Mass-Customization Through Digital Manufacturing

by

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A thesis submitted to the Graduate Faculty of
Auburn University
in partial fulfillment of the
requirements for the Degree of
Master of Industrial Design

Auburn, Alabama
August 03, 2013

Keywords: 3D Printing, Additive Manufacturing, On-Demand Manufacturing,
Mass-Customization, Rapid Manufacturing

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ABSTRACT

Manufacturing is an ever-evolving process that constantly changes how products are developed. Changes in manufacturing can affect society and companies worldwide resulting in innovative new products and processes. Industrial Designers are critical to new product development and must always stay on the cutting edge of technology. As technology changes, so must the processes associated with new product development. This study will show that on-demand manufacturing techniques are becoming more popular and may become the industry standard in specialty categories. Therefore, a new product development process is needed to keep up with new technologies currently in the market place. Research will pinpoint the need for user-customized products that can be manufactured using the process set forth in this study. This study will present various solutions for selling user customizable on-demand products that will benefit designers, customers, and consumers.

ACKNOWLEDGMENTS

This study would not have been possible without the support of my family, friends, and the Auburn University Industrial Design Department. I would like to thank my loving wife and best friend, Catherine Carter, and my precious daughter, Samantha, for their unrelenting support and devotion. I would also like to thank my parents, Boots and Carol Carter, for their support and unconditional love they have shown me throughout my life. I would also like to thank my committee members, Professor Richard Britnell, Professor Tin-Man Lau, Professor Bret Smith, and Associate Professor Christopher Arnold for their encouragement and insight throughout my career as an Industrial Designer. I would finally like to give a special thank you to Professor Clark Lundell and Mr. David Gowan for their generous support and encouragement.

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List of Abbreviations

2D	Two Dimensions
3D	Three Dimensions
ABS	Acrylonitrile Butadiene Styrene
CAD	Computer Aided Design
CAM	Computer Aided Manufacturing
CNC	Computer Numerical Control
DIY	Do It Yourself
FDM	Fused Deposition Modeling
FOB	Freight On Board
ID	Industrial Design
NPD	New Product Development
ODM	On-Demand Manufacturing
OEM	Original Equipment Manufacturer
PLA	Polylactic Acid
PVA	Polyvinyl Alcohol
RP	Rapid Prototyping
SEMA	Specialty Equipment Market Association
SLS	Selective Laser Sintering
ITU	International Telecommunications Union

CHAPTER ONE

INTRODUCTION

Problem Statement

Customization is the process by which a consumer modifies or alters a product in a specific way to meet their specifications and desires. Customization has been documented throughout society since the beginning of history. The act of customizing a product can be seen throughout the world, in all walks of life, and in various product categories. Economies of scale affect customization in manufacturing; therefore, most customization is done aftermarket by the consumer. A very common customization market can be seen in the automotive industry. An individual supplier may provide consumers with an assortment of wheel choices, while another supplier offers suspension kits and a third supplies performance engine parts. The original equipment manufacturer (OEM) cannot afford to spend money on tooling multiple styles of parts, warehousing, researching, or developing the additional parts needed to make consumers happy with their customizations.

“Hot Rodding” is a term that was coined in the early 1930’s when customizing vehicles began. The evolution of “Hot Rodding” began with the need for hauling moonshine during prohibition. Moonshiners would customize their cars with performance enhancing parts to help them outrun federal agents, starting a trend in customization (Alexander). Hot rods can also be an outward showing of the owner’s personality and uniqueness through innovations. Each owner is able to create personal touches and claim that the vehicle is the only one of its kind. Most customizations are done by "do it yourself" (DIY) individuals who can build one off items with minimal time and cost. Some modifications are simple five-minute projects, while others can involve months of research and fabrication.

New innovative products are often introduced during the Specialty Equipment Market Association (SEMA) tradeshow in Las Vegas, Nevada, each year. In 2012, over 135,000 attendees and approximately 2,250 vendors were on hand making the show the "largest small business-gathering in the United States" (2012 SEMA Show Statistics and Highlights, 2013). The SEMA show is dedicated to exhibiting the latest innovative automotive product ideas that would allow any consumer to customize their vehicle. According to the 2012 SEMA annual market report, retail sales for the show grossed nearly $30 billion (SEMA). SEMA proves that customization is important to consumers and that customization can be successful.

Allowing the consumer to easily become their own designer and, if desired, their own manufacturer is revolutionary and could change the entire way aftermarket sales are handled in the future. Consumers will purchase products they can customize easily if they are given the option and it is convenient for them to do so. The customer will have a greater attachment to the final product and will typically be willing to pay more for the final product (Carter).

Hobbyists can see their dreams come into fruition with the help of rapid prototyping machines that are capable of printing three-dimensional parts by using computer models as reference. As rapid prototyping machines become more affordable and the quality of the final product improves, products will evolve and some products will start becoming manufactured at home or in specialty stores on 3D personal printers (Anderson).

Need for Study

This study will provide novice DIY hobbyists the ability to become their own personal manufacturer on-demand. As technology grows, so do the needs of the consumer; therefore, various solutions will be defined to account for variables such as, but not limited to, the introduction of new technologies, overhead costs, equipment maintenance, and material costs.

Rapid prototyping websites are typically open source by design and flooded with random pieces and parts and spread across numerous product categories. A shotgun approach to file sharing can be confusing to a consumer and instantly turn them away from the process altogether. We will focus a portion of this study to developing an organized file management system that will be integrated into an e-commerce site. This e-commerce site will be used to promote and sell innovative and customizable designs.

There are many opportunities to pursue when it comes to customization; however, for this study we will focus on model railroads. By creating a process for a scale model, we can accurately build within the limits of current affordable desktop 3D printers and other additive manufacturing processes. Though this study will be focused on model railroads, the data and practices can be applied to other product categories as well.

Objectives for Study

The following areas will be the primary focus of this study.

Objectives

- Research companies who currently sell customized products.
- Research websites who provide consumers 3D printed parts.
- Define existing products and services currently available.
- Identify and create a set of rules for developing customizable digital files for printing using 3D personal printers.
- Define a set of scale model parts that can benefit from being customizable and printed using a 3D personal printer.
- Develop a set of products that can be customizable and printed on 3D personal printers.
- Create a mock e-commerce site to sell digital files and parts.

Definition of Key Terms

3D Printer: A machine that prints three-dimensional parts from a digital file.

Additive Manufacturing: A process of making a three-dimensional solid object of virtually any shape from a digital model. 3D printing is achieved using an additive process, where successive layers of material are laid down in different shapes.

Computer Aided Design (CAD): The use of computer programs and systems to design detailed two- or three-dimensional models of physical objects, such as mechanical parts, buildings, and molecules.

Concurrent Design: A work methodology based on the parallelization of product development tasks. The methodology helps ensure product functions are studied systematically throughout the development process.

Consumer: The end user who purchases products or services for personal use.

Customer: A dealer who purchases a product or service from the manufacturer with the intent to resell the product or service.

Customizable: To change a product according to a customer's individual requirements.

Customization: To build, fit, or alter according to individual specifications.

Digital Fabrication: A process of using 3D modeling software to develop digital 3D computer models that can later be used for manufacturing.

Digital Files: Electronic files that contains useful information, such as documents, images, or 3D models of products.

Digitizing: A digital representation made of an analog object. The digital file can later be used to recreate the analog part.

E-commerce: Buying and selling of products or services that is conducted over the Internet using websites, also referred to as electronic commerce.

Fabrication: To construct from diverse and usually standardized parts.

File Management: The grouping and structure assigned to digital computer files to provide order and structure to stored files.

Flat Packed: Ready-to-assemble furniture that is shipped in multiple unassembled pieces and requires assembly.

Fordism: Named after Henry Ford, is a notion of a modern economic and social system based on an industrialized and standardized form of mass production. The manufacturing system designed to spew out standardized, low-cost goods and afford its workers decent enough wages to buy them.

G-Code: A computer language used to tell computerized machine tools what to make and how to make it.

Gestalt: Psychological point of view that says it is necessary to consider the whole of something, since the whole has a meaning apart from its individual elements. The whole is greater than the sum of the parts.

Hobby: Activity that is done for pleasure, typically, during one's leisure time.

Hobbyist: A person who engages in an activity solely for fun.

Hot Rodding: American cars modified with large engines and custom parts and primarily designed for racing.

Industrial Design: An applied art whereby the aesthetics and usability of products may be improved. Design aspects specified by the industrial designer may include the overall shape of the object, the location of details with respect to one another, colors, texture, sounds, and aspects concerning the use of the product ergonomics. Additionally the industrial designer may specify aspects concerning the production process, choice of materials and the way the product is presented to the consumer at the point of sale. The use of industrial designers in a product development process may lead to added values by improved usability, lowered production costs and more appealing products.

Maker: A contemporary culture with focus and interests in developing concepts and products through the use of electronics, robotics, 3D Printing, CNC and various other technologies.

MakerBot: A 3D printer manufacturing company who sells affordable at home 3D printers.

MakerWare: Computer software developed by MakerBot Industries to slice 3D CAD files into G-Code computer language.

Manufacturer: The company or person who develops goods or services to be sold to customers and/or consumers.

Manufacturing: The development of goods for use or sale using labor, machines, and tools.

Mass-customization: The use of flexible computer-aided manufacturing systems to produce a custom output. Those systems combine the low unit costs of mass production processes with the flexibility of individual customization.

Mass-production: A term coined by Henry Ford to describe the manufacture of goods in large quantities, often using standardized designs and assembly-line techniques.

Napster: A pioneering peer-to-peer file sharing Internet service that emphasized sharing audio files, typically music, encoded in MP3 format.

New Product Development (NPD): The complete process of bringing a new product to market.

On-Demand Manufacturing: A process of making and manufacturing a three-dimensional solid object of virtually any shape from a digital computer model.

One-off products: A one-of–a-kind product, which has never been duplicated.

Open-Source: Computer software or files whose source code is available free of charge to the public to use, copy, modify, sublicense, or distribute.

Peer-to-peer: Allows users to download media files such as music, movies, and games using a P2P software client that searches for other connected computers.

Pirating: To make use of or reproduce (another's work) without authorization.

Rapid Customization: The ability to produce custom products at a mass-produced speed.

Rapid Manufacturing: The process of manufacturing goods using rapid prototyping machinery.

Slicing: A process used by MakerWare software to slice 3D CAD files into G-Code that a CNC machine can understand.

Rapid Prototyping: Automatic construction of physical objects using solid freeform fabrication. The first techniques for rapid prototyping became available in the late 1980s and were used to produce models and prototype parts.

Solid Modeling: A consistent set of principles for mathematical and computer modeling of three-dimensional solids.

***.STL:** A digital file format containing 3D computer models that are typically used for rapid prototyping. The file format is common throughout many software packages and has become a standard format.

***.x3g:** Digital file format created by MakerWare software when slicing a 3D CAD file for use on a 3D printer.

CHAPTER TWO

LITERATURE REVIEW

Overview

Chapter two will discuss the past, present and future of manufacturing, customization, and the hobby industry. In this chapter, each section will present the reader with critical key elements that will help defend the study in later chapters. The chapter will discuss the importance of interchangeable parts throughout history along with the invention of mass production and the assembly line. The chapter will discuss the future of 3D printing by using the hobby industry as an example.

Literature Review

Personalizing everyday life is a way of the world. Customizing is defined as modifying or building according to individual or personal specifications or preference. Each company comes up with some new and innovative way to please the customers of the world. Each company has its own niche that it is good at, and in turn does very well with that product.

Every company tries to appeal to the largest number of people possible when creating a design. Typically larger companies are able to offer more variety in their designs due to the availability of funds for, among other things, changing molds or just tweaking the colors. Customizing is largely noticeable in the automotive fields of design, where people are often trying to make their vehicle be different from everyone else's. For example each vehicle has a different cost; therefore, a cheaper vehicle may end up in a student's hands while a more expensive vehicle may end up in an executive's hands. If each vehicle is different than the next and each person is able to choose which vehicle they want within their budget, then each consumer is already customizing his or her life. Chances are that when a person purchases a vehicle of his or her choice, that choice is based on a number of things, one being a status symbol to others. If we imply that no two cars are exactly the same after a consumer purchases a vehicle, this proves that customization is in fact all around us.

Need for a Product

Before a company develops and markets a new product to sell to consumers, the company must first realize that a need for that product exists. As Usher explains:

> The realization of a product consists essentially of two steps: Design and manufacturing. However, in order to understand the process, we must look at the total life of a product. The life of a product begins with its planning the different life phases of a product. The need for a product, whether real or imagined, must exist. This may come from external or internal sources. The external causes for a new product might include a direct order from a customer, the obsolescence of an existing product, the availability of new technologies, or a change in market demands (Usher, 60).

A product can only be developed if it is determined that there is in fact a need for that product. A product will only sell if people need that product and want it or in fact need it. "The industrial design process includes several phases, such as investigation of customer needs, conceptualization, and preliminary refinement... etcetera" (Gero, 372).

This is how designers and business people decide what needs to go onto the market or what may wind up being a cutting edge design. This information is collected from surveys, polls, and other forms of data collecting. Analysis of the data allows the majority choice to be chosen for a design. If companies were to broaden their scope to everyone, there would be more business, but it would take much more work in the long run.

Mass-Customization

In order to expand their market share, companies are exploring mass-customization, but too often without knowledge of whether, in fact, their many products with little actual variety is what is wanted or needed.

> Mass-customization embarks a new paradigm for manufacturing industries, focusing on variety and customization through flexibility and quick responsiveness with the goal of developing, producing, marketing, and delivering affordable products that can satisfy as wide a range of customers as possible. To adopt the mass-customization paradigm, many companies are being faced with the challenge of providing as much variety as possible for the market with as little variety as possible between products in order to maintain economies of scale while satisfying a wide range of customer requirements (Gero, 407).

Variety is a way of saying that companies are just trying to flood the market with a bunch of junk and hoping that something appeals to consumers. To look at the paradigm in another way, a cook can throw spaghetti on the wall and odds are that one noodle may stick if it is close to done, but it may still be slightly overcooked or undercooked, or not exactly what the consumer wants. Why not customize the right way, by hearing what each person wants and customizing for each individual in particular?

Rapid Prototyping

Rapid prototyping (RP) is a process that significantly reduces the time between concept and the production of high quality prototype parts or tools. “It is the layer-by-layer fabrication of three-dimensional physical models directly from a computer-aided design (CAD)” (Bennett, Cooper; Foreword, 1). For this paper, RP is a major factor in the customization of parts, due to the ease and time it takes to produce a part. “The RP process provides designers and engineers the capability to literally print out their ideas in three dimensions” (Cooper, 1). RP is needed in any customization field to check for errors or design flaws before creating hundreds of parts that may be inadequate for the consumer.

> All of the RP processes construct objects by producing very thin cross sections of the part, one on top of the other, until the solid physical part is completed. This simplifies the intricate three-dimensional construction process in that essentially two-dimensional slices are being created and stacked together. For example, instead of trying to cut out a sphere with a detailed machining process, stacks of various-sized "circles" are built consecutively in the RP machine to create the sphere with ease. The advantage of building a part in layers is that it allows you to build complex shapes that would be virtually impossible to machine, in addition to the more simple designs. RP can build intricate internal structures, parts inside

of parts, and very thin-walled features just as easily as building a simple cube (Cooper, 1).

Figure 1 shows the progression of a sphere as it would be printed on a rapid prototyping machine. The progression starts with a small layer of material built upon the previous layer of material. The process is known as additive manufacturing and can be used to make elaborate parts that would otherwise be impossible to create. The figure shows a sphere in different stages of the print process. The first image shown on the left is in the beginning phases of the print process. As the layers are laid down, the image becomes apparent. The figure demonstrates the start, shown on the left, to the final product on the right.

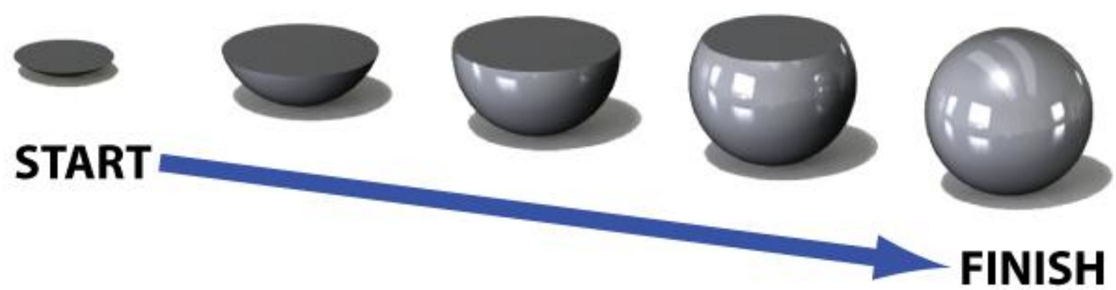


FIGURE 1: 3D Printing Progression from Left to Right

While using this method of creating a one-off part, virtually any shape can be generated that would otherwise not be feasible for mass production. Figure 2 illustrates three hollow spheres that are easily manufacturable using the additive manufacturing process. In contrast, traditional manufacturing methods will only allow individual hemispheres to be manufactured. Each hemisphere would then have to be bonded together to make the parts as shown in Figure 2.

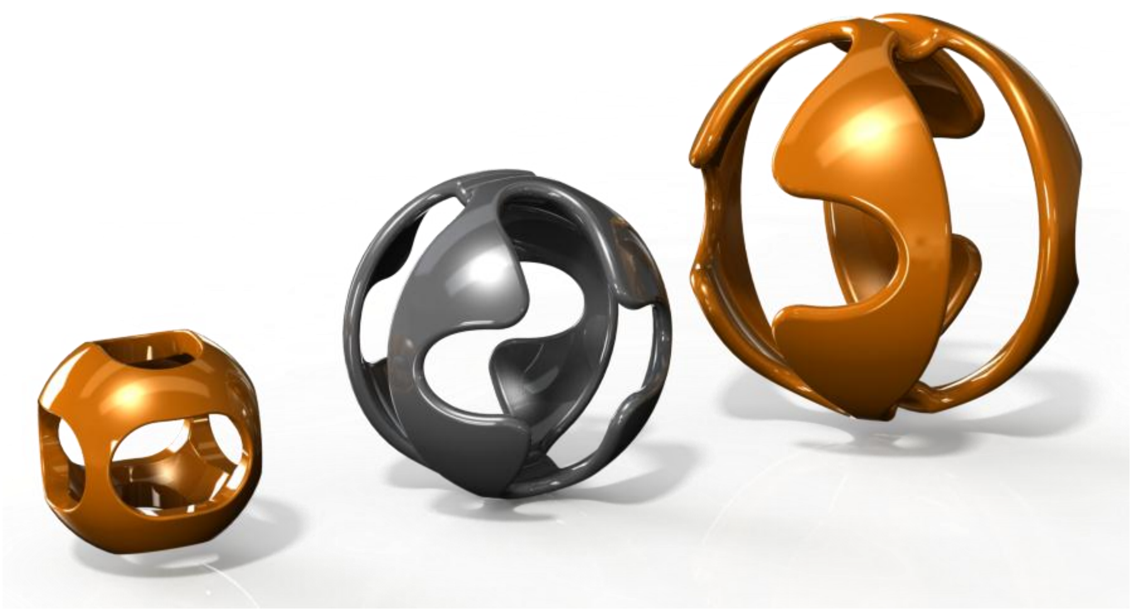


FIGURE 2: Hollow Spheres

Figure 3 shows the three spheres from Figure 2 in a nested state. The three spheres are very unique in design and together create a final product that is virtually impossible to machine. However, reproduction of this complex design is easily capable by using a 3D printer.

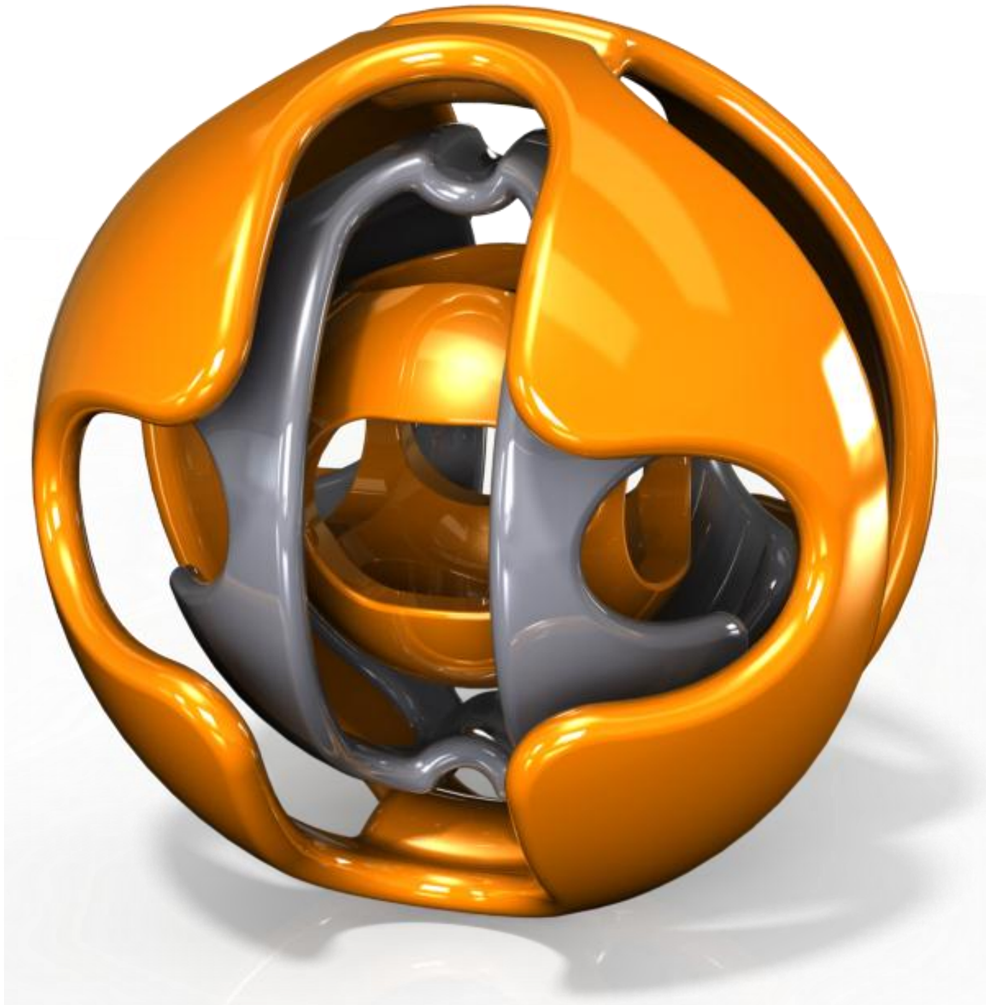


FIGURE 3: Nested Hollow Spheres

Conventional manufacturing will not allow undercuts or parts within parts, making RP a valuable tool for creating intricate structures. These features can be greatly beneficial to consumers and manufacturers worldwide.

FIGURE 4: 3D Printed Nested Hollow Spheres

Figure 4 is a 3D printed part that measures 2.5 inches in diameter. The sphere shows multiple cross sections that illustrate the build process. The cross sections in the figure are vertical, but when the part is being printed, the sections will be horizontal. From the figure we can confirm that this part was lying on the left or right side as it was printed. The base of the sphere, however, has horizontal layers that show that the part was built in the normal orientation.

Car developers are capable of using 3D printers to simplify intricate assemblies and reduce the number of parts required to develop products. The developers of the 3D printed car "Urbee 2," for example, have stated that the plastic materials used to manufacture the car are "as strong as steel, but weigh half as much" (George).

FIGURE 5: Sara Payne's Photo of the Urbee 2 3D Printed Car and Engineer Jim Kor (George).

The Urbee 2 3D Printed Car demonstrates how important RP can be in automotive customization for all types of parts.

> This process is vital in creating hard to build parts quickly and easily. By utilizing this method of production a customizing company could create intricate parts as well as simple parts for production. RP also decreases the amount of operation time required by humans to build parts. The RP machines, once started, usually run unattended until the part is complete. This comes after the operator spends a small amount of time setting up the control program. Afterwards, some form of cleanup operation is usually necessary, generally referred to as post processing. Nonetheless, the user intervention times still remain far less than that for traditional machining processes (Cooper, 1-2).

Wired Magazine's Alexander George explains that the Urbee 2 can be manufactured in 2,500 hours through an approach that has been coined as "Lights Out." The "Lights Out" approach is described as being able to set up a machine to build a part, and walking away from the machine and turning off all the lights, only needing to return when the part has been finished or more material is needed for the machine. The time it takes to manufacture the final product is continuous machine operating time and is not based on standard work hours. The machines are capable of working through the night without the need for manual labor (George). One machine operator is now capable of controlling multiple machines, unlike mass production where one operator is tasked with one machine. Due to this feature, RP is an inexpensive alternative to mass production because of the limited labor required to operate equipment. The more labor involved in making a part will increase the cost of the final product, thus proving why RP is a practical solution to new product manufacturing. The stage where labor needs are higher, post-processing, is the method of finalizing 3D printed parts by removing support material and cleaning any residual material from the part. The process will need to be minimized to ensure the cost remains as low as possible.

FIGURE 6: Sara Payne’s Photo of the Urbee 2 3D Printed Car (George).

Though not widely produced or distributed, the Urbee 2 3D Printed Car demonstrates the importance that RP can hold, not only in customization, but also prototype modeling, especially for small companies.

> As you can see, RP is a very powerful utility for prototype modeling in today's high-speed design-to-market workplace. Quick and inexpensive prototypes are the reason the technology was invented, as it is still a very important function to accommodate. RP is an excellent prototype-run

alternative, but since its creation, as all good technologies do, it has branched out into even more useful applications, including casting, tooling, reverse engineering, and direct hardware fabrication (Cooper, 6).

As the uses of RP become more widely explored and utilized, it can move into other manufacturing processes in which labor is a major cost concern. RP is a great method for the prototype-run alternative, but if it were used correctly it could possibly be a manufacturing process, rather than a pre-manufacturing process. With the average cost of a robot running upwards of $50,000 plus, and the annual operating cost of roughly $5 per hour, robots can run longer, smarter, and cheaper than a minimum wage employee (Gerstenfeld, 10).

As can be seen, RP is a valuable tool in keeping the cost of labor down, and it also allows companies to control the cost throughout the product life cycle.

From the time the development of a product begins, its cost starts to grow because of the resources used for its realization--personnel, facilities, and equipment. The price of a competitor's product in a free-market economy, however, drops with time. There are several reasons for the latter, for example, rationalization of the manufacturing process, cost driven improvements in design, and increased knowledge about the product--the ‘learning process’ (Usher, 65).

Customizing

Customizing can create new markets as well as broaden existing markets by giving consumers the ability to change products according to their personal preferences. Economies of scale limit manufacturing abilities because of cost associated with tooling and production. The law of supply and demand is a large factor in customization and can determine the success or failure in business. Finding a niche where the greatest profit margin can be acquired is the key to a successful business and is a very important consideration when deciding on the customizations to be made available for purchase. Art Hedrick explains that hard tooling is costly and can take months to develop, thus costing not only money, but time. When products change, the tooling must change as well thus costing more money and time. The cost of tooling can be broken down further to include building the tooling, downtime to maintain it, and any scrap that wasted during testing the tooling (Hedrick). Usher provides these three key areas of focus when developing products to ensure the product will have a good possibility of success:

> The decision whether to proceed with a product development project must be based on facts rather than intuition. It may appear at first that it is difficult to quantify the costs and benefits of the various development goals. Nevertheless, even the use of gross approximations is better and more easily justifiable than an instinctive decision.
>
> 1.) Product features. The features of the product determine its performance which is important in determining any of its market success. Product performance is determined by the customer and the marketplace, not merely by satisfying what is in the specifications.

2.) Product cost. This is the total product cost over its life cycle, including the purchase price and the operating, maintenance, and disposal costs.

3.) Development Speed. Time to market is obviously the most critical factor. This is the total time from the moment when someone thinks about developing the product to the time it is in the customer's hands. The speed of product development determines the time to market (Usher, 69).

Setting the bar appropriately in the customization field is the primary goal that each designer must strive to meet. If the design is not unique enough, it will not sell. If the design takes too long to build, it will not be cost beneficial to build. By jumping into the market with a new and innovative product, a rapid manufacturing company should have no problem bringing in business. By finding the proper niche where customizing is not common, a company would in turn create a market where competition is scarce and could benefit from this. Pierre Dumont, author of *iTech Post*, writes about a shoe manufacturer who is using 3D printing technology to develop customized shoes. He states that Nike has started using Selective Laser Sintering (SLS) to manufacture a new set of football cleats called the “Nike Vapor Laser Talon.”

FIGURE 7: Nike Vapor Laser Talon (Dumont)

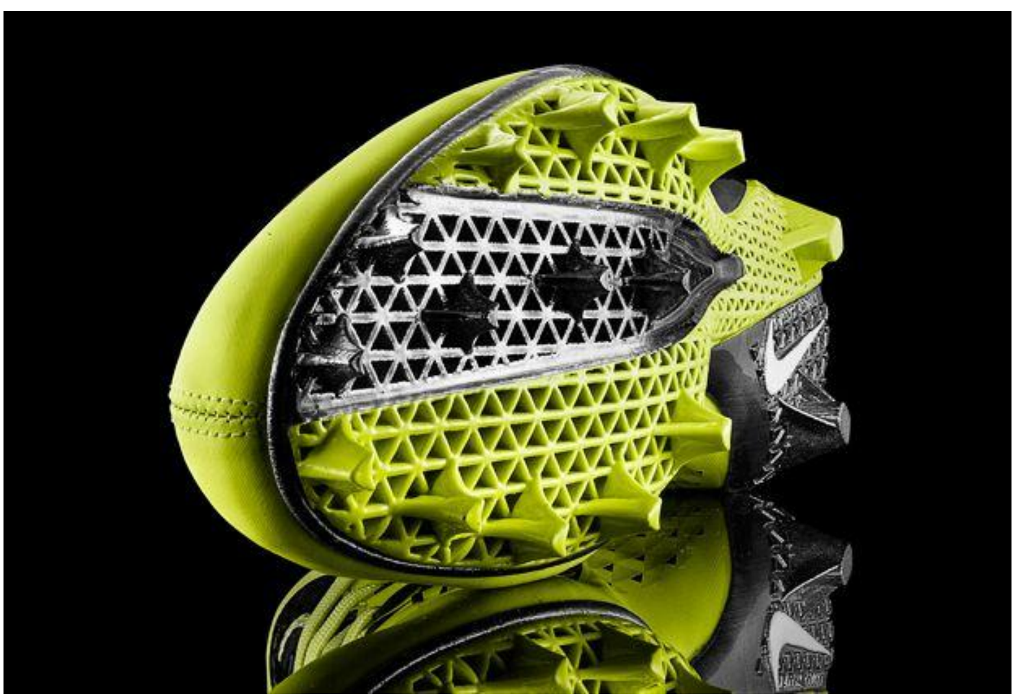


FIGURE 8: Nike Vapor Laser Talon (Dumont)

The shoes are developed using this method of manufacturing, because traditional methods of manufacturing will not allow the shoe to function as designed. The author elaborates on the manufacturing process and states that this technology can be used to provide each individual wearer their own personal shoe that is an exact fit to their foot (Dumont).

As stated before in the right job market, cutting edge designs and customized designs acquire more monetary support from vendors and individuals. Art is a good example; demand for the original is higher, and prints are typically priced based on the size and how many prints were created from the original. The same model could be utilized for other products, similar to furniture, clocks, lamps, etc. If there are two million designer shoes on the market, then the likelihood of those shoes being special is very slim; however, if there are only two on the market, then the shoes will bring more value due to the lack of flooding in the market place. “The highly competitive nature of the marketplace requires that manufacturers be able to deliver to the customer products, with the following attributes: (1) High quality, (2) short delivery time, and (3) low cost” (Usher, 59). A large company can meet high quality, short delivery time, and low cost; however, on the instance that the high quality is not present in the product, recalls or corrective actions must be made. In this case the company loses thousands, if not millions, of dollars trying to fix the product. With a smaller customizing company the likelihood of having to recall a product will be less likely due to the attention to detail given to each part. With a one-off part, quality should be first and foremost on the list of goals, followed by short turnaround time, and then cost. In theory, a rapid manufacturing company could make ten different high quality product designs before a traditional manufacturing company makes one decent product. A larger manufacturing company has to make a prototype, test it, check for flaws, fix them, and finally send the product to the manufacturing plant to be fabricated. An additive manufacturing company is capable of creating a prototype or a small run of final printed parts in-house much faster. Less impact to overall cost can also be noticed over that of traditional manufacturing methods (Additive Fabrication).

Project Time Scales

A prototype can be a valuable tool to save cost and understand the parts being made before spending time and money on tooling. Though vital, prototype fabrication can be tedious and time consuming when building the prototype using conventional methods.

> Central to industrial design creative work is modeling. Modeling is the activity whereby products are represented in a form other than in their final manufactured state. All design disciplines use models. One of the most common forms of model is the engineering drawing in which all aspects of a product (form, finishes, construction details etc.) can be represented in 2D. A commonly understood form of a model is the 3D physical model. This could be a non-functioning appearance model, a functional model to develop some technological feature, or a pre-production prototype, which is very close in appearance, construction and function to the manufactured item. The different disciplines involved in the process of new product development (NPD) have their own forms of

> models to aid the progression of their tasks. These models are critical to the success of NPD (Bennett, 2).

Models are important to design and engineering processes and can help determine the success or failure of a product by finding possible malfunctions and fixing the problems before selling the unit. According to Christopher Barnatt, manufacturing has room to advance and has the potential of developing products on-demand utilizing the RP approach (Barnatt).

> Project time scales reduced by bringing forward the engineering and ergonomic evaluation through the use of rapid prototype models, project time scales are reduced significantly. As complexity of form makes little difference to rapid prototyping costs, unlike 'hand built' conventional models, there may be financial gains. This would of course depend on the technique being employed, and whether post prototyping operations were required such as vacuum casting (Bennett, 10).

If prototypes are built using the same processes as the final manufacturing process, the beginning result and end result could be identical. With rapid manufacturing the designer has the capability of using a prototype that has the quality of a final model for testing. Materials used in the final model and quality designs are the major factors that will limit the structural integrity of the product. These limitations can be avoided by designing quality products, using high strength materials when needed, and testing them thoroughly. Once the designer has proven the concept and made changes, the product would then be ready for sales. A customer could easily walk into a store and have a product manufactured instantly while they wait. Products can be manufactured on RP machines and come off the machine ready to sell. Having quality RP machines capable of quality printing of a final product can eliminate the current process of sending a design to a factory and having it developed overseas. Each design can be customizable based on a set of criteria that could be versatile enough to work for everyone in and outside of the 51% majority for whom most designers typically design. The prototype now becomes the final product and the production time is shortened. Barnatt goes on to state higher levels of customization will be capable when manufacturing products using 3D printers. (Barnatt). A larger manufacturing company will, of course, be able to make a larger number of products in the long run. Customizing is not about flooding the market with "generic" products, but about finding the niche where customized products can be beneficial while still requiring a demand multiple times. As the demand increases and the volume of products increases, the economies of scale start to become a factor. If a manufacturer is only developing a few hundred small parts a year and each item is different than the next, then the economies of scale shows that it is more cost effective to use a rapid prototyping process as each part will be unique. Individual product cost may be higher per item in this instance but the final cost including tooling costs associated with each part will be much lower than traditional manufacturing. Chris Anderson of *Wired Magazine* explains economies of scale and the benefit of 3D printing versus traditional manufacturing through the example of manufacturing rubber duckies:

> The big win of the digital-manufacturing age is that we can have our choice between mass production and customization. Just because you can make a million rubber duckies in your garage doesn't mean you should. Made on a 3-D printer, the first ducky might run you just $20, but sadly so

> will the millionth—there is no economy of scale. If you injection-mold your ducks in a factory, though, the old fashioned way, the first may cost $10,000—for tooling the mold—but everyone after that amortizes the initial outlay. By the time you've made a million, they cost just pennies apiece for the raw material. For small batches of a few hundred duckies, digital fabrication now wins. For big batches, the old analog way is still best (Anderson).

The final cost of an item is the sum of all costs associated with the product including but not limited to, research, development time, materials, packaging, amortized tooling, and shipping fees. The final cost is referred to as the freight on board (FOB) cost, and will typically change due to delivery location. In short the total unit costs will be lower if the company only needs to run a few runs of one item in the RP process. As the market changes and new demands are needed, each product will change and old tooling will become obsolete. Tooling will only last a certain number of runs before it begins to show wear and needs to be replaced or rebuilt.

"Robots are expected to bridge the gap between automatic machines and human laborers. The primary role of robots is to reduce the human labor in manufacturing as much as possible" (Gerstenfeld, 51-2). Gerstenfeld states in his book, *Manufacturing Research Perspectives: U.S.A. - Japan,* robots handle materials so the operator does not have to. Automating a shop can be beneficial in the long run, but having numerous robots is an overhead cost that will need to be avoided to reduce initial costs. However, the benefit of having the automated machines is definitely a major advancement over a hired model maker. "With the introduction of Rapid prototyping, the viability of producing physical models from computer models represents a significant challenge to the 'conventional' working practices of the profession"(Bennett, 1). Rapid prototyping can only be viable if the prototype can save the company money in the long run by limiting quality issues and human errors in the production of a product. RP does however decrease the time it takes a model to be built but still it is only a good solution if it can save the company money. Inefficiency in the modeling process can become prevalent if the model makers do not use all of the tools they have at their disposal. For example, robots are tools that should be used when available to help facilitate those hard to build parts. In some instances time is wasted in downtime trying to model a part in a computer, rather than having it built by hand. It is sometimes a wise practice to limit the time of designing in the computer to a set duration. If a product could be created faster and more efficiently by hand, then the cost of the machine is definitely not beneficial in the long run.

Leading the Way

With the way technology moves, each company needs to be on the cutting edge of manufacturing and design processes. If a company remains on the leading edge of technology and adopts new and effective practices, they will, in turn, receive an advantage over their competitors (Bennett, Foreword).

> Today, many companies are interested in improving their competitive edge in the global marketplace where rapid changes occur due to technological innovations and changing customer demands. These companies realize that in order to bring product innovations and value-added services to the market in a timely fashion, they must know the

> wants (like-to-have), needs (must-have), and desires (wish-to-have) of their customers and quickly fulfill these wants, needs, and desires as completely as possible (Usher, 1).

Companies that want to be on the cutting edge need to allow customization for each of their individual clients. Many people customize their cars, cell phones, backpacks, and even their bodies. It is apparent in society from the day we are born we start customizing our bodies. Humans cut their hair, put make up on, and wear designer clothes. Each person is different and has different wants, needs, and desires that need to be looked at. Each person is unique and lives their life differently than the next. Without customization people would not have the statuses in life that they do. For example, a generalization can be made that superstar athletes drive big expensive cars and wear a lot of jewelry, while poor people live in a box under the over passes. This is not true for every superstar or poor person, but the mental image has stuck because of customization in our lives. We customize our lives to how we live, but we are all the same. An average person may drive the same exact car that a superstar drives, but the superstar's car may stand out more because they have thousand dollar wheels, a paint job, a sound system, or other accessories installed. In theory the two cars are the same exact vehicle, but the customization makes them completely different. Similarly, Basak Otus from the *Yale Daily News* proves this theory by stating that, "Consumers find it easier to make choices by-attribute — personally selecting individual features of a product one at a time — than when the consumer is presented with a set of finished products among which to choose. As a result of having chosen each feature himself, the consumer will display higher satisfaction and willingness to purchase the product" (Otus).

A company that can create a part by RP machine with customizable features will have an advantage over a company who is required to use traditional manufacturing methods and does not offer product options. In addition, manufacturing is limited by the capabilities of the facility and workers. The primary consideration is based on the fact that people have laws governing when they are able to work, how long they can work, how many breaks they are required to take during the day, etc. If a company utilizes their machines properly, they can create one-off models in less time and less money than the average company with human labor operating heavy machinery.

Designer Abilities (Concurrency in Design)

RP provides a way to ease communication between design and prototype team members, but some minimum standards must apply.

> As a relatively recent approach to design modeling, rapid prototyping may significantly enhance the degree of concurrency that can be employed by industrial designers. All rapid prototyping technologies rely on 3D computer models to generate the physical models, which have the capability for use in further engineering development and production tooling. The success of rapid prototyping in NPD therefore relies on the adoption of 3D computer modeling as a standard form of modeling in the design phase. This means that industrial designers must adopt CAD systems as primary modeling tools (Bennett, 5).

Designers must understand the basics of mechanics and design before they try to communicate with others. CAD systems should be known thoroughly and simple mechanics should be understood. In the RP model, designers are required to work parallel with engineers and manufacturers throughout the process of product development. This approach optimizes focus on the whole of the design from start to finish. The method also helps prevent unforeseen problems that may occur during engineering or manufacturing while obtaining the original design features desired by the designer (Ya). *Rapid Prototyping and Tooling Research* details the need for concurrent design by stating:

> Engineering and industrial design is carried out as part of the early stages of NPD and the shortest lead times are often achieved when the various activities incorporate as much concurrency as possible. The working relationships of the various designers and engineers are also a critical factor in the success of product development. The models used for product development play a large part in this relationship (Bennett, 4-5).

Concurrency in design is a topic that is important to new product development. The organization of concurrent design is critical and can make the product successful or make it fail. Concurrency in design proves that a product can be developed with different skill set individuals building separate parts and adding them to a final product. Each team works on the part or parts in which they are skilled. The final product combines the entire team’s work and provides the consumer with a quality product. However, some products are not conducive to using concurrent design. The idea of having fewer hands on a project means there is less possibility for confusion or miscommunication. The caveat to this concept is that the workload will be more cumbersome for the designer, whereas more people would be able to spread the workload. A single designer working exclusively on a project will require the designer to have a broader range of knowledge and skill sets. When other workers are introduced into working on the project, mistakes can happen or alternatively can be avoided. Engineers and Industrial Designers are skilled in different areas of product design. The primary difference between the two fields can be summed up by stating that engineering is a discipline that is focused on making a product work. Industrial design is a field that is an applied art dedicated to creating innovative products (Libohova). *Rapid Prototyping and Tooling Research* informs the reader that industrial designers do in fact have a limited amount of mechanical ability that can be used in new product development. Bennett states:

> The practice of industrial design involves the integration of engineering elements of new product development with a visual form and user interface appropriate to a particular market. Whilst having a general engineering capability, the specialism of the industrial designer is predominantly visual and ergonomic (Bennett, 1).

If we assume that a well-educated industrial designer is capable of integrating engineering into a design of a product, then we can assume that the need for an engineer is no longer needed in the development process. This assumption implies that a well-educated designer would be able to completely run a startup company producing customizable products using rapid fabrication methods. The designer should understand design thoroughly by visualizing how the product will appear in 2D or 3D concept images. The images are used to help accomplish the goals needed to develop the final product. Computers, drawing templates, pens, pencils, markers and drafting boards are all important tools that designers use as they are creating innovative designs. Most people do not realize that the aforementioned tools are only somewhat responsible for successful design. Gero reinforces this thought by stating:

> Many attempts have been made to enable creative and effective design activities using a computer. Although these attempts have been somewhat successful, we must admit that these are highly limited and many design activities are still dependent on the designer's personal ability (Gero, 371).

Two designers have different ideas. Take designer A, who can look at sand and see individual grains of sand and scrutinize every particle. Designer B may look at the sand in a different way and may see a sand castle or something more complex. Not every designer is capable of using automated machines to produce an end product. A vast understanding of mechanics and materials is needed to understand how things are assembled, built, and possibilities of fabrications. If the designer is unfamiliar with this information, then the designer will have development problems and should work closely with an engineer on the development of the product. Gerstenfeld explains in his book titled *Manufacturing Research Perspectives: U.S.A. - Japan* that technology is constantly progressing and becoming smarter and more affordable when he writes:

> Robot applications in the U.S. manufacturing have been hampered by the fact that robots are expensive, stupid and sightless. Now, however, all of that is starting to change. Artificial intelligence will be able to add sight and some "intelligence" to robots, however, that research still has a long way to go (Gerstenfeld, 10).

Unfortunately, robots are only as smart as their operators. In 2010 the Bureau of Labor and Statistics recorded 40,800 people in the United States of America were employed as Industrial Designers (Occupational Outlook Handbook, 2012-13 Edition, Industrial Designers). The household population in the United States in the same year was 300,758,215 million people (Population Estimates, Vintage 2011: National Tables, 1 Jul. 2011).

This information is clear evidence that there is a large population of people who are not skilled in ID; therefore, we can assume that the majority of the population is incapable of fulfilling the tasks of a designer. It is implied that the majority of the population is not educated in designing products, running RP machines, and they are not familiar with making use of the product development processes that help maximize the potential of the RP machines. Designers with a good understanding of product design and machine capabilities are capable of maximizing machine efficiency by reducing material waste and maximizing the build area by nesting parts. These details need to be considered when trying to create a part in the computer for manufacturing as well. A wide array of knowledge is needed if the designer decides to work alone in the product development process. Therefore, only a very skilled and talented designer would be able to achieve this goal alone.

Designers are limited only by their imaginations and their capabilities of using the tools at their disposal. 2D sketching has the potential to misinform the designer of scale or mechanics of the design. 3D CAD software is better suited for working out these issues and can pinpoint specific problems the design may face in production or in the consumer's home. Similar to 2D sketching, CAD software also has problems of its own. John Usher explains:

> There are a number of serious problems with current computer-aided design/computer-aided manufacturing (CAD/CAM) systems despite the tremendous advances that have been made in solid modeling. First, the

> current systems are generic by nature. The generic systems meet the CAD vendors' objective of making their products attractive to a large number of customers, but they are not ideally suited to each individual customer's needs. Most companies perform design work within a relatively narrow domain. They do not need the wide range of functionality provided by generic CAD systems (Usher, 29).

CAD programs are designed to fill a broad range of needs and types of design processes. Most designers and engineers will never use a majority of the functions provided in the CAD packages because most of their work will only use a few types of manufacturing processes that are common in the type of work for which they design. Many manufacturing companies will use one machine for each process in each manufacturing step, which typically only requires the use of one function of the CAD software to design the part. SolidWorks CAD software is popular commercial design software, but at home designers will struggle with the price tag of $3,995 for one license and an annual fee of $1,295 for technical support (CAPINC). SolidWorks encompasses many features and tools that can help designers develop and test parts without having to build actual parts for testing, thus saving time and money. There are free software options available for download such as Google's SketchUp. Unfortunately, a majority of the free downloads do not include critical tools needed to test the design's physical properties, strengths, flaws, or interferences.

Utilizing RP machinery that is capable of developing an entire part without the use of other machines will help designers in manufacturing parts. Designers who make use of 3D printers will require less manufacturing knowledge than traditional manufacturing methods; therefore, the software capabilities can be reduced to more generic functions. 3D printers allow more versatility in design and can help the manufacturing process by eliminating various pieces of equipment.

The industrial design process encompasses six critical elements needed to develop a product from start to finish, defined as:

1.) Sketch (2D)

2.) Sketch Model (3D)

3.) Development Drawing (2D)

4.) Rendering (2D)

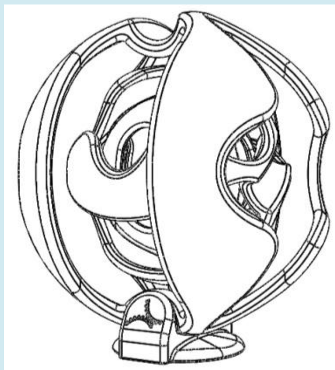
5.) Appearance Model (3D)

6.) Appearance Prototype (3D)

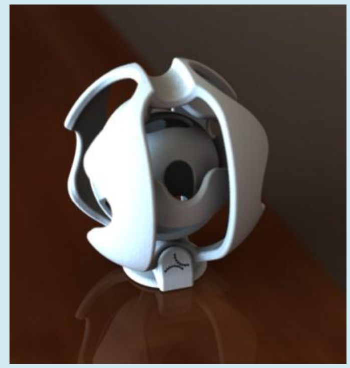
(Bennett, 2).

Industrial Design - Design Processes

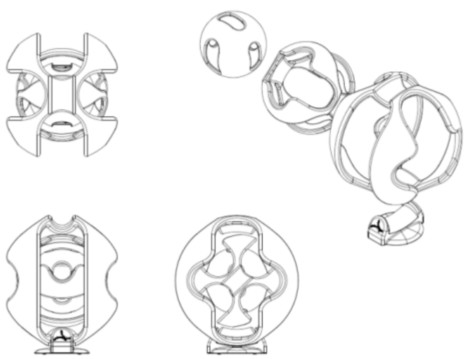
1.) 2D SKETCH



2.) Sketch Model (3D)



3.) Development Drawing (2D)



4.) Rendering (2D)

5.) Appearance Model (3D)

6.) Appearance Prototype (3D)

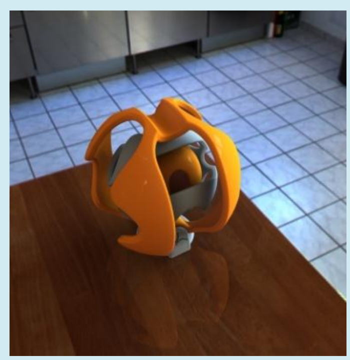


FIGURE 9: Industrial Design – Six Step Development Processes

Traditionally, both industrial designers and engineers are needed to develop new products because they require different processes.

> The 'conventional' industrial design modeling procedures, as described above, are concerned with pursuing visual and ergonomic design objectives for the product. Engineering development tends to use different forms of product models to achieve its aims. These will include mock-ups of electrical or electronic systems, engineering layout drawings, and mechanical mock-ups (Bennett, 4).

For all intents and purposes, if a designer has enough knowledge in a certain field, then there is no need for an engineer to mock up anything. A designer with full knowledge of their subject should be fully capable of mocking up all needed systems needed to complete the project. The more processes a designer can do on their own will limit the amount of outsourcing needed, which will lower the cost and result in a better end product. Efficiency of concurrent design is affected as more people are entered into the process of design. The project will be 100% concurrent if the designer is the only person who touches the project. If multiple people are added to the process, the likelihood that the project may start to suffer due to communication issues rises greatly. Carl Erickson, President and Cofounder of Atomic Object software product development company, reinforces this theory by stating:

> Communication and coordination overhead rises dramatically with team size. In the worst possible case where everyone on the project needs to communicate and coordinate with everyone else, the cost of this effort rises as the square of the number of people in the team. That's such a

powerful effect, in fact, that a large team couldn't possibly hope to achieve the goal of everyone coordinating their effort. But a small team could (Erickson).

Interchangeable Parts

Customization can be seen all around us and plays a major role in our society. The customization industry is growing fast as new companies realize the need for different and innovative personalized products. However, before the topic of customization is delved into much more deeply, the history of mass production is needed to better understand how products are made. Mass production was made famous by Henry Ford's model T in the early 20th Century, working with a concept initially developed by Mr. Honoré Blanc prior to the 18th century with the creation of interchangeable parts.

In 1778 Mr. Blanc developed identical parts that were able to replace one another in the event of a failure. Blanc developed this concept for use in firearms and is noted as one of the pioneers in using interchangeable parts. Blanc showed military men, academics, and politicians that his concept was valid when he assembled a musket by selecting random parts from a number of bins to eventually lead to the completion of a working musket. With the development of interchangeable parts came dependable and easier to fix weapons for soldiers, hunters, and enthusiasts. Prior to this development if a weapon malfunctioned or broke a part, a skilled gunsmith was needed to repair the weapon. By having interchangeable parts the need for the skilled gunsmith could be all but eliminated. Muskets can be easily repairable and not trashed as they were in previous times.

Eighteen years later a man by the name of Eli Whitney, most famously known for his invention of the cotton gin, was a strong believer in Blanc's discoveries. After his near bankruptcy Whitney started on the same crusade as Blanc. Whitney demonstrated how interchangeable parts were the forefront of modern weaponry as he laid ten identical guns onto a table and then removed all the parts and piled them onto a table. This was unheard of before Blanc, but Whitney knew that he could pick any part at random and assemble each and every gun. In front of the United States Congress he too had completed the same task of proving his point of interchangeable parts. By presenting this idea of design and production to the United States Congress, Eli Whitney created a standard for all equipment purchased by United States Government. He simply restated an idea that had been developed twenty years earlier and is still around today. Without this reiteration of a simple yet effective process, society would not be where it is today.

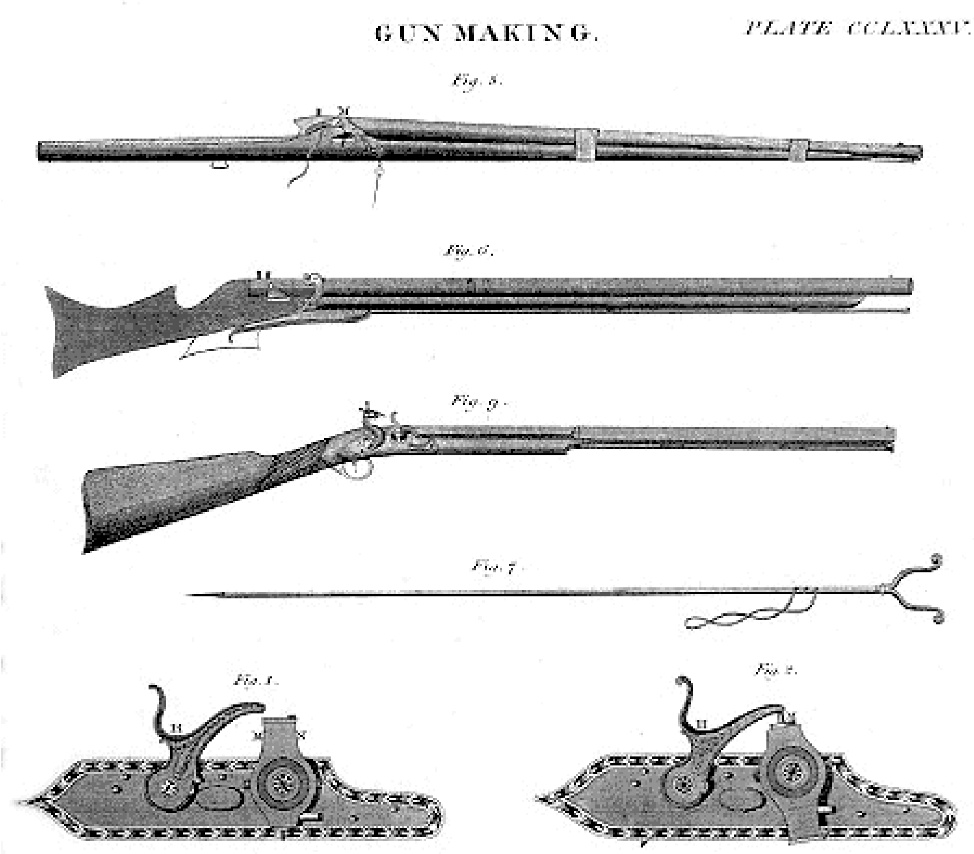


FIGURE 10: Early 19th Century "Gun Making" from the 1832 Edinburgh Encyclopedia

After the Civil War new developments were made and products began to roll off the production lines. These production lines took these interchangeable parts that were made in mass quantity and invented the industry of mass production. A new line of products ranging from sewing machines, typewriters, and, of course, rifles were all created using interchangeable parts. As each part was made, it could be stored or fitted with other parts to make the final product. Blanc saw this and utilized the fact that an unskilled laborer could now do the job of many skilled tradesmen.

Mass Production

In 1450 Johannes Gutenberg created dyes and utilized a common idea of fixed type to create a new form of mass production. He assembled the letters into a carriage arranging the characters in a strategic format. By operating this method he was able to print anything onto a piece of paper multiple times. In earlier periods each letter had to be individually printed. Multiple copies of the same piece of work could be reproduced hundreds of times with the invention of the printing press. The concept of producing one piece of work multiple times is considered to be mass-produced; therefore Gutenberg's "42-line Bible" is one of the first pieces of work to be mass-produced.

FIGURE 11: A Page from Gutenberg's Bible

Gutenberg, among others, was able to produce in mass quantity, but Henry Ford was the person who made mass production what it is today. Ford understood the need for assembly lines and established an empire one car at a time. Ford developed the Model A (see Figure 12) and, from there, the company has grown into the modern Ford Motor Company. The Model A was important to Ford because it was simple, economical, and was one of the first mass-produced cars on the market (Vaughan). Henry Ford's line foreman, William C. Klann, visited Swift & Co. slaughterhouse in 1912. During his visit to the plant he observed hogs hanging from moving hooks in the ceiling. Each butcher would make the same meticulous cuts on each hog that passed by their workstation. The outcome of this assembly line method resulted in faster processing times that required fewer people. Klann studied this approach and detailed the need for an assembly line in automobile manufacturing. Klann implemented his first assembly line in the spring of 1913 for assembling electrical components, known as magnetos, for the Model T. The magneto assembly line reduced the assembly time by 75%, which in turn helped save the company time and money (Ahrens). Ford began implementing assembly lines in 1914 with the introduction of the Model T (see Figure 13). Many industries began realizing the importance of assembly lines and started implementing them into factories around the world. Society referred to Henry Ford's new method of manufacturing as Fordism, but Ford later created the term that is known today as "Mass Production" (Brinkley & Miller).

In 2007 Ford reported producing 6.553 million automobiles for earnings of $173.9 billion (Ford Motor Company). The auto industry was affected directly by the

2008 recession and manufacturers are still recovering. In 2012 Ford manufactured 5.7 million automobiles earning $134.3 billion (Ford Motor Company).

In 2012, Ford was ranked number one in auto sales within the United States, surpassing Chevrolet and Toyota (Cain).

FIGURE 12: 1903 Model A is the Oldest Surviving Ford Production Car in Existence (Ford Motor Company).

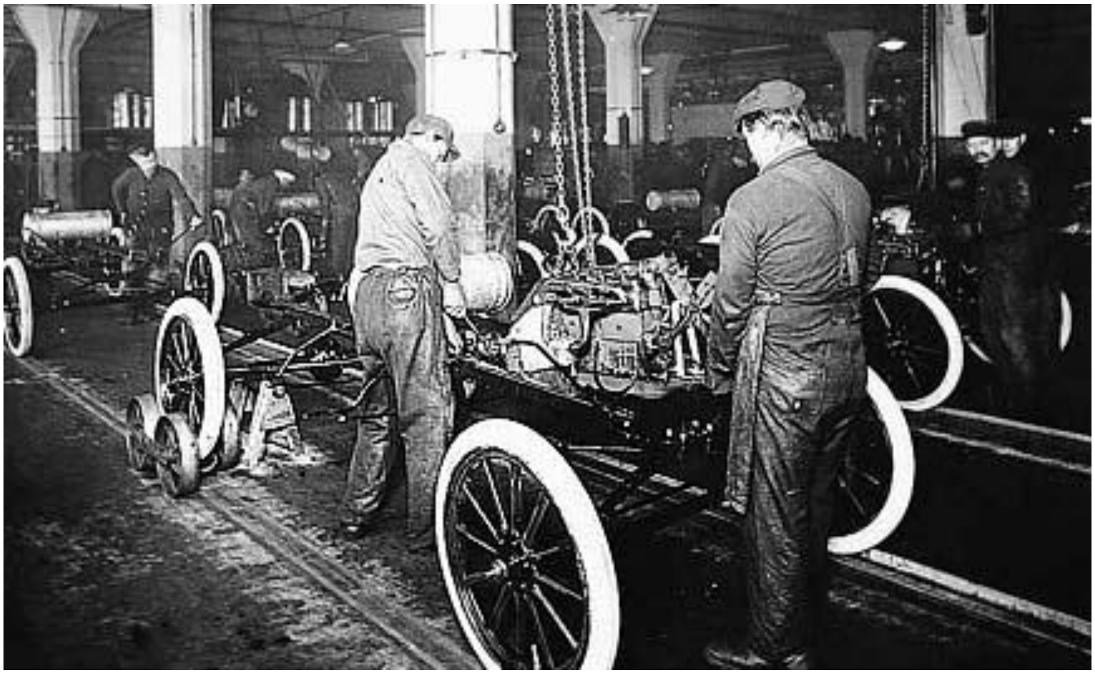


FIGURE 13: Ford Motor Company Assembly Line (Ford Motor Company)

When Henry Ford opened his factory doors in 1916, he disagreed to providing customization for his automobiles. Ford wrote in his autobiography that, “Any customer can have a car painted any color that he wants so long as it’s black.” Black was chosen based on its quicker drying time because Ford was all about speed and nothing else. Years later other companies finally caught up to him and started offering options. Options are a major factor in people’s lives. People want to feel important and that they can have a say in what they purchase. When Ford refused to update styling or add newer features, customers became unhappy and decided to go elsewhere. Eventually Ford would succumb to annual model changes in their designs.

FIGURE 14: 1928 Ford Model A (Ford Motor Company)

Today, there are a number of automakers, each with their own marketing plans. Some options include an incorporated iPod dock, headlights that turn with the steering wheel and cars capable of parallel parking themselves. Each one of the options is designed to be the next big feature in the auto industry where some designs become standard while others fail. Each year the annual model change allows the company to fix a problem or add a new marketing feature to the vehicle. In addition, customers will add and take away customizations from a vehicle to make the vehicle their own. A custom paint job, new wheels and tires, or a great sound system are only a few things that can be done to a car to make it unique (see Figures 15 and 16). Customization is a critical element to the process of evolution.

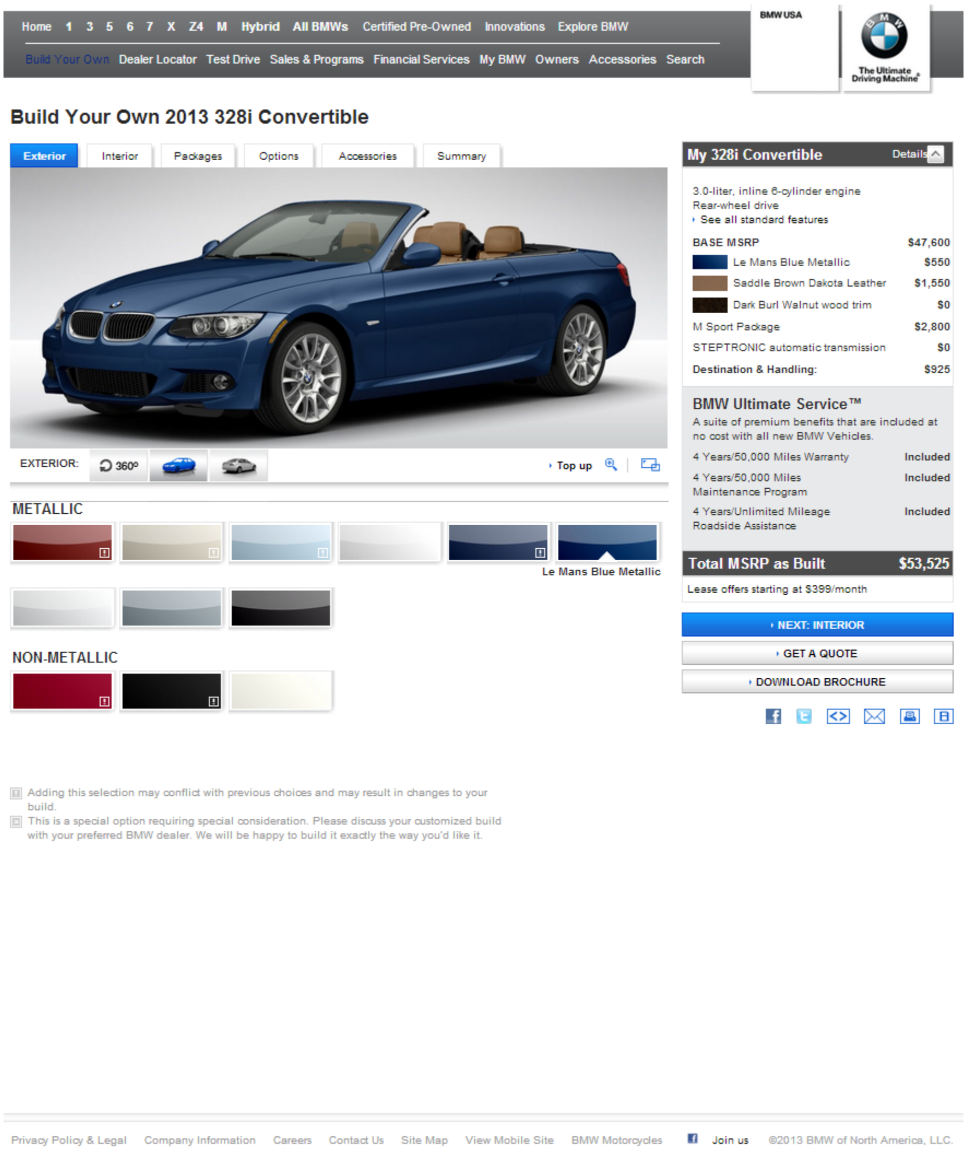


FIGURE 15: BMW Website Exterior Color Options (BMW)

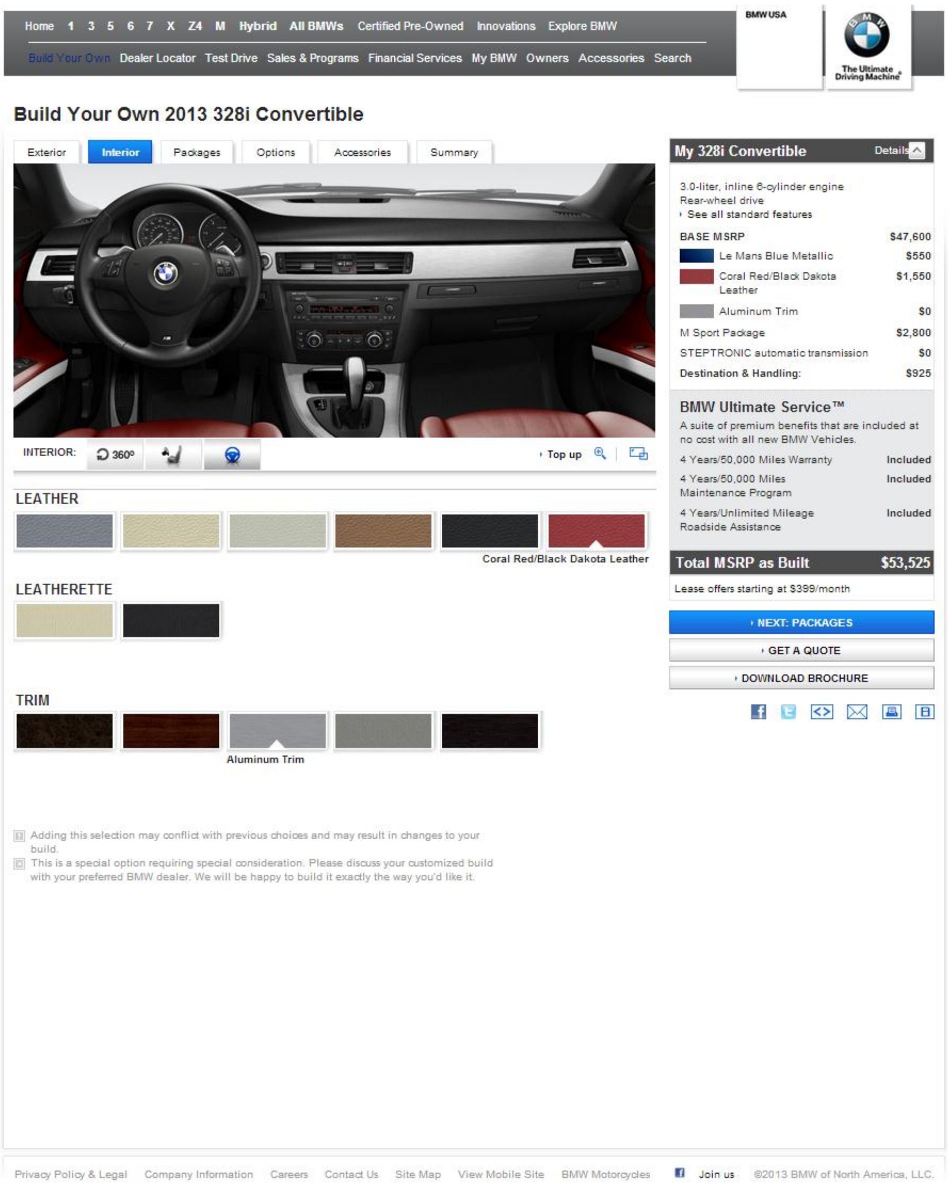


FIGURE 16: BMW Website Options (BMW)

Customization

A company is not able to produce as much inventory when they offer customization options, unless they are mass-producing one customized product. For example, in Figures 15 and 16, a client may want an iPod adapter and the High Definition surround sound system in the car. The car becomes custom as soon as the customer adds or changes one of these options that are mass-produced. Interchangeable parts are a key element when designing large projects; multiple styles of products can be used as long as one or two critical features are consistent. Manufacturers design multiple styles of radios, speakers, and various other accessories to be interchangeable, thus allowing the client to pick and choose options for their new purchase. Interchangeable parts put these new designs on the cutting edge of their industry and allow for multiple possibilities including the sales of aftermarket accessories. Although this concept of selecting an option might not be considered customizing to everyone, it is in fact a method for changing a product to meet the needs, desires, and wants of the customer. In addition, most manufacturers use interchangeable parts to build their products to help with manufacturing process, warranty replacement, and also allowing for future upgrades. Today's customization can be seen in many different product categories worldwide including automobiles, consumer electronics, and weaponry. Customization creates innovation and helps evolve society and its products as a whole.

Smart Car/ Mercedes-Benz

A French car that started production in 1998 is one of the most popular cars on European streets and is now becoming popular in cities across the United States. In the short time they have been around, Smart has sold over 45,000 Smart Fortwo's throughout the United States. These cars are small enough to get around the streets of Paris, Rome, London or New York (SmartUSA). The simplicity of the Smart is the major contributing factor that makes it efficient. Mercedes-Benz teamed up with Swatch, an innovative watch company, to develop the car. The name SMART was created when combining the two company names, Swatch and Mercedes along with "art" to create the acronym, SMART (SmartUSA). Swatch is a company that strives on being different and unique; by teaming with Mercedes-Benz the Smart Car was born. The Smart Car was developed to be a commuter vehicle that was ecologically friendly, as well as having style and appeal to the driver. Smart was able to accomplish this goal with interchangeable body panels that could be changed easily. The body panels are easily manipulated and come in an array of designs. Customization can be as simple or as elaborate as the owner chooses. Each design characterizes the person driving the car and helps present their personality to the world. Smart will introduce their third iteration of the car in 2013. The Fortwo will be offered in a variety of colors and options with personalization as a primary goal. Smart offers the consumer the ability to customize his or her own unique decals to make each car one of a kind (see Figure 17) (SmartUSA).

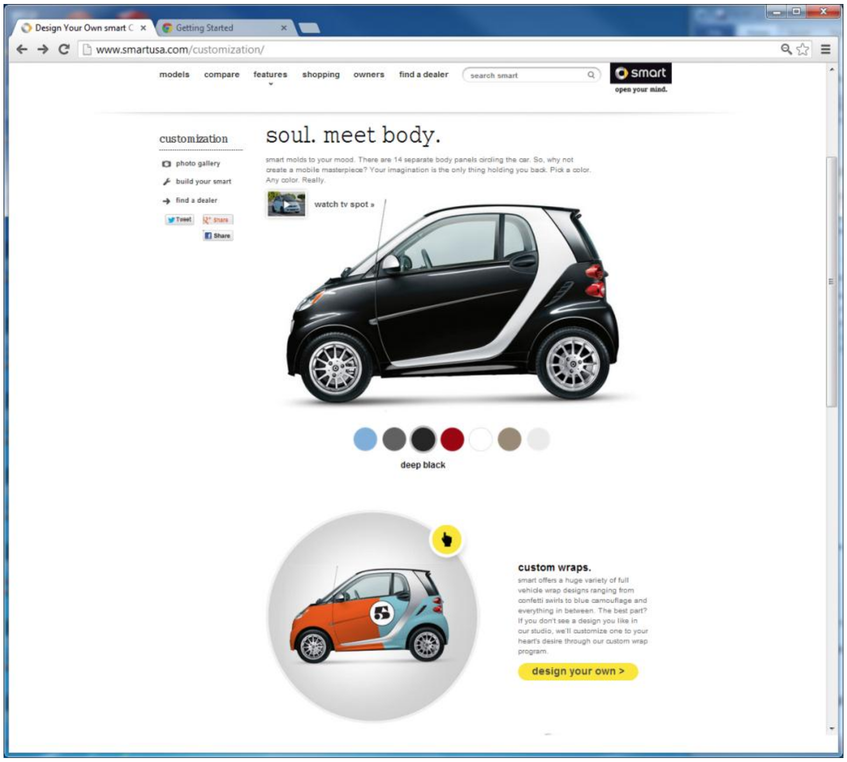


FIGURE 17: SmartUSA Customization

FIGURE 18: SmartUSA

FIGURE 19: 2008 Smart Fortwo with BRABUS Sport Package (Wikipedia)

FIGURE 20: 2013 Smart Fortwo (Wikipedia)

The “Smart Car” is an affordable mode of transportation that is easy and fun to drive. The Smart has potential of being customized as little or as much as a customer desires. Owning a Smart does not only allow the driver to get from one place to another but it also allows them to get there in style.

IKEA

IKEA is a store dedicated to selling fixtures for the home or office. Each piece sold in the store is shown on display to the customer in a showroom. The manufacturer compiles a parts list from a designer and manufactures each individual part for the order. The customer chooses which pieces they like and writes down the specific model numbers for each item. The consumer then walks into the warehouse with multiple rows of racks containing flat packed furniture and pulls the parts he needs to complete the furniture. The store saves money by not having to pay labor wages for assembling furniture. The stores are also capable of maximizing space in the warehouse with this method. A study in the Journal of Consumer Psychology referred to as the IKEA effect shows that customers who assemble their own products have a stronger attachment to the final product and also value the product higher than those who purchase finished goods. The study also discusses the value of the consumer’s labor and the confusion that helps sell a product for a less expensive cost. A consumer can purchase a product for a cheaper cost and assemble the product; however, it is typical that the consumers will not calculate their billable time. The billable time is money they could be earning if they were working and not building the furniture. The study goes on to say that the valuation of building the product is far greater than the thought of cost savings (Norton). Each flat packed box contains a detailed set of detailed instructions that show the assembly steps for the newly purchased item. Figure 21 shows the assembly method for building the new piece of furniture. The shelving can easily be shipped or moved as a flat pack, then assembled once it reaches its final destination.

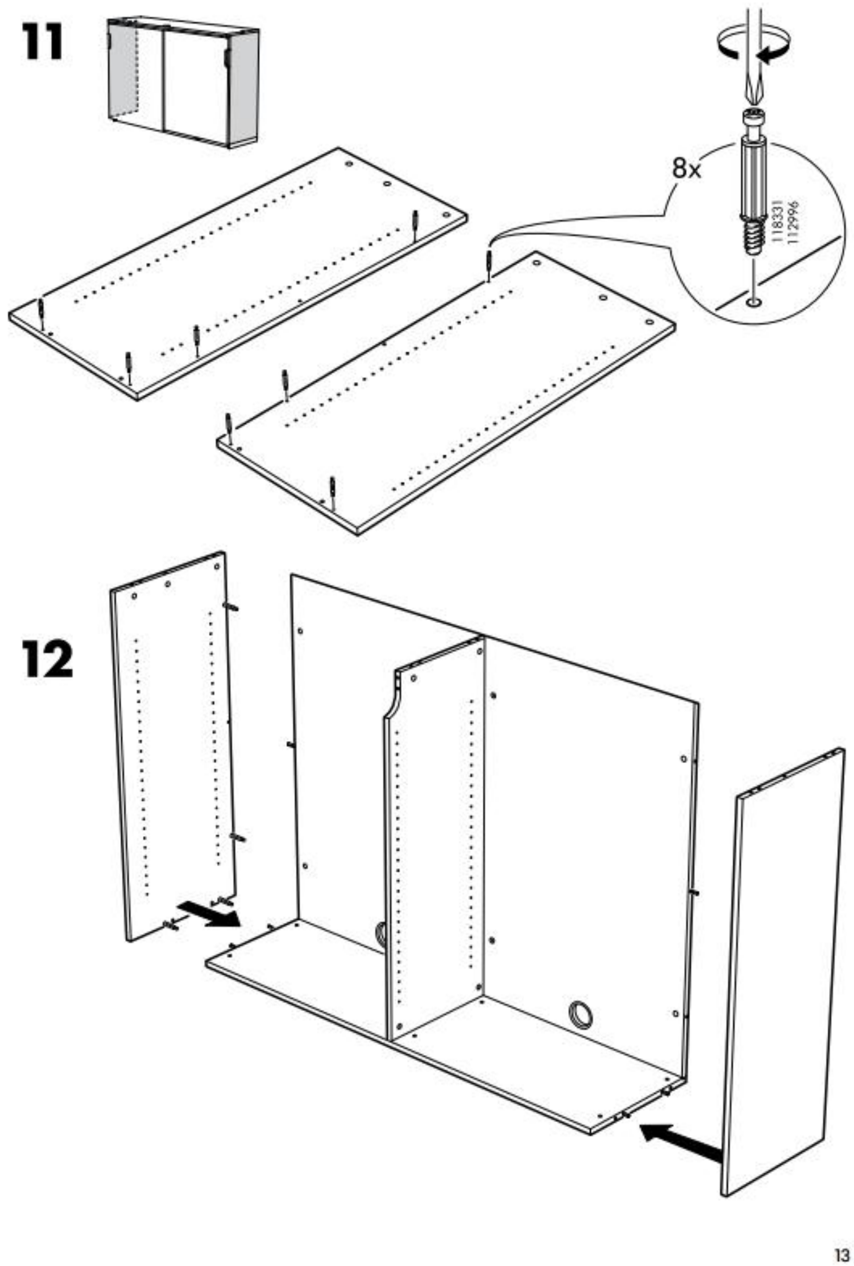


FIGURE 21: IKEA Assembly Instructions (IKEA)

Cellular Phones

Cell phones can be viewed as a status symbol in today’s society. Each phone has new and interesting marketing features that gain the consumer’s interest. The cell phone originally started out as large as a briefcase and over time has become much smaller for ease of everyday carry.

FIGURE 22: Iconic Motorola Cell Phone Known as the “Brick” from the 1980’s (What is the Brick Phone)

They can now fit into the palm of a hand and be stored in pants' pockets while having more functionality than before. There are many shapes and sizes of cell phones and each has its own importance. Originally, the cell phone was used as a communication device for the person constantly on the go. Rather than having to sit by the phone or having to schedule a phone appointment, a user is able to pick up his or her cell phone and call anyone at any time. Cell phones have evolved yet again with manufacturers constantly seeking new improvements and implementing them into their previous designs. Such improvements included games, followed by a camera that could take pictures, and shortly followed by a camera that could take video along with the still images. Today, cell phones are capable of sending and receiving emails, playing music, playing television shows, and even reminding the user of important dates or times.

FIGURE 23: Progression of Early Cell Phone Design (Norman and Foulkes)

With the advent of the smart phone a consumer is capable of surfing the entire reaches of the Internet. The iPhone is a device that allows users to do virtually anything that a personal computer can do, including checking the weather and sports, depositing checks into their bank accounts, changing the channel on the television, and even talking to a friend across the world. The iPhone is capable of playing movies and a library list of music for those who need entertainment. Cellular phones are moving away from the original goal of allowing the user to talk to someone, and now provide the user with entertainment, as well as becoming the consumer's personal secretary.

FIGURE 24: iPhone 5 (Apple)

Cell phone quantities are now outnumbering people in today's society. According to the European Union's in-house statistical office, Luxembourg had 158 mobile phone contracts in 2007, but there were only 100 people for those contracts. Business professionals are being issued cell phones for work even if they already have a personal cell phone. Other countries, such as Lithuania, Italy, and Hong Kong are similar in numbers and show that they have more cell phones than people. According to the International Telecommunications Union (ITU), in 2011 there were 7 billion people in the world and an astonishing 5.9 billion cellular phone subscriptions worldwide (International Telecommunication Union).

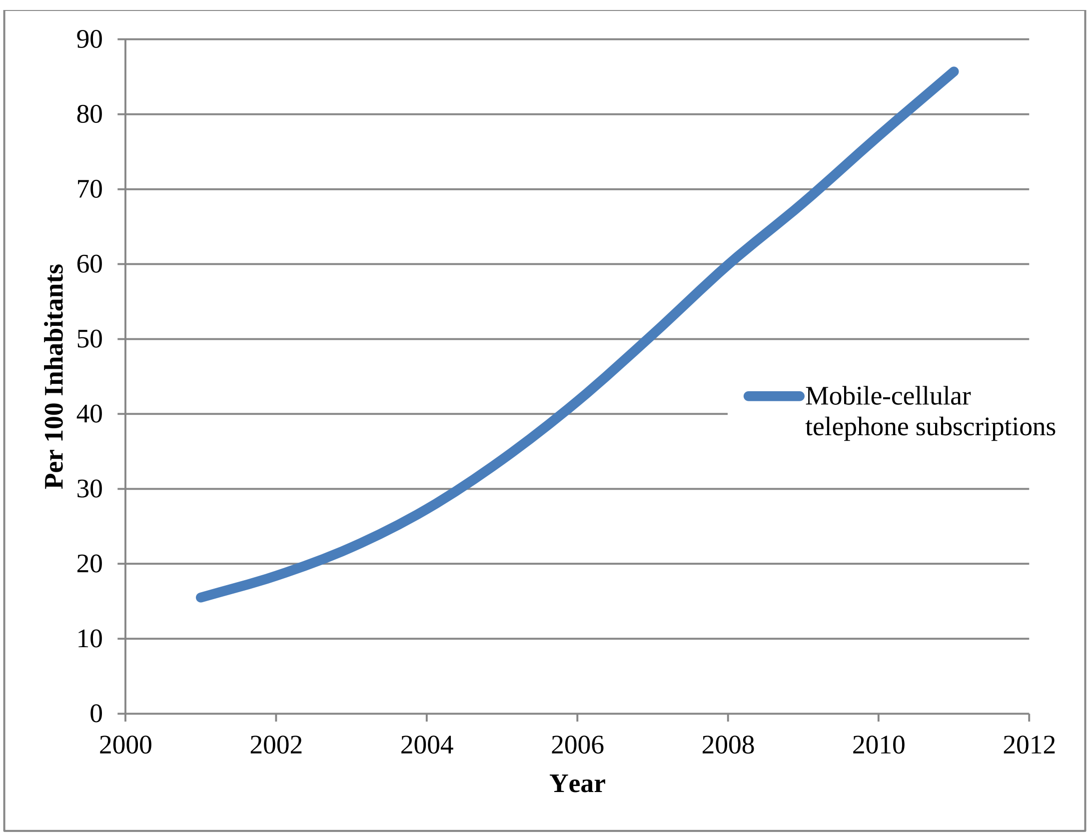


FIGURE 25: Cell Phone Subscribers Worldwide

Cell phones are continuously improving and becoming more customized as existing technologies are improved and new technologies developed. Many cell phone users pick the options they want and often add their own personal touch to the cell phones. Companies supply cases and housings for cell phones based on the type and brand of phone. Each case has its own unique appeal and presents the user's personality to everyone who sees the phone. The *New Statesman* reports that cell phone accessory revenue will top $50 billion dollars by 2015. The report does not account for any accessories that are included with the purchase of the phone. One user may have a "Hello Kitty" theme, while the next user may have a "Transformers" theme. The chart in Figure 25 shows an ever-growing trend in the cell phone industry. In 2011 the ITU reported that cell phone service was available to 87% of the world population, while service was available to 79% of developing countries (International Telecommunication Union).

FIGURE 26: Gold Plated Cell Phone (Sclick)

Customizing a cell phone is a way for the users to display their likes or dislikes while showing the world their personality. In addition, cell phones are a status symbol and can provide outsiders with an idea of who someone is. A gold plated cell phone similar to the one in Figure 26 may show that the user has a lot of money and is willing to spend it on anything. A different user may have a rubber case to help in the event that the phone is dropped or is used in harsh weather (see Figure 27). This example may show that the user is more worried about protecting their phone than having it be slim and compact.

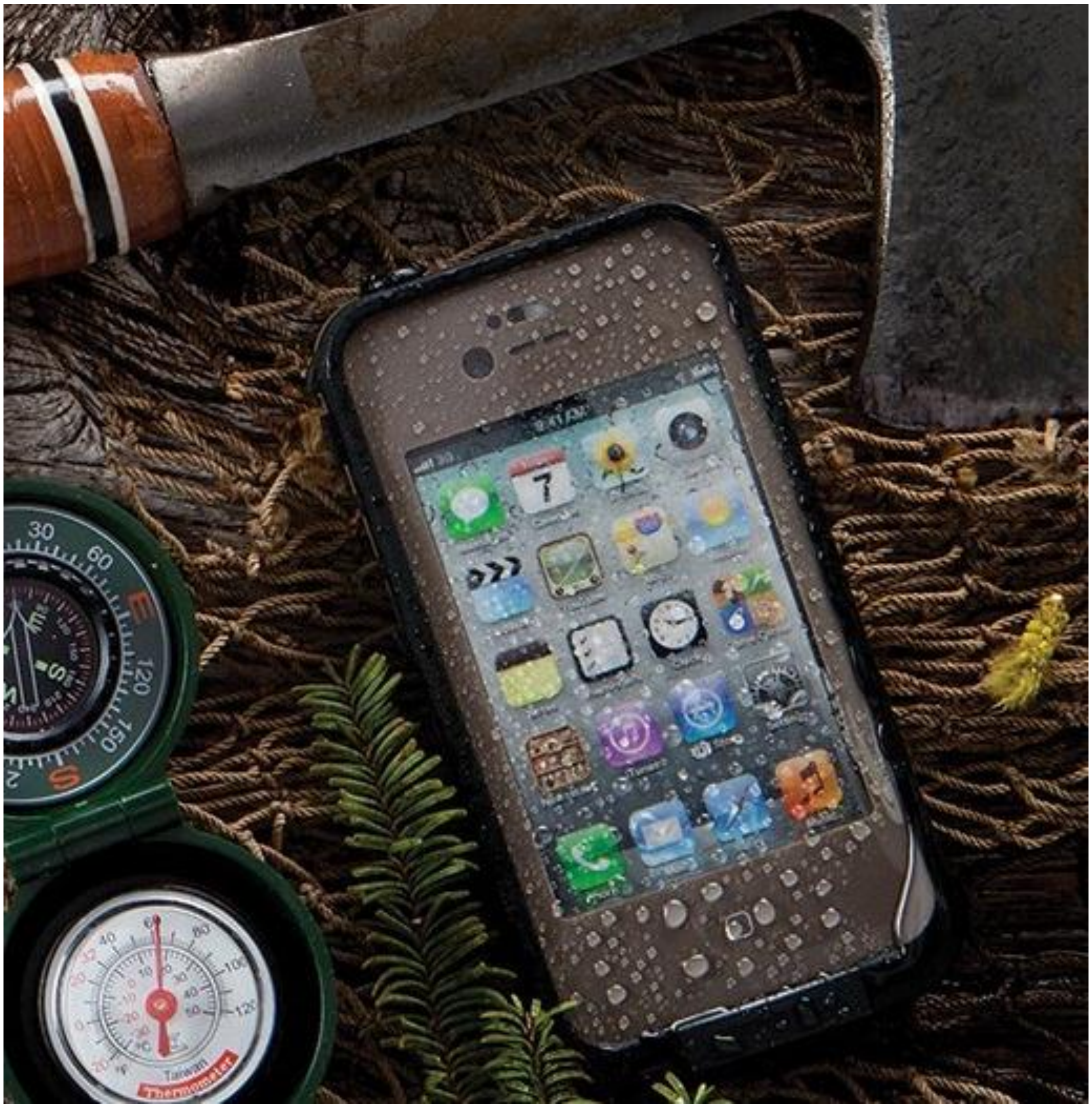


FIGURE 27: LifeProof Protective Cell Phone Cover

On-Demand Manufacturing

On-demand manufacturing is a trending topic in the world of new product development, but the concept of on-demand is firmly established and growing in the media industry. On-demand is a term that has become popular in the last few years with the capabilities of on-demand television. A consumer is capable of watching movies, television shows, or downloading music content as needed or wanted. According to technology mogul Ericsson's ConsumerLab, Internet television grew rapidly in 2010. The study showed that 93% of television watchers were watching traditional scheduled programs, but of that 93%, 70% of the users surveyed were streaming or downloading on-demand content as well (Ericsson).

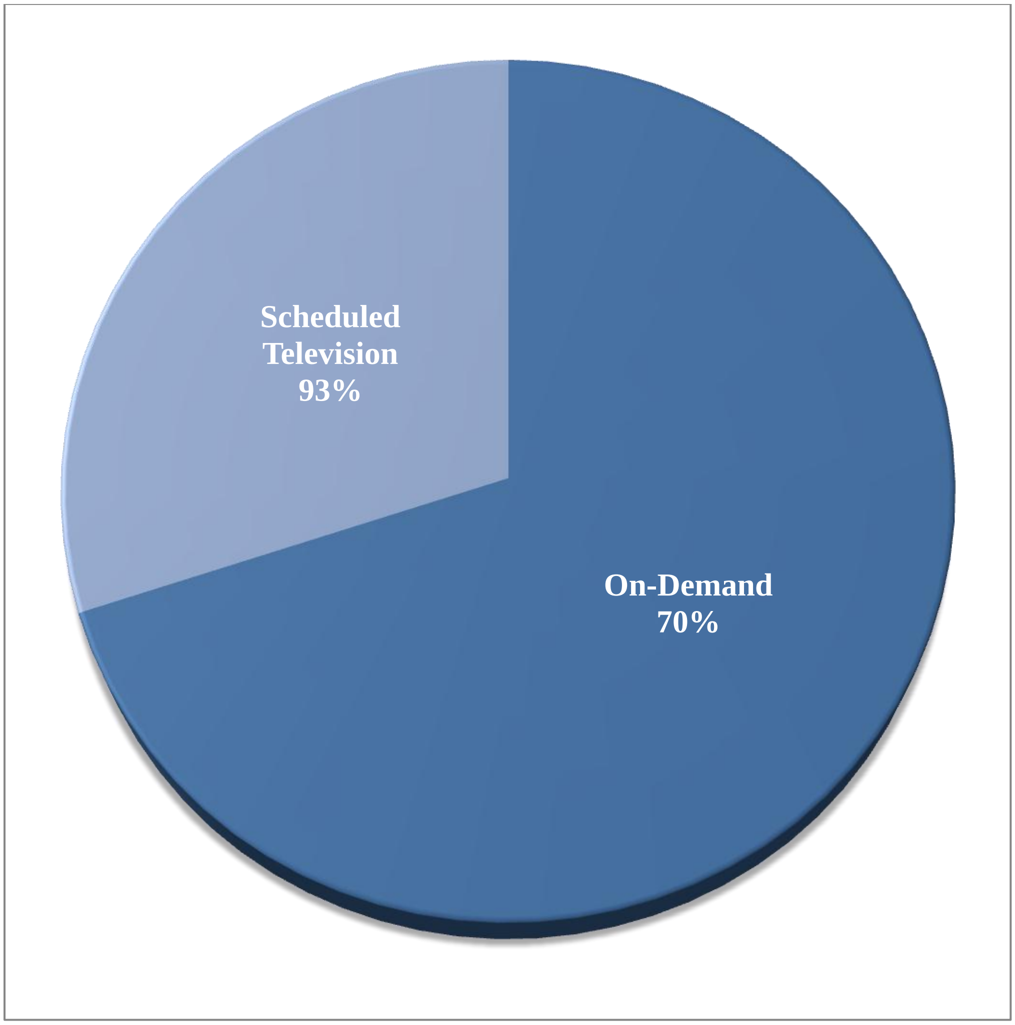


FIGURE 28: On-Demand Television vs. Traditional Scheduled Programming

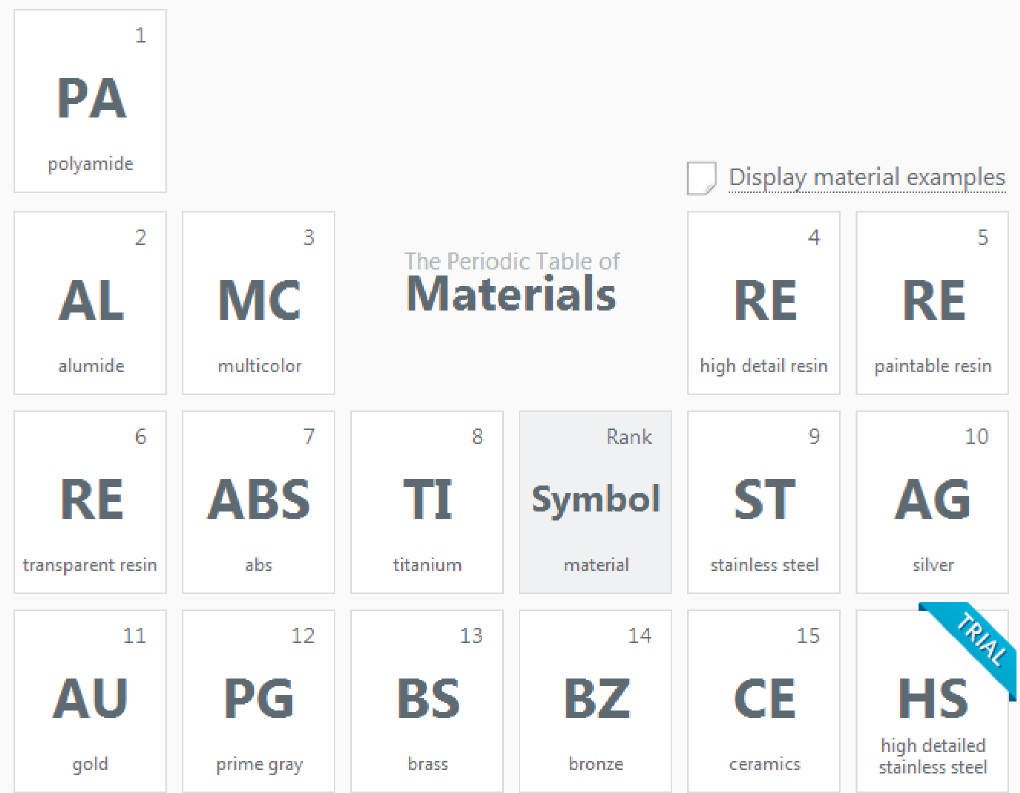
This study shows that even if consumers use the traditional methods of watching television, they still prefer to have some of their content on-demand without having to wait for an episode to air. If we infer that this trend is typical with consumers, we can conclude that consumers have a desire to acquire their products sooner rather than later. We can conclude from this study that allowing consumers to view or listen to their media at their convenience has become a luxury with which most are happy with. If we take a look into product development, we can find potential sources for creating the same on-demand process within digital manufacturing trends.

Digital Manufacturing

"**Digital manufacturing** is the use of an integrated, computer-based system comprised of simulation, three-dimensional (3D) visualization, analytics and various collaboration tools to create product and manufacturing process definitions simultaneously" (Siemens). The process of digital manufacturing can benefit from on-demand manufacturing if there is a need for the products being designed. One application of on-demand manufacturing, free 3D design software is becoming abundant and easier to use for the novice innovator. The free software is often lacking in features, but can provide a basic design with which a novice user could be happy. A few companies have been started that will compile these digital files into one location similar to a library full of books. For example, Thingiverse (Thingiverse) is an open source, non-profit website that is home to numerous designs of all shapes and sizes. Each design can be downloaded by anyone who has signed up for a free account on their website. Unfortunately, these products are not engineered or designed by a professional and may lack in strength, durability, performance, or other important characteristics that would be important when selling a product to the masses.

3D Printing

Thingiverse will not build parts for consumers; however, there are companies who will create RP parts on 3D printers for a minimal charge. Kraftwurx, i.Materialize, Sculpteo, and Shapeways are a few companies who offer affordable 3D printing to anyone with a digital file. Each of these companies will allow each consumer to design and sell their creations on their websites for a minimal fee without ever having to touch the final product. Figure 29 is a representation of the material offerings given by one company. Each company constantly develops new innovative materials with a variety of color options for their printers.



1	**Polyamide**	A strong and flexible material with a high level of detail
2	**Alumide**	A polyamide-like material with a distinctive look
3	**Multicolor**	A full color plaster
4	**High detail resin**	Lovely fine details on this photopolymer
5	**Paintable resin**	Beautiful when painted. Water resistant. If it has to be flawless
6	**Transparent resin**	See through
7	**ABS**	Strong and tough with the highest level of dimensional accuracy
8	**Titanium**	Light and the strongest 3D printing material in the world
9	**Stainless steel**	Not your grandmother's stainless steel
10	**Silver**	Sterling silver
11	**Gold**	14 carat solid gold
12	**Prime gray**	Very smooth, detailed and "luxurious" to the touch
13	**Brass**	Copper and Zinc, united as one
14	**Bronze**	What did you expect after gold and silver?
15	**Ceramics**	A food safe material that shines like no other
16	**High detailed stainless steel**	High grade stainless steel with a superb level of detail

FIGURE 29: i.Materialize Material Options

3D printers vary in shape, size, cost, materials, and resolution they can use for printing parts. There are a few different types of 3D printing processes, but the focus for this paper will be Fused Deposition Modeling (FDM). FDM is an additive manufacturing process where a thin piece of plastic filament, typically acrylonitrile butadiene styrene (ABS) or polylactic acid (PLA) is extruded through a nozzle similar to that of a hot glue gun. The plastic filament melts in the extruder and is deposited onto a build platform where it instantly cools to create a 3D part. 3D printers are designed to print one color of filament per extruder nozzle. Some machines will have multiple nozzles, while the majority of the printers will only have one nozzle due to the fact that most desktop 3D printers are still in an early developmental stage that is completely experimental. There are currently many manufacturers of desktop 3D printers on the market. MakerBot is a small company located in Brooklyn, New York, that is dedicated to the advancement of desktop personal printers. Independent designers and engineers will thrive as companies like MakerBot generate new methods for creating quality three-dimensional products. The latest MakerBot printers are capable of printing as small as 100-micron (0.10 mm) layers, which is equal to the thickness of a sheet of copy paper (O’Brien).

Layer Resolution

Layer resolution is a critical factor of 3D printers that is constantly improving as new machines are developed. Resolution is measured in microns and can be adjusted higher or lower as needed. The 3D printed part detail is affected as the resolution changes; by increasing the resolution from 300-microns to 100-microns the details become more apparent and noticeable. The amount of material being used will be the same for both resolutions, but the time to make the part at 100-microns will take longer than it will to make the 300-micron part. This is important to consider when calculating machine runtime and the perceived value of the part being made. Typically, a prototype should be printed at a lower resolution to confirm size, shape, and any features that might be questionable. Upon confirming the prototype, a higher resolution model can be made for the final product.

Quality and detail are dependent upon the layer resolution of the printer, and printers will produce better products as printers become more advanced. There are many brands of printers, ranging from build-it-yourself at home FDM printers (starting around $500 from Solidoodle.com, entry-level FDM 3D printers (average cost: $3000 from MakerBot), and of course the high end non-FDM professional printers from Stratasys and Objet that can print in 16-micron layers ($10,000 - $250,000).

On-Demand Manufacturing via 3D printing

There are many benefits to on-demand manufacturing. *Business News Daily* explains that on-demand manufacturing can limit quality issues while also bringing jobs back to the United States (Mulvey). ODM is not conducive to all product markets and will not have immediate success in certain product areas. It will be imperative to choose a category that will benefit from this method of ODM in order to continue to grow. 3D printing is becoming popular throughout the world, but it will take time before the average person can gain benefit from using a 3D printer. Brian Lane states that on-demand manufacturing is "poised to kickstart the distributed fabrication industry and provide a boost to the global manufacturing market." More people will start to own 3D printers as the technology becomes more cutting-edge, the quality of parts becomes more detailed, and consumers have easier access to digital files. Fortunately, Staples office supply chain has decided to install 3D printers into a select set of stores to test the market. Mike Senese from *Wired* magazine writes, “A new service called "Staples Easy 3D" will allow customers to upload their designs to Staples' website, then pick up the printed objects at their local office supply megastore, or have them shipped to their home or business — not unlike the photo- and document-printing service the company already offers.”

FIGURE 30: Staples Easy 3D Printer (3ders)

It is important to note that Staples, Sculpteo, i.Materialize, Kraftwurx, and Shapeways 3D printing companies have far superior non-FDM 3D printing capabilities than the average small entrepreneur business will be able to afford. These larger companies are paying a higher overhead cost, but can provide a better end product, which may be beneficial to small businesses. Although this paper is focused on FDM 3D printing, we will still acknowledge these services to help provide better solutions for the end products. Most 3D printers are only capable of printing one or two colors, but the material can be painted as desired. Hobbyists are avid painters and enjoy painting their projects to give them a realistic feeling. The hobby industry is large and can provide many useful directions for this paper.

Hobby Categories

There are many categories involved in the hobby industry, but for this paper we will focus on four main categories: Model Railroad, Plastics and Die Cast, Radio Control, and General Hobby. It is important to define the main hobby categories by sales to help understand the market potential for each category. The chart below shows the estimated sales for each category in 2010 with the sum of all categories totaling $1.47 Billion.

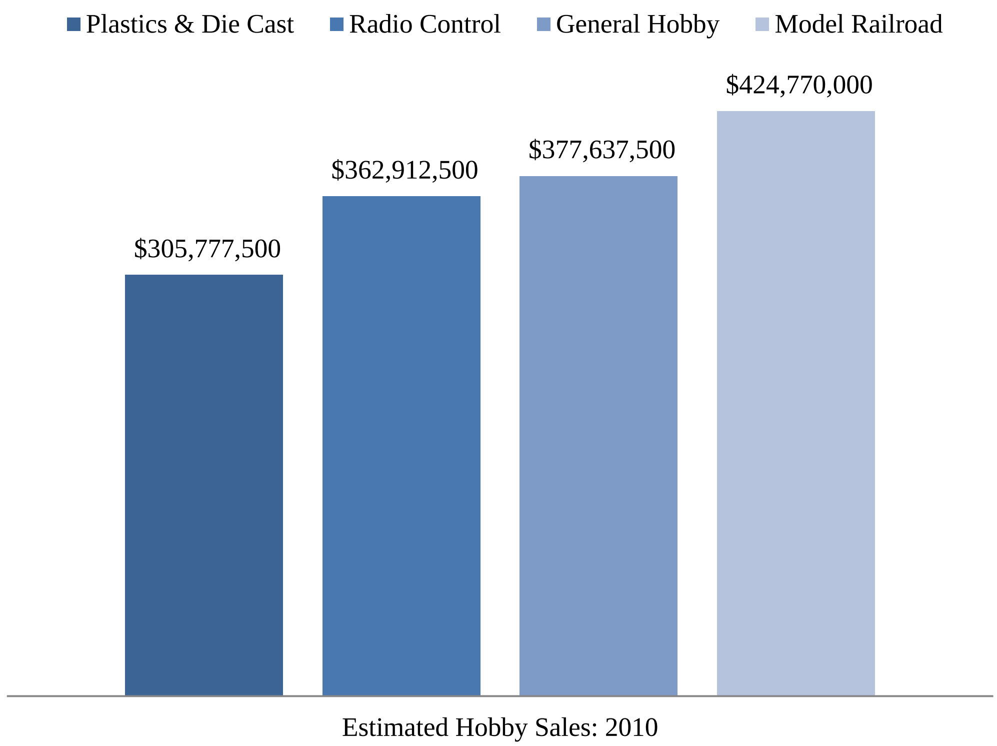


FIGURE 31: Hobby Categories by Sales (Koziol)

The information provided in the chart confirms model railroading as the most profitable hobby category, which is the primary reason that this category has been chosen for this study.

Model Railroad

Model railroading is a do-it-yourself hobby with the first models arriving in 1784. These first models were developed as prototypes 20 years before the first full-sized passenger and cargo trains were manufactured (Collectors Weekly). These scale models can be as simple as a circle around a Christmas tree or as elaborate as a complete historical recreation of a city.

FIGURE: 32: Train around Christmas tree (Sharper Image)

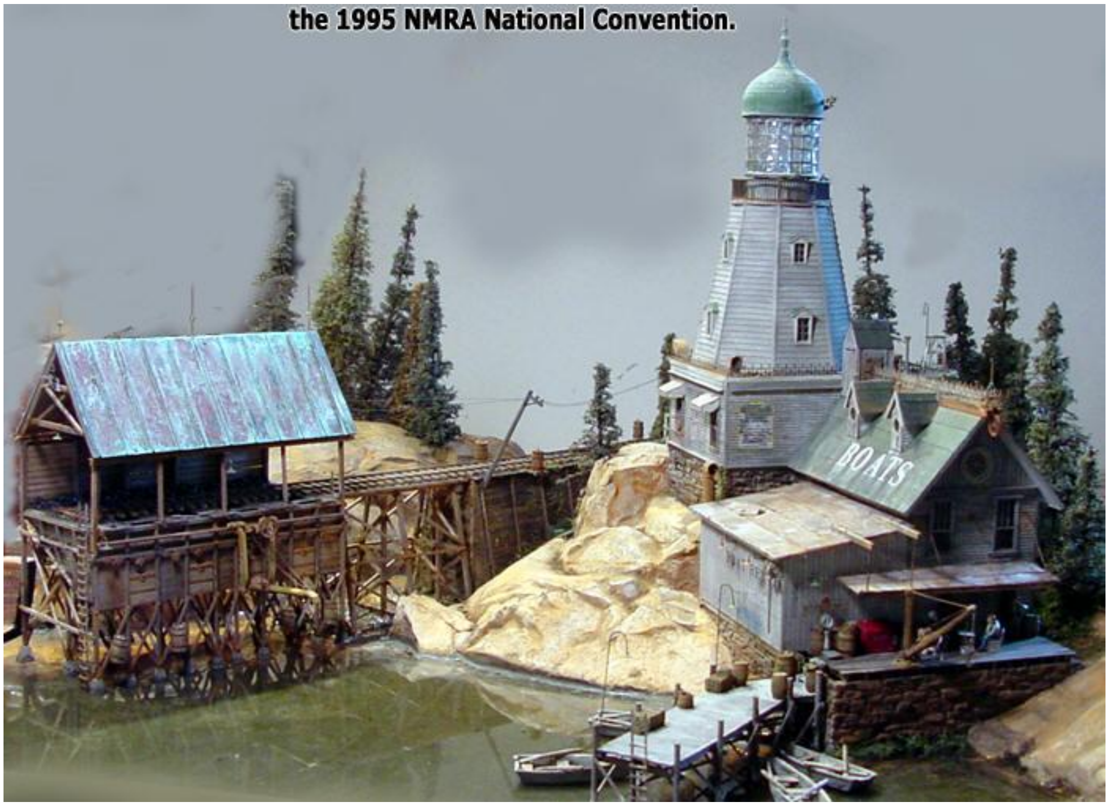


FIGURE: 33: Detailed Scale Model Building (Bendever)

Building model railroads can be very educational in history, carpentry, electrical skills, economics, model building, artistic techniques, research, logistics, planning, 3D spatial visualization, physics, engineering, and geography. Trains do more than just haul materials and people around the world; they also fuel imaginations. Children are introduced to trains at an early age and taught that they can be magical and majestic. Thomas and Friends is a popular child's television show that uses a set of trains with faces to teach children values. *The Polar Express*, written by Chris Van Allsburg, is another instance of a book that describes a magical train that takes children to visit Santa Claus at the North Pole. Trains are depicted as one of Santa's favorite toys in many advertisements across the world. Coca-Cola has many advertisements that show Santa playing and building trains for good little boys and girls around the world.

FIGURE: 34: “Seasons Greetings” Coca-Cola Santa with Train

SCALE

Railroad models are scaled in size and chosen depending on factors set forth by the model builder. Builders with limited space will typically choose smaller scale projects whereas larger builders who have large areas to work with may choose the largest scale models. Figure 35 is a reference chart that shows the most popular scale sizes (Z Scale, N Scale, HO Scale, O Scale, G Scale, and Scenic) used in the industry. Specialty sizes are excluded from this list due to the large volume and diversity.

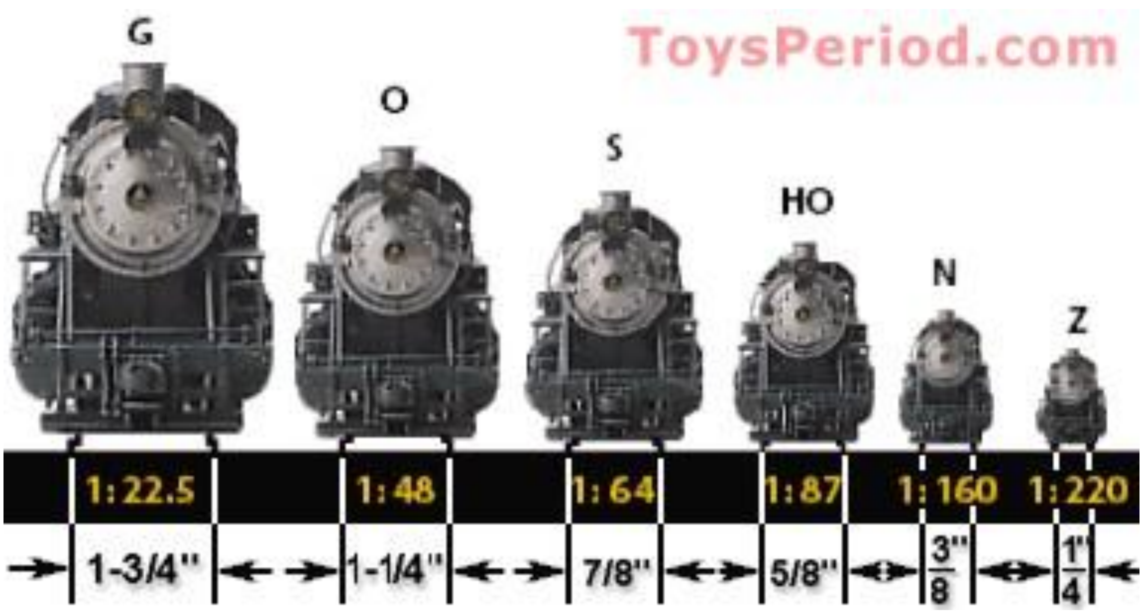


FIGURE 35: Model Train Scales (Toys Period)

Specialty size models can be larger or smaller than traditional scale models and are typically built for a specific reason. The most common example of specialty size models can typically be seen every Christmas in your local mall driving children around a circle before or after they see Santa Claus.

FIGURE 36: Specialty Scale Train (Maury)

Paul Graham, Shenandoah Valley Railway Club rail coordinator, stated in an interview with an ABC news affiliate that model trains are “timeless” and provide a way for children to interact with older generations while providing a gateway to imagination (Byknish).

Market Overview

There are many manufacturers of model trains in the market, with each company focusing primarily on one or two main scale categories. N scale is stated to be growing in popularity and parts accessible (Train Sets Only). For this study we will focus on N scale with limited reach into other scales ranges because the N category has numerous manufacturers and suppliers for each area of focus. A few of the major brands include Atlas, Kato, Intermountain, Stewart, Proto, Bachmann Spectrum, and Lionel.

Retail Sales

Most major hobby stores stock entry-level train kits and train accessories. These kits typically include a locomotive, various types of box and freight cars, a caboose, railroad track, and the equipment to provide electricity to the locomotive. These kits will often include a starter kit of accessories that can include railroad and street signs, telephone poles, and assorted human figures. Hobby Lobby lists their entry-level kits from $99 up to $120 (Hobby Lobby), while Hobby Town USA has a larger variety and a broader price range of kits from $115-$265 (Hobby Town). There are many hobby stores located around the world; a registry of hobby stores dedicated to model train building can be found on the NMRA.org website.

Accessories

Model Train accessories are a critical part of model train building, but the train is only one part of the building process. Street signs, railroad signs, buildings, landscapes, vehicles, and people are all critical parts of creating a realistic environment. The finest of details are considered when laying out design plans. Some modelers dedicate hours of research time to construct historically accurate scenes, while others will spend countless hours trying to design the next city planning solution. The modelers will build accessories if they are not currently available or if the details are not to their liking. Different painting methods are used to imitate different materials and weathering of surfaces to provide a realistic look and feel (Building Your Model Railroad). An example of the attention to detail can be seen in Figure 37.

FIGURE 37: Specialty Scale Train (Wells Green TMD)

Literature Review Summary

A manufacturer should be diverse in all aspects of design, while remaining grounded in their design approach. Manufacturers who evolve will continue to grow and be successful because they are able to keep up with current trends. The diversity will also keep them in the forefront of innovation and will create better products for consumers. Customizing is a huge part of our daily lives and should be pursued much more than it is already. If customization were to be pursued, a manufacturer would need to make sure to take into consideration the following factors: Cost, design, engineering, shipping, labor, machine costs and various other aspects involved with the manufacture of products.

Design involves a skilled eye from a designer who has a broad range of experience and understands design history. A designer should be knowledgeable about past products in order to be able to create products for the present and future. Designers with this vast knowledge will be able to sort their designs into different product categories of importance. There are many types of products on the market currently that fall into various categories, but because there are an unlimited number of future categories, the possibilities are endless, which will be beneficial to the design, the designer, and the consumer. Every individual should be able to customize their life in the style they prefer and should not be limited in selection to only products in the market currently. By creating a library of supplies that interchange, each individual part can be mass-produced. Parts that have the ability to be interchangeable as well as customizable can allow the end product to be virtually completely customizable, allowing the consumer to have unlimited possibilities. The fundamental concept of this theory states that a designer could start a small company with a few small designs. The designer would be able to choose a platform to work with and design custom parts that would be interchangeable with their platform of choice. The consumer would be able to choose from a preselected set of parts in a digital library, and make customizations based on what they would like and have it manufactured on-demand with specific changes as needed. The design company would then be able to print a part on a rapid prototyping machine and ship to the consumer directly, or the consumer could choose to download the digital file for a small fee and have the part printed at a local RP manufacturing facility.

Assumptions of Study

It is assumed that the research compiled in this documentation is accurate and valid for the use of this study. It is also assumed that the information in this project will be scalable based on the future technology and the growth of RP machines. Future technology will supply better quality machines as well as larger build platforms. Equipment prices will drop as the technology becomes more popular and understood. This assumption is largely based on the history of technology price drops over period of time, and largely based on a report by Gartner, who is a leader in information technology research. Gartner states that 3D printer costs will be reduced significantly by 2016. The report indicates printers that are currently in the $10,000 price range will be reduced down below $2,000. The research in this study is based solely on people's desires, wants, and needs. Each consumer has different style preferences resulting in diverse desires, wants, and needs for each. By assuming this fact, the reader can understand that this is merely a hypothetical situation, and that each product will always have an infinite number of options, styles, and characteristics for that product. The information given through this research will be an example of the concept process, development, and product line, but it will not be a complete line of the product(s). Mass-production and customization are on completely different ends of the design and manufacturing spectrum. There will always be a struggle in mass-customization where the two processes fight over which has more importance. The nature of a completely one-off product means that the product cannot be reproduced by mass production. Tooling, costs, shipping, and mass-producing products void the concept of having mass-customized parts. When a company uses mass-customization, each design is viewed as a whole, and each part is custom built, much like rapid prototyping. When a designer uses the mass-customization process, they look at all aspects of the design and not just the whole picture, thereby giving the end-user a quality product.

Scope & Limits of Study

The research should allow a designer to focus on designs that are interchangeable, while allowing for on-demand manufacturing of each part. The design phase of the project will be based on concepts of past and present designs. Modifying designs to be interchangeable will be based on the designer's own knowledge of parts, methods of fastening, and mechanics of parts. The methodology of this study will create an equal balance of customization and on-demand manufacturing for model railroads. The scope of the study is limited to the advancements in computer software in product design and a designer's use of the software. The designer will also have to incorporate machinery, tooling, and manufacturing capabilities into the equation of the design.

Anticipated Outcome

It is anticipated that the outcome of this study will result in the development of a method for creating designs that can be manufactured on-demand or sold as digital files for manufacture at a later time. The study will show that part selections will grow as technology improves and machines grow in size. Customization and on-demand manufacturing will be critical for this concept to be proven correctly. Customers will have the option to choose the main features, as well as any customized features for their application of the product that is important to fit their needs. Complete application customization is obtainable by giving customers a various array of choices that can result in a one-off design that can be manufactured in house on 3D personal printers. An e-commerce web page will be developed to obtain user inputs to help produce a final product to their specifications. If the concept of easily customizable products is generated and succeeds, society will have a new standard of product design. Each product will not be designed for the 51% majority of the population, but for each individual person. The major concern with this concept will be related to the individual parts rather than the whole. The process of making multiple interchangeable parts, while keeping the assembly simple and easy to install, is critical for the design model to work properly. The concept will merge on-demand manufacturing and customization into one final product, thereby creating a new and innovative way to personalize products.

Outcome: Design Criteria

Model railroading is important to this study; however, a special set of criteria will need to be developed to ensure the product is designed as intended. Each aspect from development, technology, and product variations should be considered when creating the design criteria to create model railroad products. Design Criteria is a critical portion of designing a new product or a new method of designing a product. The listed criteria are designed to be a guideline that should be used each time a model railroad or similar product is developed. The criteria details specifics such as product specifications, scale, details, and features. Each new part designed will be reviewed to ensure the product meets the goals of the design criteria.

- Must be customizable
- Must have detailed characteristics to make product unique
- Must be aesthetically pleasing
- Must use minimal material

- Must be affordable
- Must be made using a 3D printer
- Must be paintable
- Must be durable
- Must be easy to install
- Must require minimal assembly
- Must be consumer friendly

Summary of Chapter

Customization is all around us and it will continue to evolve as new technologies are developed. Products and product lines will continue to grow with the help from on-demand manufacturing machines. Consumers embrace customization as a method of expressing their personalities by constantly creating new ideas. On-demand manufacturing will help meet this fast-paced product lifecycle by printing customized parts as needed without material waste or the need for expensive tooling. *Mass-Customization Through Digital Manufacturing* can allow consumers to customize products for their specific applications without the high costs of specialty tooling or hand made products. Each product can be replicated multiple times without affecting the cost to the consumer or the on-demand manufacturer. On-demand manufacturing with current 3D printer technology is ideal for accessories related to the hobby industry. The model railroad category has the largest sales numbers of any hobby category and shows the largest potential for success in on-demand manufacturing.

CHAPTER THREE

DEVELOPMENT OF PROCESS

Overview

A key process for designing modular customized products will be discussed in this chapter. The process overview will be explained in depth with directions to help a designer accomplish the goal of creating unique customized designs. Concept development will be a critical topic in this chapter. The products that will be designed in this chapter will originate as sketches and be generated into a computer model. The computer model will help answer questions about the product before it is turned into a prototype and the final model. Therefore, the designer can obtain overall measurements of the product as well as product volume and weight. In some instances the consumer will be required to assemble or install extra components such as lights into a street lamp or a body onto a locomotive chassis. In this case the computer model will allow the designer to account for these additions by planning ahead to help avoid any issues in the at-home assembly process. Finally, in this chapter we will describe three scenarios for selling the final product to customers and consumers. A mock website will be created with the company name of Red Earth Customizations chosen for this study.

Procedures and Methods

1. Research

The plan of approach for *Mass-Customization Through Digital Manufacturing* will start with identifying an area of need. This area should be researched to understand the market and products in that market. For this study we will focus on model railroads in the hobby market category. Secondly, a product category should be chosen from this particular market, such as locomotives, accessories, scenery, buildings, etc. This product line should conform to past and present products, and should be on the cutting edge of hobby design. Each product needs to be studied closely to understand characteristics of each design. By utilizing the knowledge of past and present designs, the designer should be able to categorize each design into a certain category. Within each category of the designs, the designer must have knowledge of the techniques used to assemble each product and how they will function on the vehicle. Large-scale vehicles and small-scale vehicles are not completely identical; therefore each part will require special detail in assembly to offer the perception that the part is the same as a full-scale part. The designer will be able to research new and old parts alike to design new innovative products that can be customizable on a scale level. The designer will need to understand the mechanics involved with their platform and the requirements of each design created. The designer will list customizable features that are available for each part and will only provide the end user with those listed options.

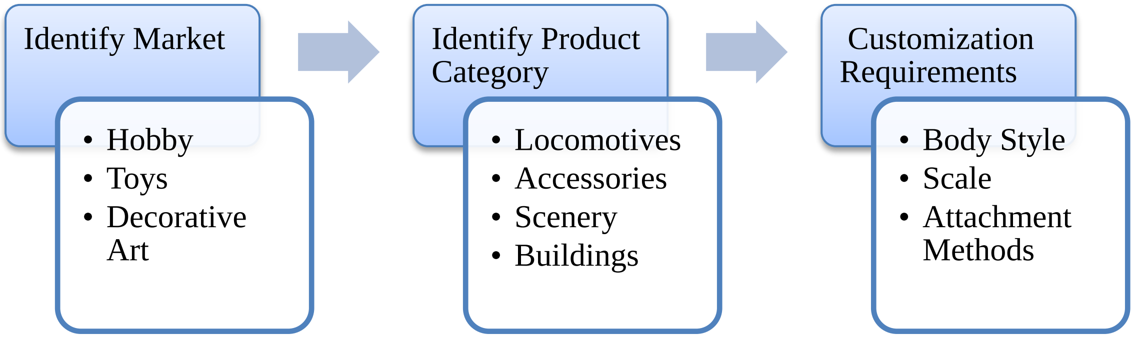


FIGURE 38: Research Flow Chart

A mock e-commerce website will be created with each feature that the consumer can choose on-demand. Upon selection the digital file will be chosen and can either be downloaded in a digital file format, or the part can be manufactured and shipped to the end user for an additional fee that includes the cost of manufacturing. If the consumer chooses to download the file, they will not have to pay the fee upfront for manufacturing and will be able to take the downloaded file to their preferred on-demand manufacturing site for manufacture.

2. Development

- Concept ideation will include concept images, computer models, and prototypes.
- On-demand manufacturing will be used to manufacture a set of scale parts.
- E-commerce: An e-commerce mock website will be created to sell digital files or a final manufactured product.

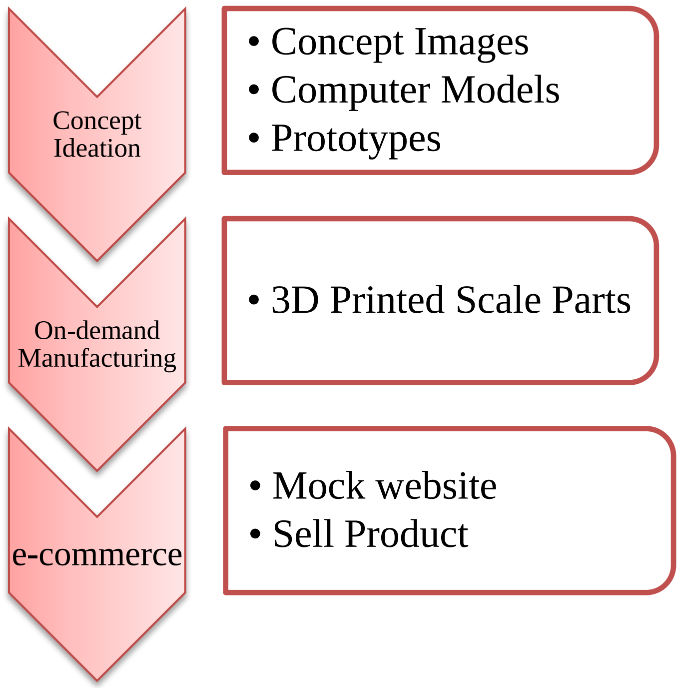


FIGURE 39: Development Flow Chart

3. Implementation

- Sales: Sales of the files/ product will prove that the concept is valid and can be beneficial for designers to pursue.

All research will be based on information gathered from hobby magazines, Internet web pages, brochures, catalogs, encyclopedias, and other library sources. The primary goal of this thesis is to develop a new method for on-demand manufacturing that will be beneficial for the future of digital manufacturing and increase small business capabilities.

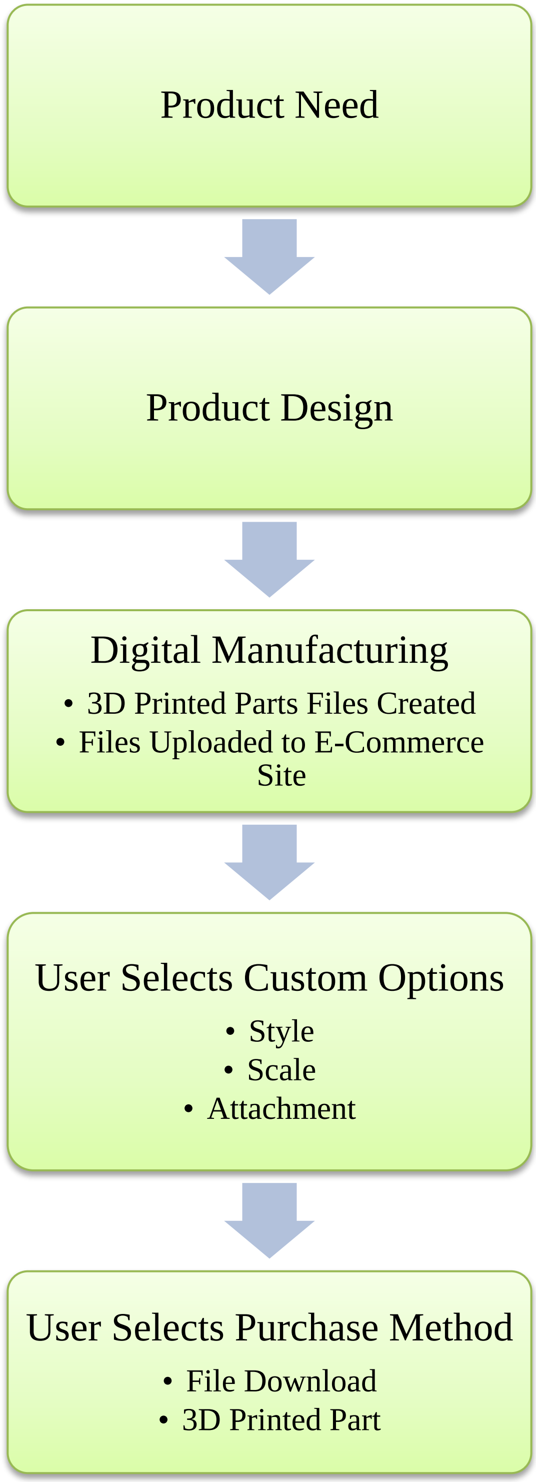


FIGURE 40: Implementation Flow Chart

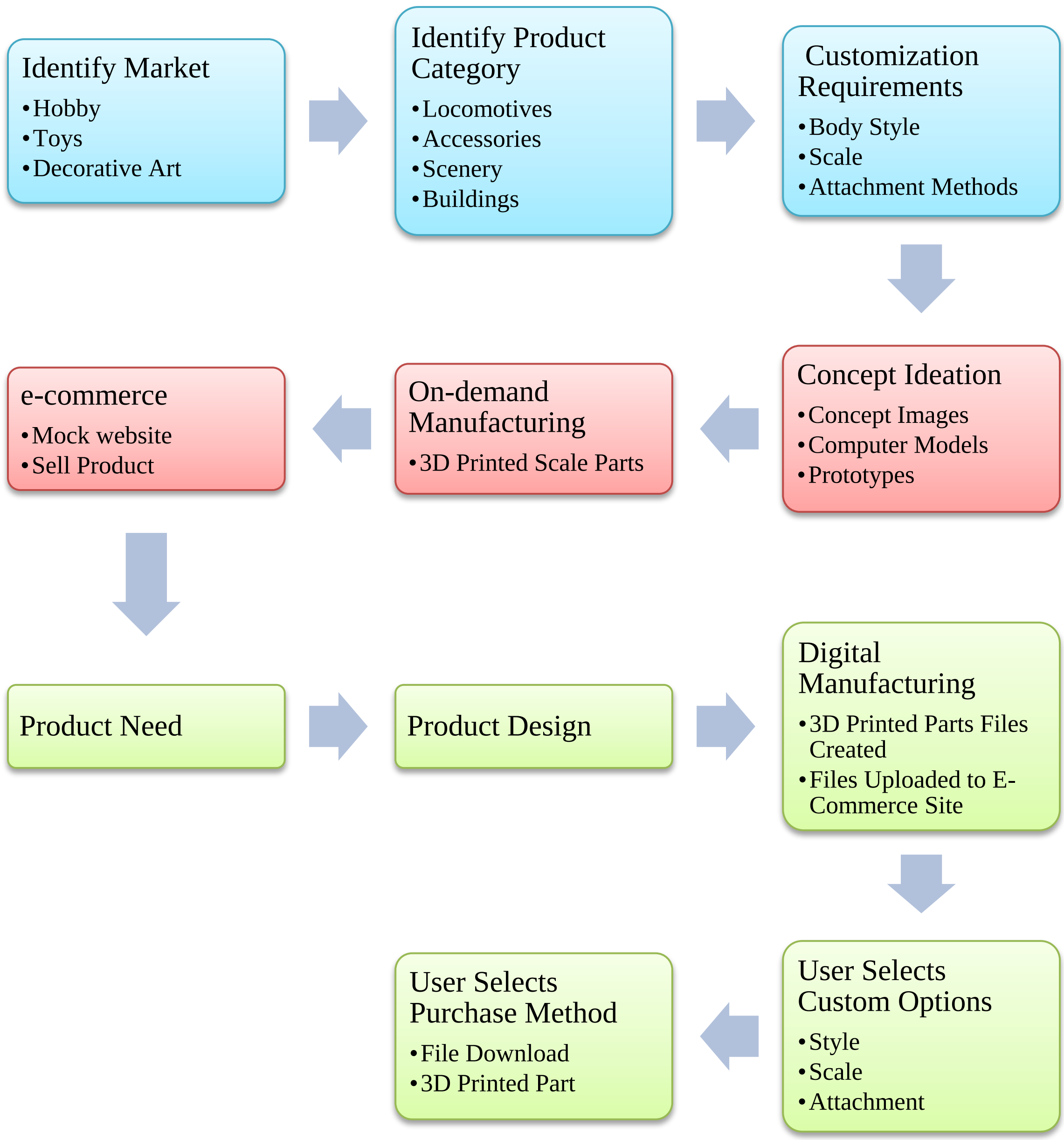


FIGURE 41: Complete Process Flow Chart

Opportunity and Design Strategy

Opportunity can be found in many areas of model train building. The key is to pinpoint the areas where the largest customization typically takes place in modeling and focus on that specific area. The concept development process for this study will focus on the idea of selecting individual parts to create a final product. The final product will need to be customizable and scalable to match the needs of the consumer and to fulfill the requirements of this study. The models developed in this study are intended to illustrate the theory presented in this study.

Customization

Mass production is not ideal for customized products mainly due to the large number of design possibilities and materials required to manufacture each product. To understand this better we will need to develop a customization Punnett Square. Reginald C. Punnett developed the diagram known as the Punnett square to help biologists determine genetic probabilities of offspring. In this study the Punnett square will list all possibilities of products that can be created from a set number of parts. The user will be provided a number of options to select to create their customized design. The Punnett square will grow as more options or selections are added. This study will be limited to three options with three selections for each option, but it can be as large or small as the designer wishes. To understand the square better, we need to know the number of selections required, along with the number of choices for each selection. Figure 42 requires two selections to be made to complete the product. The chart uses generic variables that correlate to a specific part. Each selection has three options available, making this a 3x3 square. We need to multiply the square in order to find the total number of unique designs available. In this instance 3x3 = 9; therefore, we will have nine unique designs. For this example we will use generic variables to demonstrate the final outcome of a custom product.

		Selection 1 Front Options		
		A	**B**	**C**
Selection 2 Rear Options	**1**	A,1	B,1	C,1
	2	A,2	B,2	C,2
	3	A,3	B,3	C,3

FIGURE 42: Two Option Punnett Square

The Punnett square can be modified to have more than two selections resulting in a larger possible outcome. A 3x3x3 matrix would create 27 unique designs that would allow the consumer to select their own customized design. This study will be limited to a 3x3x3 concept to help simplify the design process. Figure 43 allows the consumer to choose the front or rear selection as desired, but they will be prompted to choose the Accessory selection only after the front selection has been chosen. The first step in making a selection would be to choose the “Front” selection: A, B, or C. The second step would be to choose the “Accessory” selection: 1, 2, or 3. The final step the user would need to select the “Rear” selection: i, ii, iii. If at any time “Selection 1” is changed, then “Selection 2” will require a change as well.

Selection 1 Front Options		A			B			C		
Selection 2 Accessories		1	2	3	1	2	3	1	2	3
Selection 3 Rear Options	i	A, 1, i	A, 2, i	A, 3, i	B, 1, i	B, 2, i	B, 3, i	C, 1, i	C, 2, i	C, 3, i
	ii	A, 1, ii	A, 2, ii	A, 3, ii	B, 1, ii	B, 2, ii	B, 3, ii	C, 1, ii	C, 2, ii	C, 3, ii
	iii	A, 1, iii	A, 2, iii	A, 3, iii	B, 1, iii	B, 2, iii	B, 3, iii	C, 1, iii	C, 2, iii	C, 3, iii

FIGURE 43: Modified Punnett Square Requiring Three Selections

Selection 1 Front Options		A			B			C		
Selection 2 Accessories		1	2	3	1	2	3	1	2	3
Selection 3 Rear Options	i	A, 1, i	A, 2, i	A, 3, i	B, 1, i	B, 2, i	B, 3, i	C, 1, i	C, 2, i	C, 3, i
	ii	A, 1, ii	A, 2, ii	A, 3, ii	B, 1, ii	B, 2, ii	B, 3, ii	C, 1, ii	C, 2, ii	C, 3, ii
	iii	A, 1, iii	A, 2, iii	A, 3, iii	B, 1, iii	B, 2, iii	B, 3, iii	C, 1, iii	C, 2, iii	C, 3, iii

FIGURE 44: Modified Punnett Square Showing C, 3, ii Selected

Nine individual parts are required for a 3x3x3 matrix to work correctly. Each part must be modular and interchangeable with other parts in the set. The entire theory of customized designs will fail if even one part is designed without this goal in mind. The problem with adding multiple selections to a Punnett square is that the options start relying on previous selections as they do in a hierarchy chart. The hierarchy chart example in Figure 45 demonstrates a process where options are narrowed down to create a finalized product. The hierarchy chart and the Punnett square accomplish the same goal and will produce the same outcome. Unfortunately the hierarchy chart and Punnett square methods become cumbersome as more than two selections are required. These two methods do not work as efficiently if options are chosen in a random order.

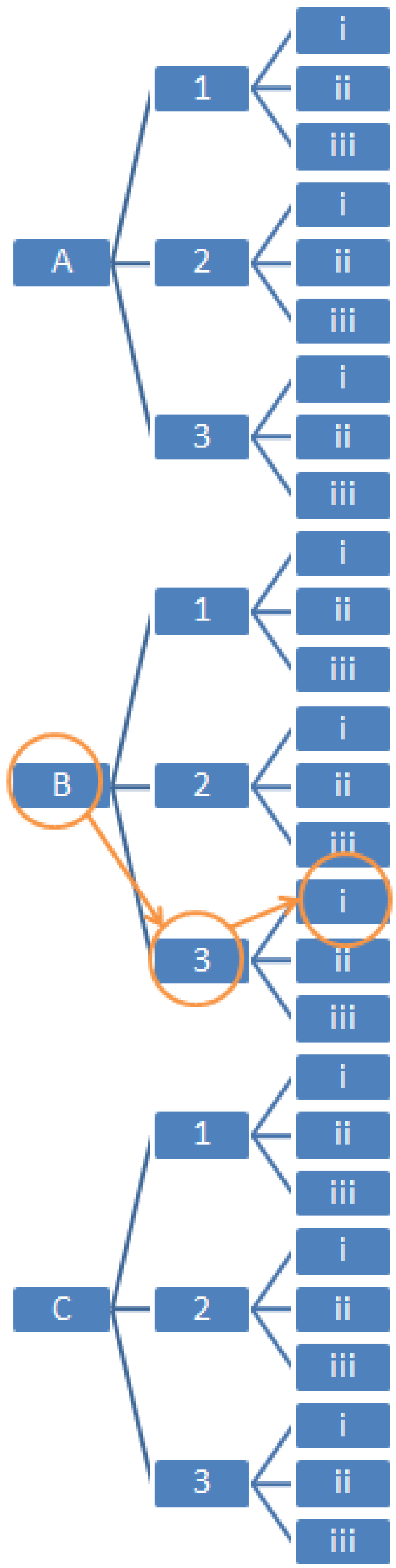


FIGURE 45: Customization Hierarchy Chart with B, 3, i Selected

The hierarchy chart in Figure 45 has the same number of components as the previous square example, but the user must make their selections from left to right. This is known as a parent and child relationship. This relationship is important if one option is not available or will only work with one specific design. The chart demonstrates a one direction process where option B, 3, i has been chosen. If the user changes their mind and decides to change to option C, the entire selection process must be restarted. This chart forces the user to make selection A, B, C first, 1, 2, 3 second, and finally i, ii, iii. To prevent a funnel effect when selecting options, the consumer needs to have freedom to change a selection without it affecting other selections. Figure 46 is a simplified variation of the Punnett square and hierarchy list that will be implemented later in the study to help make the selection process easier for the consumer.

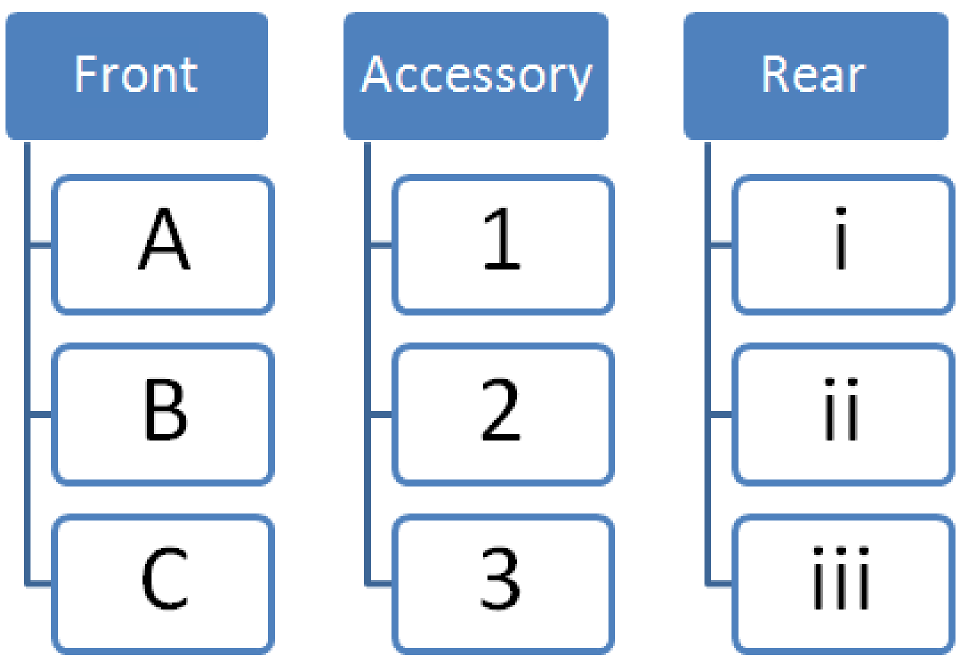


FIGURE 46: Modular Customization Selection List

Product Concepts

Concept sketches will be used to provide direction for customized parts that will be developed for this study. The sketches in this section are modular train locomotive parts that will be used to create a final product. The concepts developed in this section will correspond with a specific square in Figure 46. There will be nine individual designs created; of which three will be locomotive front sections, three accessories, and three rear locomotive sections. In this phase the designer will need to consider characteristics of each part that will be affected as other parts are changed.

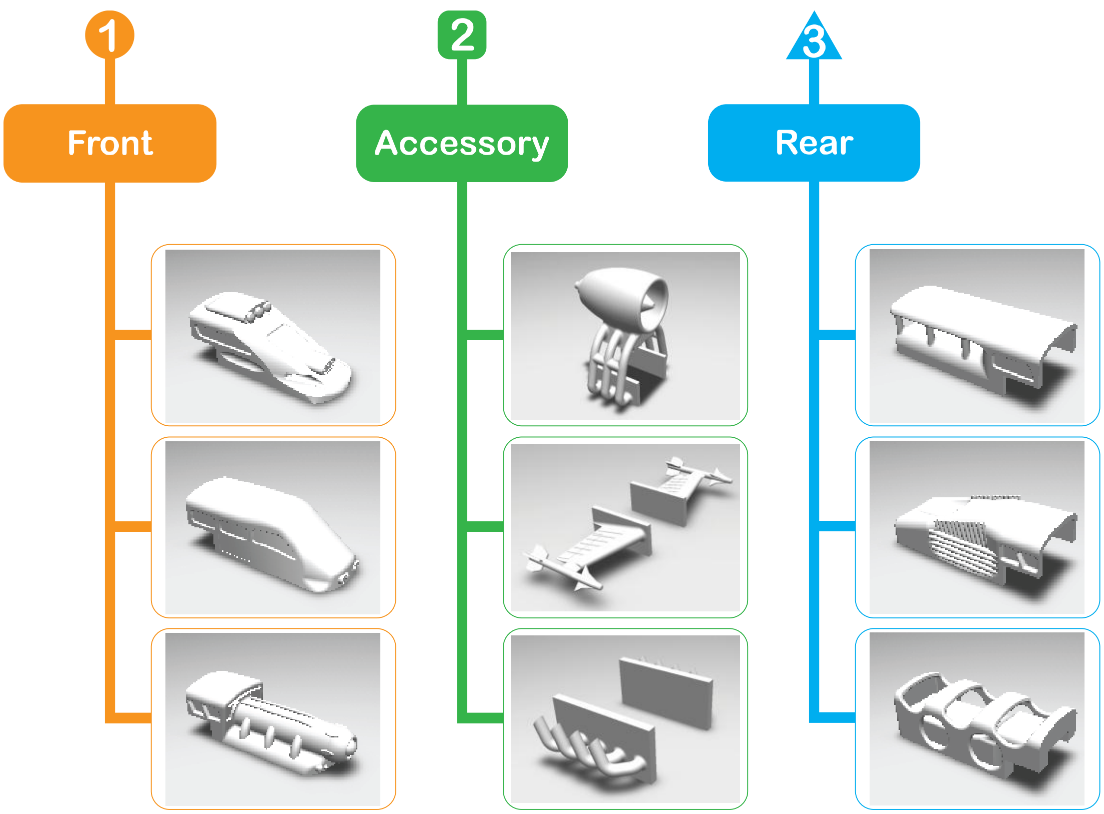


FIGURE 47: Locomotive Concept Images

The conceptualization in this phase of development is critical and will determine the outcome of the final product. The concept sketches have been designed with a selection of critical elements that are mandatory for the train locomotive chosen for the study. Each component will be required to mate correctly to each part it interacts with, without jeopardizing any other configuration. The most critical area of the design for this prototype is the mating surface between the front section and rear section. The accessory will also be an important consideration in the design. The accessory will be adaptive and will change as different selections are made for the front and rear.

Computer Models

The computer model section is dedicated to developing the computer models needed to print finalized concepts on the 3D printer. SolidWorks is the 3D modeling software that will be used for this study. SolidWorks is capable of calculating material weights, densities, volumes, areas, and many other specifications that will be useful to the designer as he or she develops parts. Computer modeling is a critical portion of the design phase because it can pinpoint any issues with the design or assembly of parts. Once the nine major parts are designed, a design table will be created to generate each of the 27 unique designs. The designer will then be able to see each configuration and make adjustments as needed to fine-tune the individual parts. SolidWorks is also capable of rendering the final models to help provide the designer and consumer with a 3D image of what the part will look like once finished. Upon approval of the final designs, 27 *.STL files will be created from the single SolidWorks file. The *.STL files can later be imported into MakerBot's MakerWare software.

FIGURE 48: Nine Individual Locomotive Parts

The computer models have been developed using SolidWorks 2013. Each model has been designed with care to ensure the critical design element is cohesive between all components. The nine computer models have been tested and confirmed with the use of a customization chart.

Customization Chart

The customization chart is designed to ensure the Gestalt of the product has been considered and that each part complements the next and the whole. The designer must layout each variation into a chart to guarantee that each of the 27 concepts will produce a quality result.

The designer will insert the final computer image of each variation into a chart as a visual reference. Figure 49 is an example of this method using the modified Punnett Square with the nine individual parts to create the 27 unique variations. The designer should use the modified Punnett Square over the hierarchy chart for this step because the hierarchy chart will only show individual parts, whereas the modified Punnett square will show the final image of each product.

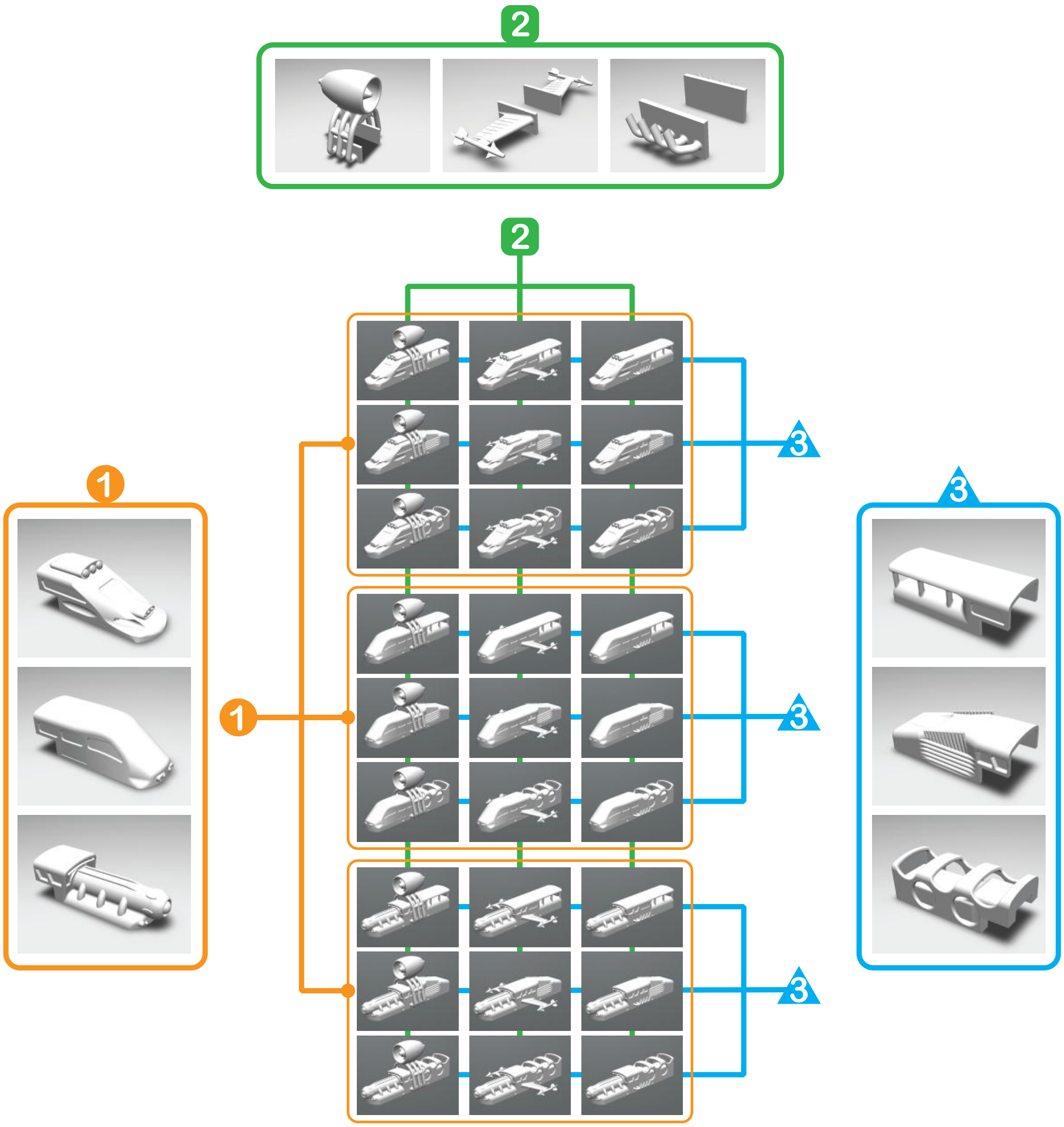


FIGURE 49: Customization Chart using the Modified Punnett Square

Selling Final Product

We can assume that there are two types of people who would be interested in 3D printed products. We can break them down into two very simple categories, those with 3D printers and those without. The people with 3D printers can be broken down into hobbyists and entrepreneurs. The statistics previously shown in this study proves that of the 300 million people in the United States in 2010, only 40,800 were professional designers. The information suggests that there is a large portion of the population that does not have a need or the skill set to own a 3D printer but still may desire the ability to easily purchase on-demand parts. This study will ensure that all 300 million people are capable of purchasing parts easily and on-demand. This study will allow anyone with or without a computer or 3D printer the opportunity to purchase these 3D printed parts no matter their skill level. However, when we discuss selling a product, we do not necessarily suggest a physical 3D printed part. In this study we have three solutions for selling the final product.

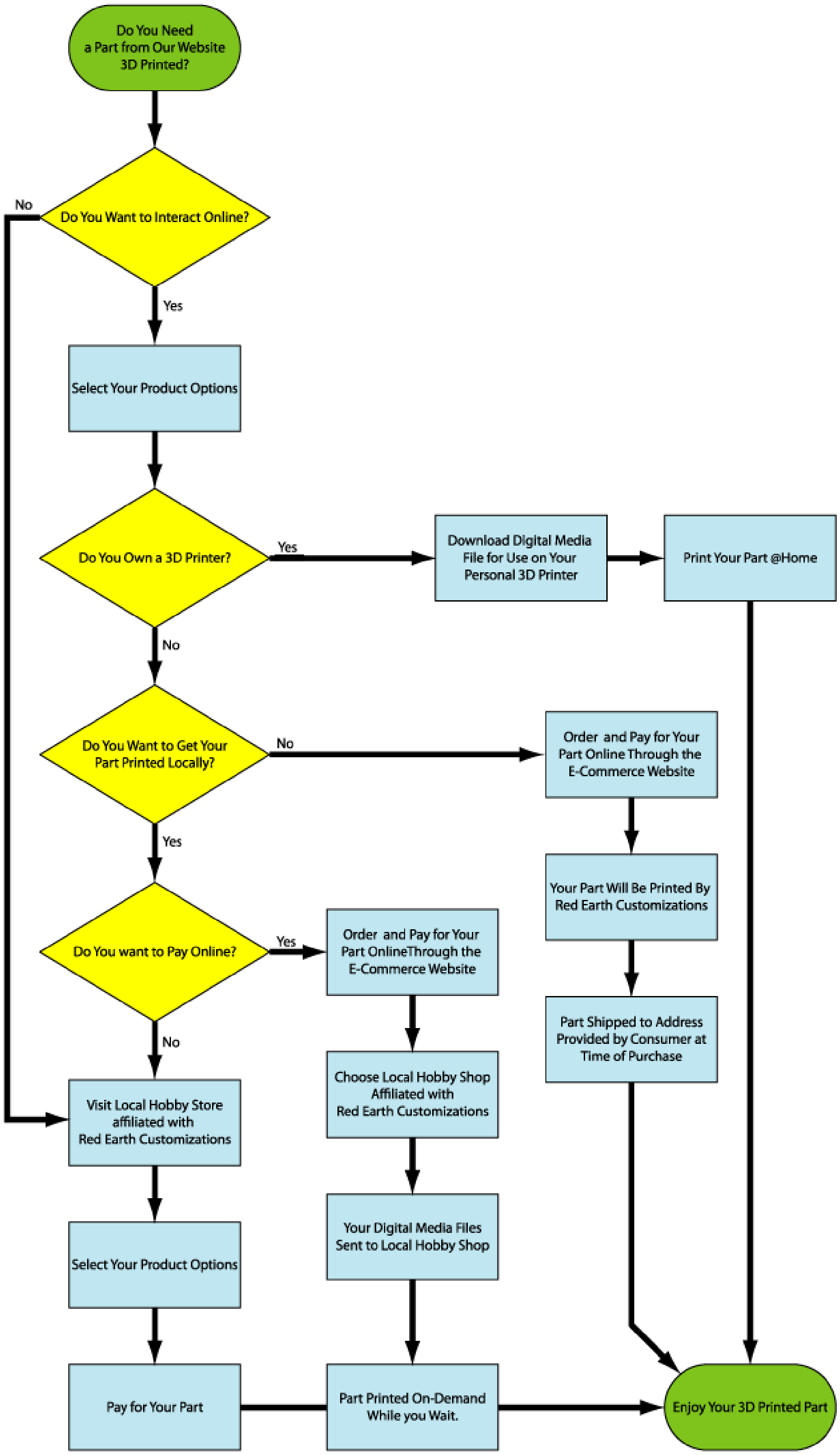


FIGURE 50: Business Model Flow Chart Structure

Selling Physical Products to Consumers

The original method of selling physical parts to consumers is the most common and understood. For the purposes of this study, this method of sales starts with the consumer visiting the Red Earth Customizations website, choosing the product they want, and purchasing it. In return, Red Earth Customizations will take the order, print the design, and mail it to the consumer. Red Earth Customizations will charge for material and labor costs associated with this method.

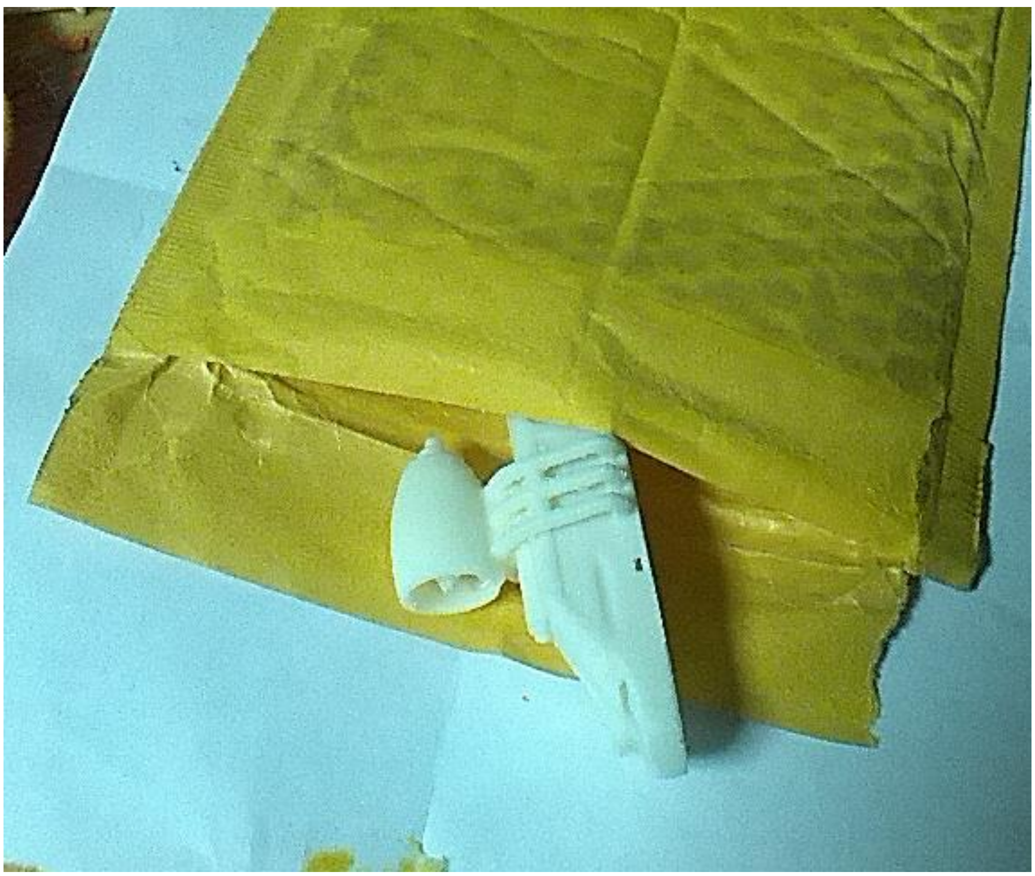


FIGURE 51: Physical Product Being Shipped

Selling Digital Files to Consumers Worldwide

A variation of the above method is designed to target the at-home hobbyists who own their own 3D printer. In this instance the consumer will visit the Red Earth Customizations website. They will go through the product selection process and confirm and pay for their design. A digital file will then be provided to the consumer to download. The file will have a single user license that can only be used on one machine. The file will not work on other machines if the consumer tries to sell the file or gives it to someone else. This method of sales is preferred due to the lack of manufacturing labor involved in the process. Apple iTunes has been successful in this approach of selling digital music and video files. Record companies are able to reduce material costs and retail costs by using digital files rather than compact discs. The same method of savings can be applied to this study for the use of 3D printed parts. The designer is capable of selling the digital files multiple times and to multiple users without the need for investing in materials.

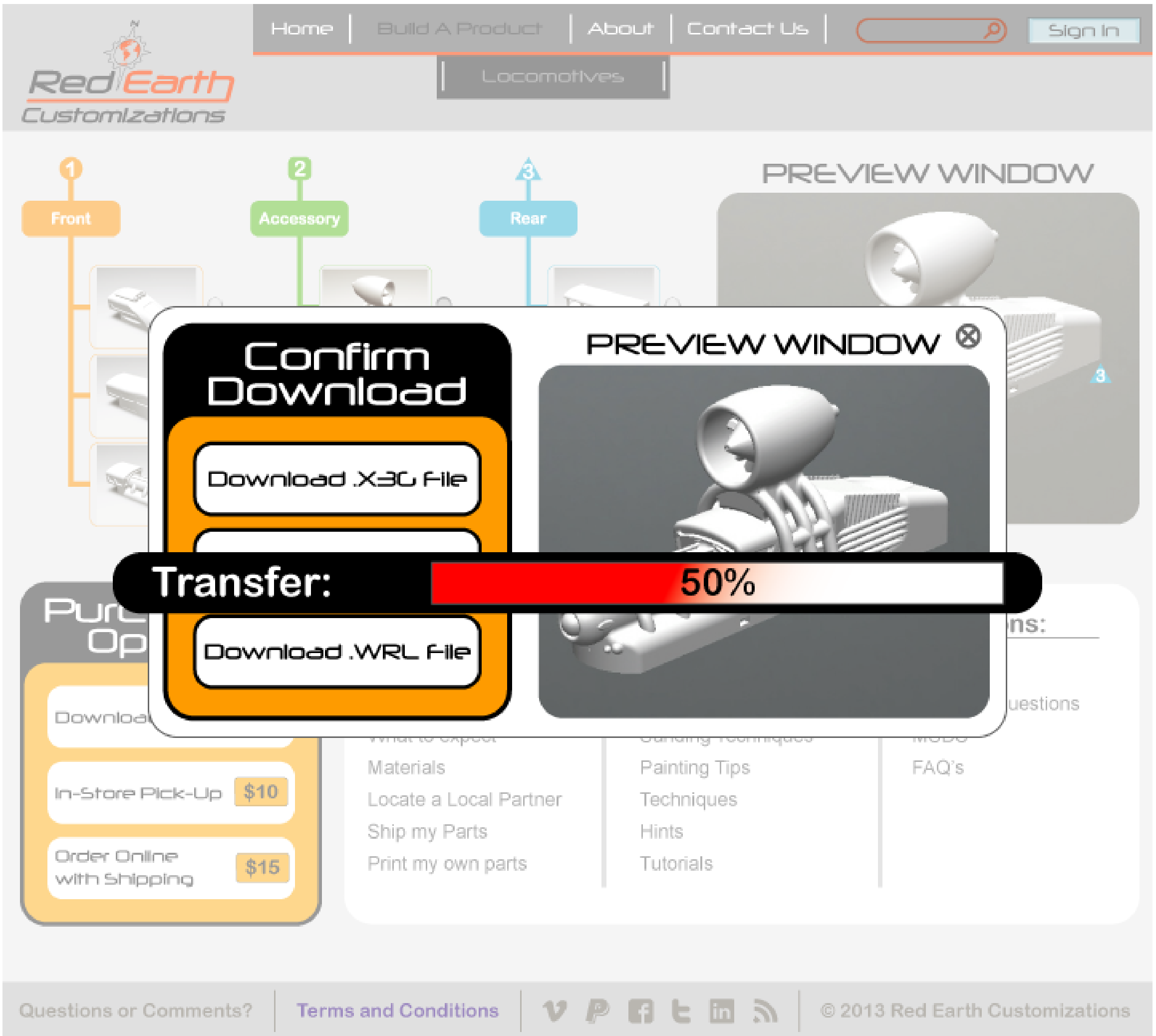


FIGURE 52: Digital File Purchase

Selling Digital Files to Small Businesses Worldwide

An alternate solution to selling digital files is to set up a franchise of small on-demand factories that are dedicated to printing 3D parts. Hobby stores who adopted this concept could purchase popular files and have them printed in house multiple times. The business would be capable of purchasing a license to use the files on multiple 3D printers at one time. The digital files are the property of the store, but shall not to be sold to consumers. Each store would be capable of printing and supplying specific parts for their region without stocking shelves with products that may not sell. Consumers would visit their local hobby store, choose a design from a library of parts and purchase the selected design. The customer would be able to observe their part as it is being manufactured on-demand directly in front of them.

FIGURE 53: Hobby Store 3D Printing

Summary of Chapter

Chapter three is the developmental phase of creating a process for customizing products that can be created with rapid prototyping technologies. The process is designed to provide a guideline to designers to help them design products that can become unique customized parts. The development started with a method of arranging nine individual parts to create a set of 27 unique design concepts. Various flow chart options are provided to the designer to help them design a customized product. A set of nine individual parts was developed once the process was determined. Below is a product lifecycle flow chart that iterates that each product can be continuously updated.

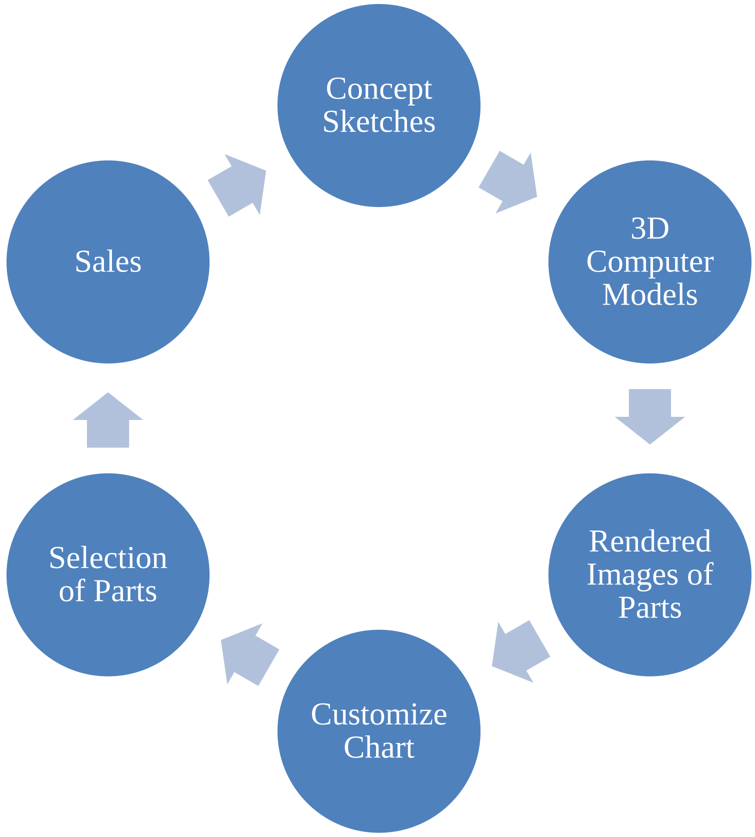


FIGURE 54: Product Development Life Cycle

The development process began with a series of sketches, followed by 3D models created in SolidWorks. The models were rendered and inserted into a customization chart to show the 27 possible variations of products available to the consumer. The customization chart is used to allow the consumer to select the product options they desire, followed by the purchase of the parts. The life cycle will start over as new parts are conceptualized and inserted into the product lineup. Equally as important to the development of the product is the method of selling the product. Three business strategies for selling the products are introduced in this chapter with the strongest recommendation in digital file manufacturing.

CHAPTER FOUR

APPLICATION OF PROCESS

Overview

It is critical to understand all elements of the design phase and how each will affect the final product. There are many variables that can affect the quality of the final product as well as cost. This chapter will focus on the development of a final product and branding the product line.

3D Personal Printer

The 3D printer being used for this study is an experimental MakerBot Replicator 2X. The printer was chosen for its entry-level pricing and high quality. The Replicator 2X is a dual extruder system capable of printing two colors during a single printing process. MakerBot is currently selling the Replicator 2X for $2,799 through their E-commerce website.

FIGURE 55: MakerBot Replicator 2X – Experimental 3D Printer (MakerBot)

Materials

MakerBot offers a range of materials and colors of plastic filament that can be used in their Replicator 2X. The printer is capable of printing Acrylonitrile Butadiene Styrene (ABS), Polylactic Acid **(**PLA), and Polyvinyl Alcohol (PVA). ABS and PLA come in an ever-growing assortment of colors, while PVA is only offered in a natural color. ABS and PLA are common thermoplastics, meaning they become soft when heated and can be formed into various shapes to create a final product. ABS is known for its impact resistance and strength and is used in many durable products. PLA is a material that is created from renewable resources such as cornstarch and sugar cane, resulting in a more ecofriendly product. PVA is a water-soluble material that provides support to the part as it is printing. The material can easily be removed from the part when water is introduced to the part. The materials are typically sold in 1kg (2.204lb) spools and come in various diameters. The Replicator 2X uses a 1.75mm filament that is offered in numerous color options.

FIGURE 56: MakerBot - Roll of Blue Plastic Filament (MakerBot)

FIGURE 57: MakerBot - Roll of Natural Plastic Filament (MakerBot)

Material Cost

Material properties and cost are important factors that need to be considered when printing parts that will be sold to consumers. ABS and PLA prices on MakerBot's website range from $43 for natural filament without colors, $48 for standard colors, $55 for neon colors, and $90 for glow in the dark filament. MakerBot currently offers 27 colors in ABS and 7 colors in PLA, with the promise of more to come in the near future. However, parts printed on the 3D printer will only use a fraction of material that is on a roll. To calculate the cost of material accurately, we need to break the cost down further. If we assume the final product will be painted, then we can use natural PLA or ABS for this application. To determine an accurate cost of material we need to find a smaller unit of measure that is more suitable for calculating these types of parts. The industry standard for 3D printed parts is the cubic inch and will be ideal for our application. To obtain the volume of material being used, we need to understand that 1kg of ABS is equal to 58 cubic inches while 1kg of PLA is equal to 48 cubic inches of material (Team Bastech). Figure 58 shows that ABS is 21.6% cheaper to print than PLA. For this reason, this study will use ABS for its significant cost savings and durability.

ABS	PLA
1 Spool = 1kg (58in^3) = $43	1 Spool = 1kg (48 in^3) = $43
$43 / 58in^3 = **$0.74 per in^3**	$43 / 48in^3 = **$0.90 per in^3**

FIGURE 58: Material Cost per in^3

MakerWare

The Replicator 2X is capable of printing a wide range of parts and is only limited by the user's imagination. The process of printing a part on the 3D printer requires the translation of a solid model into a numerically controlled language known as G-code. This code can be created using various types of software that can be acquired on the Internet. The G-code is populated when a computer model is inserted into the program. The software will slice the model into layers that correlate to the height of the print layer defined by the software. MakerWare is proprietary slicing software developed by MakerBot for exclusive use with their printers and is the software that will be used for this study. The software has an easy-to use layout that allows the user to determine which extruder will be used, what material will be used, and the size and placement of the product on the print bed.

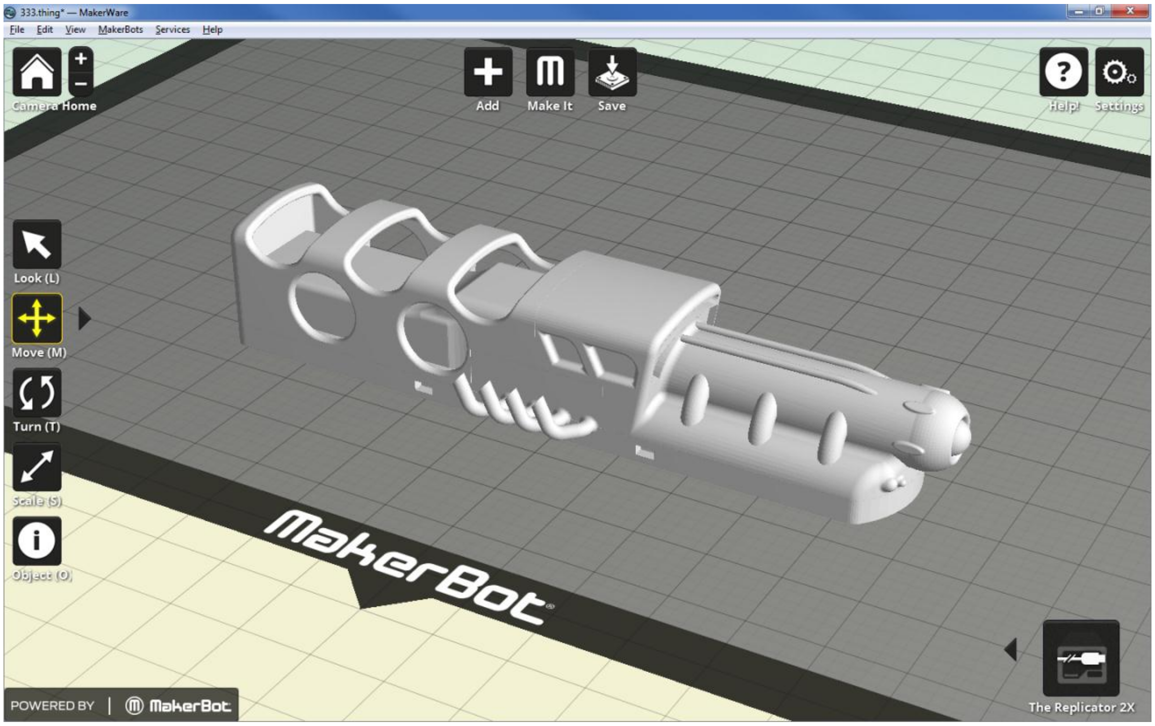


FIGURE 59: MakerWare Software

MakerWare will output the G-Code into a file format (*.x3g) that can be saved onto an SD external media drive. The Replicator 2X will read the file and run through a series of prompts. Once the operator has confirmed the build in the machine, the printer will start extruding material to create the final product.

Slicing

There are a few variables that are adjustable when 3D printing. Quality is determined by layer resolution, infill percentage, number of shells, and the layer height. The infill is the core of the part and determines how much support is inside the part. The 3D printer is capable of printing solid parts as well as hollow parts. Hollow parts are less structural, but take less time and material to build. More infill means that the part will be stronger and cost more, but will be more structural. Less infill means the part will have less internal structure, cost less, and will be ideal for appearance models. The numbers of shells also help determine the strength of the part. Shells are printed only along the perimeter of the part and increase part strength as the shells increase. Layer height is the most critical variable when trying to make a high quality part. The part becomes more defined as the layer height gets smaller, but the time and cost rise significantly per print cycle (MakerBot). This study will use the predefined medium setting as seen in the MakerWare image in Figure 60.

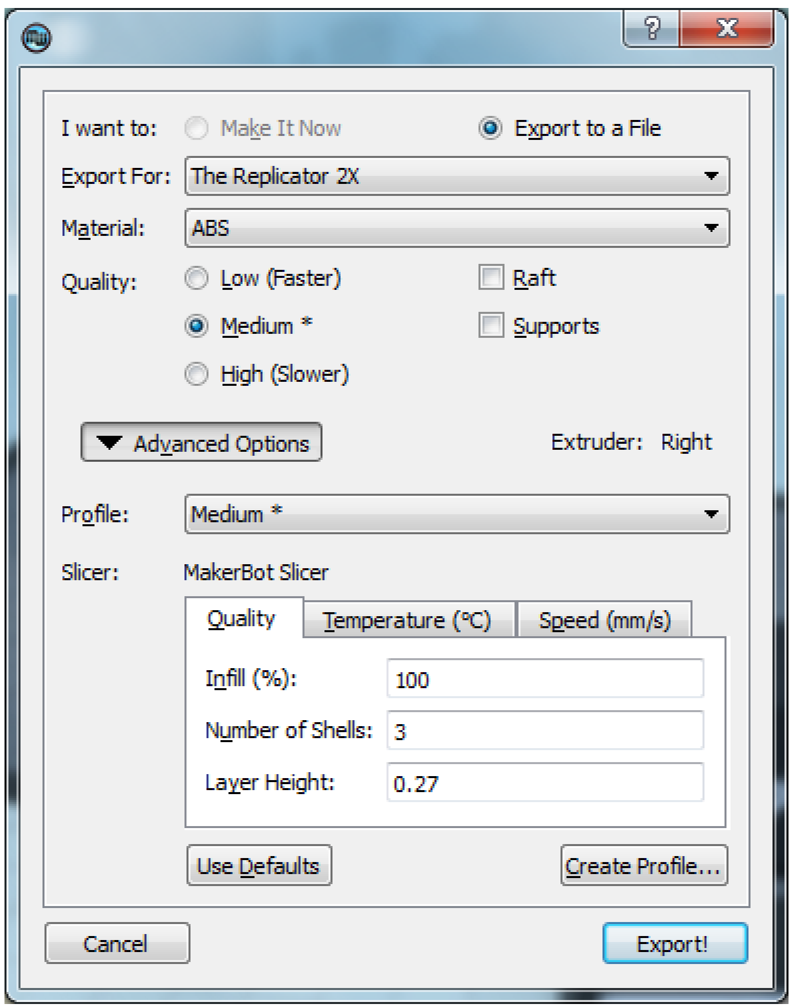


FIGURE 60: MakerWare Slicing Settings

Printing

The design of each part will be printed in this phase of the study to determine if any changes need to be made to the final product. The first printed parts will be non-painted prototype parts and may be identical to the final printed part if nothing requires a change. Quality will be reviewed during this phase, while confirming fit and finish before the design is finalized.

Prototype Parts

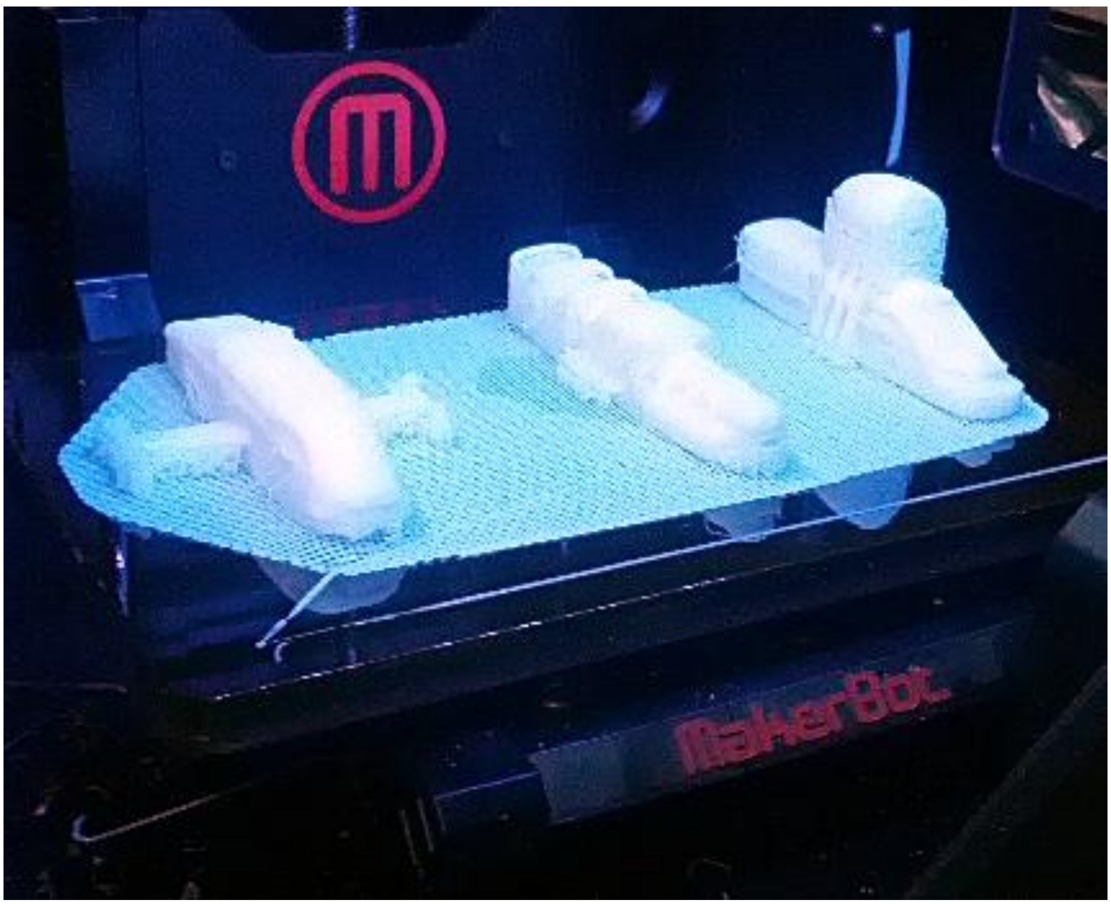


FIGURE 61: 3D printed Prototype Parts with Raft and Support Material

Final Product

The final product for this study is the part that is ready to be sent to the consumer. The part will be acquired in its raw form, meaning that the part will be unpainted. The hobby industry is known for their passion for creating products that they had a hand in creating. The consumer will have a greater attachment to the 3D printed part if they are able to paint the part to match their requirements. The image in Figure 62 displays the final product in the raw form, while Figure 63 illustrates the final painted product.

FIGURE 62: Image of Unpainted Locomotive Parts

FIGURE 63: Three Painted 3D Printed Locomotives Utilizing All Nine Components

Branding

Branding is a critical element to any design. The name of a company must be unique and it often helps if there is meaning to the name. A company logo can be beneficial to help promote a product and create brand awareness for those products. This section will be dedicated to creating a limited brand identity for the set of 3D printed parts developed in the previous sections. The scope of this study will only include the branding of the Red Earth Customizations Logo and a mock website design.

Company Name

The company name chosen for this study is Red Earth Customizations. The company name has a deeper meaning to the author than it may appear on the surface. To break the name down further we can discover that Red was derived from the Hebrew meaning of Adam. Earth is derived from the Adam in the Old Testament and is also a play on words in Hebrew of adamah, meaning Earth. Therefore, Red Earth Customizations can essentially be defined as Adam's Customizations. A logo is often the next phase of branding that follows the creation of the name. The logo will be designed to help strengthen the brand and provide an identity for the company.

Company Logo

With the name Red Earth Customizations chosen for the company, a logo concept needs to be developed. The font chosen for the text is Neuropol, which has been modified slightly to maximize the best results. An icon for Red Earth Customizations should be chosen carefully to help support the product being sold by the company, while defining the characteristics of the company. The logo development for this logo started with a map of the western hemisphere of Earth derived from the company name. Secondly, a gear was used because it is a mechanical part that can be seen as a symbol of functional innovation throughout history. The last element to the logo design is the compass rose, which is often associated with navigation and pioneering new endeavors.

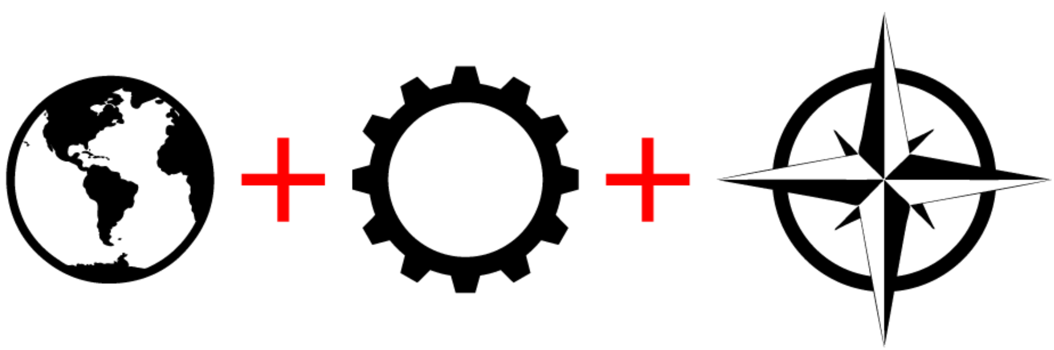


FIGURE 64: Logo Development

FIGURE 65: Logo Design

Mock Website Development

A website is needed to allow the consumer to make each selection needed to develop their own unique product. An intuitive interface should be developed to help the user make selections. The interface should have images of each individual part available for the product. The results of selecting a specific part should be shown instantly in a real-time visual interface. At any precise moment the user can see their product as it would be 3D printed and shipped to their door.

Figure 66 demonstrates the suggested method of laying out a selectable chart with each of the nine options. The options can be chosen in any order and does not funnel the user into a specific direction. The figure shows that a user can change any selection during the customization process without having to restart the selection process.

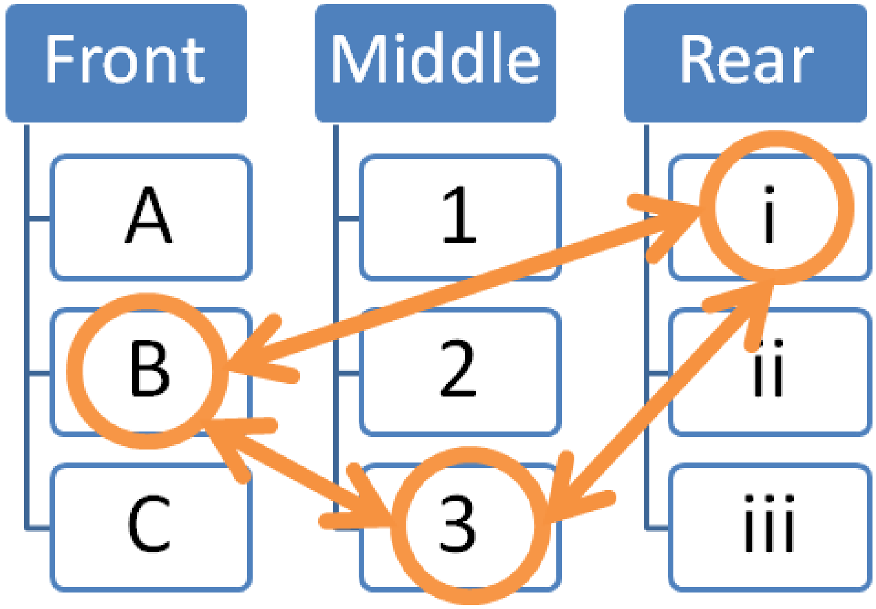


FIGURE 66: Options Selected B,3,i

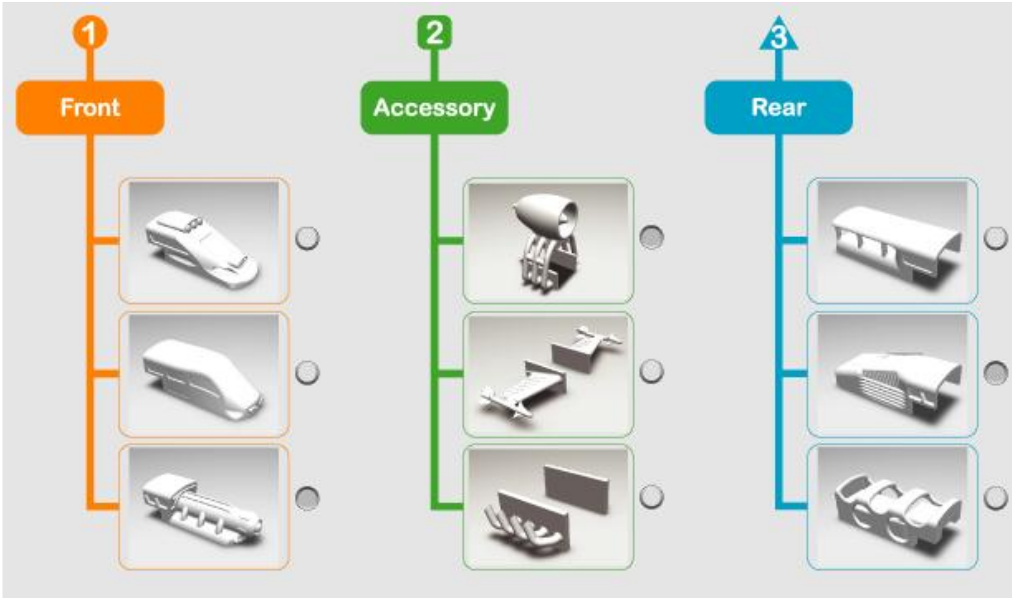


FIGURE 67: Website Screenshot of Product Selection Process

FIGURE 68: Website Screenshot of Real Time Display

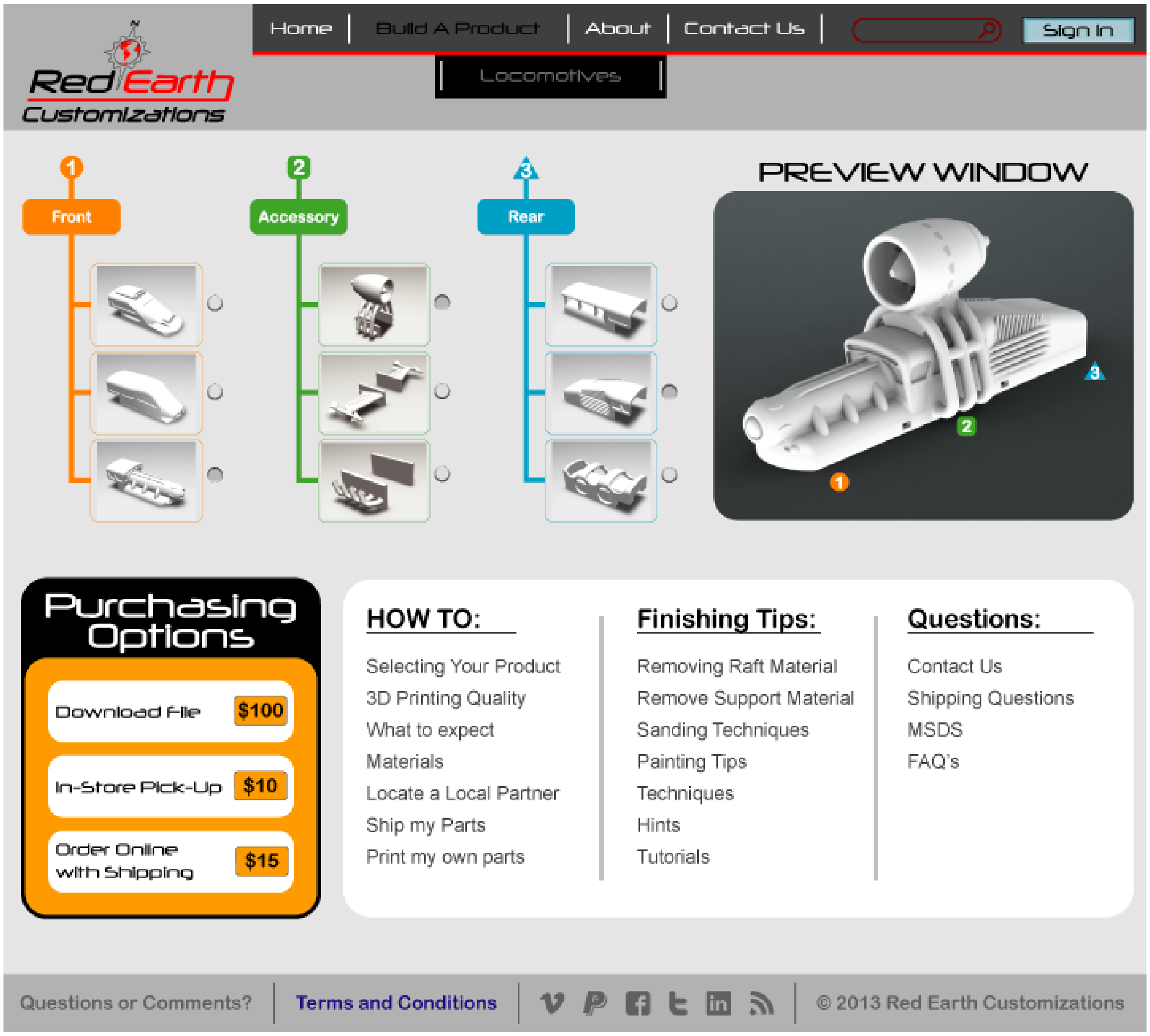


FIGURE 69: Website Screenshot of Finalized Product Chosen

Summary of Chapter

Chapter four introduces the MakerBot Replicator 2X personal 3D printer and the items needed to make the printer operational. The printer is an additive manufacturing machine that extrudes plastic material to make a part. Materials are an important consideration when developing 3D printed parts. Acrylonitrile butadiene styrene (ABS) was chosen as the primary material due to its durability and affordable cost of $0.74 per in^3. The chapter discusses the use of MakerBot's special software, MakerWare, for preparing files to print. MakerWare uses a slicing effect to create special code, G-Code, that can be read by the Replicator 2X.

Chapter four goes on to use the information gathered from the previous sections to develop a set of prototype parts. The parts are then studied to correct any issues in the printing process. After the prototype designs were approved, the final products were printed and painted. As the chapter progresses, the focus is shifted toward brand identity. A company name, logo, and website are designed to sell the final product.

CHAPTER FIVE

CONCLUSIONS

Summary of Study

The study of digital file manufacturing started with a goal of introducing rapid prototyping and customization into a world of consumer products. Customization is the future of new products, and 3D printers are the future of manufacturing. A process was created in the study to help designers plan for the future of 3D printing. The term on-demand is a very important concept for this study. On-demand manufacturing represents a new direction in product development where the consumer requires a product immediately rather than waiting.

The information in this study was collected and documented using photographs, charts, and graphs. The study is designed to be a guideline for developing digital manufacturing files, while also creating a process for starting an on-demand manufacturing company.

Chapter one is the introduction to the study that informs the reader that consumers desire to be different and stand out above their peers. Customization has been the answer for years, but there are limitations. Traditional manufacturing is not conducive to customization and can limit product innovation. The study stresses the need for new products and is the basis for the research.

Chapter one includes definitions for key terms, as well as the literature review defining the need for the study through factual evidence.

Chapter two is the culmination of design research that takes a funnel approach to narrow the scope of the project into a pinpoint direction for the study. The study begins with the invention of interchangeable parts and transitions into customization. Examples of customization are included in the study with supporting evidence of each company growing. The study begins narrowing down to digital manufacturing and the use of rapid prototyping machines and 3D printers. The heart of the chapter becomes apparent with the introduction of the hobby industry and the opportunity in railroad modeling. The rest of the chapter is dedicated to confirming the need and potential success in model railroading for this study.

Chapter three is dedicated to developing a process through the use of a concept design. The study uses modeling a customized locomotive as the center for the design. An introduction to the Punnett square and a hierarchy chart detail methods of developing the design, while also showing the problems with each. A modular customization selection list is created as a variation of the Punnett square and the hierarchy chart. Sketches are then used to develop concepts to create customizable parts that can be developed on the 3D printer. The sketches are then translated into three dimensional computer models that can be manipulated and studied in further detail. A modified Punnett Square is used in product development to allow each design variation to be considered while designing the final product. Chapter three is concluded with three directions that are detailed in this chapter for a designer to sell their customized products to consumers globally.

Chapter four discusses many of the tools and materials that will be used in the study to fabricate the final parts along with the development of the product. The product is a modular model locomotive for the model railroading industry. The locomotive has nine individual parts that create a set of 27 unique combinations of locomotives.

Recommendations for Further Studies

Future designs will vary as new technology grows and becomes more reasonably priced. Technology is a fast moving industry and will change the outcome of this study over time. As time progresses, the results of study should evolve and encompass new technology to remain innovative. Implementation of this process into hobby stores would provide useful results for a future study and would provide important test data to prove the study is beneficial. Alternate studies would be beneficial to reinforce the concept of on-demand manufacturing. Open source information and data are constantly changing the way technology is approached and can easily make all intellectual property unprotected from at home part replicating. Stealing intellectual property is also known as pirating and became popular when Napster, a peer-to-peer file sharing service, violated copyright laws. The same problems Napster faced in 2000 will be evident in any digital files if precautions are not taken. It is recommended that on-demand manufacturers instill ethics in their product development to ensure intellectual property remains safe. A guideline for on-demand manufacturing should be developed to make each manufacturer or 3D printer owner accountable for anything they fabricate. Accountability is not only limited to pirating products or digital files, but is also critical to ensure that liability for any damages a product may cause is accounted for by the manufacturer. The accountability will ensure that manufacturers make quality products that are safe for consumers.

Manufacturers who are capable of replicating iconic products at home no longer need designers and engineers to make consumer products. 3D printers are currently experiencing large growth in the technology industry. This effect is causing the market to be flooded with open source product designs. A large fear with open source product design is the quality of part. A seven-year-old child can design a car steering wheel and offer the downloadable file online for free. Unfortunately the person downloading the file does not know if an engineer or a child designed the file. This will create liability issues in the industry, causing products to ultimately suffer. A new study needs to be created as the growth becomes less unstable and regulations are implemented on open source products.

Synopsis

This thesis is intended to create a process to help designers embrace the future of technology. The study also offers a set of guidelines for designers to develop unique modular concepts that can be printed on 3D printers. Manufacturing methods may change as technology advances, but the processes listed in this study should remain similar.

This study offers designers an innovative solution for new technology advancements and will hopefully allow them to develop innovative products for the future. Solutions are provided to help designers conceptualize customizable products, while also laying out a business strategy for selling final products. The outcome of this study is a set of 27 unique N-Scale locomotive train bodies that were created using the process and guidelines set forth in this study. The outcome of this study provides designers with three business models for selling customizable products. Businesses who prefer not to design products have the option of downloading digital files that will allow the company to manufacture products with minimal overhead costs. To prove this theory a set of 27 unique N-Scale locomotive train bodies were created using the process and guidelines set forth in this study. The final customizable locomotive will be sold on Red Earth Customizations mock e-commerce website, but it is only a small portion of this study.

The study proves the concept of customized products through digital manufacturing is a plausible alternative to traditional manufacturing methods. Customized products will provide consumers with a plethora of options so they can be different than the next person on the street. On-demand manufacturing will help develop the future of customization and can potentially revolutionize manufacturing the world over. This study will help carry customizable on-demand manufacturing into fruition, and will also allow the 300 million people in the United States with the ability to purchase on-demand parts. The study accounts for consumers with and without 3D printers, and provides three directions that can evolve manufacturing into a more personal experience.

Findings

The findings of this study show that on-demand at home 3D printer technology still has major improvements that need to be addressed before quality products can be sold to consumers. With current FDM style printing there are two major factors that determine the cost and overall success of the final product. The two major factors that are critical to the development are the time that it takes to build the product and the resolution quality of the product. As the resolution quality of the product increases, so does the time it takes to build the product, thus increasing cost. As 3D printer technology improves and is developed further, quality will increase, time to build the product will decrease, thereby, resulting in a lower cost to build each product. This trend will only make on-demand manufacturing grow and become more desirable as time progresses.

This study illustrates that customization is a critical aspect of new product development and will become more evident as time progresses. New product development strategies should evolve as manufacturing methods grow and become more versatile. Designers who are focused on the Gestalt of a product can develop numerous products using minimal parts and labor to do so. This study defines a process that can help the future of product design evolve with technology by using an example of a model train. Twenty-seven unique model locomotives were developed in this study using only nine individual parts and the process outlined throughout this study.

3D printer technology may not become prevalent and may not be practical in every home in the near future, but the possibility that a consumer will be able to purchase a 3D printed part can almost be guaranteed. This study defines three critical options that would allow small businesses and large businesses the opportunity to sell customizable 3D printed parts to consumers while still providing the at home user the same luxury. President Obama stated in his 2013 State of the Union Address that 3D printing will revolutionize the future of manufacturing. He later implied that the next manufacturing revolution will arrive on the build surface of 3D printers and will be capable of displaying the coveted “Made in USA” logo.

FIGURE 70: Made in USA logo

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