: an instruction that says exactly how to do or make something ("Dictionary and Thesaurus | Merriam-Webster", 2016).

Chapter 1: Introduction

Problem Statement

Product customization is the ability for consumers to include their personal preferences and specifications into a finalized product. Customization ensures consumer value because consumers play an integral role in creating a product that will address their personal needs. Allowing the consumer to become part of the design process is progressive, but not everyone has the aptitude for design, nor should they. Don Norman (1988) says in his book titled *The Design of Everyday Things*:

> Well-designed objects are easy to interpret and understand. They contain visible clues to their operation. Poorly designed objects can be difficult and frustrating to use. They provide no clues— or sometimes false clues (p. 2).

This means we cannot simply build an infrastructure that permits consumers to create or design whatever they want; rather, as designers we must build a product platform for mass customization that allows consumers to choose their specifications but retains brand language and ultimately produces "well-designed objects." Companies that have been successful in achieving productive "mass-customization" typically have large manufacturing infrastructures that have allowed them to sustain the transition from mass production to mass customization. Companies cannot achieve the same economies of scale that they are able to achieve using traditional mass production processes, which is a common problem for mass customization. Economies of scale are a reduction in the cost of producing something brought about especially by increased size of production facilities ("Dictionary and Thesaurus | Merriam-Webster", 2016) However, emerging technologies and approaches are making it easier for manufacturers to achieve the same economies of scale while offering the option to mass customize products. So, what does this mean for companies that are transitioning from traditional manufacturing approaches to mass customization product platforms? It means that by developing a strategy and an approach to designing product platforms for mass customization, companies will effectively offer customer-centric value through their ability to provide variety and options for mass customized products.

Need for study

The production of products and the systems that have been developed to produce them are becoming flexible, agile, and more robust because of the technological advancements in manufacturing industries. The ability to use mass customization platforms to gather consumer specifications and incorporate them directly into production without increasing the lead-times or production cost is new for the manufacturing industry. Since the strategies for mass customization are relatively new, there aren't many standard approaches to developing product platforms for mass customization in the production industry. This creates a need for standardizing approaches to designing product platforms for mass customized products.

This study will focus on defining the difference in approaches to mass customization as well as researching what companies are currently doing to adapt to new approaches toward mass customization; new approaches could involve leveraging emerging technology such as 3D printing. In addition, this study will develop strategies for designers to consider when they are creating different consumer options for mass customized product platforms.

There are many markets and opportunities for mass customization but to illustrate the approaches and strategies developed herein, this study will use the development of a product platform for mass customizing lower limb prostheses. The approaches and strategies developed in this research will be demonstrated by using customer specifications to customize a lower limb prosthetic. While product platforms for mass customization, in this study, will be illustrated by the development of custom lower limb prostheses, the strategies that are developed from this research could be applied to the majority of manufacturing industries.

Objectives

The following areas of research, development, and design are the primary focus of this study for creating an approach to designing mass customized product platform. This thesis will identify ways for designers to create product platforms for mass customization.

Objectives:

- Research approaches and strategies for mass production
- Research companies that offer different types of mass customization
- Research the approaches and strategies to offering mass customization
- Research emerging technologies that are enabling mass customization
- Research product platforms for mass customization
- Develop guidelines for a designer to implement/consider when they are designing mass customized product platforms
- Design a product platform for mass customization for designing lower limb prostheses
- Design and develop a lower limb prosthetic using mock consumer specifications

Assumptions

It is assumed that all of the information gathered during this research is accurate and appropriate for this thesis. It's also assumed that the research within this project will be adaptable based on the size of the company using service platforms for mass customized products. In addition, this research should be expandable as emerging technologies continue to develop by becoming more accurate, quicker, responsive, and more affordable. This assumption is based on trends in technology development; technology often decreases in price as its capabilities become greater. For example, the advancements that the computer industry has experienced for personal computers or the increase in smart phone technology.

The research for mass-customized product platforms is based on the assumptions that consumers have a desire to include their specifications into final products that will be tailored to their individual needs. It is also safe to assume that companies using mass customization platforms have a manufacturing infrastructure and sales strategies that support this. Mass customization will not replace mass production especially for industries that are considered to be "essential" products like detergent or lumber. This research simply suggests the opportunities and growth for companies that can implement mass customization strategies to allow consumer customization at different degrees of design.

Assuming these points, designers will understand that this study is to develop a guideline that will assist them in developing a successful approach to designing mass customized product platforms. There will be a variety of different configurations that a designer can use to create successful mass customized product platforms. Designers approaching this development should understand that this involves far more than simply product output. They must begin with the ability to generate variety and then follow the guidelines for implementing consumer specifications, introducing those into the manufacturing process, and finally delivering customized products.

Scope & Limits

This research, when applied by designers, should generate a mass customized product platform that affords consumers with the opportunity to input their specifications that can be processed by manufacturing facilities, which can then be fabricated into customized products. The approaches and strategies chosen by the designer should apply to their company's organization as well as the consumer demands. Designers should implement the use of emerging technologies to maximize the growth and possibilities for mass-customized products. The scope of this research may be limited by the size of a company and its ability to include different approaches, strategies, and technologies. The scope is also limited by the growth of the emerging technologies specifically because of price and developments.

Anticipated Outcomes

It is anticipated that the outcome of this research will provide designers with a synthesis of guidelines for designing product platforms for mass customization. Product platforms for mass customization, as referred to in this research, are the platforms created that allow the customization of a product. These platforms should be built and created by designers to ensure that consumers customize desirable products. This research will describe the different strategies and approaches toward developing product platforms for in-store customization (often collaborative customization) and web-based customization service platforms. This research will also show the differences between mass customization and modular mass customization.

Providing designers with a comprehensive approach toward designing product platforms for customization will allow them to analyze a company strategy and create a platform for customization. By understanding a company's industry, choosing a method of mass customization, defining the approach toward mass customization, and the technologies that will be leveraged, designers will be able to create a product platform for mass customization specific to that company. This will provide consumers with the option to input their specifications based on a decision point set forth by the designer.

This study will illustrate how to design a product platform for mass customization, using the guidelines developed by this research, to create a mass customization platform for lower limb prostheses.

Chapter2: Literature Review

Introduction

For the history of product development, the concept of mass production is a relatively new system for manufacturing. For centuries, craftsmen and artisans created custom finished products from raw materials. Craft-based production required a great deal of knowledge and specialized skill sets, but tools and technologies evolved to propel the manufacturing of goods into the system of mass production that is familiar today. The growth of technologies prompted product manufacturing to shift from craft based goods to products developed with interchangeable parts under the American System of Manufacturing. Henry Ford expanded The American System of Manufacturing by coining and creating the concept of an assembly line (Ford Company History, 2016).

Further, new technologies being employed in the industry today are changing the production processes yet again by generating products using digital design and fabrication ("Just in Time" - JIT | Investopedia 2003). These new processes are continuing to change the way companies and designers approach product design and production. Ultimately, manufacturing is a process that will continue to advance with the development of new tools and technologies. Manufacturing processes that are constantly changing will affect how products are being designed and produced. As processes and technologies change, designers should adapt and understand the next wave for product development. Some designers are exploring a new approach to product development referred to as "mass customization ("Just in Time" - JIT | Investopedia 2003)." *The Business Dictionary* (2016) defines mass customization as:

> The production of personalized or custom-tailored goods or services to
> meet consumers' diverse and changing needs at near mass production prices;

enabled by technologies, it portends the ultimate stage in market segmentation where every customer can have exactly what he or she wants (n.d.).

Giving each consumer exactly what he or she wants is a difficult task to achieve unless there is a well-designed system or platform to receive consumer input, incorporate that into the manufacturing process and output customized products. The challenge for the manufacturer becomes being able to produce accurately, on time and for a competitive cost relative to the current cost of mass-produced products. The concept of mass customization encompasses either a "modular mass customization" similar to NikeID or mass customized one-of-a-kind products like tailor-made suits. There is a wide range of design opportunity between these two basic forms of mass customization. This research will explore how to design a product platform that will be positioned between the two.

Today, every consumer has different wants and needs when they are shopping to purchase a product. This creates a large demand for customization among consumers because many mass-produced products offer limited options in a product line. Designing a mass customized product platform will allow consumers to incorporate their own ideas by designing for their personal needs. For certain industries, well-designed product platforms can assist and guide the consumer through the design process for their end product. In a sense, consumers become an integral part for the development of the item they purchase. This may be appealing to consumers because their purchase experience involves personalizing their product. Pine also notes that the consumer demand to customize their products is a catalyst for the manufacturing industry to start integrating mass customization approaches. Companies can offer a wider selection of products or begin to offer minor adjustments to products such as color choice. Pine

(1991) notes in his article titled “Mass Customization: The New Frontier in Business Competition”:

> Mass customization is the new frontier in business competition for both manufacturing and service industries; the concept at its best is to increase the variety and customizability without the corresponding spike in costs but at the very least it will be the mass production of individually customized goods and services (p. 8).

If the production industry gradually begins to offer choices among product options, it will create more diverse product lines. Hopefully, gradual custom manufacturing changes will mature into mass customizable production processes. By continuing to use and develop technologies such as digital design and fabrication, customizing personal products may be limitless in the future. The research within this study will identify the need for mass customized product platforms. The guidelines created using this research will illustrate how to design a product platform that allows consumers to become involved in the design process of their product. Developing a mass customized product platform will not only increase consumer satisfaction, it will increase production efficiencies and the opportunities for customizing individual products.

Mass Production

For thousands of years artisans and craftsmen have been developing tools, finished goods, and products for end users. Until the 19th century however, tools and products were commonly created one-by-one at the request of a consumer or end user. Tanenbaum (2016) supports this thought in an article for the Encyclopedia Britannica titled “Mass Production”, stating that it would take years for a craftsmen to learn a particular trade; they made their own tools and were typically identified by their craft because of the close association they had with consumers. The development of tools and manufacturing machinery has been a key advancement in the human ability to create products consistently and reduce the production time. In *Digital Design and Manufacturing,* Schodek (2005) acknowledges that:

> The development of tools has long been acknowledged as one of the defining characteristics of human evolution. They have served to increase human power, improve precision, and generally be the enabling devices that have defined our unique ability to make tools used in turn to make other tools, and thus ultimately create a stunning world full of artifacts (p. 17).

If tools have constantly developed to become the driving force of the production industry for the entirety of humankind, then tools and technologies will inevitably progress to become more efficient than they currently are today.

Whipps (2008) documents that the concept of mass production was first recorded in Asia around 600 A.D. with their ability to carve wooden blocks that were then used to press ink onto paper. The idea of setting text reduced the need for scribes and increased the idea of "mass producing" written work. This initial concept of type setting was tedious and required typesetters to lay the text on paper. With hundreds of characters in Asian languages, their process never spread. This idea was later revisited and made famous by Johannes Gutenberg with his development of the printing press in 1436 (Figure 1). The English language has a fraction of characters in comparison to many Asian languages, becoming a far more conducive fit for the printing press. Gutenberg's invention used wooden and metal individual characters of type that were fixed into a tray, rolled with ink and pressed on paper. This meant that once the type was set, multiple copies could be reproduced countless times. This invention expedited the printing process dramatically resulting in a mass production of type, documents, and books. This increase in the publication of type ultimately created a higher exchange of information and led to an increase in the overall literacy rates. Gutenberg's ability to recreate the same sets of type repeatedly makes the printing press one of the very first "tools" used for mass production. One of Gutenberg's first and most notable prints is the Gutenberg Bible. The prints were so revolutionary that the first set of 200 illustrated Latin Bibles sold before Johannes Gutenberg set the last page.

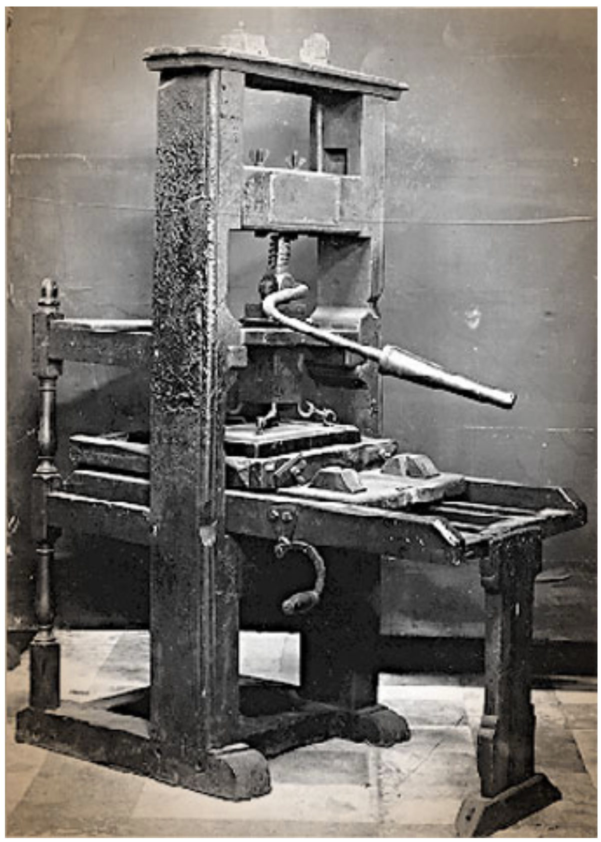


Figure 1: Johannes Gutenberg's Printing Press, circa 1450 CE. © ASME May 2012, Nancy Giges.

Many other inventors, businessmen, and craftsmen attempted to replicate Gutenberg's success through mass production. However, before the industrial revolution the term "mass production" did not really exist. It was difficult for industrialists to understand mass production methods prior to defining the criteria needed to create them. To help better understand this concept, Tanenbaum (2016) defines mass production as:

> The application of the principles of specialization, division of labour, and standardization of parts to the manufacture of goods. Such manufacturing processes attain high rates of output at low unit cost, with lower costs expected as volume rises. Mass production methods are based on two general principles: (1) the division and specialization of human labour; and (2) the use of tools, machinery, and other equipment, usually automated, in the production of standard, interchangeable parts and products (p.1).

Two general principles of mass production Tanenbaum notes can be seen in civilizations throughout history. Ancient Egyptians creating a division of labor among the slaves during the construction of the pyramids, while Greeks and Romans had a division of professions among artisans and craftsmen (Kraft, 2016). Tools date back to the earliest evidence of Nomadic tribes and settlers discovered thousands of years before the Common Era; reference Figure 2 (Kraft, 2016). It wasn't until later during the eighteenth century that these production principles were developed further, eventually creating the system of mass production.

Figure 2: Woodworking tools including heavy stone axes, gouges and adzes recovered from archaic sites, circa 4000 BCE. © New Jersey Skylands 1996-2016, John Kraft.

For the history of mass production, the Gutenberg print press was the greatest tool created during its era. Until the first signs of the industrial revolution in the 19th century, there aren't many inventions or developments that promote the concept of mass production. Tanenbaum (2016) discusses the next innovations that paved the path toward the industrial revolution; he lists five notable developments in the textile industry, describing them as:

> (1) John Kay's flying shuttle in 1733, which permitted the weaving of larger widths of cloth and significantly increased weaving speed; (2) Edmund Cartwright's power loom in 1785, which increased weaving speed still further;

> (3) Hargreaves' spinning in 1764; (4) Richard Arkwright's water frame in 1769; and (5) Samuel Crompton's spinning mule in 1779. The last three inventions improved the speed and quality of thread-spinning operations. A sixth invention, the steam engine, perfected by James Watt, was the key to further rapid development (p.1).

The sixth invention Tanenbaum notes, the steam engine, sparked the beginning of the industrial revolution by developing an energy source more efficient than previous energy sources. This caused the manufacturing structures in Europe to change from craftsmen's homes into larger production facilities. The transformation toward the industrial revolution became apparent as these production facilities began creating more consistent products in shorter periods of time. The contributions to the production industry from Europe during the start of nineteenth century were unlike any preceding them, but many historians attribute the great advancements in mass production to the United States (M*ass Production* (2003) in *The Dictionary of American History)*. M*ass Production* (2003) in *The Dictionary of American History* supports this idea by saying:

> Even with the early successes in Europe, scholars of technology attribute the widespread adoption of mass production to trailblazers in the United States. With its abundant waterpower, coal, and raw material, but shortage of workers, America was the ideal place for building skill into machinery.

Machinery and tools for manufacturing products rapidly advanced in the western world during the nineteenth century. The idea to create machining processes that produced interchangeable product parts was introduced. This was a pivotal development toward manufacturing products for the masses because using interchangeable parts made some production processes standardized. The article *Mass Production* (2003) from *The Dictionary of American History* credits the American inventor Thomas Blanchard as one of the pioneers for using mechanized production processes to make firearms for the federal army; his efforts were supported by the War Department, which funded and promoted other application for mass production. Developments in mechanized production processes and the use of interchangeable parts mark the beginning of the mass production era in the western world. This production process was referred to as The American System of Manufacturing.

According to Pine (1991) mass production was based off of The American System of Manufacturing. These structures were so closely related that The American System of Manufacturing became part of the principles for mass production (Figure 3). While many businesses utilized ideas for the division of labor and interchangeable parts, Henry Ford is responsible for combining these ideas and integrating them into a set of mass production principals for the automobile industry. As a result, Ford is often called the "Father of Mass Production"; his principles for mass production were so innovative, mass production was also referred to as "Fordism." He made his fame by creating an assembly line while developing a low-priced automobile for the blue collar working man known as the Model T (Figure 4), which Ford referred to as the "universal car".

Figure 4: Henry Ford standing with 1921 Model T (The Antiplanner, 2013)

A line foreman named William C. Klann introduced the idea of "flow" using assembly lines in Ford manufacturing facilities. Klann and his colleagues saw the efficiency of assembly lines in continuous process industries such as distilling alcohol, cigarette manufacturing, flour milling and the "disassembly" lines in slaughterhouses (Pine 1991). The slaughterhouses they visited used conveyors to carry hogs and cattle through a disassembly process that decreased the time it took to remove and package the meat. The flow of an assembly line allows automatic movement of work and brings it to the worker. This idea for flow in a manufacturing facility meant that workers would no longer work at a workbench to complete each individual part; rather workers remain on a line and complete a task over and over as parts are fully developed by moving down the assembly line. In 1913, the engineers at Ford began experimenting using Klann's idea for conveyor systems began implementing flow into the Model T assembly line

(Pine 1991). Ford and his engineers discovered the need for an assembly line (Figure 4) once they understood mass production's economies of scale. Economies of scale are achieved by manufacturing strategies that reduce the cost of production while increasing the number of products that can be made.

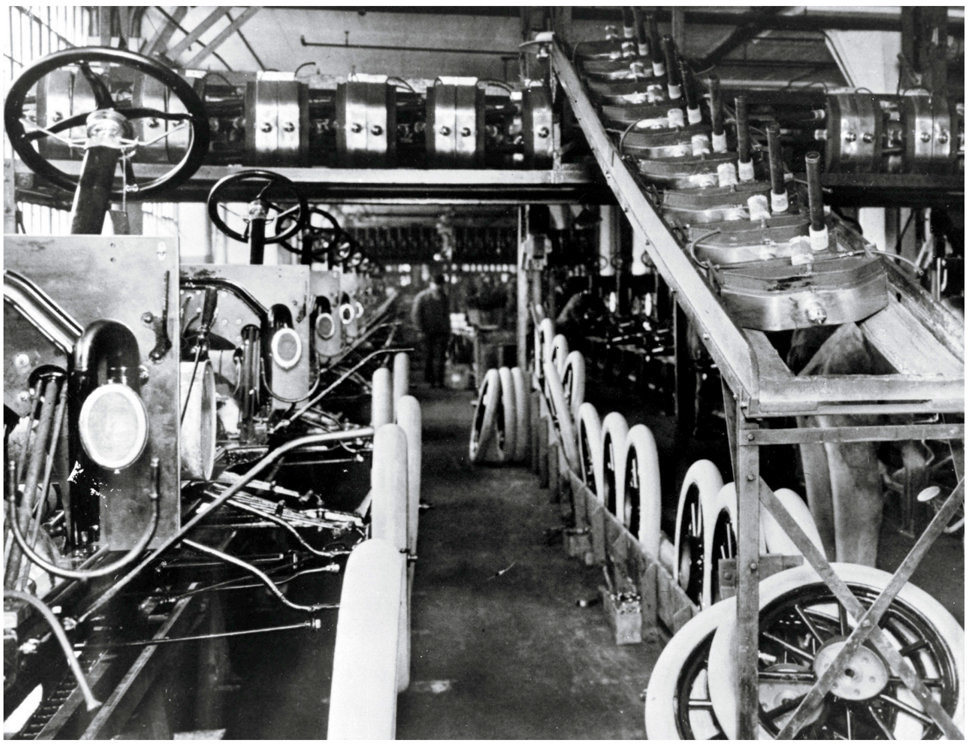


Figure 4: The moving assembly line at Ford's Highland Park Plant, circa 1914 CE.

(The Antiplanner, 2013)

By creating conveyor belt systems for completing parts, subassemblies, and full assemblies, Ford was successful at reducing the overall cost and production time dramatically. Gelderman (2016) in *Encyclopedia Britannica* notes that between 1913-1914, Ford's production plant was able to deliver parts and assemblies on its assembly lines with precise timing; chassis were completed every 93 minutes, which was a large improvement over the 728 minutes required by Ford's previous production methods. The increase in productivity resulted in a decrease in the cost for a Model T (about $850 in 1913) and an increase in pay scale for the factory workers. Gelderman (2016) in *Encyclopedia Britannica* also states that during 1914, The Ford Motor Company was able to increase its wages to $5.00 per day from the previous $2.34 per day; Ford also shortened the work day to 8 hour shifts which divided the factories work day into a three-shift day. Before The Ford Motor Company implemented its structure for mass production, profits were made by paying workers as little as they would take and pricing vehicles as high as consumers would consistently pay. Ford, however, was adamant about achieving low prices to capture the largest market share and he aimed to meet that price with an equal volume and efficiency. The increase in production and the reduction of cost was made possible only through the economies of scale which eventually allowed Ford to produce a Model T every 24 seconds in the 1920's.

The economy of scale principal affords manufacturers the opportunity to produce a large quantity of products and focus on selling them later. Pine (1991) states that until "Fordism," manufacturers weren't focused on lowering costs using the economies of scale; instead they produced products with a higher quality at a higher output rate, which in fact drove the price upward. To increase product output using The American System of Manufacturing, companies would increase the number of machines and workers. The difference with mass production is that companies want to focus on decreasing the number of skilled workers and increase the skill and speed of the production machinery. This required a seamless flow in the production processes, which was the ultimate need for using an assembly line. Utilizing an assembly line, companies were able to reduce production costs because fewer workers were being paid and faster machines were used to increase productivity and efficiency. This ensured that more products were produced, at a higher rate. While this may increase some fixed costs, it also reduces the cost per unit. Ford's plan was successful because a primary goal was to lower production cost as well as the price for the consumer, which truly created products for the masses. Pine (1991) goes on to say:

> Lowered costs meant prices could also be lowered; an internal logic came into play in the development of Mass Production. As prices were lowered, more people could afford the products and would buy them, resulting in greater sales and therefore greater production. (p. 16)

Reducing the cost of production and the price per car increased the demand for Ford Model T's. Mass production economies of scale were able to work well for Ford because Model T's were a very standard automobile which all used the same chassis. Standardizing a vehicle was revolutionary but this meant that all Model T's coming off the assembly line were the same. At the time, Ford only intended to make one model, the Model T. So what would this mean for consumers that wanted options?

Hessman (2004) discusses how initially, Henry Ford had little regard for consumer wishes; Ford wrote in his autobiography that one morning he told his sales team, "Any customer can have a car painted any colour that he wants so long as it is black." There is skepticism to whether he meant this in a literal sense but it frames his outlook on consumer options and customization. To Ford, it was all about achieving "full-speed" production on the assembly line so black was chosen because of its faster drying time. However as a salesman, Ford understood that his business wouldn’t continue to expand without paying close attention to customer suggestions as well as competitors strategies. The Dodge brothers and other competitors began making subtle design changes to their automobiles in addition to offering different colors. Ford would also follow the trend by offering design changes for different models.

By offering options, companies place a limit on their ability to mass-produce at full-speed. Options however, are a large factor in a consumers purchasing experience. The consumer wishes to feel like they are considered and desires options that are appealing to them. An issue with mass production is that industries are making assumptions for the options that consumer's want/need. The notion for offering options throughout a product line will prompt a paradigm shift from full-speed mass production toward production methods that produce more customized products. This paradigm shift is a change in the approach to mass production, by redefining the guidelines, in the pursuit of offering variety to consumers. Hessman (2014) says in his article titled "Have It Your Way: Manufacturing in the Age of Mass Customization" that, "The world, it seems, wants something impossible: mass customization -- all the charm of artisanal production with all the advantages of mass production."

Today, automotive companies and most product manufacturing companies will offer a variety of customizable options to their consumers. Each company has its own sales strategy, but companies typically provide a selection of options across product lines; consumers also have a choice of options between different companies' products. Customizable options specific to the automotive industry include, among others, exterior color, interior material, sunroof options, sound system upgrades, engine modifications, and tires. For some automotive companies, including Ford, consumers can use digital customizing platforms to customize and order a vehicle (Figure 5 and Figure 6). Each option may become an add-on for the consumer or an element used by the marketing team to entice consumers to explore and buy exactly what they are shopping for. Clothing brands like Adidas and Tommy Hilfiger allow consumers to 3D scan body measurements and use these to shop for apparel online ensuring a custom fit (Figure 7). These new technologies however, cause a problem for the demand of older, established mass produced products (Pine 1991). Options and variety being offered to the consumers is causing yet another change for mass production processes. Pine notes the need for an evolution in mass production, saying:

> Creating variety and customization in production cannot be done through the specialized techniques of Mass Production; creating variety requires most of all flexibility in manufacturing processes, the antithesis of Mass Production. The system must therefore be changed. While still producing as high a volume at as low a cost as possible, it must produce a number of different, high quality products via short production runs, short changeover times, and low work-in-process. This requires general-purpose machinery and highly skilled workers. (p.46)

Creating variety for the consumer is important, but adapting production processes to create custom products at mass production economies of scale is the next step in the evolution of product manufacturing. Companies that can adapt to stay ahead of this curve can be successful at gaining a piece of the mass customized product market share. Davis (1987) says in his book *Future Perfect,* "The general message is, the more a company can deliver customized goods on a mass basis, relative to the competition, the greater is their competitive advantage."

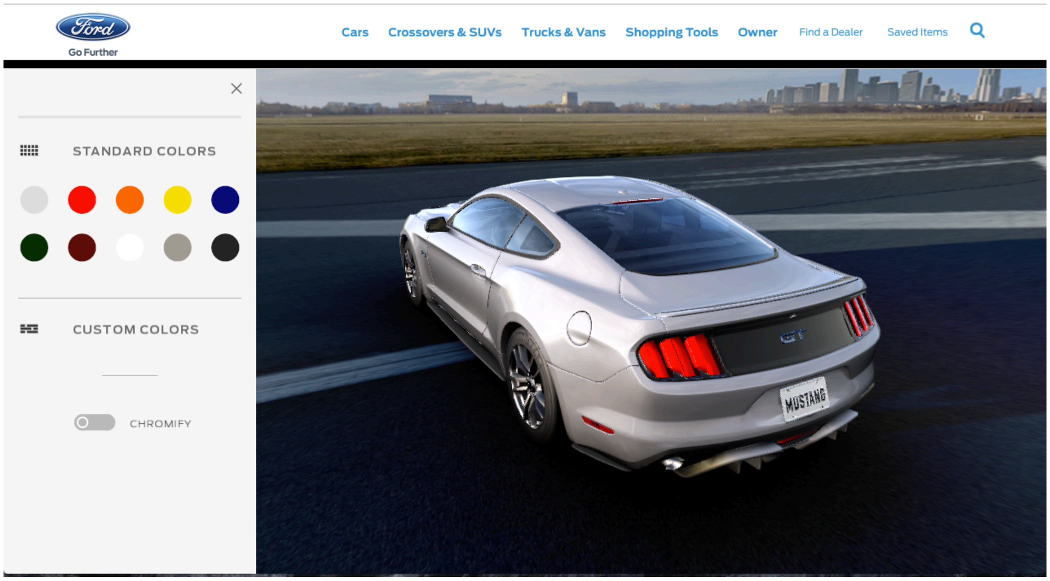


Figure 5: Ford website color options (Ford, 2016)

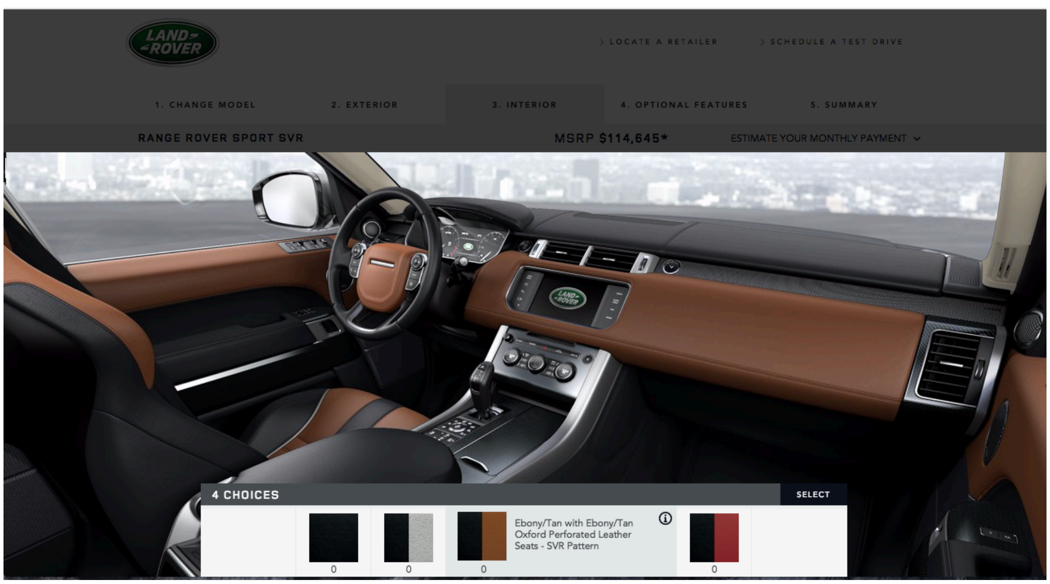


Figure 6: LandRover website interior color options (LandRoverUSA, 2016)

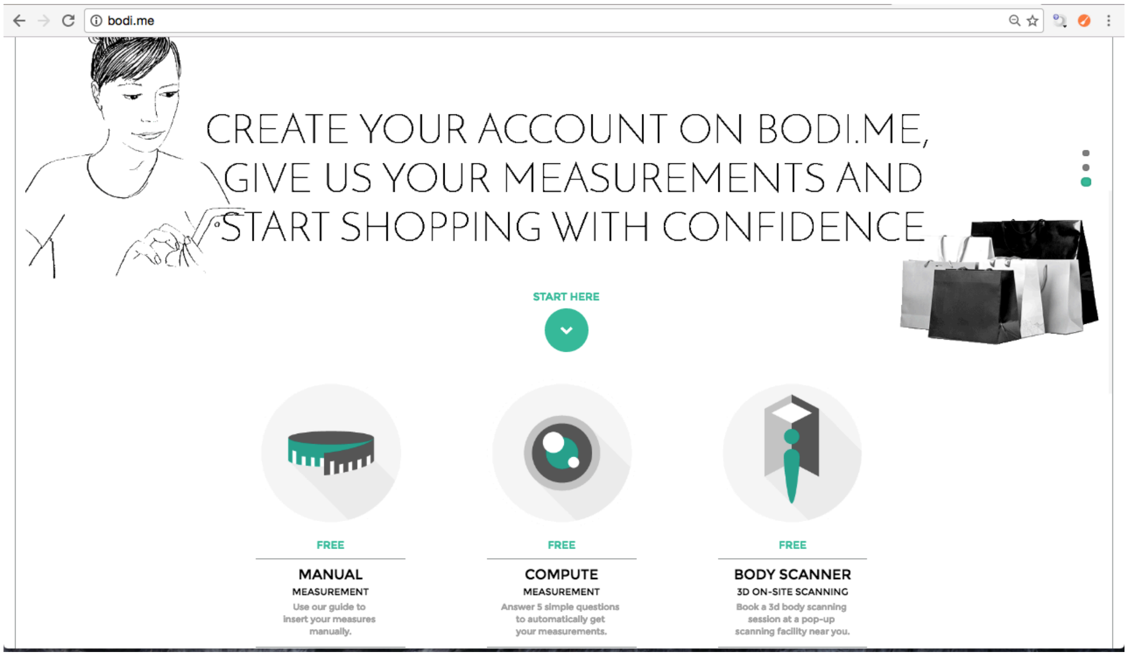


Figure 7: Bodi.me website for 3D scanning sizes (Bodi.me, 2016)

Mass Customization

Mass customization is the concept for companies to provide consumers with products and services that are personalized to meet specific individual needs. It allows consumers to become an integral part of the design process by choosing different features or options for a product, without significantly increasing the price point. Consumers are still limited by the design boundaries set forth by designers. Designers should create a broad range of options for consumers to select from, allowing consumers to design to size specifications and other personalized options. However, rules must be setup by designers so that companies retain their brand identity and to ensure that good designs are being created and produced. Good design should be subjective to the designer and the company they are working for. This is a much different approach to product manufacturing, design, and distribution than the approach of the revolutionary mass production process that preceded it. In the past, mass production was serving homogenous markets and providing the same products to serve a variety of different needs. Now, mass customization is allowing consumers to tailor these products to specific needs and personal specifications. Investopedia ("Mass Customization" 2003) defines mass customization as:

> The process of delivering wide-market goods and services that are modified to satisfy a specific customer need. Mass customization is a marketing and manufacturing technique that combines the flexibility and personalization of custom-made products with the low unit costs associated with mass production.

When we think of how complex the structure for mass production is, especially within a large scale manufacturing industry such as the automotive industry, it seems that developing a structure for mass customization would be incredibly challenging. It also seems that mass customization will be very expensive for both the manufacturer and the consumer. The closest production technique that allows consumers to customize their products is engineering-to-order, which gives consumers the ability to customize exactly what they want. With that, companies offer a large variety of options to the consumer however; it is typically very expensive to engineer products on demand. How can industries manage to offer variety in their products to meet the needs of each individual consumer while maintaining their brand identity, operational efficiency, and economies of scale production? Jordan Reynolds (2014), a manager of innovation at the consulting firm Kalypso, says in a blog post that while mass customization seems to be the exciting new thing, it really takes old elements of our production systems that have existed and restructuring them to achieve customized products for the masses at a competitive price point.

What is interesting about mass customization however, is while designers are enabling consumers to include personal specifications; designers still identify boundaries for customization. It is the designer's responsibility to determine how open customization options will be for consumers. It is the designer's job to identify the options that consumers may select. Designers should create options that are realistic and create a desirable outcome for the company as well as for the consumer. If the consumer requests obnoxious customization options, designers should discourage these choices or refuse to customize them.

Indochino

Indochino is a web-based men's custom suit company that strives to offer stylish yet affordable custom fitting suits. Suits have been customized for centuries; they were not sold in "standard" sizes until the mass production revolution. Men visited tailors to have their measurements taken; the tailor would then sew and alter a suit to fit perfectly. Today, however, tailor-made customs suits are very expensive to make. By taking advantage of technological innovations as well as the economies of scale, Indichino offers tailor-made suits at a competitive cost relative to retail suits. The process for ordering a custom made suit through Indochino has an appeal in itself. Indochino has a couple options to begin customizing a suit. First, customers begin by taking their measurements with the help of a friend. Indochino offers measuring tapes for $1.00 that ship for free. They also offer "The Tailors Kit" (Figure 8) that can be purchased for $29.00, (a $29.00 credit is later added to the customers account) which includes 16 different garment swatches of the customer's choice along with two measuring tapes. The customer then follows easy step-by-step videos provided by Indochino (Figure 9) to take their own measurements at home. These measurements are then added to the customer's user profile on Indochino's web-based customization platform. Next, customers chose the garment they will be customizing, with options for tuxedos, blazers, vests, pants, shirts, and of course, suits. Once the garment is selected, there are additional options to choose from (Figure 10). After the order is placed, it usually takes about a month to process and deliver the custom garments to the customer. Because ordering a custom suit from the internet involves risk regarding sizes, Indochino guarantees quality assurance by offering a $75.00 stipend for local tailor alterations along with refunds and remake options if the customer is not satisfied. Indochino's operating model is well thought out, as described in a long quote from Akash Patel (2015). In his blog post for the Harvard Business School titled *Indochino: Transforming the Custom Suit Industry*, he says:

> Indochino's operating model is a complex balance of production planning, purchasing, materials management, distribution, forecasting, and customer service. Wool is purchased from Australia, milled in Italy, and constructed in Shanghai. The factories in which the suits are constructed were traditional mass suit producers that made 10,000 suits every 4 months; Vucko convinced these manufacturers to reconfigure their entire floors, instead operating on a new "mass customization" model that produces one new suit every 1-2 days. Indochino pays the factory workers but does not own any assets, a decision reflective of its business model that keeps all input costs low and passes the savings on to the customer. Traditional suit manufacturers have grown to welcome Indochino's production model because the higher margins on custom suits more than offset the loss in output.

The company sees success from its ability to be agile by using these lean manufacturing techniques to produce only what is purchased, which keeps inventory low. While the company has seen all of its success through an e-commerce platform, in 2014 Indochino began opening pop-up stores throughout North America so consumers could be involved in the experience of customizing a suit. There are currently 10 showrooms setup in major cities across North America. A unique industry like custom suits presents an opportunity for companies like Indochino to take advantage of truly mass customizing products for end users.

While Indochino provides a product that is created through mass customization, while customizing their products, consumers must still remain within a specific set of boundaries set forth by Indochino designers. Indochino has setup a selection of suit styles, garments, and customization options that direct consumers toward desirable outcomes. These parameters have been created so that Indochino is confident when they provide their custom suits to consumers that the final product will be a well-designed suit. Boundaries are created so that consumers may not provide specifications that are unrealistic or may turn out unpleasant. If a consumer demands that he wants a suit made from Jell-O that dissolves when it rains, Indochino can't and shouldn't provide this product to the consumer.

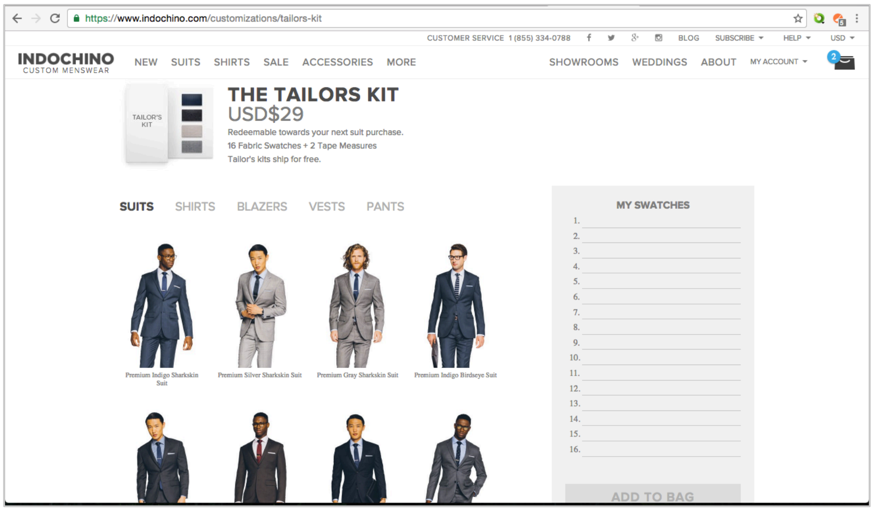


Figure 8: The Tailors Kit (Indochino)

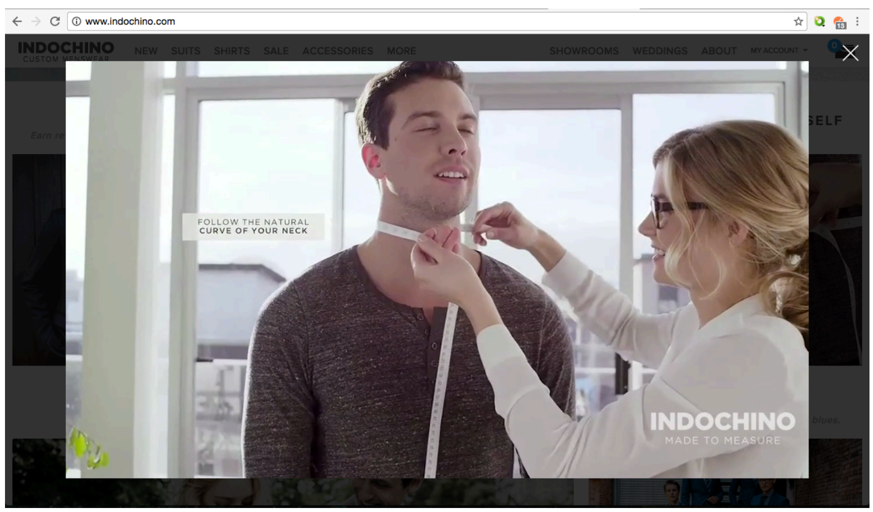


Figure 9: Step-by-Step Videos (Indochino)

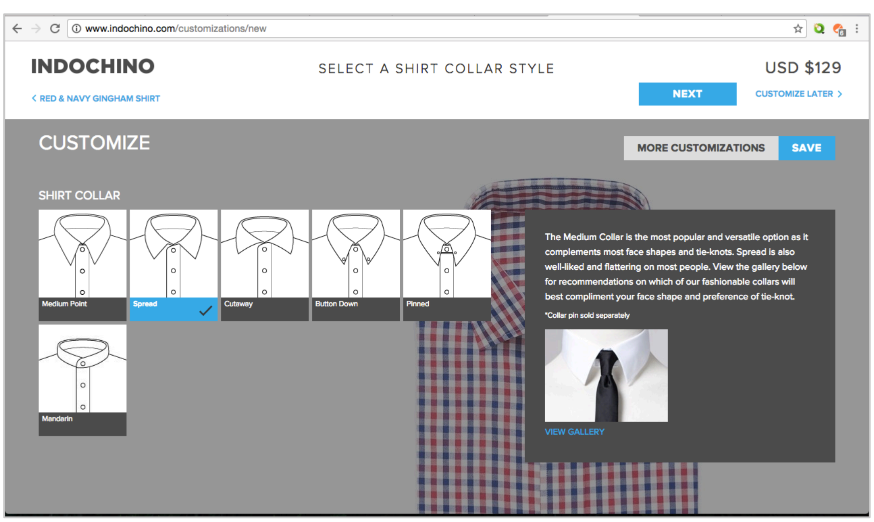


Figure 10: Garment Customizer (Indochino)

Nervous System

Nervous System is a generative design studio that works at the intersection of science, art, and technology (Nervous, 2016). The following information is from the Nervous (2016) website. Inspired by all of the life forms around us, Nervous System uses computer simulation to generate original designs based on reoccurring patterns and processes that happen in nature. Nervous reticulate earrings, for example, are inspired by the redundant branching patterns of veins in the leaves of plants (Figure 11). Once the designs are generated, they use digital fabrication to instantaneously produce their creations. Nervous creates and sells an eclectic collection of art, jewelry, and home décor to a very diverse group of consumers. Nervous System began in 2007 by taking advantage of the emerging technologies such as digital modeling, rapid prototyping, and ecommerce platforms. These tools allowed them to explore many different avenues for customization. They provide a unique method for mass customization by using algorithms and different variables to produce very unique designs. In a write-up on their website, Nervous (2016) says:

> To evolve such forms, we systematically engage in generative processes. Instead of designing a specific form, we craft a system whose result is a myriad of distinct creations. These systems are interactive, responding both to changes in specific variables and to physical inputs. There is no definitive, final product, instead the many designs created allow for mass customization (2016).

In a project completed in 2014 called Floraform, Nervous used generative designs inspired by the biomechanics of growing leaves and blooming flowers to generate a collection of their work

(Figures 12 &13). This study was an experiment to plant a "digital garden" with designs growing at different rates through space and time (Nervous, 2016).

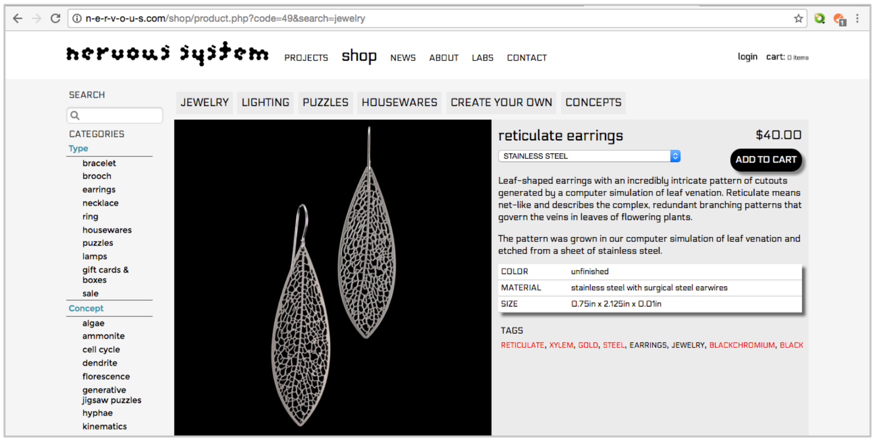


Figure 11: Reticulate Earrings (Nervous)

Figure 12: Floraform System (Nervous)

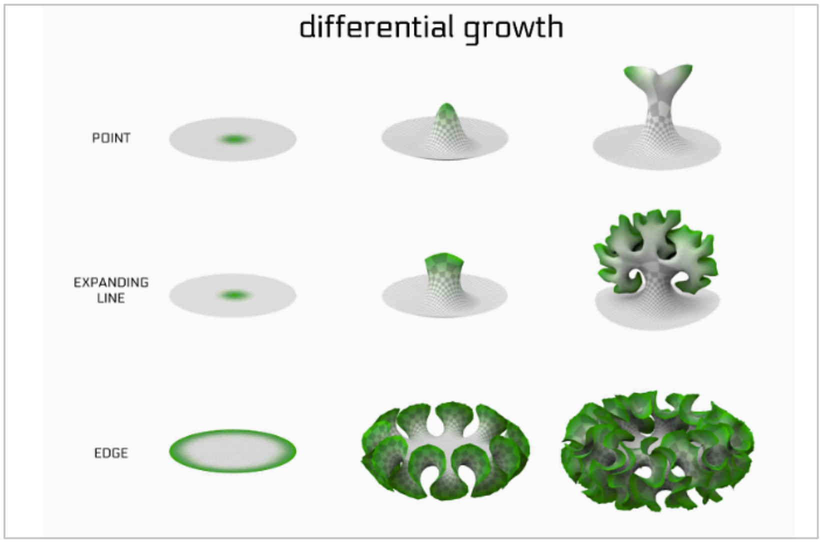


Figure 13: Floraform Differential Growth (Nervous)

Utilizing these same approaches to generative design, Nervous (2016) lets its customers co-create products using the same process. A project that has received great public response is the "Kinematics Dress" which was originally created in 2014. Using the same concept for generative forms, Nervous System developed a concept to successfully print an entire nylon dress in a single 3D printing process without the need for assembly (Figure 12). The dress is composed of thousands of interlocking parts (Figure 13), which move fluidly to mimic the properties of a dress you would purchase at any high-end retailer. To push the boundaries of customization even further than the men's custom suit company, Indochino, Nervous offers a customization platform that allows consumers to scan in their body measurements for a perfect fit (Figure 14). In addition, users then have the ability to customize the pattern and color of their dress. This breakthrough in science, technology, fashion, and customization is now included in the permanent collections of the Museum of Modern Art and the Cooper Hewitt, Smithsonian Design Museum (Nervous 2016).

While Nervous has the ability to create very customized and personalized forms, it is important to note that they provide guidelines for consumers to design within. While they mass customize kinematic dresses to meet individual user specifications, they are still working inside the criteria for a dress design. Nervous designers have setup boundaries for their products that they offer for customization. This is still allowing consumers to become an integral part in the customization process by personalizing designs, sizes, and cosmetic specifications but it is also making sure that the final product will be a dress. The same idea applies to all of the products that Nervous allows consumers to participate in customizing.

With its unique business model and diverse products, Nervous System is attracting a very broad audience. Leveraging the technological advancements of the production industry and coupling that with a very unique design process, Nervous is successfully providing a wide array of mass customized products and services.

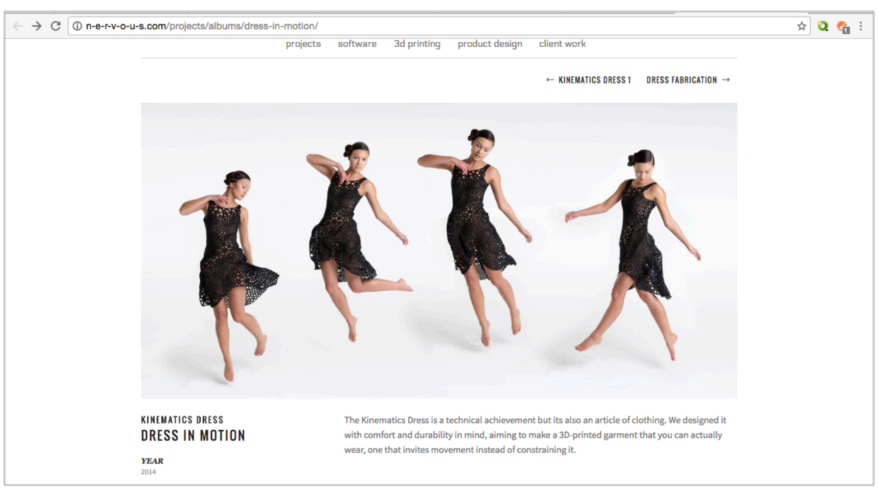


Figure 14: Kinematic Dress (Nervous)

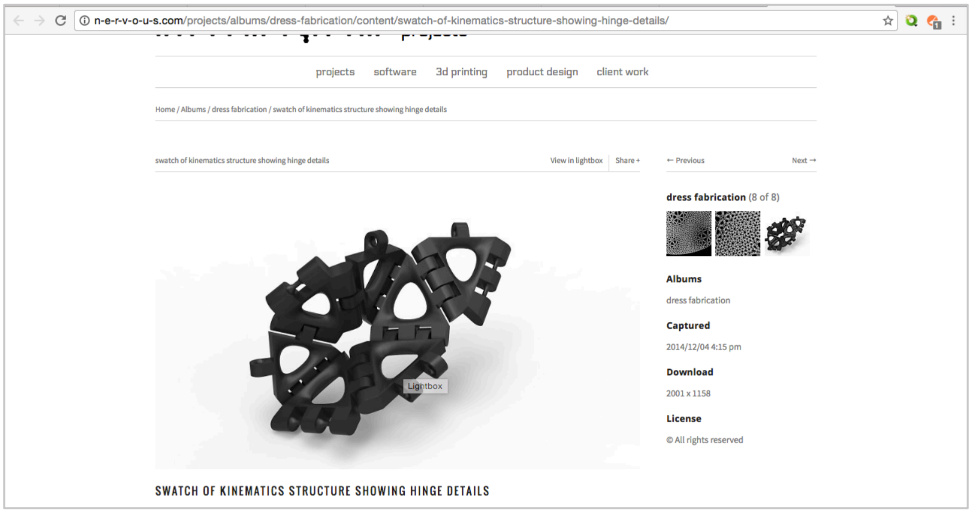


Figure 15: Kinematic Structure Detail (Nervous)

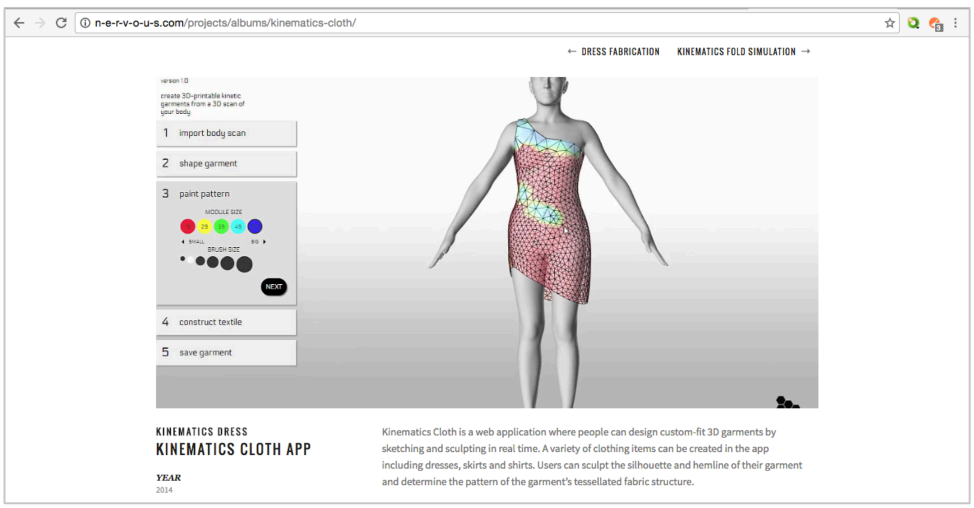


Figure 16: Nervous User Customizer (Nervous)

Modular Mass Customization

For mass customization to succeed, industries must be able to communicate with consumers on a large scale and deliver their expectations and specifications directly to the production line without the need to engineer or make changes in the manufacturing processes. Reynolds (2014) says that, "after all, it's the engineering effort that really drives the cost of customization in the traditional engineer-to-order system." This has been a complicated challenge for manufacturing companies to overcome. This complication creates a series of questions that prompts investigation of what it takes for mass customization to be successful. First of all, without engineering-to-order products or making production changes, how will industries be able to guarantee that the final deliverable will meet quality standards of the company and expectations of the consumer? How will companies assure that they retain their brand in a customized product? Most importantly, how will the company ensure that they are able to produce and manufacture a product specific to the consumer? A solution developed within the manufacturing industry is to embed design and engineering into all aspects of the consumer ordering process as well as the manufacturing processes prior to offering the consumer the ability to customize a product. This requires a platform that flows smoothly, to allow consumers to order a product and ensure that the production line receives and processes the order seamlessly. The manufacturing industry has termed this "modular mass customization." Reynolds (2014) states that modular mass customization involves three of the following basic components:

1. Breaking product architecture down into modules. Designers should modularize product so these modules can be arranged in different ways to create finished goods that meet unique customer needs.
2. Leveraging new artificial intelligence technology that creates rules for how these modules can be arranged. What can be done, what cannot be done. These types of rules define the total range of configurability.
3. Allowing customers to interface with technologies that help them arrange their own product configurations from a portfolio of modules, and choosing the way they are assembled into a final product. (p. 2)

It seems as though that mass customization will only see success in higher end luxury markets where the demand for customized products are greater and more profitable. Nike and other footwear companies have capitalized and excelled at modular mass customization using specialized web portals for consumers to design personalized footwear and other products.

Modular mass customization is successful because designers are able to predetermine each combination for a finalized design. While there may be many options available to the consumer, designers are ultimately responsible for defining what selection of options may be created. This is beneficial to designers because they are able to direct consumers toward desirable outcomes by only allowing consumers to select from options that will create well designed products. This approach has a more certain outcome than the system for mass customization, which offers far broader boundaries for customization. The important difference is modular customization has a limited number of possible outcomes while mass customization allows for more customization and personalization.

NikeID

Nike is a worldwide athletic lifestyle brand that has been at the forefront of the industry for mass customization. Nike's customization platform, NikeID (Figure 15), allows users to design their own personalized shoes from a variety of predetermined options provided by Nike designers. The platform offers a wide variety of options for the consumer to choose from including color, material, soles, stitching, personalized lettering, and more. This allows the consumer to participate in the design and creation of their own athletic shoes. To do this, Nike leverages the idea for "modular mass customization." Designers and engineers have worked together to develop a variety of options for the consumer to choose from so that consumers can combine their favorite elements into a unique sneaker design. To retain the Nike brand, designers and engineers have restrictions limiting how far the "customization" can be pushed, so that the final design remains within the boundaries of Nike's branding guidelines. This is important because NikeID designers are leading consumers toward desirable outcomes for both the company and the consumer. While there are a large variety of combinations to select from, designers have constructed guidelines for consumers to remain within. Consumers indeed can select colors and options that may not compliment each other but they will not be permitted to adjust the guidelines. For example, a consumer is not permitted to add a high heel on their NikeID sneaker using NikeID's service platform for customization.

Launched in 1999, NikeID was originally a digital customization platform allowing consumers to customize the design of their athletic shoes. Nike received such great response to this digital platform from around the world that it began to open up "customization studios" called NikeID Studios. Now with 102 NikeID Studios around the world, customers can find a NikeID Studio in major cities such as Paris, Hong Kong, and Los Angeles. Here, customers have access to a digital customization platform and an experienced customization sales team, as well as a studio full of unique designs to draw inspiration from (Figures 16 & 17). Having an experienced customization sales team to work with ensures that consumers will be encouraged to design a great looking final product. It has since launched from a digital customization platform for shoes into an enhanced digital customization platform, offered in stores and smartphones. NikeID offers a selection of lifestyle, running, training, basketball, football, soccer, baseball, golf, skateboarding, tennis, sandals, and custom shoes to choose from when beginning your design on NikeID. While Nike mainly focuses on footwear, they have continued to experiment by offering consumers the option to customize other athletic equipment and apparel.

By archiving the custom designs created, Nike has developed a gallery of customized products for consumers to chose or draw inspiration from. In a sense they are using each consumer that designs a shoe as a designer and marketing tool. Zaryouni (2015), author of L2 Daily blog titled *Nike the Leader of Product Customization,* states:

> Seventy-two percent of brands that have customized products have made user designs sharable. Similarly, 98% link to customization tools from product pages and 72% allow users to save their creation for future reference or purchase. (p. #)

Sharing consumer's designs not only shows the breadth of customization but it also promotes creativity and design amongst NikeID users. Consumers can then promote their designs as well as NikeID with an option to upload their final design onto social media platforms for everyone to see.

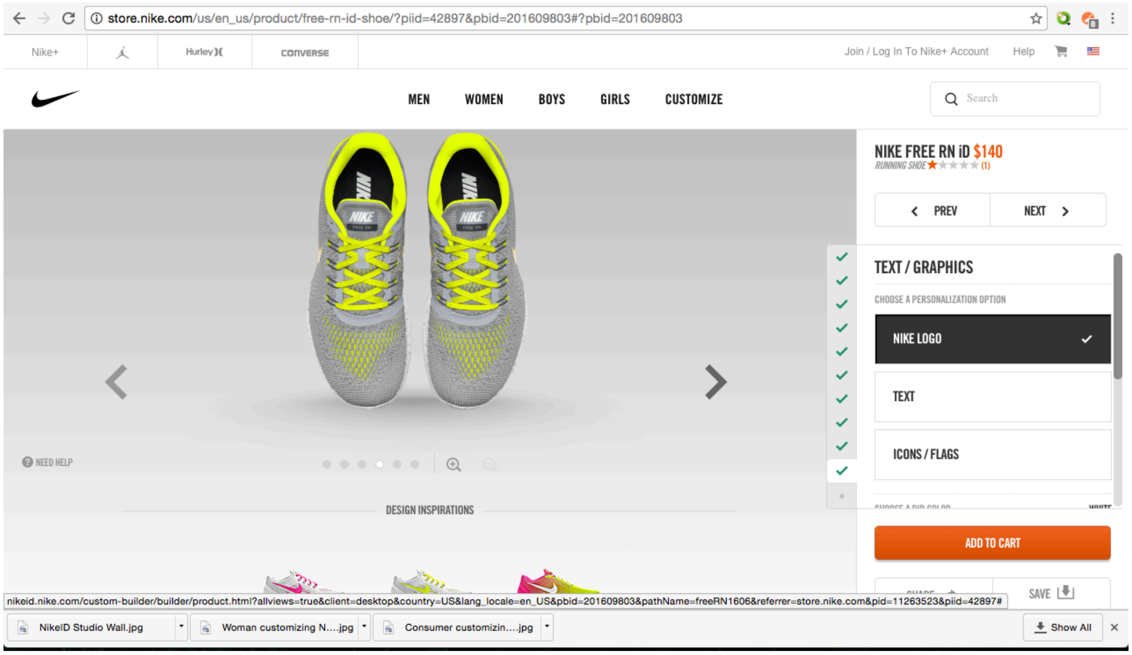


Figure 17: NikeID customization platform (Nike)

Figure 18: Nike consumer customizing shoes (Nike)

Figure 19: NikeID Studio (Nike)

Microsoft Xbox

Microsoft is an American technology company known for developing, manufacturing, and selling computer software, consumer electronics, personal computers and gaming consoles. Xbox, released in 2001, is a gaming brand developed and owned by Microsoft. While many generations of the Xbox gaming console have been released to customers and gamers worldwide, Microsoft has recently begun to incorporate ideas for mass customization into their products and interfaces. An addition created to use with the Xbox gaming console is the Xbox Kinect, which allows users to interact with their gaming console through movements, gestures, and verbal commands without the need for a controller. The console uses a series of 3D motion sensors to interpret movement. The sensory technology has been so well refined that some users have used the device for 3D scanning. In the future, this presents an opportunity for users to scan in their body measurements to use for online shopping. This opportunity prompts us to reevaluate the process of being fit for custom clothing, apparel, or other products that require a custom fit.

When we think of video games or virtual realities, we often times think of our ability to customize the gaming platform. The user is typically given the option to make a profile, player, vehicle, armor, and select other elements of the game to personalize the experience. This creates a unique element of customization that is embedded into modern video games. Xbox is going further by offering its users the opportunity to customize elements other than just the variety of options within the game. What if they can allow users to customize the tangible pieces of the Xbox including the game consoles or controllers themselves? In June of 2016, Microsoft did just that by releasing the Xbox Design Lab, which allows users to customize their gaming controllers. After all, the gaming controller is the part of the gaming experience that users have the most intimate relationship with. Users get to know the controller well enough that there is no need to constantly look away from the screen to select a command.

In an attempt to make this relationship even stronger, Xbox is giving the user the ability to design 7 separate parts of the Xbox wireless controller (Figure 12). The online customizer takes users through a 7-step process allowing them to choose colors for the controller body, bumpers, D-pad, thumb sticks, ABXY, back, view, and menu buttons. As the controller is being customized, users have access to a 360° rendering of their controller. Xbox boasts that there are 8 million options to choose from, using a slogan "8 million ways to make it yours." By taking advantage of "rule-based customization" techniques, Xbox Design Lab is allowing consumers to customize their own wireless controllers for only $10.00 more than the suggested retail price of a standard wireless controller. This is a great example of how Microsoft and Xbox have leveraged their mass production infrastructure and optimized it to give consumers exactly what they want.

Mass customization as discussed in this research, is the idea that consumers get to include specifications to meet their own personal wants and needs. Xbox Design Lab is a good example of how consumers are required to design within the rules set out by designers. Xbox Design Lab wouldn't nor should it permit the customization of a different game console controller. For example, Xbox Design Lab shouldn't allot consumers to provide specifications to create a Playstation controller. While this seems straight forward, this exemplifies that while consumers get the freedom to customize a product, it is the designer's role to control the options that can be customized.

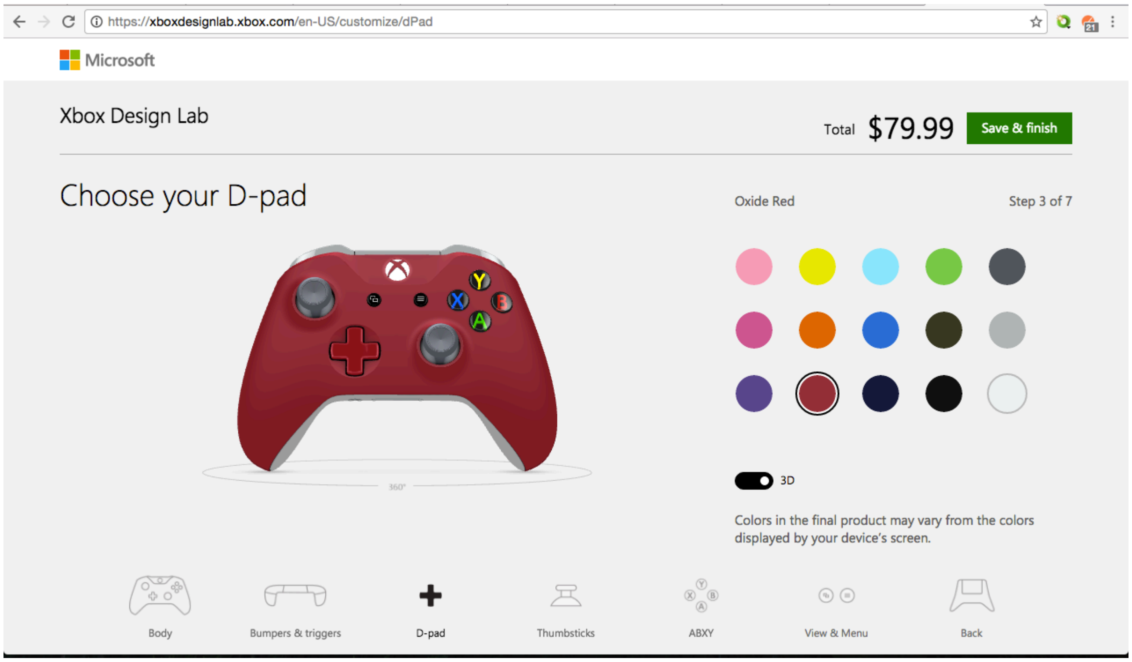


Figure 20: Xbox Design Lab customizer (XboxDesignLab)

Four Approaches to Mass Customization

During the last few decades, the product and service industry has been dramatically changing by becoming more customer-centric. Businesses place many resources into providing good customer service as well as a positive overall customer experience. With that, the approach to running a business, specifically a product and or service business is changing. It is requiring businesses to enhance the user experience by creating innovative processes to deliver and package products, as well as creating different approaches for the overall purchasing experiences. E-commerce has created another avenue for businesses to expand and provide more benefits to their consumers. However, as consumers needs become increasingly diverse, similar business strategies will certainly add unnecessary costs and complexity to operations (Gilmore & Pine, 2016).

As a response to the changing market, companies began implementing mass customization techniques in an effort to provide unique value and experiences for consumers. Companies tried to stay ahead of the curve, rushing to provide consumers with options to personalize their products through mass customization, but what many companies realized was that they did not do enough preliminary research to discover what types of customization their consumers are really looking for (Gilmore & Pine, 2016). As a result, companies that failed to do their due diligence beforehand incurred those same unnecessary costs and operational issues that they were initially trying to avoid. Realizing the need to help different companies implement an approach for mass customization that will work appropriately for different industries, James Gilmore and Joseph Pine created a framework titled *The Four Approaches of Mass Customization*. They developed 4 distinct approaches to different styles of customization (Figure

21), which they refer to as collaborative, adaptive, cosmetic, and transparent customizations. The following sections will describe these approaches in further detail.

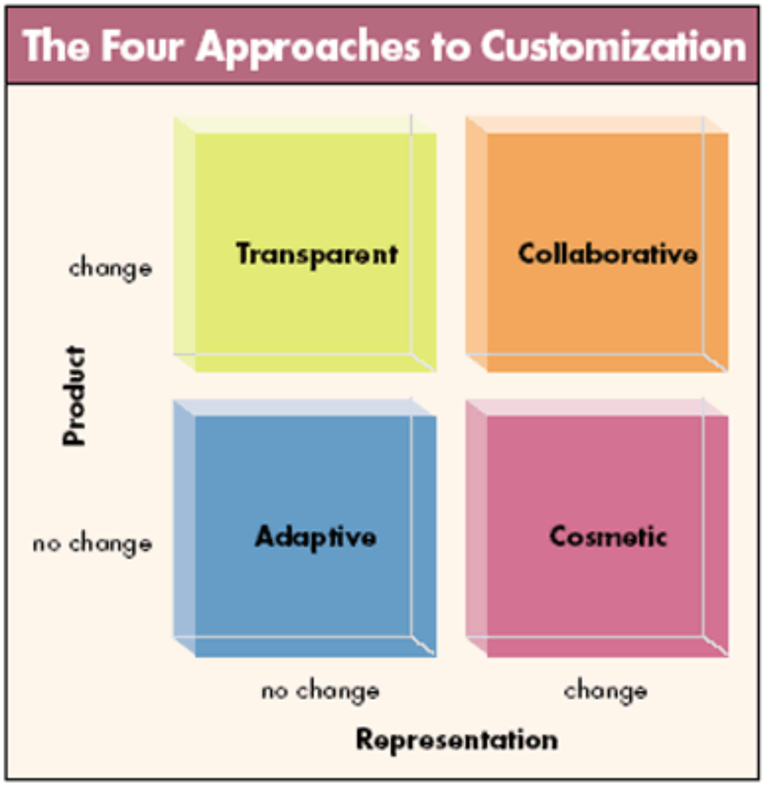


Figure 21: The Four Approaches to Customization
(Gilmore & Pine, 2016)

Collaborative Customization

This approach is the most common approach referred to when discussing the idea of "mass customization." It involves an experienced professional working together with the consumer to help them identify the precise customization for the product or service that they are shopping for. It is a combination of excellent customer service along with a customization platform that allows representative to assist the consumer throughout the customization process. Often times, users do not have enough knowledge to fully customize a product or service themselves, creating a need for "collaborative" customization. Gilmore and Pine (2016) say, "collaborative customization is a model appropriate for businesses whose consumers can't exactly articulate what they want and grow frustrated when forced to select from a plethora of options." They continue to exemplify their notion for collaborative customization using a Japanese eyewear retailer, Paris Miki, as an example of what they describe to be a perfected collaborative customization platform. Gilmore and Pine state that Paris Miki spent five years developing the Mikissimes Design System, which eliminates the customer's typical process of going through countless options to find the correct pair of glasses. First the customer has their picture taken; the system, incorporated with artificial intelligence, then selects eyewear with appropriate attributes based on the customer’s face shape, style, and preference. Once the system has selected a variety of eyewear based on these results, the customer can view the different selections digitally overlaid on his or her picture. The customer will then work with the optometrist, collaborating to adjust the shape and size for a great look and fit. Following this same process, the customer continues working with the optometrist to select options for nose bridges, hinges, and arms to complete the design. Finally the glasses are sent for production in-house and ready for the customer the same day. This approach to mass customization has yielded success for Paris Miki because of the companies' ability to take advantage of technologies. Ultimately, this saves time for both the company and the customer because consumers can explore options in a fraction of the time and have confidence in their selections.

Adaptive Customization

Adaptive customization is the idea for companies to integrate options for customization into a final product so that customers can add personalized options into their product after they have purchased it. Gilmore and Pine (2016) say that rather than providing a variety of customizable options prior to a customer selecting a product, adaptive customization creates standard goods and services that can easily be customized and reconfigured to each customer's personal preference without the need to interact with the company during or after purchase. By using this approach, companies still provide great value but reduce the need to directly interact with the customer. With options for customizability built into a standard product, customers receive most of the value through their interaction with the product independently. Technologies within products often play a role in the adaptive customization process, such as sensory agents and software that can define patterns of use and optimize the products functions to best serve the user.

Gilmore and Pine use Lutron Electronics Company's lighting systems to exemplify a successful execution using adaptive customization in their products. Lutron's customers maximize value from the Lutron lighting systems using the ability to program lighting settings for different environments, moods, and needs. The ability to save settings eliminates the need for the user to fumble with switches or dials anytime they wish to adjust the lighting environment. The idea is to connect different lights in a room and allow users to program different effects for parties, romantic moments, or quiet evenings of reading. By integrating options for customization into the end product, companies are still providing the value of mass customization to a large group of users.

Cosmetic Customization

The cosmetic approach to mass customization should be implemented when the customers uses the product in the same way but they have a specific need to customize the product's presentation. Rather than the product itself being customized, often times, the cosmetic customization approach focuses on the packaging or how the final product is displayed. This idea is best described in a long example provided by Gilmore and Pine (2016) that says:

> For example, the product is displayed differently, its attributes and benefits are advertised in different ways, the customer's name is placed on each item, or promotional programs are designed and communicated differently. Although personalizing a product in this way is, frankly, cosmetic, it is still of real value to many customers. Witness the billions of dollars that consumers spend each year on such products as embellished T-shirts and sweatshirts. (p. 1)

Gilmore and Pine use Planters Company as an example to demonstrate the importance and need for a cosmetic approach to mass customization. With a very diverse group of retail customers, Planters receives very diverse merchandising demands; Wal-Mart wishes to sell larger quantities of nuts while gas stations wish to sell smaller quantities because each retailer is working to market to their specific customer bases. Instead of limiting their retail clients to standardized options, Planters has adapted their manufacturing processes to provide each of their clients with exactly what they want. A lot of this change and adaptation took place in manufacturing facilities; the company adjusted their production lines to meet the needs of customizing cosmetic changes for packing the same product, peanuts. Gilmore & Pine believe that:

> When performed well, cosmetic customization replaces piecemeal and inefficient responses to customers' requests with a cost-effective capability to offer every customer the exact form of the standard product he or she wants.

Transparent Customization

The final approach to mass customization described by Gilmore and Pine (2016) is transparent customization; this involves providing the customer with a unique product or service without the customer realizing that the product or service has been customized specifically for them. This approach should be used when the customer's needs are predictable either by a pattern or continuous demand because it alleviates the need for the customer to repeatedly place similar orders. Using the transparent approach, companies must give great attention and observation to their customers without much interaction with them. Companies will provide customization in such a way that the customer is satisfied with the product or service and develops a trust that the product will be correct and delivered on time. Customers of the transparent customization approach may have a retainer with the company or get billed quarterly over the course of a year. This creates a large responsibility for the company providing the product or service because they must be sure that the customization options they select for the consumer are accurate and serving their customer best.

Gilmore and Pine use a Midwestern company based out of Cleveland, Ohio, named ChemStation, as an example to help better describe the approach to transparent customization. ChemStation provides industrial soap to a variety of companies to use for services such as carwashes and cleaning factory floors. ChemStation formulates custom mixtures based on their analysis of different companies' needs and provides scheduled deliveries to their customers, often times storing it in a designated location. By monitoring the companies' tanks, ChemStation can predict patterns of use and can ensure that the soap never runs out. Arguably, transparent customizers may provide a better product or service the longer they are working with their consumer. This approach saves time for the seller and the customer because the product and service are satisfactory as long as the seller is providing a consistent product and great customer service. Gilmore and Pine support, this saying:

This practice eliminates the need for customers to spend time creating or reviewing orders. They don't know which soap formulation they have, how much is in inventory, or when the soap was delivered. They only know—and care—that the soap works and is always there when they need it.

Combining Approaches

While all four of these companies have entirely different approaches to the mass customization strategies, they are similar in that they defy the traditional approach when providing products and services (Gilmore & Pine, 2016). The paradigm is shifting and companies are no longer providing only standard products to broad markets. Instead, companies like those listed in the four separate approaches are providing unique value in offering consumers the ability to customize their products and services using the most effective approach. This enhances the seller and consumer relationship by building loyalty, increasing revenue, and helping sellers to gain a competitive advantage within their market. By following the considerations to the four approaches for mass customization (Figure 21), companies can leverage the most effective approach to maximize efficiency and customer satisfaction.

However, often times these approaches can be and should be combined to develop the most effective mass customization strategy. The key to developing a successful customization strategy is to develop an approach that provides the most value to the consumer. In many cases, that will mean applying elements from each of the four approaches to customization when appropriate. Even the companies listed in the examples above combine some elements of each approach, for example. Lutron's ability to be an adaptive customizer yet still collaborate with many of its customers to discuss matching new lighting to existing lighting, colors, and even syncing their lighting with existing security systems. Each of these unique demands requires collaboration on some level. The approaches developed by Gilmore and Pine are merely suggestions and not hard and fast rules to mass customization; Gilmore and Pine describe the approaches as a framework to design customized products and supporting business processes. As businesses move into the future and production paradigms continue to shift, making mass customization more of an industry standard, businesses must be able to adapt by developing customization capabilities as well as an infrastructure that supports them to meet the needs of individual consumers.

Emerging Technologies Enabling Mass Customization

Mass customization is growing rapidly and its becoming an industry standard for many consumer markets at some level. Successful mass customization is driven by two main goals. The first is identifying the opportunities for consumer customization and creating a seamless process for the consumer to provide their options and expectations, typically through a digital interface, which is received by the production line and produced with the same economies of scale as mass-produced products. The second goal is to create a competitive cost structure relative to previous production processes even as the manufacturing infrastructures become more complex. To reach these goals, companies are implementing a variety of technologies that are enabling successful growth using different approaches to mass customization. These approaches also include developing technologies such as online customer configuration platforms, CAD/CAM, and 3D scanning as well as digital fabrication which involves 3D printing, CNC machining, and laser cutting. Other manufacturing strategies and technologies have been developed to embrace the growth of mass customization such as on demand manufacturing (ODM) and just-in-time (JIT) manufacturing which is a manufacturing strategy developed by Toyota. The following sections will describe these emerging technologies in more detail.

Digital Fabrication

Digital fabrications are production processes, either additive or subtractive, in which the production machine is controlled by a computer. Additive processes use technologies such as 3D printing while subtractive processes involve technologies such as computer numerical control (CNC). Digital Fabrication is becoming an integral part of mass customization because of its quick customization capabilities, flexibility, decentralization, cost, and its continuous development. Digital fabrication using CAD makes customizing products fairly easy. Using a customization platform, users can input their options and specifications into 3D generative programs or, for more advanced customizers, they can use CAD programs like Autodesk and Solidworks to create a digital model that is representative of exactly what they want. Production processes such as 3D printing and CNC machining can then develop these models with quick production times and minimal waste. The ability to customize products by leveraging digital fabrication is creating an easy process for the consumers and arguably an even easier job for the manufacturer.

Flexibility is another key advantage to utilizing digital fabrication. Using technologies such as CAD/CAM, often times, different customized products can be produced using the same technologies. This means manufacturers minimize the production processes and they also minimize the number of machines and laborers they need for production, which requires less time, space, and resources. Previously, "engineering-to-order" processes would use different manufacturing processes to develop the final product. Flexible digital fabrication allows manufactures to use the same set of tools to create a large variety of final products; production flexibility makes it worth it to invest in tools that have the ability to adapt and respond to different demands ("Digital Fabrication - Open Source Ecology", 2016).

Digital fabrication also means decentralization. In the past, manufacturers used large-scale production facilities, which were expensive to start and operate. Leveraging the benefits of digital fabrication, designers and manufacturers both have the ability to fabricate instantaneously as long as they have access to these emerging technologies. Digital fabrication also creates an opportunity to exchange digital files. For example a company customizing products in Michigan could outsource their designs to California, have it digitally manufactured in Georgia, and then shipped directly to the consumer. This concept of decentralizing all of the processes creates a competitive advantage for companies utilizing digital fabrication as a means of production. Digital fabrication costs are typically very low relative to the costs of traditional production facilities. As the technology continues to develop, costs will continue to lower and the capabilities of these processes will become more diverse, more efficient, and more accessible for producing mass customized products.

CAD/CAM

According to Autodesk, a software development company for architecture, engineering, construction, manufacturing, and entertainment industries, CAD/CAM (computer aided design and computer aided manufacturing) is defined as the computer software that is used for designing and manufacturing products ("Autodesk | 3D Design, Engineering & Entertainment Software", 2016). CAD is the computer-based technology allowing designers and engineers to quickly develop accurate parametric prototypes, which are typically used for visual/analysis models. CAM software uses the data created in the CAD software to generate tool paths that drive the machines (3D printers, CNC, and laser cutter) that will create physical parts from the computer-generated designs ("Autodesk | 3D Design, Engineering & Entertainment Software", 2016). These technologies are commonly used during the product development process because of the immediate turn around time, editing capabilities, and quick production that result from using CAD/CAM technologies.

In a typical production environment, designers, and engineers will be required to work together on a project toward a common goal. Having a CAD/CAM platform that both the designer and the engineer can leverage to complete their jobs but also contribute toward the final goal will maximize the efficiency of the production processes. CAD packages usually include a variety of plug-ins that both the designers and engineers will use to contribute to the final design. The designer will use plug-ins for visualization such as rendering and appearance tools, while engineers can utilize parametrics and run a variety of analytic tests. In the book titled *Digital Design and Manufacturing*, Schodek (2005) states,

> CAD tools are also extensively used in various analysis tasks: from mold-flow analysis to finite-element analysis to collision and impacts emulations. These simulation and analytic tools enable the designer to foresee critical issues that may impact the complex and time-sensitive interrelationships of design, engineering, manufacturing, and marketing tools. (p. 14)

CAD tools are also used in manufacturing to develop tooling and manufacturing processes. The tooling processes derived from CAD/CAM are used to run 3D printers, CNC's, and laser cutters.

CAD/CAM tools and technologies have dramatically impacted the way in which products are designed, developed, and manufactured. They increase efficiency by minimizing the time it takes to make edits and produce final prototypes; they also decrease the disconnect between designers and engineers producing the finalized products. Schodek (2005) goes on to say that CAD/CAM technologies, in addition to saving time, have become vital in managing the complex relationships between various parties working cohesively to develop any product and ensure quality. Primarily a digitally based technology, CAD/CAM has also enabled designers and engineers from around the world to collaborate because of the ability to share and manage complex data instantaneously. CAD/CAM has largely impacted the mass customization industry because of its abilities to create variety within products instantaneously. Companies like Nike that are offering options to customize products, are leveraging CAD/CAM technologies in some of their production processes. While companies like Nike are using CAD/CAM technologies, these systems are also available to DIYers and makers on a smaller scale. The technology has become more affordable, and communities like Thingiverse are providing platforms for design, creation, and rapid prototyping of all kinds. As CAD/CAM continues to develop, it will open greater opportunities for the mass customization industry.

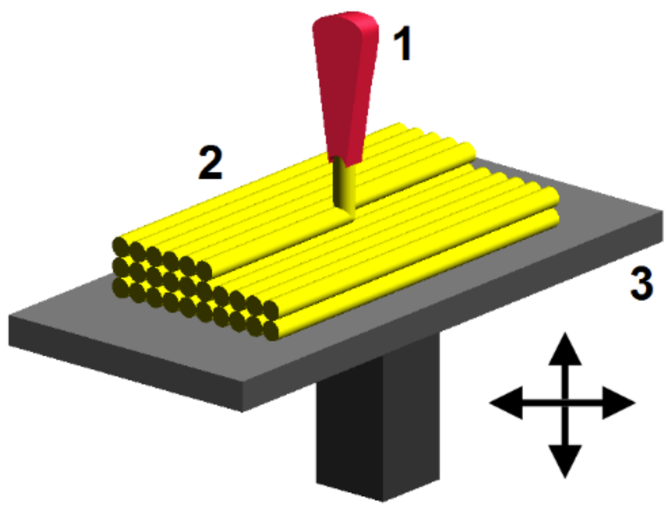
3D Printing

3D printing is an additive manufacturing process for creating three-dimensional products from a digital CAD file. There are a variety of 3D printers and CAD software programs, but typically the printing process requires that a 3D model developed using CAD software must be "sliced" by a separate program that enables the 3D printer to read and understand the 3D model data generated by the CAD program. 3D printers do not use the same software and technologies, nor do they all use the same slicing software. This requires users to learn different programs depending on which CAD software and 3D printer they use to 3D print products. Once the digital file is sliced, it is ready to send to the 3D printer to print. One of the most common methods for 3D printing and the method relevant to the research herein is material extrusion. Fused deposition modeling (FDM)(Figure 22) is a common type of 3D extrusion used by most personal 3D printers. The process involves pushing a filament through a heated extruder head, very similar to how hot glue guns function. An online article titled, “What is 3D Printing?” (2016) states that:

> The FDM technology works using a plastic filament or metal wire which is unwound from a coil and supplying material to an extrusion nozzle which can turn the flow on and off. The nozzle is heated to melt the material and can be moved in both horizontal and vertical directions by a numerically controlled mechanism, directly controlled by a computer-aided manufacturing (CAM) software package. The object is produced by extruding melted material to form layers as the material hardens immediately after extrusion from the nozzle.

FDM 3D printers are capable of printing a variety of different materials to achieve different properties including toughness, rigidity, translucence, UV resistance, biocompatibility, water-resistance and more. The most common material filaments for FDM 3D printing are ABS (Acrylonitrile Butadiene Styrene) and PLA (Polyactic Acid), but a variety of other plastics and materials are available for printing (“What is 3D Printing?”, 2016).

3D printing increases the opportunity for rapid prototyping, but it also increases the ability to customize products. The users have a lot more control of the design because of the ease of use, cheap material costs, and digital editing capabilities that allow for a wide variety of customization inputs. 3D printing reduces the resources needed to develop a prototype and also supports creative freedom when developing a product or object. There are many companies at the forefront of the 3D printing industry that are paving the way for this innovative approach to developing, designing, and manufacturing products. Makerbot is a startup based out of New York that is focused on innovation for professional, educational, and at-home desktop 3D printers. Thingiverse (Figure 23) is a web-based company that offers digital designs for physical objects, which can be downloaded from their open-source platform by everyone. Users can join and access digital files that are ready to be printed or altered to the customer's preference. Users can also upload their own projects to Thingiverse to be downloaded by the rest of the community. This is increasing the exchange of designs as well as opportunities to customize products on a mass production scale.



Fused deposition modelling (FDM), a method of rapid prototyping: 1 – nozzle ejecting molten material (plastic), 2 – deposited material (modelled part), 3 – controlled movable table. Image source: Wikipedia, made by user Zureks under CC Attribution-Share Alike 4.0 International license.

Figure 22: Fused Deposition Modeling ("What is 3D printing? How does 3D printing work?", 2016)."

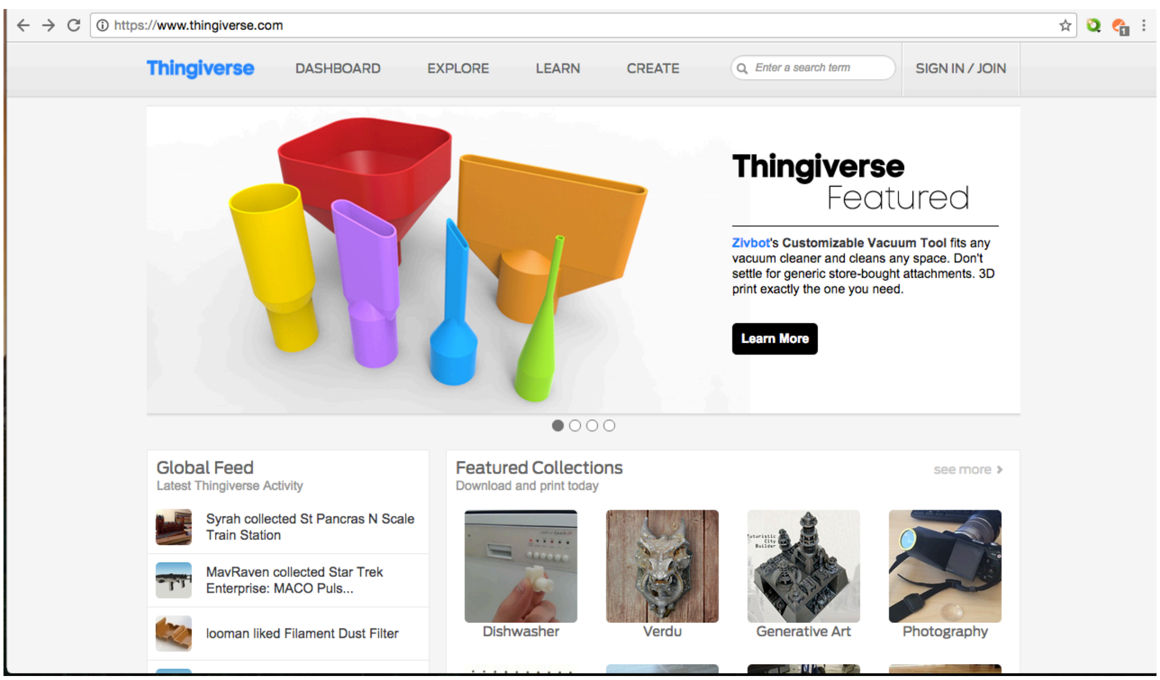


Figure 23: Digital Designs for Physical Objects (Thingiverse)

Computer Numerical Control (CNC) Technology

Computer numerical control (CNC) is a machining process often utilized in production industries which uses the computer data developed in a CAD program to control and operate the machining processes for grinders, laser cutters, lathes, mills, routers, and other industry specific production processes. CNC machining processes ensure a higher quality of manufacturing because they eliminate the human factor, which increases the skill in production process. In Schodek's (2005) book titled *Digital Design and Manufacturing* he states,

> Numerical control (NC) technologies allow automated equipment to be controlled and operated in real time through the use of symbolic language–another way of saying machines can be told what to do at any time (at any speed) by using numbers and letters arranged in a regular way. The now relatively old concept of NC, coupled with computers to produce CNC, is at the heart of today's robust computer-aided manufacturing industries, as well as robotic manufacturing and a host of other enterprises. (p. 237)

Some industries have been able to successfully automate entire production processes using CNC technologies. For example, cutting commercial signage, etching awards, dental milling, and automobile production all rely heavily on CNC technologies to produce and develop the final product with little human interruption (Schodek, 2005). CNC technologies are consistent, precise, fast, and less expensive than traditional production processes, making them an industry standard for manufacturing. This technology has provided great versatility within the production industry by creating tools that would not exist without the development of CNC, such as laser cutting, electric discharge machines, shape-cutting machines, water jets, and electron beam welders (Schodek, 2005, p. 238). The common computer processing language that is used to run most of the CNC technologies is referred to as "G-code", which defines the path for a machine to move along specific axes. CNC technologies are typically run on 3 axes but more advanced technologies permit for 5 axis rotation (Figure 24). These processes, which are primarily automated, can increase the opportunity for customization within the mass production industry because they can produce objects and products from computer-generated designs. This means that by working with consumers to generate a digital design, companies can leverage CNC technologies to automate some of the production processes to ensure accuracy based off of the consumers specifications. CNC technologies will be a critical component for developing a mass customization platform.

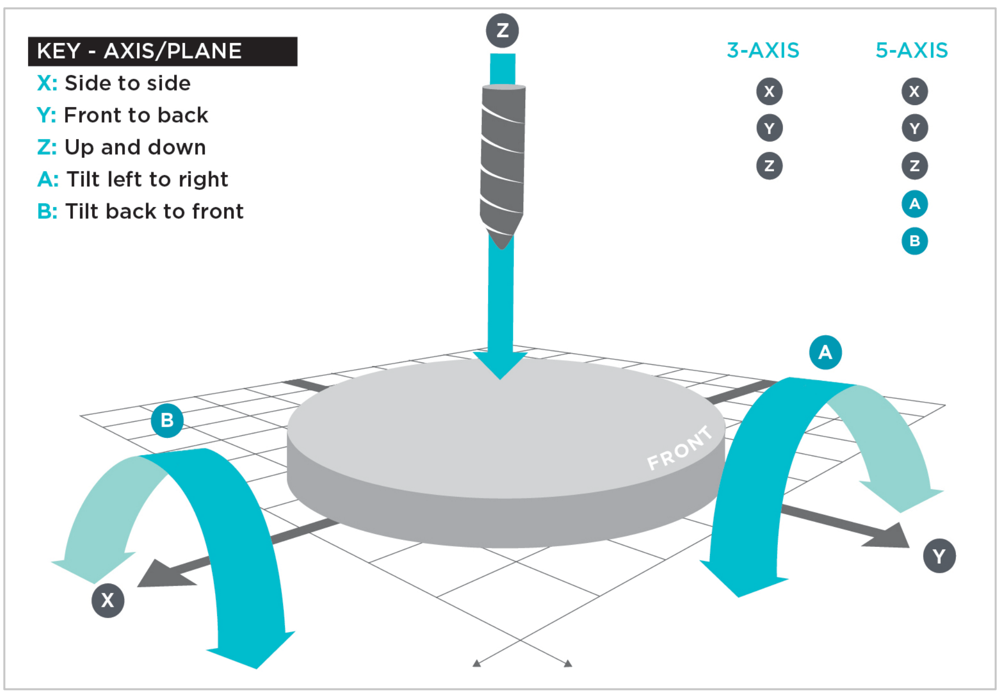


Figure 24: Milling Axis of Operation (Inside Dental Technology, 2016)

3D Scanning

3D scanning is the process by which a physical object is scanned with a device that collects data from an object's shape and appearance that can be used for creating digital 3D models. The digital models are used for a variety of applications including reverse engineering, design, quality control, prototyping, and more. 3D scanning is used in a variety of different fields, but for the purpose of this study, the focus of 3D scanning will primarily be used to obtain geometry for design and reverse engineering. 3D scanners come in many different prices ranges, which typically correspond to the quality and accuracy of the 3D scan. In the production industry, 3D scanning for customization requires precision; these scanners will be more expensive but they will provide the accuracy needed for customized products. An e-book titled *Design for 3D Printing* (Bernier, Luyt, Reinhard, & Bass, 2015) describes a few instances in which 3D scanning is already being used to customize products in healthcare, saying:

> 3D scanning is used in medicine and in fashion to take the exact measurements of a subject in order to create a custom accessory. For example, prostheses for people with one leg can be made from a scan of the intact opposite leg (p.114).

The ability to digitally scan objects and body parts to produce data that can be reconfigured to design around means that designers and engineers using this technology will have the ability to ensure more precision in their sizing and fitting. Products or objects that can be worn or have a sensitive need for ergonomics can be designed using 3D scanning to increase value for the consumer by ensuring a perfect fit.

Service Platforms for Mass Customization

Service platforms for mass customization are the channels used to connect companies directly to their clients; these channels are typically modeled by one of the following: in-person consultation, showroom, or web-based customization platforms. Each of these channels provides consumers with the opportunity to include their personal choices and specifications in a final product. Creating a platform is essential to providing consistency and expediting lead times in a mass-customized product market.

To develop a platform, companies must consider the following: the consultation channel they will use to reach consumers, the fabrication methods for creating the final product, fabrication timeline decisions, and finally the companies' approach to mass customization. Figure 25 shows the decisions made, by the companies recalled from the previous case studies, to configure their mass customization platforms. Each company has a unique approach to collect, process, and bring the consumer's choices to the production line; in addition, each company has a unique means for delivering the end product to the consumer. Some companies are able to automate their systems, which can reduce labor costs and arguably, decrease human production errors.

Conversely, other companies are required to become directly involved in the consumer decision-making process, through consultants, to assist their consumers in choosing the options that will fit their specific needs best. Higher-end products will typically involve more collaborative customization while lower-end products such as NikeID shoes may require less consulting. Finally, manufacturing companies will determine the number of variables possible and develop a decision point for consumers to choose the options they will include. To provide variables, industrial designers and engineers must collaborate and develop concepts to determine the boundaries of customization for their consumers. Bhatia and Asai (2007) describe the idea for designer conceptualization and creating boundaries by stating that:

> The product evolution process starts with conceptualization, where a designer visualizes various themes and hundreds of designs under those specific themes. The visualization of these themes and styles takes place by using different tools and techniques such as demand forecasting data analytics software, production planning software's, design development software's and styles tracking across the globe by using web-based services. (p. 7)

Mass customization platforms are a resource for companies to analyze their consistency, trends, and patterns. This helps companies ensure they are providing the best possible value through their concepts and options for mass customization. With the accuracy of web-based analytics, manufacturers are able to record trends and demands as they are happening. This allows companies to react quickly to consumer trends and demands, increasing the companies' agility and adaptability.

Responsive supply chains are much different from traditional manufacturing supply chains, which were often a combination of suppliers, manufacturers, distributors, and retailers (Bhatia & Asai, 2007, p.7). Traditional approaches tend to be static and non-responsive due to lengthy lead times and product standardization. Traditional approaches require tooling to generate specific parts whereas mass customization platforms are beginning to take advantage of digital fabrication opportunities. Emerging technologies are enabling companies to complete production via CAD/CAM, which can complete the same precision as traditional manufacturing but in complex forms. The advent of these emerging technologies is forcing companies to restructure their traditional supply chain infrastructure. Developing technologies, like CAD/CAM, are permitting manufactures to move away from traditional approaches toward mass customization platforms that are allowing a direct channel from the manufacturer to the consumer. This means companies using mass customization methods may eliminate unnecessary middlemen. Bhatia & Asai (2007) state that:

> Traditional way of buying goods happens through the channel of wholesaler and retailer. Mass customization challenges this process and tends to eliminate these mediators in the value chain. (p. 8).

By eliminating the intermediaries with the use of mass customization platforms, companies are in effect cutting down on the lead-time that it takes to get a consumer's specifications into production, which is ultimately reducing the overall lead-time that it takes for a custom product to be finalized. By utilizing a mass customized product platform, companies can reduce the overall development and production times of a product; as a result, product-life and development cycles will become shorter, allowing manufacturers to respond quickly to changing consumers' needs.

Company Case Study	Consultation Channel	Fabrication Methods	Timeline Fabrication Decisions	Harvard Review Approach
Ford	In-person/ showroom/ web-based	Traiditonal/ Automated		Collaborative/ Adaptive/Cosmetic
Indochino	Web-based/ showroom	Traiditonal/ Automated		Collaborative
Nervous System	Web-based	Automated		Collaborative
NikeID	Showroom/ web-based	Traiditonal/ Automated		Collaborative/ Cosmetic
Xbox	Web-based	Traiditonal		Cosmetic
Paris Miki	In-person	Traiditonal		Collaborative
Lutron Lighting	In-person	Traiditonal		Adaptive/ Collaborative
Chem Station	Web-based	Traiditonal/ Automated		Transparent/ Collaborative
Planters	In-person	Traiditonal/ Automated		Cosmetic/ Collaborative

Figure 25: Mass Customization Platform Strategy

Strategies for Mass Customization

Companies adopting mass customization production methods must develop strategies that will make them successful in the mass customization market, creating an immediate need for designers and engineers to define the scope of customization that a company is able to develop and provide to its consumers. Companies must be able to design variations of the products that they are offering to be customized. The companies must also have the ability to deliver consumer specifications to the production line for manufacturing at a competitive cost and in a timely manner. This means setting up strategies for product customization that define boundaries, which specify a company's capabilities and capacity for creating mass customized products.

A benefit to offering a particular range of options for customization is that it allows companies to forecast what consumers can customize. Creating boundaries for mass customization will help companies develop strategies to build platforms that will be productive, flexible, and adaptive to manufacturing changes. While it is important for companies to focus on approaches toward mass customization, emerging technologies, and building a mass customization platform, it is also important for companies to strategize how they will leverage the use of digital design, modularity, and just-in-time manufacturing. These strategies, if used properly, create organization that will help companies maintain a competitive advantage in the mass customization market by maximizing their efficiency and responsiveness to consumer trends and demands. Without an industry standard for mass-customized product platform strategies, each company must develop a strategy that will prove successful in their own particular market.

By implementing digital design strategies, companies can utilize technologies that afford consumers with customization platforms that allow the consumers to visualize their products digitally as they customize the products. Typically, this means designers and engineers have already developed a variety of options for consumers to choose from. Digital design strategies augment the customizing experience by allowing consumers to see different configurations that will fit their specific needs best. It also gives companies the ability to process digital files, which standardizes processing consumer specifications for production.

Incorporating modularity into strategies for mass customization means that companies offer a series of standardized parts that can be rearranged and configured in a variety of ways during the customization process. Schodek (2005) states in his book titled *Digital Design and Manufacturing* that:

> A modular approach is an additive design strategy that enables product variety by combining different standard modules that themselves may be mass produced. In this discussion, the term "module" refers to a self contained, distinct, and identifiable unit that serves as a building block for an overall structure. (p. 337)

The ability to standardize parts during mass customization processes allows companies to be fast and accurate during production and delivery. Many rule-based customizers are able to integrate some modularity in different aspects of their customization process. Nike, for example, has a series of different color lowers that customers are able to choose from; presumably, these lowers are created in a mass production process but offered to the consumer in a variety of colors, sizes, and materials in the mass customization process. Figure 27 is an example for creating variations of products using modular components. Utilizing a modular approach creates an organizational structure of hierarchy for both customization and production processes.

Just-in-time (JIT) manufacturing is another strategy that increases efficiency for production and decreases waste by limiting inventory using lean manufacturing techniques. Investopedia defines just-in-time manufacturing (“Just in Time" - JIT | Investopedia 2003) as:

> An inventory strategy companies employ to increase efficiency and decrease waste by receiving goods only as they are needed in the production process, thereby reducing inventory costs. This method requires producers to forecast demand accurately.

The strategy for JIT manufacturing means that parts or materials for a product may not arrive until they are needed, instead arriving just in time for production. JIT strategies decrease production times and companies reduce their need to store parts and materials. JIT is an effective strategy for mass customization platforms because customized products receive consumer specifications at some point in the production process; this method allows companies to deliver parts and materials just as consumer specifications are received.

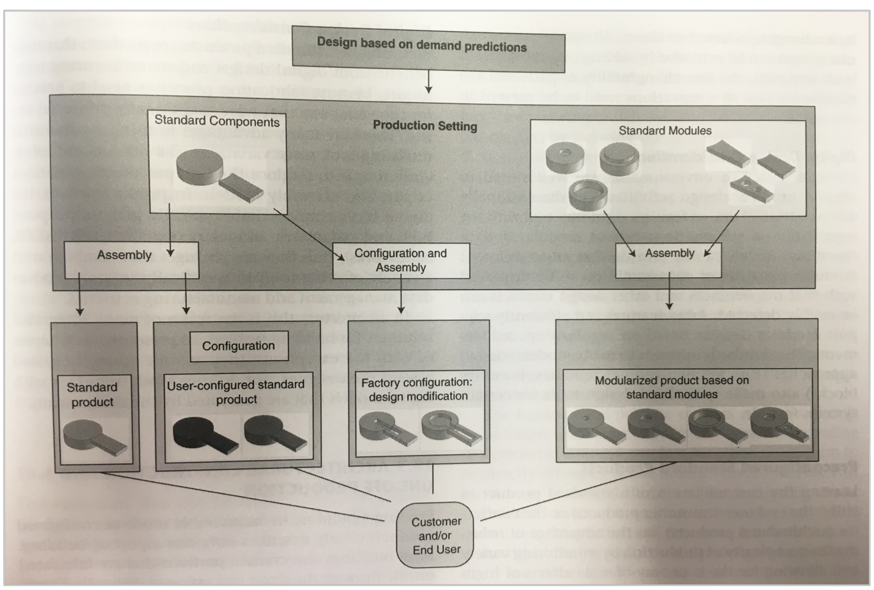


Figure 27: Creating variation using a modular approach (Schodek, 2005, p. 337)

Literature Review Summary

The product manufacturing industry is experiencing another industrial revolution. This time, companies in the manufacturing industry are beginning to reconfigure their approach to mass production. Companies are changing their strategies from the production of traditional standardized products toward products that meet the specifications of individual consumers. Designers play a pivotal role in defining the boundaries for the customization options. Emerging technologies combined with heightened consumer needs have created a new approach toward manufacturing, known as "mass customization." The primary goal of mass customization is to create customer-centric value by offering consumers a variety of product options to choose from. Abandoning traditional mass production methods, "mass customizers" are utilizing technologies that make their companies more agile and responsive to consumer trends and needs. As a result, each company, based on the particular industry, is developing a unique method for offering and delivering product options to its consumers. Without an industry standard for mass customized product platforms, it is important for companies to develop the appropriate approach when designing a product platform for mass customization. The basic concept for this research is for designers to create a product platform that leverages the correct approach to mass customization. It also explains the need for designers to be in control of defining the rules and boundaries for customization; consumers should not be allowed to customize every aspect of a product or this would eliminate the role of the designer. Designers should then establish appropriate means of manufacturing and fabrication for developing a mass customized product platform. Manufacturing and fabrication methods will often times create parameters for customization that designers must identify. Following the guidelines, based on this research, this thesis project will be a resource for designers when they are designing product platforms for mass customization.

Chapter 3: Developing Guidelines to Designing Product Platforms for Mass Customization

This chapter will present a number of different considerations for designers to use when they begin designing a product platform for mass customization. The considerations have been developed based off of the previous research but they are entirely new ideas. These ideas have been organized to help designers create a product platform for mass customization. These considerations are listed in sequential order but may not always be utilized in this exact order. Instead, designers should use these considerations as a guideline for determining the type of customization to leverage, manufacturing methods, boundaries for customization, and for developing a product platform for mass customization that a company will use. These considerations should assist designers in creating a platform for mass customization that is appropriate and unique to their particular company.

The Design Process

Since the considerations aren't used in sequential order, the design process (Figure 28) is referenced to provide a visual understanding for how these considerations may fit within the design process. The generic design process is somewhat linear but what designers should know is that as they move through the design process, often times, designers will return to an earlier step based on outcomes or findings during the ladder part of the process. The considerations within this chapter will cause designers to move through the design process in a similar manner, moving throughout the design process rather than from start to finish. This creates a much more circular design process rather than a linear one because as designers move through the design process, they should be learning and apply what they've learned to earlier processes.

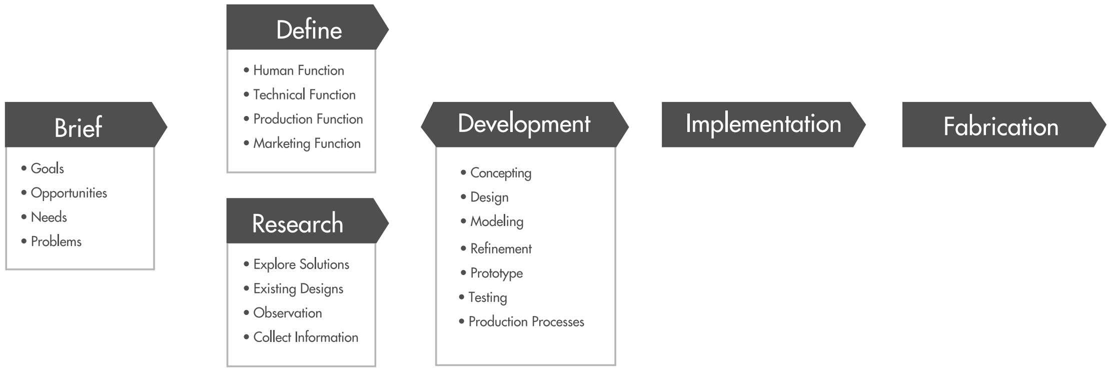


Figure 28: Generic Design Process

Service Platforms for Mass Customization

In addition to creating a product platform for mass customization, designers should also consider how they would approach using a service platform for mass customization. Service platforms for mass customization are the channels used to connect companies directly to their clients; these channels are typically modeled by one of the following: in-person consultation, showroom, or web-based customization platforms. Each of these channels provides consumers with the opportunity to include their personal choices and specifications in a final product. A service platform for mass customization that is web-based should provide the consumer with the ability to access the service platform from a PC, mobile device, or digitally from a storefront. Service platforms requiring consultations or in-person collaborative customization may require designers to develop a service platform as mass customization software, requiring consumers to visit a storefront or meet with a company representative to complete the customization process. Both situations require a service platform to be designed in a way that provides users with a visual representation of the customized product, an easy-to-use platform, and boundaries that define the capabilities for customization.

Consideration 1: Mass Customization or Modular Mass Customization

Identifying the method of mass customization that a company will use to design, develop, and manufacture mass customized products will determine a company's capability for customization; likewise, it will also establish the possibilities of customization for the consumers. Designers should determine whether a company will offer mass customized products, modular mass customized products, or a combination of both. By identifying the method for mass customization, designers can clearly define design boundaries that specify exactly what options may be customized by the consumers and the limits for customizing a product.

Description

Previous research within this study indicates that mass customization allows for a higher degree of customization and design involvement for the consumer. The consumer plays a very important role during the design process to provide certain specifications for customization. Consumers should become an integral part to providing specifications, which increase the human function within a final product. The result is often a very personalized product, which is sometimes one of a kind. While mass customization affords the customer with the ability to provide and incorporate a greater level of personal detail, mass customization is not engineering-to-order. There may be very broad design opportunities but the consumers will not be permitted to design a product that breaks the rules that have been setup by the designer.

Determining whether to leverage mass customization or modular mass customization should begin while designers are defining the functional criteria and researching. Defining the functional criteria for a mass customized product platform and researching generally work together. As designers research, they are defining potential production processes and what a product needs to do and can begin to determine whether a product platform should leverage mass customization or modular mass customization.. This is represented by Figure 29.

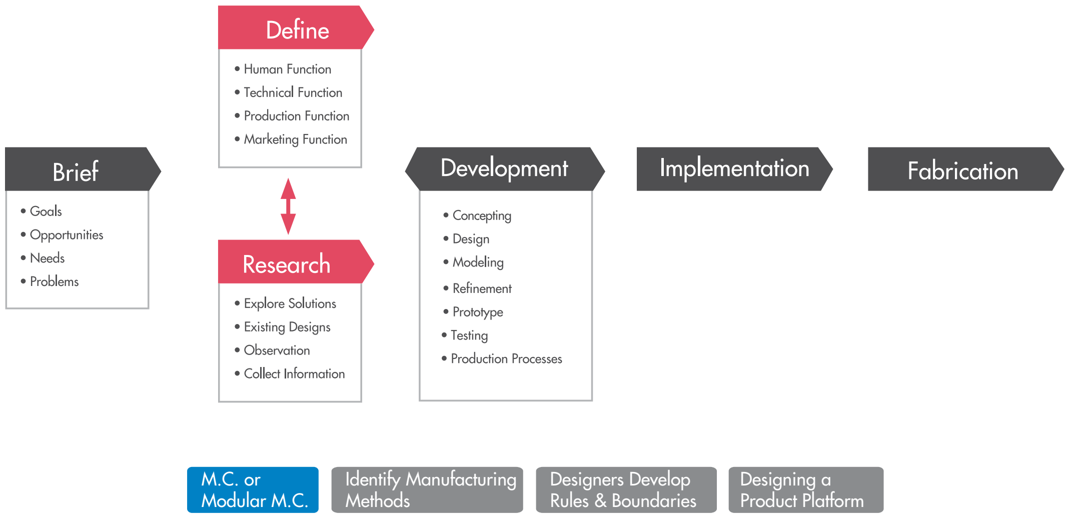


Figure 29: Design Process, Define & Research Consideration 1

Mass customized products, while they are very customizable, should have some level of predictability for what the final product will be. Due to the variety of options and design opportunities that are offered for designing mass customized products, designers are required to establish boundaries as well as limits for customization that are appropriate to a particular industry. These boundaries will begin by clearly identifying the customization capabilities of their company. Next, designers should establish the scope of their work by defining the options they can fulfill during the customization process. Options defined by the designer that would be offered to the consumer are options such as materials, size, color, finish, styles, functions, form and other predetermined stipulations. By identifying these options, the consumer will have a clear expectation, and the designer will have an understanding of the company's customization capabilities, which reduces the chance for errors. Mass customization affords consumers the ability to select styles but offers a high degree of personalization and customization options for the user. Modular mass customization also offers consumers the ability to select the style but often times provide customization through predetermined interchangeable parts for consumers to select from. This means that during modular mass customization, designers are generally responsible for the aesthetic and the design of the interchangeable parts. Consumers play a part in combining the interchangeable parts that meet their specific wants or needs. This creates value for the consumer by allowing them to personalize a product while still becoming apart of the design process. Both approaches should begin with a base design, this will help designers determine the functional criteria for what a product needs to do. This will in effect determine the amount of customization that a product may require. Figure 30 demonstrates provides a visual representation between the two main approaches toward mass customization.

Figure 30: Mass Customization & Modular Mass Customization

Mass customized product platforms will offer a higher degree of personalization, which will often provide more options. Modular mass customization leverages predetermined changes. While identifying whether to use mass customization or modular mass customization, during the research and defining processes, the degree of personalization should still be fairly broad because designers have not established any rules or boundaries. A customization scale is shown in Figure 31 to reference the degree for personalization or predetermined changes.

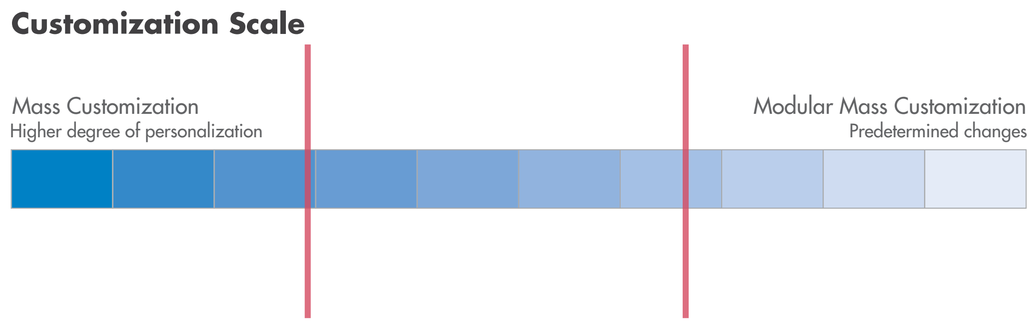


Figure 31: Customization Scale

As designers begin moving through the design process toward development and implementation (Figure 32) they should begin to identify how they will use mass customization or modular mass customization. This will be based on the following considerations but as designers get closer toward implementation they should be able to identify the degree of personalization they are able to provide the user (Figure 33).

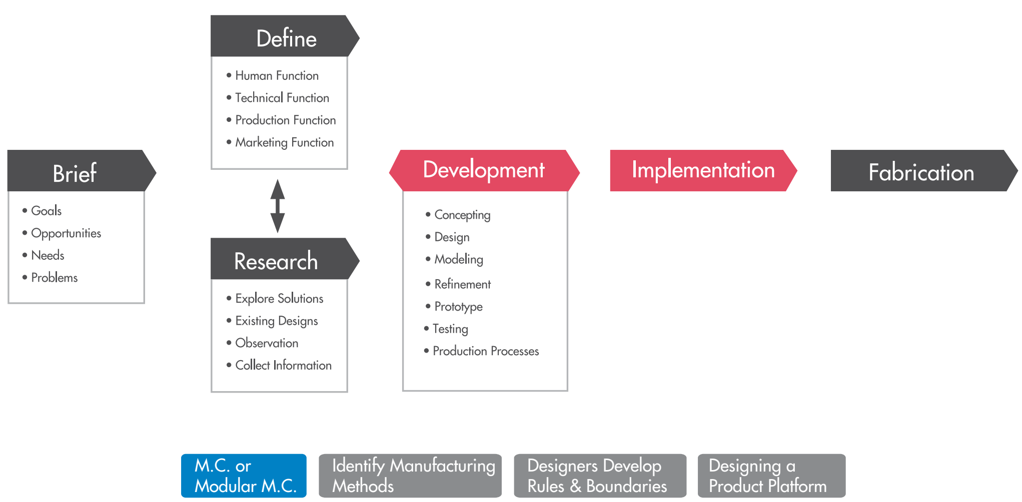


Figure 32: Customization Scale Design Process, Development & Implementation Consideration 1

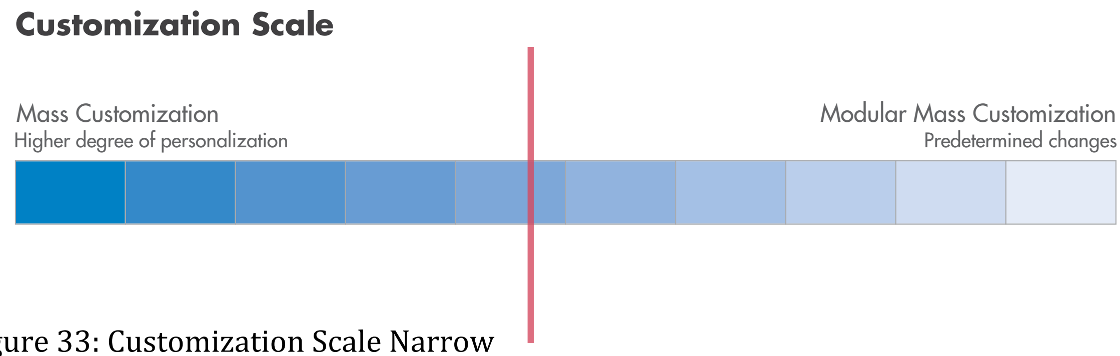


Figure 33: Customization Scale Narrow

Customizing form is an option that emerging technologies are allowing for consumers to customize further than traditional manufacturing techniques would allow. This provides consumers with the opportunity to generate unique personalized products. With 3D modeling/printing capabilities, form can be adjusted and leveraged by consumers using mass customized product platforms. While customers can and should be able to leverage the capabilities for adjusting form, designers must still develop a scope of customization that a particular company is capable of producing and should remain within those guidelines. For example, a consumer may not be able to visit a mass-customized jeweler and request to change the form of a bracelet to a shoe. Designers should take advantage of form adjustment to customize a personalized fit for the user. 3D scanning and printing are permitting the design and creation of products that can be tailored to individual consumers during the customization process. This can provide value by producing a product that is very specific to the end user.

Due to the variety of options and customization used in different industries, mass customized products will have a different number of options for consumers to choose from based on the product that would be customized. These options should be dependent on the company's industry as well as their capabilities for customization. This unique method of customization makes designing, developing, and producing these customized products more expensive because of the large number of options for consumers to choose from. As a result, mass customization is often used in higher end products. Mass customization will typically be selected as the method of customization based on the product that a company chooses to customize. The customization scale in Figure 34 represents a scale for mass customization for the companies referenced within this research to give designers an idea for the capabilities of mass customization.

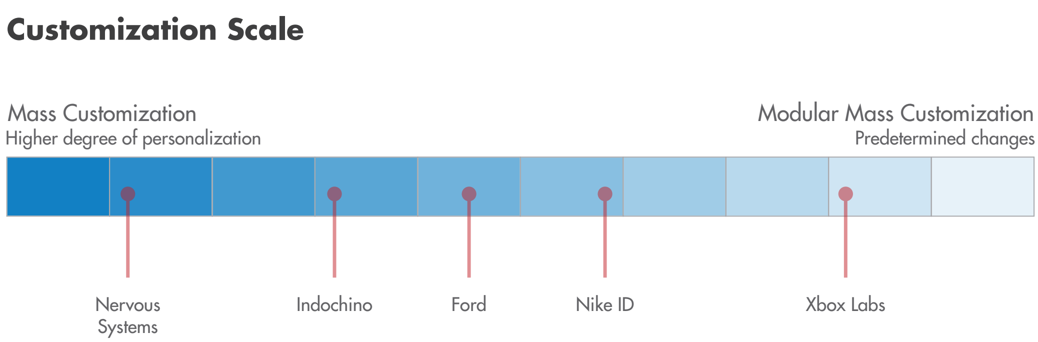


Figure 34: Mass Customization Scale (2016)

The process for mass customization typically involves one of two approaches. The most common approach is for a consumer to collaborate with a designer or an intermediary to provide custom specifications for a mass customized product; the intermediary will allow or deny the decisions made based on the rules of the product platform set out by the designer, which will be discussed in the following consideration. The other approach is for a company to generate a large number of mass customized products for a consumer to choose from. Nervous System leverages both approaches but utilizes this second approach to create a large number of products based off of biomimicry and generative designs. They use 3D printing to develop a variety of one of a kind products created from the rules crafted by the designer. This provides the consumer with very unique and customized products, however consumers don't play a very large role in providing personal specifications.

Another approach to mass customization is modular mass customization, which has been described in previous research. Modular mass customization leverages clear design boundaries created by the use of predetermined modules and interchangeable parts for consumers to choose from. The concept involves producing a variety of separate modules or design options such as size, material, and other variables to select from. Each design option is selected by the consumer and assembled to produce a final product personalized to the consumer's specifications. A good example reused throughout this study to exemplify this concept is NikeID, which offers consumers a number of options to choose from when they are customizing a NikeID shoe. It is the designer's responsibility to design these interchangeable parts, which will ultimately create the boundaries of customization for a product. By determining the interchangeable parts and boundaries, designers will be able to clearly identify the capabilities of customization that their company will be able to offer. In addition, designers will be able to setup a series of steps for the consumer to go through as they construct a modular customized product platform. These steps may include variables such as colors, sizes, materials, designs, features, form, and other options that consumers will be able to choose from. Modular mass customization creates a more streamlined manufacturing supply chain, resulting in higher product output at a lower cost compared to mass customized products.

Both approaches should start with a base design (foundation) where the customization/design process begins. Designers should create a design that serves as the foundation for consumers to select options that can be customized. While mass customization will offer a broader variety of options to the consumer, designers will still be responsible for establishing the module for customization. In some instances companies will develop mass customized products that are one of a kind for consumers to select from. Nervous Systems exemplify this concept through their generative designs. However, mass customization will typically involve a consultation or intermediary to work with the consumer while they provide their specifications. If a consumer requests an option that will produce an undesirable product, it is the designer's responsibility to discourage the option or deny the option. Creating a base design makes the final product somewhat predictable. If consumers go to the suit tailor to customize a suit, then they should leave with a customized suit.

In some instances, designers will encounter a need to combine both of these methods for mass customization. As an example, designers may find that during the customization of a modular mass customized product, most users choose the same standard module but during a different step users wish to fully customize that module. In this case, it would be beneficial to utilize a module or interchangeable part for the standardized module; then allow the consumer to fully customize the module that is important to them. When combining approaches, designers should ask themselves "Should modules or interchangeable parts be used?" Standardized parts in a custom design can leverage interchangeable parts to reduce the cost and eliminate the need for a consumer to provide custom specifications for that particular part. Designers should define the boundaries and clearly identify what will be truly customizable and what will be standardized or modular. Figures 35 & 36 demonstrate flow charts for how the designer may offer mass customization and modular mass customization to the consumer

Considerations

Consideration 1.1: Create a base design for mass customized product platforms.

Consideration 1.2: Consider whether interchangeable parts should be used.

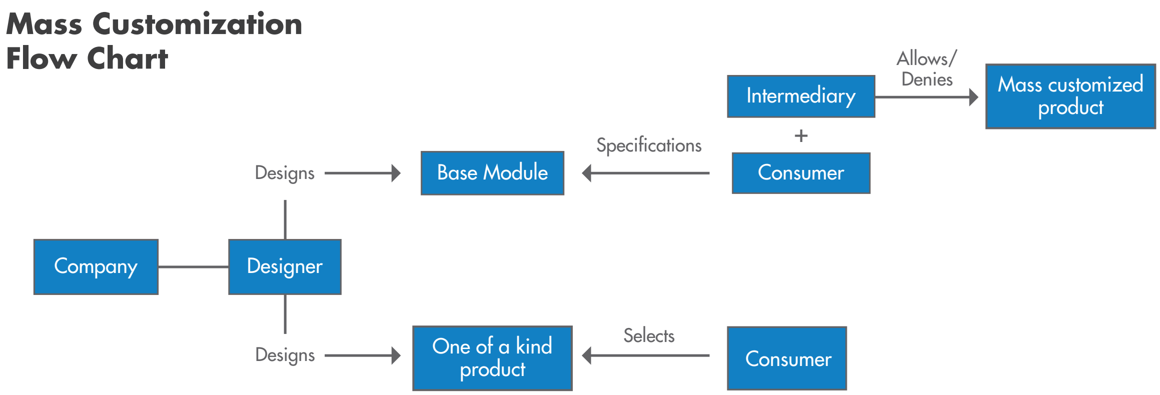


Figure 35: Mass Customization Flow Chart

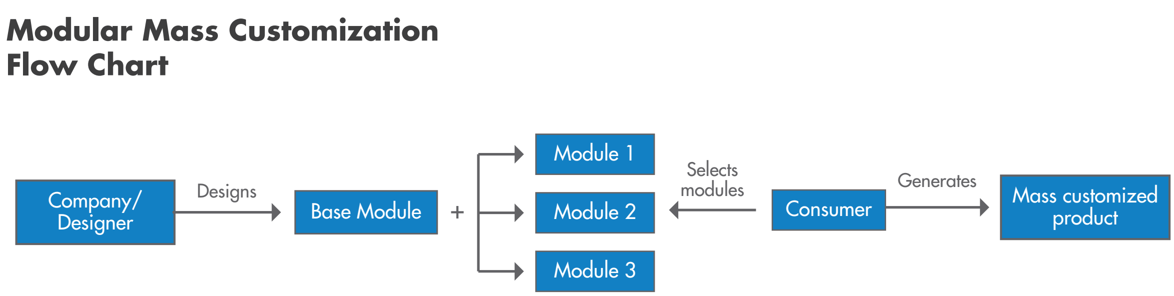


Figure 36: Modular Mass Customization Flow Chart

Consideration 2: Manufacturing Methods for Production

This consideration will discuss the approaches for selecting manufacturing methods to be used during the production processes for mass customized product platforms. Every company should have a unique approach for manufacturing mass customized products. As discussed in the previous consideration, manufacturing methods establish the customization capabilities that a company is able to achieve for mass customized products. This will contribute toward defining the boundaries of customization for a product platform. This consideration should help designers choose manufacturing methods that are appropriate to a company's industry by maximizing the human function while maintaining the brand identity, ensuring cost feasibility, and quality control to develop well designed products.

Description

Before using this consideration, designers should have an exact idea for the base design, the product, or the interchangeable parts they will be producing for a mass customized product platform. This consideration should then assist designers in identifying the manufacturing methods that will be needed to produce them. Designers should begin by determining if the manufacturing methods to be used will be new methods or existing methods that are already in place. If they will be utilizing existing methods, designers should answer the question – "Will a company’s existing manufacturing methods be capable of producing the mass customized product?" If so, designers should continue by evaluating what changes need to be made to current manufacturing methods to produce a mass customized product. Determining the manufacturing methods for mass production will begin while designers are defining the functional criteria and researching potential manufacturing methods (Figure 37).

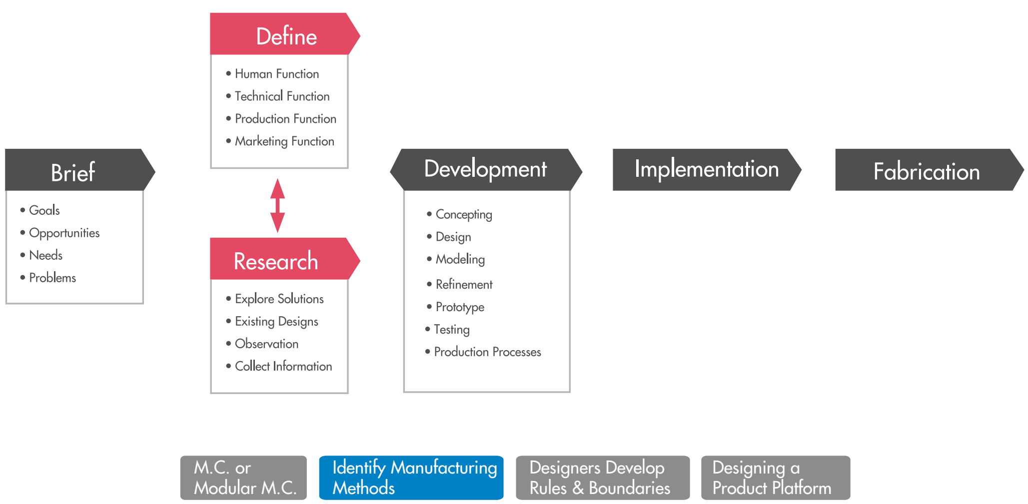


Figure 37: Design Process, Define & Research Consideration 2

In addition designers may also consider which emerging technologies could be integrated into the supply chain production process to increase capabilities for customization. Existing manufacturing methods are most commonly methods used for mass production, which may cause constraints in some instances. These methods can be adapted to create mass-customized products but typically existing methods, as they are, will only allow for modular mass customized products or customizable products that use interchangeable parts. Figure 32 demonstrates opportunities between traditional manufacturing and digital fabrication.

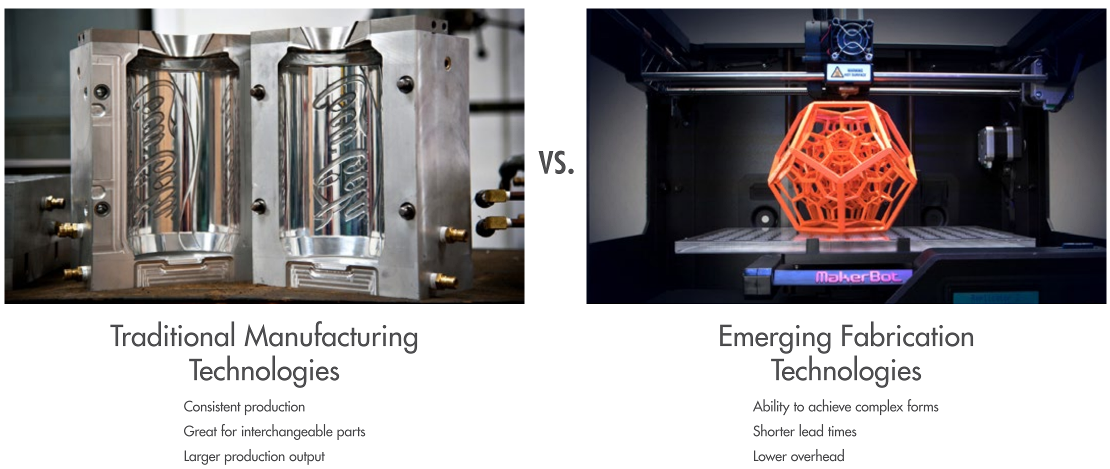


Figure 38: Traditional Manufacturing vs. Emerging Fabrication Technologies

NikeID embraces similar methods for customizing shoes and many car companies use interchangeable parts for customizing cars. Theses companies offer a variety of different options (interchangeable parts) to the user and then create a "custom" deliverable based on specifications provided by the consumer. Designers may easily adapt existing manufacturing methods to offer consumers mass-customized products using this approach, but they will need to identify the changes that need to be made to the supply chain to achieve mass-customized products.

Using existing manufacturing methods expedites the process for designers to begin producing mass-customized products. It may require reconfiguring the supply chain and retooling; however, this will be quicker and far less expensive than developing new manufacturing methods for an existing company. In addition, technologies and strategies such as digital fabrication, modularity, and just-in-time manufacturing can be integrated into existing supply chain manufacturing methods, which will increase capabilities for customization. For example, introducing CNC ornamentation into existing manufacturing methods may provide an opportunity for consumers to personalize products by etching or engraving their names into a final product; in addition, digital manufacturing methods such as 3D printing would enable designers to expand the opportunities for customization greatly while still utilizing existing manufacturing methods that are already in place. Strategies such as just-in-time manufacturing can also be put in place so that companies only produce and store what they need, eliminating overhead and waste. By integrating developing strategies and emerging technologies, designers can utilize existing manufacturing methods but increase the capabilities for mass customization. As designers move through the development process and consider different strategies and fabrication processes such as 3D printing, this causes designers to return back to defining the functional criteria, specifically the production function for mass customized product platforms. In addition, designers can begin researching options for production and fabrication before they return to the development and implementation processes. Designers may find opportunities to digitally fabricate complex forms with shorter lead times and lower overhead. This concept is illustrated in Figure 39.

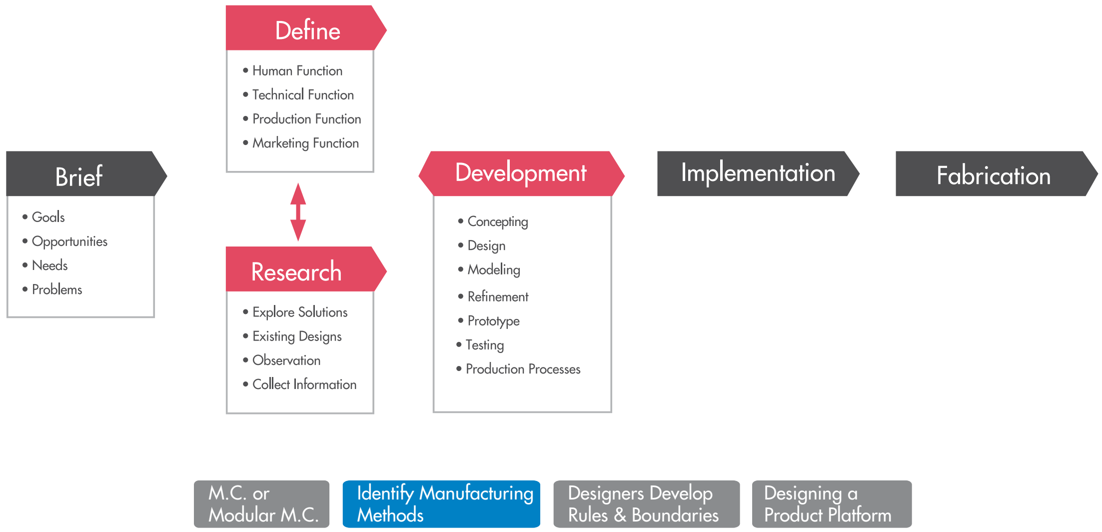


Figure 37: Design Process, Moving from development back to defining & researching Consideration 2

On the other hand, starting from the ground up, choosing new manufacturing methods for mass customization provides designers with more flexibility for customization. Based on the product that will be mass customized, designers should select new manufacturing methods that have a high degree accuracy, efficiency, and customization capabilities. Emerging technologies, specifically digital fabrication, will allow for very high degrees of customization especially for mass customized products. Technologies such as 3D printing and CNC machining utilize some form of 3D modeling or CAD software that allow for a high level of control by the designer and consumer alike. By integrating these manufacturing methods during the front end of production, designers will be able to offer far more options for mass customization. As designers develop strategies for new production processes, it is advantageous to implement processes that will provide the highest capabilities of customization to both the designer and the consumer. This ensures that the manufacturing methods chosen will adapt and provide different opportunities for customization in the future.

Production methods whether they are new, existing, or a combination of both, should be cost effective and appropriate to a particular industry. Designers should strive to eliminate additional processes and reduce lead times. Designers should be responsible for identifying an industry standard by researching competitors and companies in parallel markets. This will help develop a foundation for manufacturing methods by ensuring that they will be appropriate for their particular industry. Manufacturing methods should also be relatively cost effective so that production processes will not increase the total cost to the point that it is cost prohibitive for potential consumers to purchase a product.

Developing manufacturing methods that maximize production efficiency will allow companies to produce more products with shorter lead times. The goal of the designer is to develop a supply chain manufacturing method that eliminates unnecessary costs, steps, or processes; minimizes defects; and maximizes output. This will be the result of proper design research and planning. Designers should ensure that the methods chosen would be accurate and develop consumer specifications properly. Lastly, designers should strive to implement strategies and methods that will achieve the most value for consumers that are customizing products.

Setting up the anticipated volume for production will assist designers in establishing manufacturing methods for their business. As previous research in this study shows, there is an advantage to standardization in mass production. Mass production achieves exceptional economies of scale when parts can be standardized. As a result, designers should identify what volume a business would be producing to indicate if there would be opportunities for standardization. On the other hand, if the volume is not enough to achieve great value from the economies of scale, designers may opt to use different manufacturing processes that are more economical. 3D printing can be implemented which reduces waster, eliminates overhead, and still achieves good economies of scale if products remain within a size that is achievable by 3D printing technology that is available. Understanding the size and volume of a mass customized product platform will help designers as they choose the best approach for manufacturing methods for production.

Considerations

Consideration 2.1: Ensure that manufacturing methods are appropriate by maximizing production efficiency, accuracy, and customizability.

Consideration 2.2: Setup the anticipated volume for production.

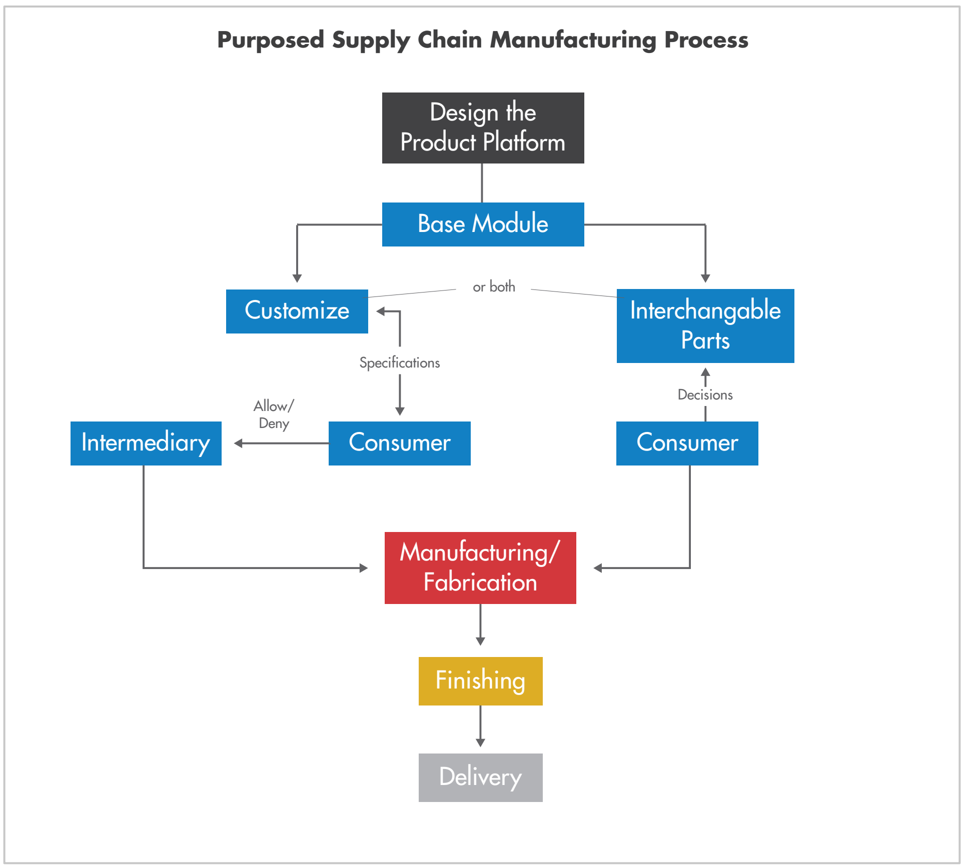


Figure 38: Purposed Supply Chain Manufacturing Process (2016)

Consideration 3: Rules and Boundaries for Mass Customization

It is the designer's role to setup rules and boundaries for every product platform for mass customization. This typically happens after some kind of customization approach is identified and manufacturing and fabrication processes begin to take shape. It will be much easier to identify rules and boundaries if designers understand the type of mass customization they are providing as well as the production processes they will use to get there. Rules are explicit or understood regulations or principles governing conduct within a particular activity ("Dictionary and Thesaurus | Merriam-Webster", 2016). For mass customized product platforms, designers should clearly identify the rules for customizing a product as they pertain to the company, the consumer, and any intermediaries involved in the customization process. Rules may be identified as form, size, colors, or other variables for solutions. Figure 39 shows a visual representation of this.

Figure 39: Rules for Mass Customization

Boundaries are an imaginary line that show where an area ends and another begins; they are points where two things become different ("Dictionary and Thesaurus | Merriam-Webster", 2016). Boundaries as they pertain to mass customized product platforms define the functional criteria for where consumers/companies customization capabilities begin and end (Figure 40).

The goal of developing boundaries for mass customized product platforms is to clearly identify the capabilities of customization for the company and the consumer. A company should understand its capacity for customizing a selected product and the consumer should have some understanding of their options while customizing. In addition, boundaries clearly identify the product that is being customized, which creates an expectation for the final product. Regardless of the degree of customization, the end result should be somewhat predictable, determined by the base design set forth in the previous consideration. It is the designer's responsibility to establish, define, and enforce the rules and boundaries for mass customized products.

Boundaries for Mass Customization: are considerations overarching an entire product platform, which define the functional criteria for where consumers/ companies customization capabilities begin and end.

Functional Criteria

Technical Boundary: What is the product capable of doing?

Production Boundary: What is the company capable of manufacturing?

Human Boundary: What Should consumers be allowed to customize?

Figure 40: Boundaries for Mass Customization

Description

To begin designing the rules and boundaries for a mass customized product platform, it is important to understand that the designer is responsible for making the rules. Rules contribute toward developing well-designed customized products. Ultimately, designers should know how much customization to offer the consumers, based on the product platform they are configuring for mass customization. The amount of change will depend on the product being customized. Creating rules and boundaries typically occurs during the development process shown in Figure 41.

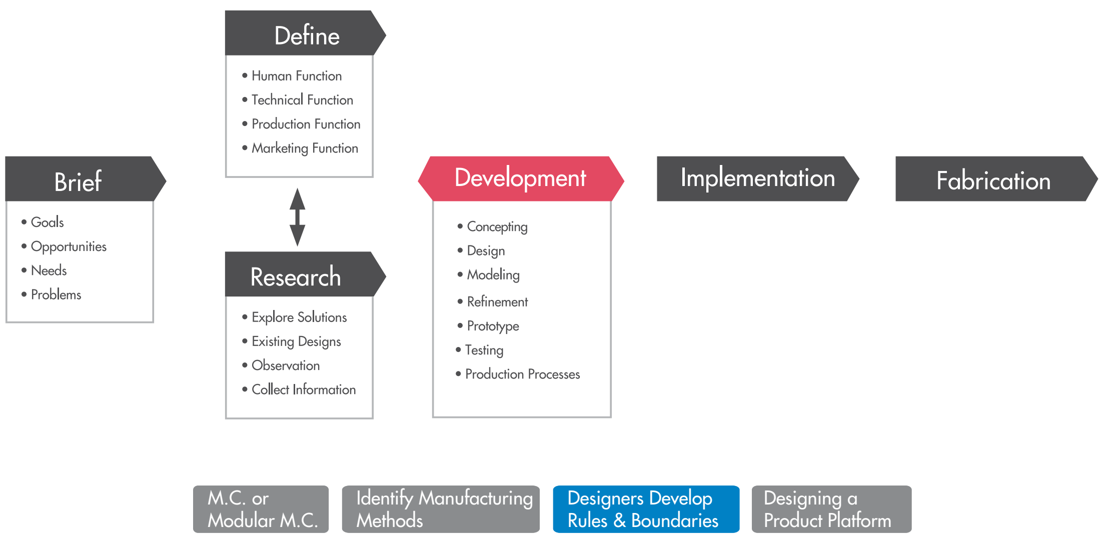


Figure 41: Design Process, Development, Consideration 3

As discussed in the first consideration, designers should begin with a base design and create a set of rules that define the variables of solutions. While there may be a very large number of variables, it is still important for the designers to create the rules so consumers may not create a customized product that is undesirable. Product platforms for mass customization should indeed allow consumers to make design decisions but designers should be responsible for directing those decisions toward well-designed final products. Mass customized products will typically have a broader more general set of rules because of the high degree of customizability. On the other hand, product platforms for modular mass customization will have more definitive rules and boundaries for customizing. This illustrates that as designer moves toward development for mass customization platforms, they may return to redefine the functional criteria based on the boundaries for mass customization. This will cause designers to move back in the design process before moving back forward toward development and implementation, illustrated in Figure 42.

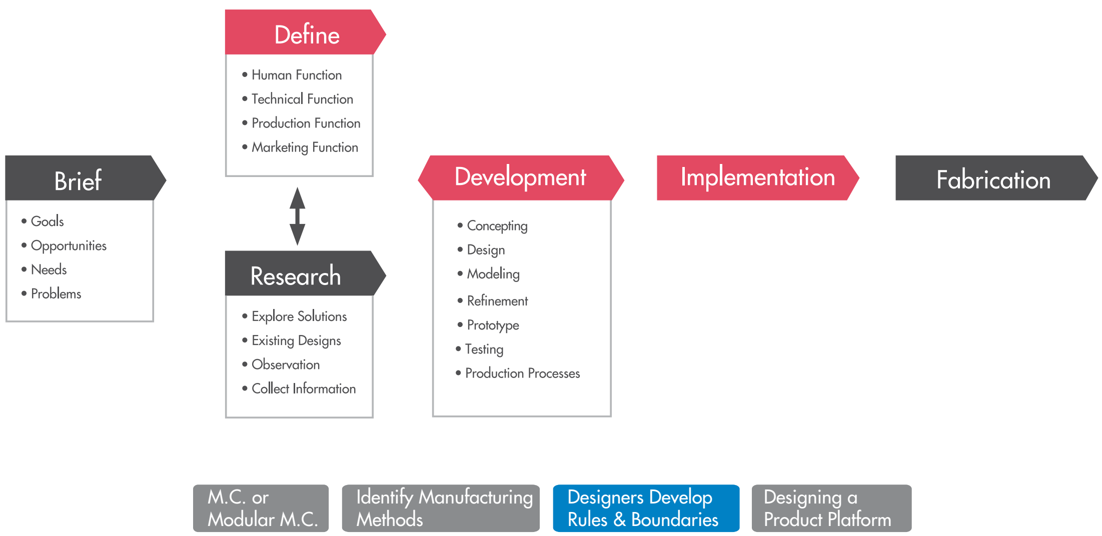


Figure 42: Moving back toward defining functional criteria toward development and implementation, Consideration 3

Product platforms for mass customization will generally leverage some kind of collaborative approach to mass customization. Collaborative customization generally requires a company representative to manage in-person consultations to assist the consumer through the customization process. They are in control of the customization process and act as an intermediary between the company and the consumer to guarantee that the designer's rules are followed. This approach is leveraged for a variety of different reasons; however the most common reason for using collaborative customization is because consumers lack the knowledge needed to customize a product independently or their inability to articulate exactly what they want.

For some products, consumers do not have enough knowledge or understanding to customize a product independently. This is common in the assistive technology industry for products such as orthotics or glasses for vision. The majority of consumers are limited by their knowledge for the product being customized, requiring consultation or collaboration with a more experienced professional. This method is not limited to the assistive technology industry, products customized in the furniture industry may require collaborative customization because the consumer may not understand the customization capabilities of a company, or have an understanding for human factors, which can't be expressed through a web-based service platform for mass customization. Many industries manufacturing mass customized products will require an in-person consultation to maximize customization capabilities and ensure they are providing consumers high quality products as well as a positive customization experience. In addition, companies that offer a high degree of customization will offer a large variety of options, which may overwhelm consumers. This can cause uncertainty because consumers are not exactly sure what the correct choice for them would be. Utilizing collaborative customization allows companies to work directly with the consumer to answer questions to guarantee that a product is designed safely, to specifications, and customized to its full potential within the rules set forth by the designer.

Companies may also use collaborative customization when the product being customized requires measurements, body scans, or other procedures that may require an experienced professional. Collaborative customization seems to be more common for mass customized product platforms because companies can explain the customization capabilities to consumers more in depth. However, Indochino, a custom tailored suit company discussed in the literature review, designs fully custom suits using a web-based platform, allowing the consumer to provide the specific measurements required. Product platforms using mass customization techniques are not limited to using collaborative customization although for many industries it maximizes customizability and provides the best consumer experience.

Defining the boundaries for customization is important to determine the capabilities of customization for the company creating mass customized product platforms, but it is also important so that consumers understand the opportunities for customization. Boundaries for customization represent the guidelines for customizing a mass produced product. This doesn't always mean the physical limitations for customizing a product; boundaries are setup to ensure that a product is well designed and appropriate. Often times however, the manufacturing methods of a particular company can constitute their capabilities for customization. These are part of the parameters that will be discussed in a later consideration. However, a designer must understand the manufacturing and fabrication capacity of a company to ensure they are maximizing customization capabilities as well as making sure the customization options they've designed are achievable. By leveraging digital design and fabrication, designers are able to broaden the boundaries of customization for companies and consumers customizing products using mass customized product platforms.

3D printing can commonly be used to achieve customized forms for consumers. It is rather ambiguous to develop guidelines or rules regarding form; customization of form should typically be offered for a customized fit or function of the product. For prosthetics, consumers are required to have a customized fit to make sure that the user is safe. On the other hand, Nervous Systems offers customization of form, which is primarily cosmetic. Although in both cases, there are boundaries specified by the designers to guide the consumer through the customization process. If the consumer is customizing a Nervous System ring, then they will not and should not be able to change the form to a shoe.

Creating boundaries for mass customized product platforms creates an expectation for the final product. It creates predictability for designers to identify what types of customization they are able to provide and produce. It also allows the consumer to anticipate what the final product may be. Creating boundaries is necessary so that the designers can remain in control of the customization process to design and create desirable products.

Considerations

Consideration 3.1: Designers set the rules for mass customization.

Consideration 3.2: Define the boundaries for mass customized product platforms.

Consideration 4: Designing a Product Platform for Mass Customization

The final consideration provides designers with important suggestions to consider while designing a product platform for mass customization. A mass customized product platform is a product created from a base design with the opportunity for consumers to provide specifications to customize products or select modules that makeup the final product. The objective of this consideration is to provide designers with guidelines for designing product platforms for mass customization and parameters or limits that will lead to well-designed final products. Parameters are a constant or limit that control what something is or how something should be done ("Dictionary and Thesaurus | Merriam-Webster", 2016). Parameters specify any limitations or constraints for producing mass customized products.

Description

As suggested in the previous considerations, it is the designer's role to define the approach to mass customization, manufacturing methods, and the rules and boundaries for a mass customized product platform. Likewise, it is the designer's goal to design a mass customized product platform that maintains the identity of the product being customized with quality control and cost feasibility in mind. Parameters should be thought of as physical limitations that control the customization of a product. Parameters include things such as laws and regulations to designing customized products and limitations based on production processes. When a designer begins defining parameters for a product platform, they should identify how far the consumer is able to customize the entire product dependant on any constraints or limitations such as laws, regulations, or manufacturing processes that prohibit certain customizability. In addition, designers should consider how much control a consumer has on customization or based on a company's ability to produce those specifications. If the designer is creating a product platform for customized sneakers, then the consumer should not have the ability to include roller skates for their sneakers, unless that is a parameter created by the designer and achievable by the production processes. Since many of the prelimnary considerations have been identified or at least somewhat thought out by the time designers are developing a product platform, this consideration is heavily used during the development process. Figure 43 describes where Consideration 4 would be considered within the design process.

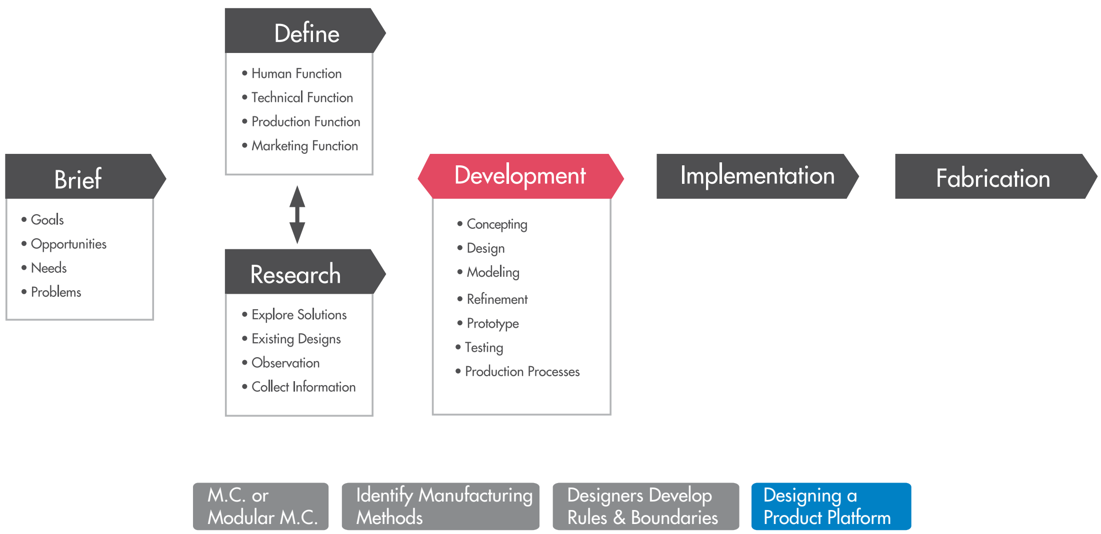


Figure 43: Development, Consideration 4

The designer should create a product platform that creates a product that is representative of the company but tailored to meet the individual needs of the consumer. If a platform is created that allows consumers to customize every aspect of a design, then designers jobs become obsolete. Designers provide value by being able to identify and develop parameters for mass customized product platforms. These parameters and limits should indicate how much control the consumer can have during the customization process; parameters will be based of on laws, regulations, and manufacturing processes. The designer should develop a product platform that provides consumers with the ability to customize a product to some degree but ensure that a company is able to produce those customized consumer specifications. This will build credibility and create a certain brand identity for a company. Maintaining a company's brand identity while offering consumers the ability to include customized specifications proves to be a difficult task. Designers can achieve this by developing a well thought out plan including rules and limits for what consumers can customize and what a company is able to customize.

In addition to identifying what consumers can customize based off of the companies ability to produce customizations, designers must establish how much influence consumers may have on product designs. This will often be determined by the parameters and limits set forth by the designer. Parameters for customization correlate directly to the manufacturing and fabrication processes discussed in the previous consideration. These processes can provide higher levels of customization or create limits and constraints. The manufacturing methods of a particular company ultimately constitute their capabilities for customization. A designer must understand the manufacturing and fabrication capacity of a company to ensure they are maximizing customization capabilities as well as making sure the customization options they've designed are achievable. Manufacturing methods can define the parameters of customization to some degree but designers leveraging emerging technologies for customizing products will be able to offer a higher degree of customization. Emerging technologies such as 3D printing and CNC fabrication can provide higher degrees of customization but it is still the designer's responsibility to identify how much control customers will have when they are specifying customization options. Designers should indicate parameters to ensure that the customization of a product is appropriate and can be executed.

Designers creating product platforms must begin by defining base design for mass customization. They will be required to develop the base design, the rules, and the boundaries for customization. Once the base design for a product is established, designers should then identify the parameters for what consumers are able to customize and what a company is able to manufacture.

Mass customization will tend to have broader parameters for customizability and consumers will play a more integral role in the design process. In addition, the design and fabrication processes should allow for a higher degree of customization to complete a final product. Especially if designers offer digital design and fabrication. If designers can offer consumers broader customization parameters, it will increase the value that a consumer may get from mass customization product platforms. Consumers receive more value and will typically be willing to pay more for a product that is customized to their personal specifications. The greater the parameters for customization, the more value a designer can offer to the consumers.

Modular customization will not provide as broad of parameters as mass customization because of the limitations in the production processes for developing modular products. These products are generally a combination of predetermined modules, which limits the degree of customization that consumers may specify. However, designers can create a large number of modules, which in turn creates a large number of possible final products. This approach enables designers to leverage a platform that allows for interchangeable parts which increases the economies of scale that a company would be able to achieve. In addition, designers can offer variety but ensure their manufacturing and fabrication processes remain flexible and responsive because the combinations of interchangeable parts are predictable. By leveraging the ability to swap or interchange parts, designers can avoid undesirable outcomes. They should not permit the consumers to select outcomes that will create poorly designed products. Modular mass customization still allows the consumer to select options that meet their current wants and needs but the process provides more standardized results. The outcomes for modular mass customization are even more predictable that the results of mass customization.

Considerations

Consideration 4.1: Define the parameters for customizing.

Consideration 4.2: Identify which parts can be customized.

Chapter 4: Application of Design Considerations

Introduction

Within the application of the design considerations, a team project is referenced which is used for the foundation of this project. The project consisted of a three person team working with a client user to develop a customized below knee prosthetic leg. This project is used as reference and merely the groundwork for this thesis study; the rest of the application and research herein was completed individually.

This chapter will discuss the considerations from Chapter 3 as they apply to the design and development of a custom 3D printed lower limb prosthetic leg. A prosthetic is a substitute or replacement of a body part designed to restore function, for cosmetic reasons, or both ("Dictionary and Thesaurus | Merriam-Webster", 2016). The current market for prostheses offers many options for amputees; particularly lower limb loss amputees. However, research generated during class discussions, referenced below, show that common trends in the prosthetic market are the shortcomings for prosthesis designs (Industrial Design Course, personal communication, Spring, 2016). Amputees required to use prostheses incur a variety of issues because of the standardization of most prosthetics. Many users experience limitations or feel discomfort because many prosthetics are designed so that they are affordable for users and easy to manufacture for the masses. Insurance companies play a large role in commanding high prices for prostheses. As a result, it is very common for amputees to receive only one basic walking leg that does not provide amputees with the ability to do anything other than walk. These issues create an opportunity for prosthetic advancement and the potential to serve a large community of limb loss victims, particularly LLL victims. Emerging technologies like 3D printing are helping designers to design for and address the individual wants and needs of amputees. 3D printing makes it possible to create customized designs that are specific to the user (Industrial Design Course, personal communication, Spring, 2016). There has been significant research and development done in the prosthetic market however, manufacturing and testing prostheses requires a professional license or manufacturing licenses (Industrial Design Course, personal communication, Spring, 2016). Some laws and restrictions differ between states, making it very difficult for designs and innovations to be developed and exchanged (Industrial Design Course, personal communication, Spring, 2016). This makes it very hard to innovate within a market that requires many certifications and permission through a lot of red tape. As a result, the following study serves only as an exploration for designing and creating custom prostheses, directed toward meeting the specific wants and needs of individual amputees.

To begin the process for designing prostheses that better serve the wants and needs of individual users, our three-person team asked ourselves "How can we create prostheses that are more affordable and meet the needs of individual users?" As we identified problems, opportunities, goals, and needs for our design brief (Figure 44), we began with very broad solutions.

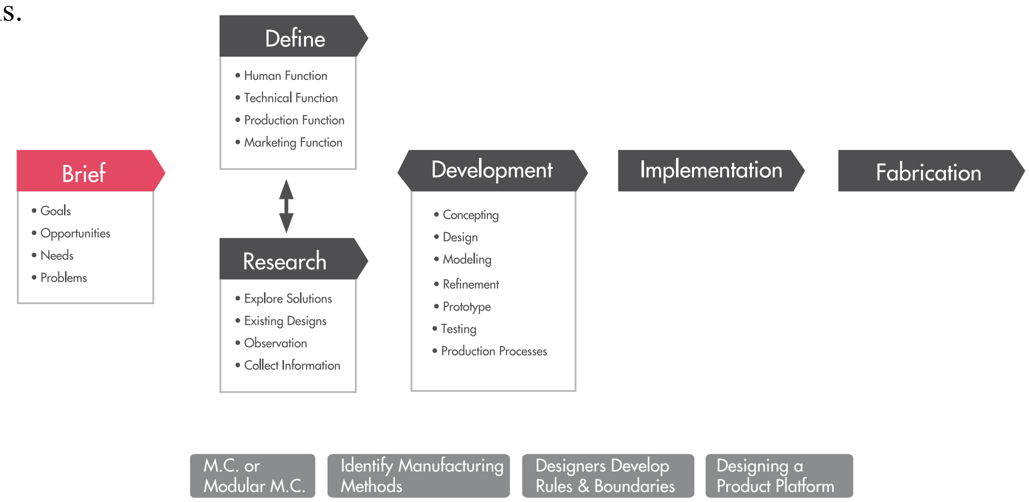


Figure 44: Design Brief for Application of Considerations

Many ideas were generated beginning as sketches shown in Figure 45, but without experiential market knowledge for prostheses, the design team needed additional resources. A licensed prosthetist from Alabama State University Montgomery, and a client user, double below the knee amputee, became participants in our project. The licensed prosthetist was influential because of his knowledge for prosthetics but he also provided an understanding for laws and regulations. The client user provided feedback and specifications that became the focus of the project and ultimately contributed to the final design. Their involvement in this project provided direction; they played an important role in this study by directing the designs toward feasible solutions.

Figure 45: Shift System concept sketches

Lower limb prostheses (LLP) in the most fundamental form are composed of a sock or sleeve worn by the amputee to protect the residual limb, a socket that holds the residual limb, a pylon that provides height and length, and a foot that meets the ground (typically for walking) Shown in Figure 46.

Figure 46: Basic LLP (Transtibial Prosthetics Devices & Treatment - P&O Care. (n.d.).)

Amputees have identified various wants and needs for individual components that make up LLP. However, market research gathered during class discussions indicates that prosthetic users primarily desire a better fit for their sockets (Industrial Design Course, personal communication, Spring, 2016). To reiterate, the socket is the connecting component between the residual limb and the prostheses; the socket must match the amputee's anatomy to ensure that problems with walking or skin/bone irritation do not occur. While this is the common goal for prosthetists, research also shows that many prosthetic users incur a variety of problems including MRSA, bone spurs, numbness, and walking issues resulting from poorly fit prostheses (Industrial Design Course, personal communication, Spring, 2016). A common problem is that amputee's residual limbs will change over short periods of time causing the fit of the prostheses to change. Since many insurance companies will only provide one prosthetic during a certain period of time, getting socket adjustments made is typically cost prohibitive. The client user for this project also experienced similar issues. Working long hour's outdoors with poorly fit prostheses, his residual limbs were exposed to sweat and heat causing MRSA infections on both residual limbs shown in Figure 38.

Figure 47: Image of client user's MRSA infection on residual limb

These were painful and prevented him from walking for lengths of time. He expressed the need for better fitting sockets as well as material explorations that would help breathability for his residual limbs. In addition, he communicated a need for a very unique foot that would allow him to remain low to the ground but would not inhibit his ability to sit back on the heel of the prostheses. Understanding that this client user isn't alone in his request for better fitting sockets and more comfortable materials, the design developments are directed toward serving the larger population of LLL amputees. Our team's redefined question is "How can we develop a design so that the sockets are customized to the user while the foot design remains modular to meet the specific needs of each individual?"

Moving from defining the brief into defining functional criteria and researching, (Figure 48) we began identifying some of the design and fabrication methods we would use for this project. We decided to utilize digital design and fabrication because of the great potential for altering a base design quickly and easily. In addition, using Digital fabrication would allow us to prototype complex forms with much shorter lead times.

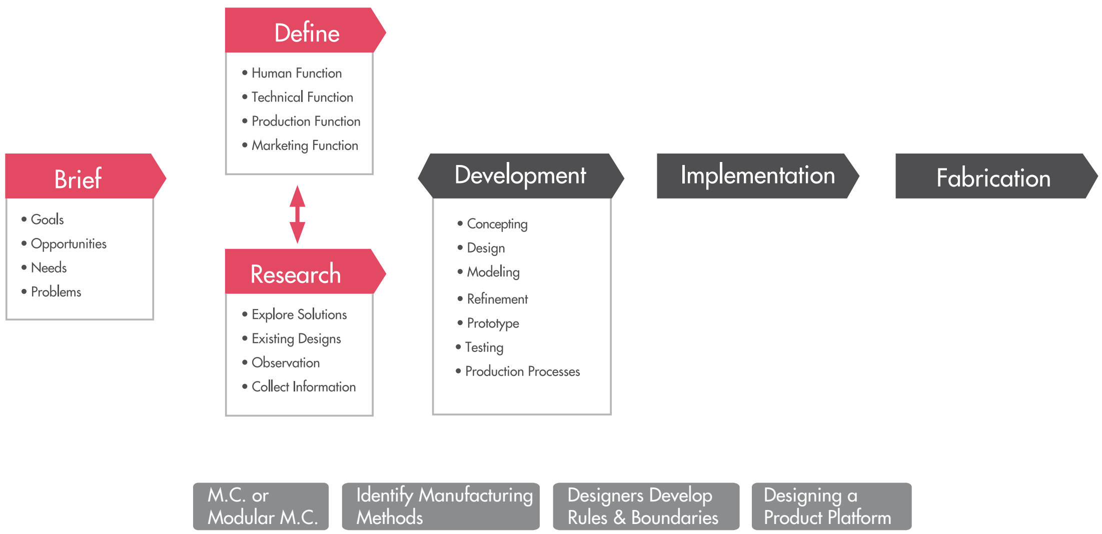


Figure 48: Design Brief, Defining, and Reaserching for Application of Considerations

Shift System

Shift System is the name chosen for this project to represent the company designing and developing customized prosthetic solutions. The concept for the Shift System is formed on the premise that prosthetic designs should have the ability to adapt and "shift" based on the needs of individual users. The company name should resonate with prosthetists because of Shift System's ability to innovate and shift market expectations; it should also be memorable to consumers because Shift System's will shift consumer expectations for prosthetic solutions.

Branding is an important element for companies, especially for companies developing products. It is important for consumers to recognize a company or brand that consistently produces exceptional solutions. Creating a brand and developing consistency is important to retain customer loyalty and achieve growth for a business. It is also important to develop consistency in branding to gain a competitive edge within business markets. To create a brand identity for Shift System, an iconic logo was developed to describe the focus of the company shown in Figure 39. The logo is created from a plus sign, which signifies the ability to add-on, and it is split in the center to describe modular connections; the Shift System plus sign is held in a circle, which describes the continuation of design and development. The word-mark "Shift System" is coupled with the logo to create an energetic, memorable logo design that will create consistent company branding.

Figure 49: Shift System logo

Consideration 1: Mass Customization or Modular Mass Customization

Based on the previous research, it is understood that methods for mass customization are typically separated by mass customization, modular customization, or a combination of both. Mass customization offers broader customization capabilities, as opposed to modular customization, which identifies which choices can be selected from modules or interchangeable parts predetermined by the designer. Shift System is difficult to categorize when determining whether the method for customization is mass customization or modular customization. Although the LLP will be mass customized to meet individual users personal wants, needs, sizes, and specifications, each component begins with a standardized design for customization. The interchangeable part that Shift system uses is a modular connection point, which consumers have a low desire to customize and can be easily interchangeable. Shift System uses a specialized approach toward mass customization, which involves using a combination of both methods for mass customization. Beginning this consideration during research process and defining the functional criteria (Figure 50), Shift System began by identifying the functional criteria for LLP first. In the most basic form, the user has to be able to walk but the socket should be mass customized to fit individual users. The foot attachment should be customized to increase the value for what a LLP can do.

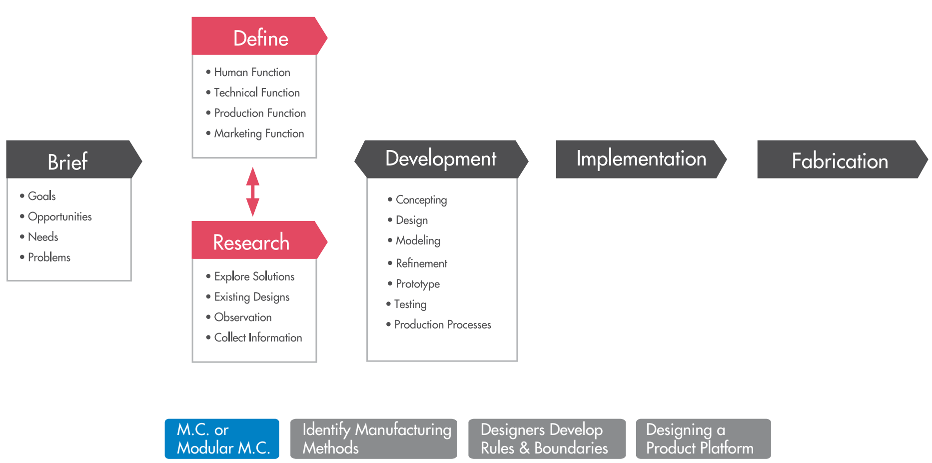


Figure 50: Define and Researching Process, Consideration 1

The combination of both methods for mass customization allows Shift System to determine its capabilities for customization. Understanding the customization capabilities create certain expectations for prosthetists and consumers alike. Prosthetists' experiential knowledge, coupled with their knowledge for the customization capabilities of Shift System, helps them to achieve the most value for amputees in customized LLP. Amputees should also have an understanding of Shift System's customization capabilities in order to contribute during the customization process for designing LLP. Moving into development (Figure 51), Shift System's degree of personalization was still somewhat broad, shown in Figure 52.

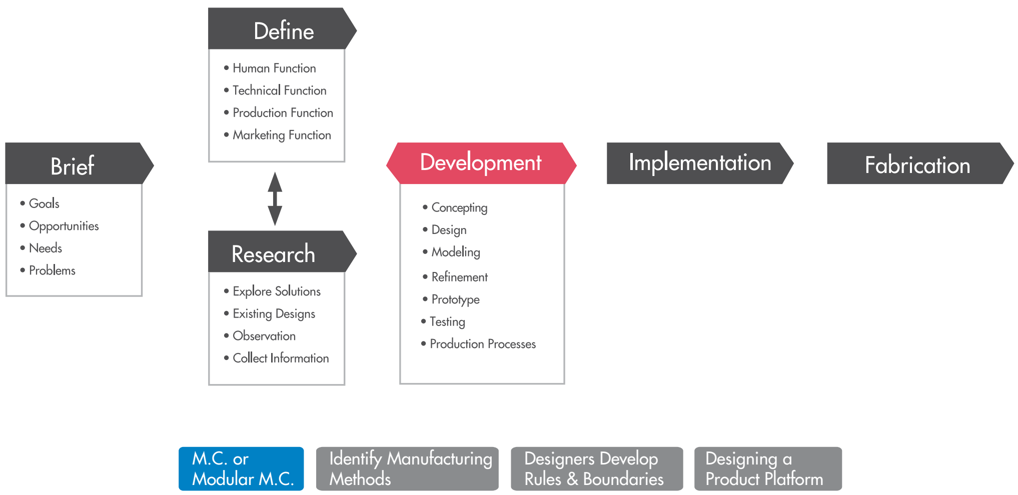


Figure 51: Development, Consideration 1

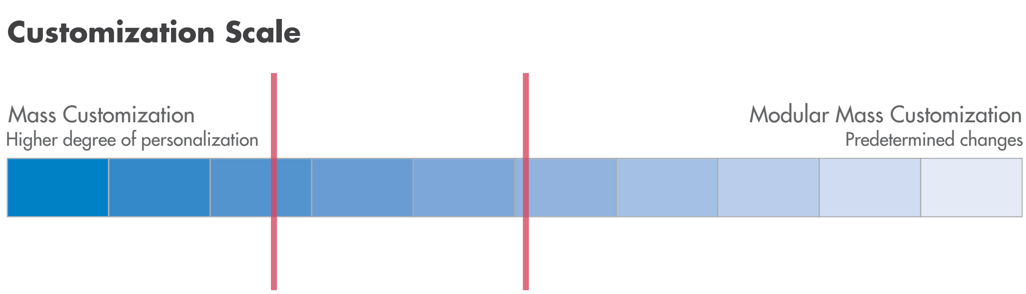


Figure 52: Shift System degree of customization during development

Consideration 1.1: Create a base module for the mass customized product platform

The base design for Shift System's product platform for mass customization is a lower limb prosthetic. There are four main modules that work together to create the prosthetic leg. The product platform is designed so that the inner socket can be personalized and customized to fit the user precisely. The outer socket is a base module that cradles the inner socket. It is a standard module developed by Shift System but can be customized to meet the specific needs of the consumer if the prosthetist agrees that the customization choices are appropriate. The bayonet mount, which is the connection point between the inner socket, the outer socket, and the bayonet mount is a modular component which offers little opportunity for customization by the consumer. Lastly the foot attachment has a very high level of customization based on the consumer's wants, needs, and functions. This allows consumers to design a foot attachment that is specific to their wants and needs (Figure 53), as long as it is safe and practical then the designer and prosthetists should permit it

Figure 53: Modular foot attachment opportunity

Moving from development toward implementation (Figure 54), Shift System is able to better identifying the degree of customization, which they are able to provide to consumers (Figure 55). Shift system is able to provide mass customization to its consumers by allowing consumers to specify design details that will address consumer's specific problems or needs. Consumers are able to work with prosthetists to specify customization options for the inner socket, outer socket, and the foot attachment. Allowing the consumer to become an integral part of the customization process creates value by allowing amputees to design solutions for their existing problems or design for opportunities. It also ensures that Shift System is providing solutions that are specific to the wants and needs established by amputees and prosthetists. While specifications for the Shift System are primarily functional customization options, it is possible for consumers to become a more integral part to the aesthetic design of LLP. This idea will be discussed further while defining the rules and boundaries for this product platform.

Shift Systems allows the consumer to create a custom fit socket based on 3D scan data shown in Figure 53. Amputees work with the prosthetist to choose from a variety of different materials based on the purpose and function for the LLP. Consumers can select options such as having the socket cut low at the rear of the knee to reduce impingement and irritation. Next, consumers can choose from a selection of predesigned outer shells, which serve as the protective layer that the socket fits inside of. The inner and outer shell are shown in Figure 54.

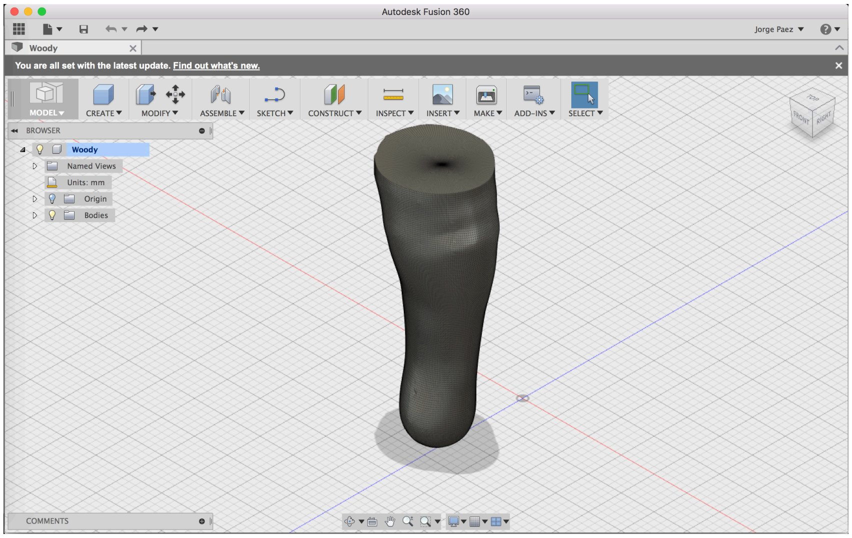


Figure 53: Shift System 3D Scan Data (2016)

Figure 54: Shift System Inner & Outer Shell (2016)

Consumers can choose to use the standard design for the outer socket or incorporate design options of their own such as breathability, low cut rear, or other options that apply to specific problems or needs. The modular connection point is a standardized bayonet mount shown in Figures 55 and 56. It can only be customized to add or reduce height. Otherwise, the consumer cannot alter the modular connection point.

Figure 55: Shift System modular bayonet mount, 2016)

Figure 56: Shift System modular bayonet mount w/ socket and foot (2016)

The last major option for customization is the foot, which contributes to the function of the LLP. Shift System offers a selection of interchangeable feet that can be selected as standardized options or customized to specifications. Amputees may also work with their prosthetist and Shift System to design a customized foot. For this project, the client user in collaboration with the prosthetist identified a need to customize a work foot for working low to the ground. The work foot needed to be small so it would not impede the client user while he is kneeling or working low to the ground. The client user also requested a design that had a toe for balancing and a heel to sit back on while kneeling on the ground. The Shift System design created to address these specifications is shown in Figure. It is 3D printed from a nylon and carbon fiber filament. The top of the foot has an opening the attatch to the bayonet mount. The gold piece is a flexible damper to reduce shock while walking. The bottom is a nylon and carbon fiber filament attached to high-density polyurethane foam for traction and stability. An example of the foot is shown in Figure 57 and an exploded view of these components is shown in Figure 58.

Figure 57: Shift System Modular Work Foot (2016)

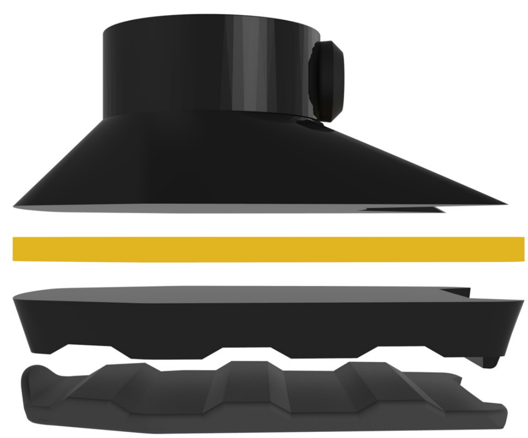


Figure 58: Shift System Foot Exploded View (2016)

Prosthetists are the key element during the process for customizing LLP. They must ensure that while consumers are identifying their personal design specifications, the choices are safe and appropriate for the consumers needs. Research indicates that during initial consultations, amputees often have impractical ideas but the prosthetist is responsible for focusing their decisions toward practical designs that are suitable for an amputee's injury as well as their abilities (Industrial Design Course, personal communication, Spring, 2016). The prosthetist act as intermediaries for Shift System and allow or deny consumers the ability to include certain specifications.

Shift System's initial meeting with the licensed prosthetist and the client user began with a variety of broad concepts, some of which were unrealistic. Although, issues that were repeatedly brought up were infections caused by material choices on the client user's current prostheses, as well as the functionality while working outdoors, using his walking prostheses. The client user also discussed issues like having too much height while using his walking prostheses. He also mentioned having trouble balancing on his shins because he has no heel to sit back on. These issues and opportunities continued to be discussed in different ways and the licensed prosthetist indicated that these are problem areas that customized prostheses can augment by providing better "work legs." Shift System worked with the licensed prosthetist and the client user to address these issues and create customized solutions tailored to solve these problems. The refined solutions shown in Figure 59 began as sketches, which were used for the development of the client user's customized Shift System work leg.

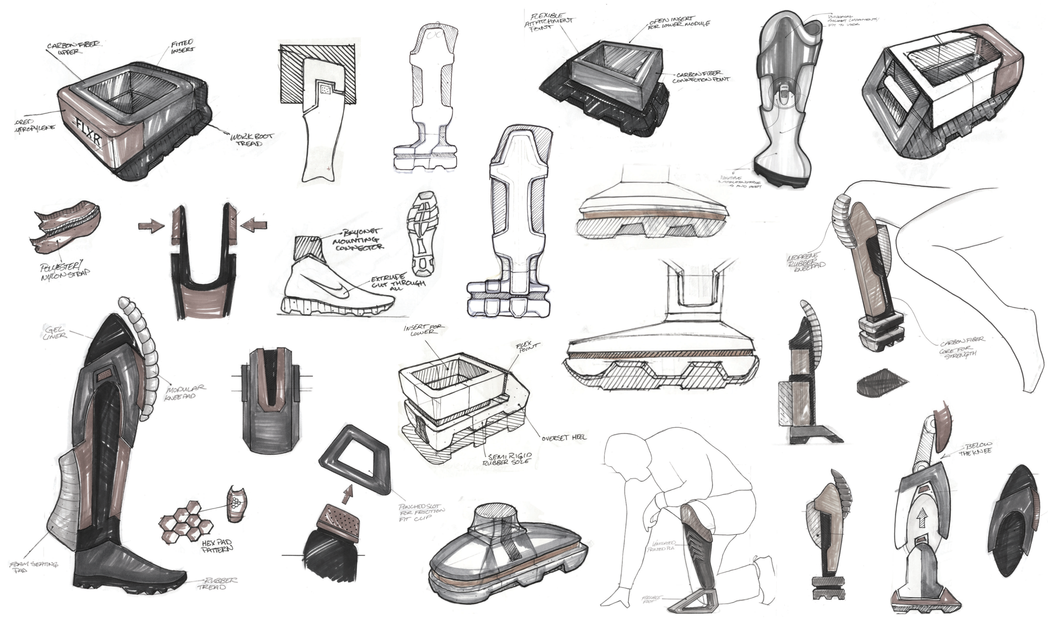


Figure 59: Shift System concept refinements (2016)

After inputting the client user's scan data through a high-resolution surface modeler to create custom fit sockets, the client user worked with the licensed prosthetist and Shift System to chose the material for the inner sockets. The nylon filament was specified to 3D print for his inner socket, the nylon is softer on the client user's residual limbs and provides more breathability than his current walking prostheses. For his outer socket, with the help of the licensed prosthetist, the client user specified that using a nylon filament with layers of carbon fiber filament would be appropriate for the rigidity demanded by a work leg. For both the inner and outer socket, the client user identified that he needed a low cut rear that would reduce impingements as well as irritation when he kneels for lengths of time. The modular connection point used is a standardized bayonet mount but reduced in height to meet the client user's particular needs. The work foot has been customized so that it is low profile and easy to walk around on. It provides a front toe, which is used for balancing, and a heel to sit back on when working on low surfaces. The lower sole is made from high-density polyurethane to absorb shock and provide traction. The foot is completely customized and tailored to the client's specifications set out during the collaborative consultation. Figure 60 shows an exploded view of each component for the Shift System LLP.

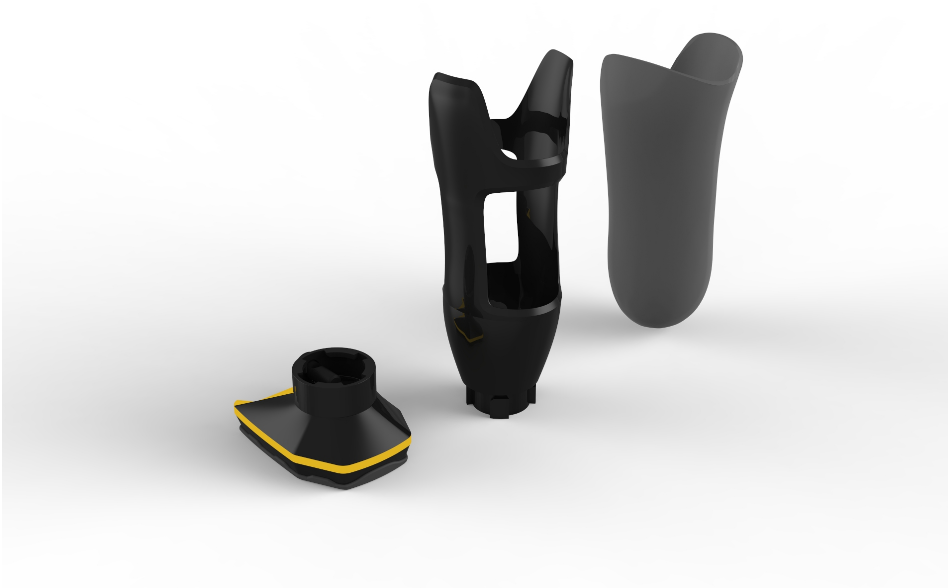


Figure 60: Shift System Work Leg Exploded View (2016)

Consideration 1.2: Consider whether interchangeable parts should be used.

While a majority of the Shift System LLP is mass customized, Shift System begins each step leveraging a modular approach toward mass customization. Each step provides an opportunity for customization beginning with a base module. Standardization of these modules provides prosthetists and amputees with a starting point to build and customize from. The inner socket is created using mass customization but it is printed as a nylon filament unless specified otherwise. Consumers can choose the existing outer socket designed by Shift System or consumers may work collaborate with their prosthetist and Shift System to create a customized outer socket. The bayonet mount, which serves as the connection point between the sockets and the LLP feet is modular. They are designed to be interchangeable and selected based on the height that is desired in the LLP. Lastly, the feet that Shift System offer are modular components; the interchangeable designs could include feet for training nubs, showering, walking, athletics, and working. The feet are base modules, which means that they can be purchased as standard parts from Shift System or consumers can collaborate to create a more customized foot. Consumers may work with their prosthetists to customize the form of existing base modules for foot attachments or create an entirely new form and function for a foot attachment. This is how Shift System provides great value to its consumers through their product platform. The ability to create a customized foot to meet individual wants and needs is very unique and Shift System is able to achieve very customized solutions. Consumers collaborate with their prosthetist to ensure that designs are appropriate and safe but they may develop foot attachments that are entirely customized.

Shift System leverages both methods of mass customization because of the unique need to incorporate mass customization with modular customization. The benefit of having mass customization is so that the LLP are designed and tailored to the specific needs of the consumer. However, Shift System is able to leverage modular customization by providing prosthetists and amputees with a base module to use as the starting point. In addition to using a base module, modular customization standardizes processes such as designing and developing the modular bayonet mount. Since the main manufacturing methods use digital fabrication, the design files begin with a base module but may easily be manipulated to meet the needs and specifications outlined by prosthetists and consumers. The ability to leverage digital design and fabrication make it easy to mass customize LLP based off of modular customized parts.

Consideration 2: Manufacturing Methods for Production

Shift System manufacturing methods primarily focus on utilizing digital fabrication as the main processes for manufacturing and fabricating mass customized LLP. Since digital fabrication techniques typically provide a higher degree of customization, Shift System is able to offer a broader range of customization capabilities. Since both mass customization and modular customization approaches are leveraged, Shift System methods for manufacturing are personalized to meet the company's production needs. Since our fabrication processes were mainly identified in our design brief, this consideration was revisited during the development process (Figure 61).

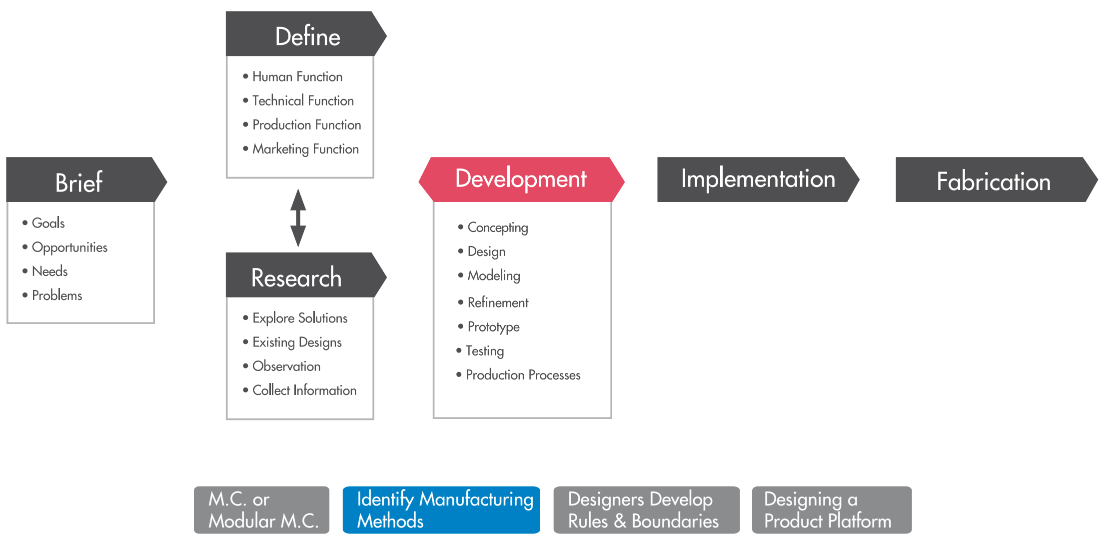
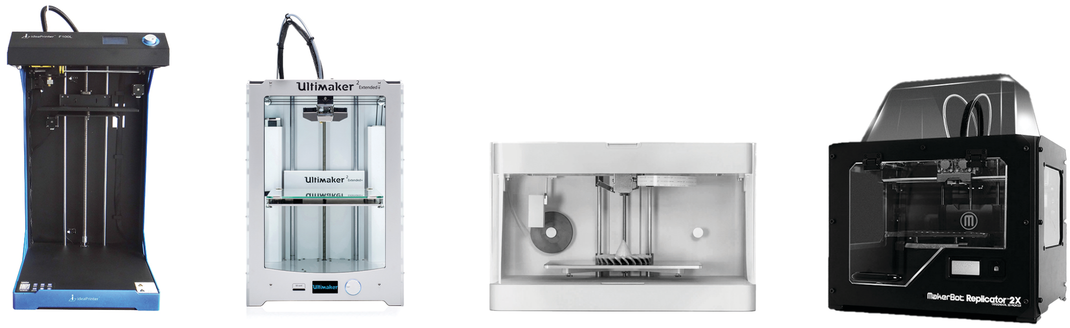


Figure 61: Development, Consideration 2

Consideration 2.1: Ensure that manufacturing methods are appropriate by maximizing production efficiency, accuracy, and customizability.

Shift System focuses on implementing new manufacturing methods for producing mass customized LLP. Shift System leverages digital fabrication along with more mature manufacturing methods such as the integration of modular components and just-in-time approaches. These methods allow Shift System to provide a very broad range of customization capabilities. The primary manufacturing process for Shift System is 3D printing, which allows for a very high degree of customization as well as a large range of materials for consumers to select from. Using 3D printing allows Shift System to customize each component for LLP due to short lead times and low manufacturing costs.

After collaborating with the licensed prosthetist and the client user to determine the specifications that would be used to create the client user's customized LLP, Shift System began its process for fabrication. Since the specifications were input using 3D modeling software, the digital files were required to be sliced and sent to the 3D printer. To complete the client user's customized LLP, Shift System used an Ideamaker 3D printer, Ultimaker 2 Extended 3D printer, Mark 2 3D printer and a Makerbot Replicator 2X to produce the final customized prostheses, all shown in Figure 62. After the licensed prosthetist and the client user selected the material filaments that would be used, Shift System began slicing the digital files for printing and began printing them on the 3D printers. The fabrication process took a few days to complete.



Ideamaker | Ultimaker 2 Extended | Mark 2 | Makerbot Replicator 2X

Figure 62: 3D printers used to create Shift System Work Leg

The manufacturing methods are appropriate for mass customizing LLP because of the ability to alter each design to meet consumer's specific wants and needs. In addition, 3D printing only uses the material needed to make the parts specified, which eliminates unnecessary manufacturing waste and overhead of mass produced products. 3D printing production is also very quick which reduces the overall lead-time for completing customized LLP. Transferring digital files is a benefit of using digital production processes for manufacturing. This means that Shift System designers can receive specifications and return a design for approval in the same day. In addition, digital files can be shared among prosthetists and consumers to further the development of successful customized designs. Shift System fabrication methods ensure production efficiency, accuracy, and customizability.

Consideration 2.2: Setup the anticipated volume for production.

The manufacturing methods used by Shift System's maximize production efficiency because of the ability to create LLP as they are needed. This eliminates unnecessary overhead and storage of products that haven't been purchased yet. This aligns with the principals of just-in-time manufacturing. By eliminating the need to produce products that haven't been purchased, Shift System can focus on customizing products for consumers that need them, making production more efficient. Using digital fabrication is also beneficial because it allows prosthetists to collaborate with designers to address very particular needs and concerns. This ensures that consumers are working within the boundaries of customization but maximizing the value through their personal specifications. Prosthetists assist consumers during this process to ensure maximum value but to also ensure a safe and proper fit. The risk and liability involved with providing assistive technology means that the manufacturing accuracy must be perfect for consumers to use Shift System LLP. 3D printing technology has developed so that the accuracy of 3D printing is almost exact, ensuring a safe and proper fit.

Lower limb amputees are only a fraction of consumers on the market especially when comparing them to larger markets and industries. This means that Shift System serves a very niche market to begin with so achieving economies of scale through volume standardization proves difficult. However, Shift System does expect to produce at a mass customization scale, which anticipates enough volume to constitute standardizing part on some level. Shift System may not design every LLP as an entirely new customized solution for consumers needs; instead, base modules have been created that address a variety of consumer needs and may be manipulated accordingly for each individual. This creates some standardization but not large enough to constitute using many standardized parts. The bayonet mount is the only standardized part but it can also be altered to meet height specifications provided by the consumer.

Consideration 3: Rules and Boundaries for Mass Customization

Defining the rules and boundaries for mass customization was heavily considered during development because the approach toward mass customization was identified. In addition, Shift System has identified 3D printing as the primary fabrication process. However, it became apparent that there were opportunities to expand the rules and boundaries for customization based on the use of 3D printing and such a high degree of personalization for the end user. Ultimately, this consideration moved from the development process through research to redefine functional criteria for how much customization that Shift System could offer to the consumer (Figure 63).

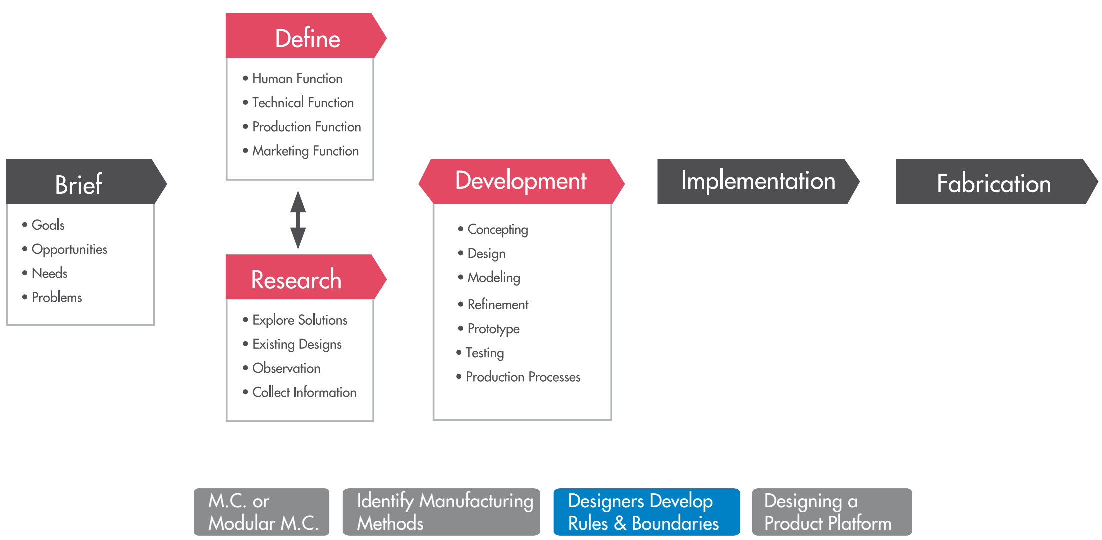


Figure 63: Moving backward from development toward defining and researching, Consideration 3

As Shift System researched opportunities for customization, we realized that this particular project was very specific to the function for the final user. The focus was the human function and the ability to work on the ground. Shift System realized however that 3D printing provides large opportunity to allow the consumer to become part of designing the aesthetic. If boundaries are created which control customization to some degree, users can indeed customize a large part of the aesthetic. During research, we discovered Bespoke Innovations, which designs prosthetic fairings used to create a beautiful aesthetic for prostheses. Bespoke innovations has setup boundaries that permit the consumer to identify the look but ultimately, a Bespoke designer is responsible for executing the final product, ensuring that a well-designed product is developed. Bespoke focuses mainly on aesthetic instead of function, but it was a discovery in our research that prompted innovative aesthetic design. Shift System explored ideas for altering the final aesthetic as well as the function for the user. While our end result is primarily function, this could be an opportunity pursued in future development. Figure 64 shows concepts for customizing the function as well as the aesthetic for lower limb prosthetics.

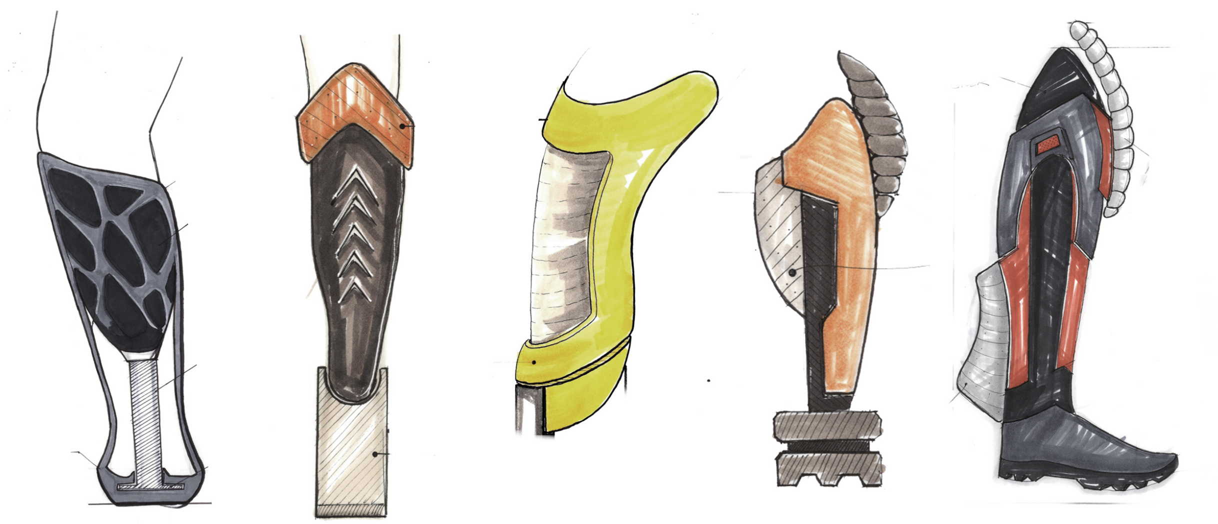


Figure 64: Aesthetic exploration for lower limb prostheses

Shift system defined its rules and boundaries for customizing LLP before beginning to generate customized designs. The rules include designing a LLP that is safe, functional, and appropriate for the end user. A prosthetist is used for a collaborative consultation to ensure these rules are met and enforced. Working to provide the consumer with the maximum customization opportunity, as Shift System moved through the development process, 3D scanning and 3D printing technologies were leveraged to allow consumers to design very customized LLP. Digital design and fabrication implemented by Shift System allows prosthetist to collaborate with consumers to edit the form of LLP to meet specific wants and needs of the consumer. Moving from development toward implementation (Figure 65), one of the most important rules was that the final prototype and deliverable must be test fit. A licensed prosthetist would be responsible for fitting the customized design and ensuring that it was safe, functional, and appropriate for the user.

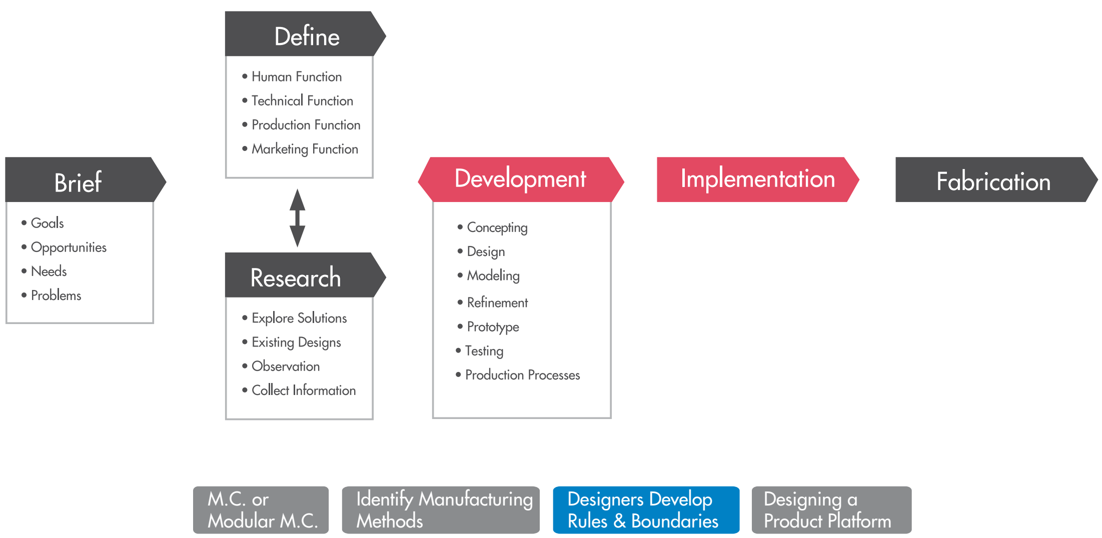


Figure 65: Moving from development toward implementation, Consideration 3

Consideration 3.1: Designers set the rules for mass customization.

Shift System designers understand the high degree of customization that is needed for customizing LLP. When developing the rules for the product platform for mass customization, designers strived to provide the most value possible by allowing consumers to become a fundamental part in the design process. Using prosthetist as an intermediary, designers rely heavily on their expertise to control the rules and boundaries for customization. It is the goal to allow consumers to meet specific needs but only if the final product is a desirable outcome that is safe, functional, and appropriate for the end user. If a consumer requests to design a prosthetic with six toes, the prosthetist should discourage this decision and direct the consumer toward a more appropriate design for their need. Customization shouldn't happen simply because the user has the ability to make customized design decision

A collaborative design consultation is implemented for Shift Systems customization process because of the absolute need for the involvement of a licensed professional to ensure that Shift System prostheses are safe and tailored to the specific wants and needs of the consumer. The prostheses industry is full of laws and regulations that increase Shift System's liability for developing assistive technology. By using a collaborative approach to mass customization, Shift System can mitigate issues, injuries, and mistakes by using experienced professionals to gather and document consumer specifications. Many consumers will not have the knowledge it takes to customize LLP without assistance. This is largely the reason for implementing a collaborative approach and using a prosthetist as the intermediary. The prosthetist provides knowledge for safety, laws, opportunities, customization capabilities, and an invaluable understanding of prostheses that consumers could not learn on their own. The prosthetist also functions as an educator to teach amputees about their injury, opportunities that are specific to the amputee, as well as the customization capabilities of Shift System. Typically consumers have a preexisting relationship with their prosthetist that relies on trust, which increases the benefit for using a collaborative approach. Prostetists are often familiar with amputee's conditions, which help them to provide a better consultation. Collaborative customization may also make it easier for amputees to adapt to new customized prostheses; a recommendation from their prosthetist may reassure them that customized prostheses provide new possibilities and solutions. The collaboration process however is not only limited to the prosthetists and the amputee; prosthetists must collaborate with Shift System designers to communicate the wants and needs of the consumer as well as the limitations and any problems. Prosthetist play a major role in deciding what is feasible for customized LLP. In affect the prosthetist enforces the rules defined by the Shift System designers; that is to create prostheses that meet the individually wants, needs, and opportunities of amputees but ensuring that the design is safe, functional, and appropriate for the end user. Amputees should be allowed to specify which design choices will meet their needs but it is the prosthetists responsibility to allow or deny those needs. The collaborative approach to mass customization maximizes benefits for consumers and Shift System.

During the initial collaborative consultation, Shift System met with the prosthetist and the client user to research and document how a Shift System consultation would flow. The consultation began with the prosthetist evaluating the client user's injury, examining his residual limbs, and accessing potential issues with the client user's current prostheses. During this consultation, the client user discussed his need for breathability because of the painful MRSA infections he was recovering from. He also discussed his need for reduced height in his LLP because he found it unnecessary to be normal height while he was working low to the ground.

An example for this is shown in Figure 66. The client user explained that it would be very beneficial to be able to walk for short distances and kneel down without his LLP coming off of his residual limbs, shown in Figure 67. After consulting with the licensed prosthetist, the client user determined that he needed a customized "work leg." The work leg focused on fixing the problems that the client user incurred with his previous LLP, but also explored opportunities to meet his specific needs. After discussing these specifications with the prosthetist at length, the licensed prosthetist approved beginning the customized design process.

Figure 66: Client user's problem working low to the ground

Figure 67: Client user's current prostheses buckling

Consideration 3.2: Define the boundaries for mass customized product platforms.

Shift System takes advantage of digital design and fabrication, which provides broader capabilities for customization than traditional manufacturing. This gives consumers more control over the design and form of the final LLP. This provides value to the consumer because designers and prosthetists can alter base modules to meet the needs of individual consumers. However, boundaries have been setup to guarantee that Shift System prostheses retain their brand identity and create a desirable and well-designed lower limb prosthetic. The boundaries setup by Shift System are to produce LLP that are well designed and appropriate for the end user. The consumer has the ability to work with a prosthetist to determine personalized solution through customized designs. The boundaries define how much customization input consumers have for the Shift System product platform.

The boundaries for the Shift System LLP are different for each component of the product platform. The inner socket is developed using 3D scan data of the amputee's residual limb to form a fit that is consistent with the geometry of the amputee's lower limb. Consumers are provided the option to create a low cut in the rear to reduce friction or impingement but they do not have the option to adjust the form of the inner socket. This boundary has been established to guarantee amputees with a safe and proper fit. Shift System does not see any value in letting the consumer change the design of the inner socket. The outer socket has similar boundaries because it holds the inner socket in place. Unless consumers have a good argument for changing the form or the design of the outer socket, then the prosthetist will typically deny the consumers request. Unless the prosthetist sees value for changing the design of the outer socket, then the outer socket will remain in line with the Shift System design. Consumers may select cosmetic changes such as the material or color as long as Shift System is capable of fabricating the colors and materials selected by the consumer. These materials and colors must be realistic expectations and should be options that Shift System is capable of producing. The prosthetist must agree with the material selection chosen by the consumer.

Shift System uses a modular bayonet mount as the connecting component that attaches the inner socket, outer socket, and the foot together. This component is an interchangeable part, which has been standardized for the Shift System product platform. Consumers may not change this design but they may choose from a variety of different sizes that add height to the LLP. Using an interchangeable modular connection point expedites production processes and standardizes this component of the product platform.

The final component to the Shift System product platform is the foot attachment. The foot design has the widest boundaries for all of the components that make up Shift System LLP. Shift System affords the consumer with the opportunity to collaborate with the prosthetist to customize a foot that meets the specific needs of the individual consumer. Shift System could offer a variety of base modules for the foot attachment that include training nubs, showering, walking, athletics, and working feet. The foot attachments are base modules, which means that they could be purchased as standard parts from Shift System or consumers can collaborate to create a more customized foot based off of the preexisting modules. In addition, consumers can customize their own foot attachment with the help and guidance of the prosthetist to meet a specific need as long as the prostheses retain their brand identity and create a desirable and well-designed lower limb prosthetic. This allows Shift System to provide great value for the consumers by creating broad boundaries to solve unique problems for a variety of different amputees.

Consideration 4: Designing a Product Platform for Mass Customization

The Shift System product platform is created using a base design for each component of LLP. Each component has the ability to be customized through a collaborative consultation to meet the specific needs of individual consumers. Parameters have been set out to define the customization process to determine how far customization can go and which parts can be customized. Consideration 4 as it applies to Shift System's development and design of a LLP begins while defining the functional criteria and research solutions and existing designs (Figure 68).

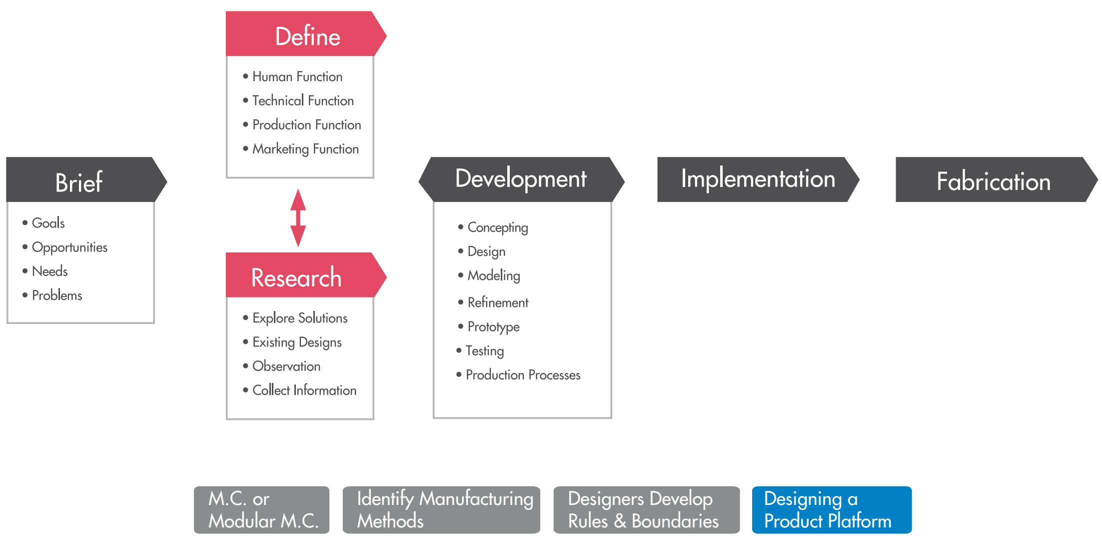


Figure 68: Beginning during research and defining the functional criteria, Consideration 4

Consideration 4.1: Define the parameters for customizing.

Shift System provides a very unique product platform for assistive technology with unique opportunities for mass customization. Laws and regulations for the assistive technology industry create parameters for customization that demand a licensed prosthetist to act as an intermediary. To customize LLP that follow the parameters created by the assistive technology industry, in-person consultations take place between an amputee and their prosthetist. During the in-person consultation, prosthetists will gather specifications related to the wants, needs, pain points, and opportunities for an amputee. The prosthetist will also evaluate the lower residual limb to determine whether the amputee is eligible for designing and using a customized lower limb prosthetic. K-levels shown in Figure 69, have been setup by insurance companies to determine the mobility of an amputee; the prosthetists determines amputees K-level, which indicates their mobility and also determines the prosthetics that will be covered by insurance companies (Freedom Prosthetics LLC, 2016).

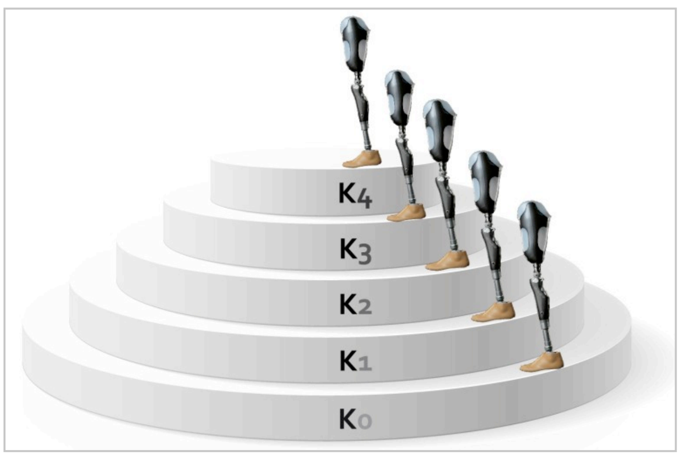


Figure 59: Medicare's K-Levels – Freedom Prosthetics LLC (2016)

If the consumer is eligible, the design process would move into development (Figure 70), which required prosthetist to capture two separate 3D scans (Figure 71) to ensure that the proper measurements have been taken. The scanning process involves marking any concerning areas with positioning targets (Figure 72) that indicate pressure points and areas to protect.

When the 3D scan is generated, these targets will show up on the computer so that the prosthetist is aware of protecting these areas.

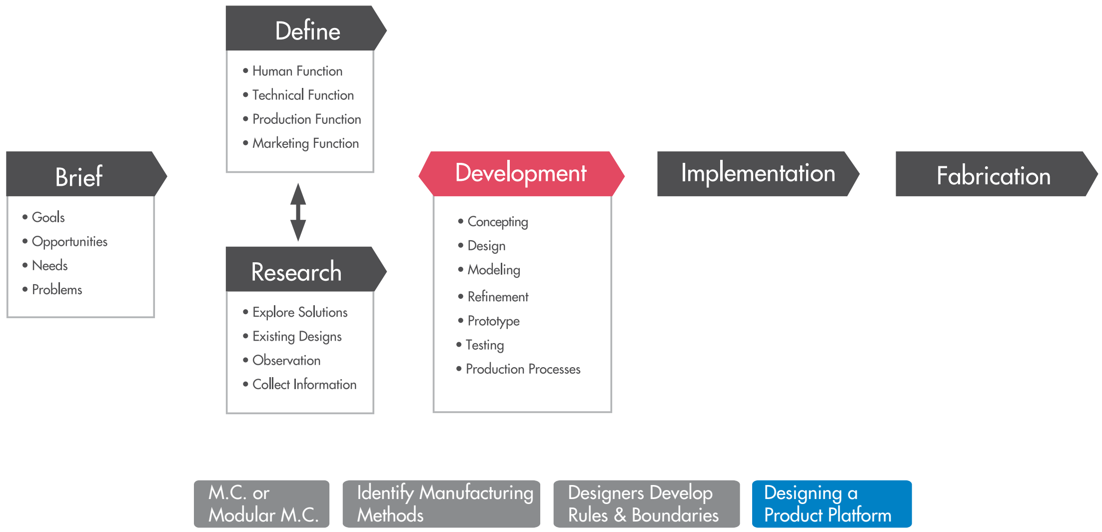


Figure 70: Development process, Consideration 4

Figure 71: Client's 3D scan (2016)

Figure 72: Clients's positioning targets, 2016)

Meshmixer (high resolution surface modeler) or the equivalent, computes the scan data to make it configurable within 3D modeling programs shown in Figure 73. Once the scan data is adjustable to use in CAD, prosthetists work with amputees to complete the customization process as exemplified in the first consideration. Shift System provides a large gallery of customized designs to show customization capabilities and provide users with ideas for form, color, size, material, function, feet, and many other options that may be customized to the consumer's specifications. Form is unique during the customization process because consumers will have the ability to work with prosthetists to generate a form that is specific and unique to their particular needs. Since CAD is the primary design tool, Shift system is able to create very unique forms specified by the consumer. Upon completion, the specifications are sent to a Shift System designer; after designers receive the specifications, they will be able to produce a computer-aided design, which they will provide to the prosthetist and amputee for review. If there are no changes to be made to the CAD, prosthetist and the consumer will indicate that the LLP is ready for production. Licensed prosthetist are familiar with the parameters for laws and regulations for fitting and designing prostheses, making them a necessity to the customization process.

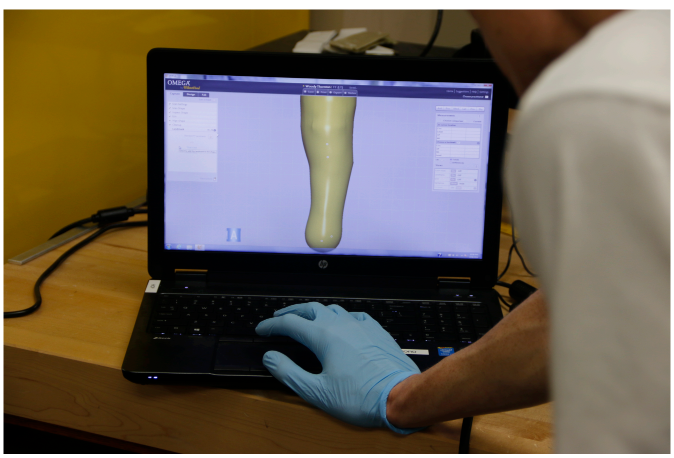


Figure 73: Client's imported 3D scan data, 2016

After the lower limb prosthetic is customized, developed, and prototyped, Shift System begins moving into implementation and fabrication (Figure 74). The final prosthetic will be packaged in Shift System packaging and shipped directly to the prosthetists office. Shift System products serve as assistive technology, which means that Shift System assumes great liability. To ensure the prostheses are safe, the final products are shipped to the prosthetist for the consumer to test (Figure 56). Consumers are then required to size and test the customized prosthetic with the assistance of an experienced professional. Prosthetist check for any limitations, ensure a proper fit, and proper function before providing the final product to the consumer. This is also a chance to guarantee that the product has been designed to the correct specifications.

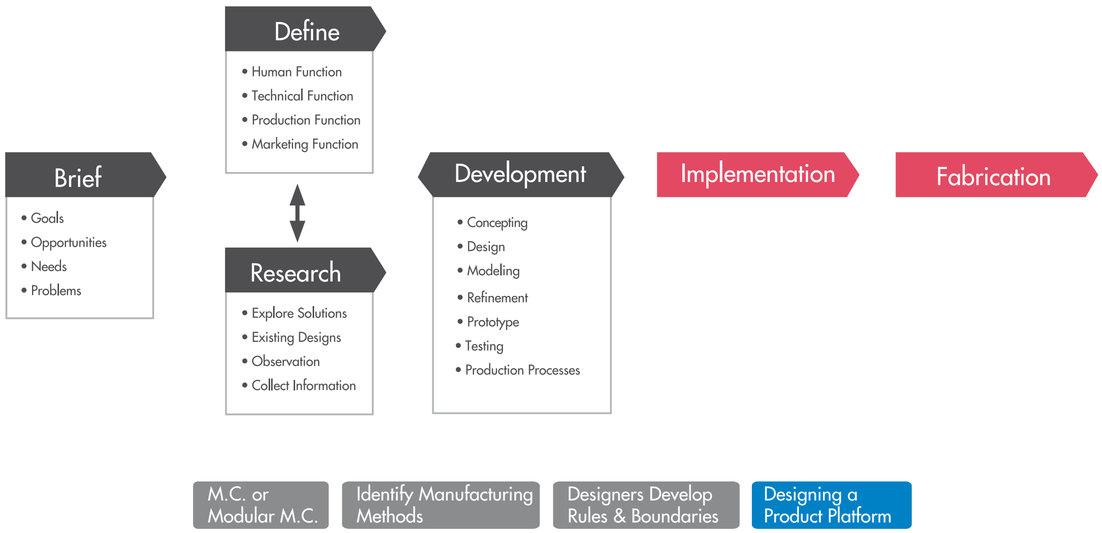


Figure 74: Implementation and fabrication, Consideration 4

Figure 75: Client testing prosthetic fit (2016)

Manufacturing and fabrication processes are also parameters that have been considered by Shift System. The use of base modules to edit and customize create a good starting point for consumers and prosthetists to generate solutions that are specific to the consumers needs. Utilizing digital design and fabrication creates wider parameters for the design and customization however, these designs are limited to lower limb prostheses because of the size. In the future as technology becomes greater, larger prosthetics may be created.

Consideration 4.2: Identify which parts can be customized.

Shift System allows for the consumer to collaborate to design LLP that meet their specific wants and needs. However, Shift System has established a platform for which parts may be customized. As discussed in the previous considerations, Shift System creates an inner socket generated from the consumers scan data to ensure that the inner socket is customized to fit the residual limb perfectly. The outer socket is a standardized Shift System design unless the prosthetist agrees with reasoning to let the consumer create a custom outer socket. The modular bayonet mount may not be customized. Lastly, the foot attachment is very customizable allowing the consumer to edit and alter a base module or work with the prosthetist to design an entirely new foot attachment to address a particular want or need. Shift System is able to provide value to consumers by allowing them to specify the exact function of the foot attachment.

The Final Solution

The design of the Shift System lower limb prosthetic for the client user was required to meet specific requirements. It was required to first and foremost meet the requirements defined by the laws and regulations developed by the assistive technology industry and enforced by the licensed prosthetist. It was also required to meet the design requirements developed by the product platform for Shift System. Lastly, it was required to meet the specifications identified by the client user to reduce pain, injury, and fatigue while working. Shift System designers have met this criterion based on user research and the implementation of customized designs. Since this project was a collaborative design, the designs were driven by the designer but customized to meet specific needs of the client user. The design is shown as an exploded view in Figure 76 and shown in full in Figure 77.

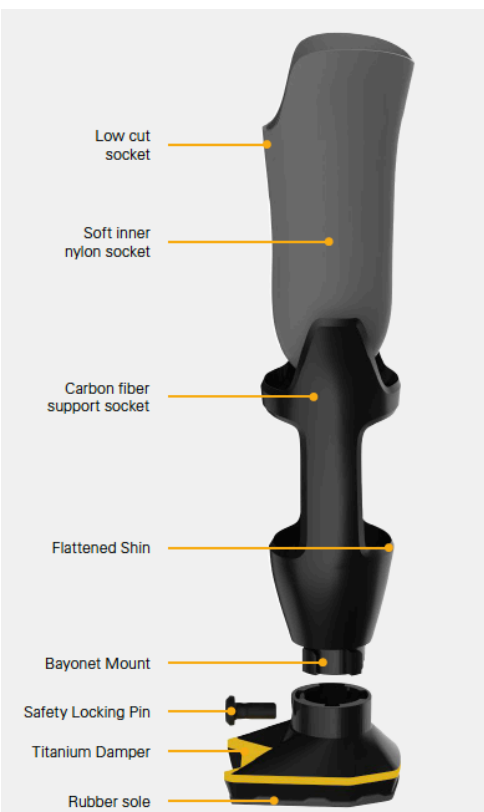


Figure 76: Shift System Work Leg Exploded (2016)

Figure 77: Shift System Work Leg (2016)

Summary of the Chapter

While Shift System was a hypothetical study, the development of a mass customized product platform for LLP has the potential to help a very large group of lower limb loss victims. The ability for Shift System designers to provide value to consumers by creating LLP that are designed to address and meet the needs of personalized problems is a revolutionary concept for the assistive technology industry. By leveraging emerging technologies and coupling those with more mature manufacturing and production strategies, Shift System could reach competitive economies of scale relative to the traditional production of LLP.

It is important to note that to create a successful product platform for mass customization that the designer is in charge of controlling the design decisions not the consumer. While the consumer's role is to choose specifications that are appropriate and personalized to their wants and needs, they do not control customization decisions. By developing rules, boundaries, and parameters for mass customization, designers can control the customization and develop a successful product platform for mass customization.

Chapter 5: Conclusions

Summary

This thesis was intended to research and explore the opportunities for designers to develop an approach to designing product platforms for mass customization. Over the past decade, emerging technologies such as digital design and fabrication are changing the way designers approach designing and developing products. These technologies are acting as a catalyst toward a second industrial revolution, transitioning from mass production toward mass customization. The developments within this research promote designers to construct a well thought out plan to offer consumer centric products through mass customization. Designers must remain in control of the opportunities for customization to ensure that products are customized appropriately and produce well-designed final products. This means that consumers should not be permitted to customize options simply for customizations sake. This thesis is intended to help designers create a design process that leverages emerging technologies for mass customization. It offers a set of guidelines for designers to use when they are developing a mass customized product platform. While technologies may grow and advance the design principles developed herein should remain the same.

This thesis provides an example for how to leverage product platforms for mass customization through the design and development of a lower limb prosthetic to meet the specific needs of a client user. Customizable solutions are provided to the amputee by following the considerations developed by this thesis. The outcome of this study generated a digitally designed and 3D printed lower limb prosthetic that was customized by the client user. Introducing this concept to the assistive technology industry would allow prosthetists to better serve their clients and meet the individual needs of a wide population of amputees.

This study proves that utilizing a mass customizable product platform for LLP can effectively serve the individual needs of consumers. Through the use of emerging technologies such as digital design and fabrication, a successful product was produced based on rules, boundaries, and parameters for mass customization. The considerations developed within this thesis proved successful for customizing lower limb prosthesis but can be and should be applied to many product platforms for mass customization to create successful mass customized products.

Future Research

Emerging technologies will eventually mature and new technologies will develop but the findings and considerations developed should still be applied toward product platforms for mass customization. As the technologies progress however, these considerations should be applied toward new technologies to continue to explore opportunities for mass customized product platforms. Future studies should consider applying these considerations and research developed herein toward other product categories with the intention of broadening the possibility for mass customized product platforms.

A component of mass customized product platforms for mass customization that should be researched further to contribute toward this study are service platforms for mass customization. Service platforms for mass customization are briefly discussed in this research. These are the channels used to connect companies directly to their clients; these channels are typically modeled by one of the following: in-person consultation, showroom, or web-based customization platforms. Service platforms serve as the interface for consumers or intermediaries to provide specifications. They are the component that allows the customization process to happen and should be considered for future research.

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