Guidelines for the Design of Digitally Fabricable Products for the Intent of Digital Distribution

by

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Abstract

With the availability of low-cost 3D modeling and digital fabrication tools and software, a culture of “digital making” has emerged. With companies like Opendesk and Thingiverse providing open source resources for at-home or “do-it-yourself” furniture and other products, the consumer now has the power to create his or her own - thus limiting the need for a “middle-man.” Because digital making is relatively new, there is a lack of standardization or guidelines for digitally fabricable designs. This thesis will serve to guide and assist a designer or maker in the design of digitally fabricable products for the intention of maximizing sales or digital distribution.

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Chapter 1: Introduction

1.1 Problem Statement

Globalization and the availability of open source 3D modeling and digital fabrication tools and resources has initiated a movement towards the democratization of design. This movement, called *open design*, involves the development and creation of products through the use of open-source tools and publicly shared design information. Through open design, traditional mass manufacturing and distribution systems are eliminated, and the production of the final object is put into the hands of the final user, creating a more sustainable supply chain. Open design can be misconstrued as lacking incentive—though a design may be publicly shared and accessible, this does not indicate that a designer or maker will not be compensated for their work. Because of the availability of open source digital fabrication tools and software, there is no clear delineation between the maker-creator and the designer-creator, nor is there a regulatory body for open designs. Therefore, requisite documentation and a framework for developing and designing products that can be produced universally is essential. While individuals wishing to sell their digital files have a few choices of marketplaces where they can sell their work, these platforms tend to lack curation and quality control, allowing anyone to participate regardless of a product's veracity. Because this is a relatively new field, there are no clearly defined processes to assist the industrial designer in utilizing open design for monetization. This study will provide insight into open design and the development of digital design files for the purpose of maximizing online distribution and generating sales.

1.2 Need for Study

Technology and an increasingly interconnected world have increased the accessibility of "custom made" products from only those who can afford it to the global masses. Inexpensive and easy access to digital fabrication tools and programs has provided almost everyone the opportunity to quickly create and produce 3D models and tangible objects from their homes, makerspaces, workspaces, and more. With technological shifts changing the way people live, there is no one-size-fits-all mold for how an individual chooses to design their life. Consumers are used to customization and personalization, with marketing leveraging social media in an effort to appeal to millennials and Generation Z. The new generations are shying away from mass produced big box stores and are seeking individuality and innovation. While there are initiatives like Thingiverse and Shapeways, designers who wish to produce digital designs are unable to differentiate themselves from the hobbyists. Furthermore, because digital fabrication has gained traction in the consumer market only in the past decade, there is a lack of data and information regarding marketing, distribution, as well as the design of digitally fabricable products.

1.3 Objectives of Study

The objective for this study is to provide the designer with an approach to utilizing computer-aided-design software to design products that can be digitally fabricated and sold.

Objectives:

- Because the nature of open design is vague and relatively unestablished, it is imperative to identify what characteristics are essential for the generation of open product design.

- Research and analyze current options for like-services and parallel industries
- Research marketing for digital products and files
- Research digital fabrication processes and materials
- Research practical applications for digital fabrication
- Develop guidelines and a flowchart for an industrial designer to learn how to get started and whether they should be trying to monetize their digital design files
- Develop general guidelines for how to build products for digital distribution
- Develop a system to assist the designer in choosing what platform to use to distribute their product

1.4 Assumptions

The research and guidelines developed in this study assume that the designer or maker has some knowledge or training in design and of design principles, as well as the desire to utilize digital fabrication to design physical products and distribute them in a digital manner. It takes into consideration the current technologies and resources that are available in the digital fabrication industry. Furthermore, the assumption is made that the designer has existing knowledge of how to use 3D or 2D CAD modeling software and understands how to use the machines for fabrication, or at least knows how they work. The designer should also be aware of the capabilities and limitations of the manufacturing process that they intend to use. For CNC milling, this study assumes that the designer will be primarily working with plywood in standard sheet sizes, on a 3-axis machine.

1.5 Scope and Limitations

Because of the abundance of open-source computer-aided-design software, a digital "maker culture" has emerged, allowing users to generate and share their digital design files online for digital fabrication. This study is geared towards designers and design professionals who wish to develop and sell digital files for products that can be digitally fabricated by an end user, or sell digitally fabricated products. While there are a variety of digital fabrication methods, ranging from 3D printing to laser cutting, this thesis will focus primarily on the development of a framework that depends upon the use of more common types of digital fabrication, namely the 3D printer, laser cutting machine, and CNC router to develop and design goods. While new processes and machines are being developed and introduced, this study will only consider the ones currently available in market. Furthermore, this study does not include guidelines for creating business entities or issues related to product certifications, regulation, or liability.

1.6 Anticipated Outcomes

It is anticipated that this study will produce a guideline that will assist the designer or maker in the development of a digitally fabricable product that will be distributed in a digital manner. It should offer the designer a comprehensive understanding of how to proceed once they have decided to design a product, as well as provide them with considerations and resources to assist them on their journey.

Ch 2. Literature Review

2.0 Introduction

With the emergence of digital fabrication and the availability of computer-aided design software, online repositories for the distribution of 3D models have become more prevalent, allowing individuals to share and download digital files in just a few clicks. This literature review will serve as an introduction and background into the design of products for digital fabrication, as well as considerations including licensing and intellectual property, pricing, customization, and marketing.

2.1 DIY "Maker" Movement

The roots for the maker movement can be argued as stemming from a variety of influences—like American Puritanism, to the counterculture of the 1960s, or DIY technologists (Rosner & Fox, 2016; Turner, 2018). While craft and do-it-yourself is by no means new to the American society, most agree that the modern day maker movement originates from the creation of the first Fabrication (or "Fab") Lab at MIT by Professor Neil Gershenfeld and the introduction of *Make:* magazine by Dale Dougherty (Turner, 2018). Gershenfeld introduced the concept of a FabLab—a public space that offer users the use of digital fabrication tools—like laser cutters, 3D printers, CNC routers, microcontrollers, among other devices, as well as the opportunity and environment to learn how to use them. *Make:* magazine, on the other hand, was marketed as a movement, allowing DIY enthusiasts an opportunity to come together; as Forbes reported in 2008, "Dougherty... started drawing connections between a different set of distant dots: the profusion of powerful, cheap electronics; a deft software hacking community; crafting as

popularized by Martha Stewart; and the growing green–or recycling–rage" (Corcoran, 2008, para. 11).

Dougherty and *Make:* also coined the term "makerspace"—a term that FabLabs also fall under, essentially a workshop environment that provides "access to tools and materials, such as laser cutters, 3D printers, and micro-controllers, and where the principles of DIY cultures are facilitated by open software and hardware" (Menendez-Blanco & Bjørn, 2019, p. 471). Any environment that allows for the public use of digital fabrication and other tools will be defined under the umbrella term "makerspace".

Maker culture is defined by sharing and community, and is based on the principles of learning: hands-on creation, transdisciplinary collaboration, and sharing (O'Duinn, 2012 as cited in Troxler & Wolf, 2017).

2.2 Digital Maker-Entrepreneur

Individuals involved in the maker movement are considered to be "high-tech do-it-yourselfers, who are democratizing access to the modern means to make things" (Gershenfeld, 2012, p. 48). While digital makers are typically hobbyists, some choose to take their hobby further and turn it into a business. These individuals are called "digital maker-entrepreneurs." Wolf and Troxler (2016) indicate that these digital maker-entrepreneurs are still firmly planted in the principles of the maker culture. Their business models are influenced by openness and community, and they may share their designs for free on platforms like Thingiverse (see 2.14.1) but also sell variations on platforms like MyMiniFactory (see 2.14.2) and Etsy (see 2.14.8).

2.3 Microenterprises and Self Employment

Globalization as a result of the internet has made it possible for small businesses to reach the global masses. Microenterprises, a subset of small businesses, are those that "employ five or fewer individuals and specialize in the sale and manufacture of highly customized or personalized goods and services" (Church & Oakley, 2018, p. 884). According to the Association for Enterprise Opportunity, microbusinesses account for 92% of all U.S. businesses (2013). This growth can be attributed to the availability of specialty websites like Etsy, a marketplace for handmade and creative goods that launched in 2005. According to The Royal Society for the encouragement of Arts, Manufactures and Commerce (RSA) in the UK, these websites lower the barrier to entry for such microbusinesses by diminishing "the need for people to commit to a minimum level of business activity" (Dellot, 2014). Furthermore, these platforms also give sellers access to a large customer base, while simultaneously allowing them to cater to a niche market (Church & Oakley, 2018).

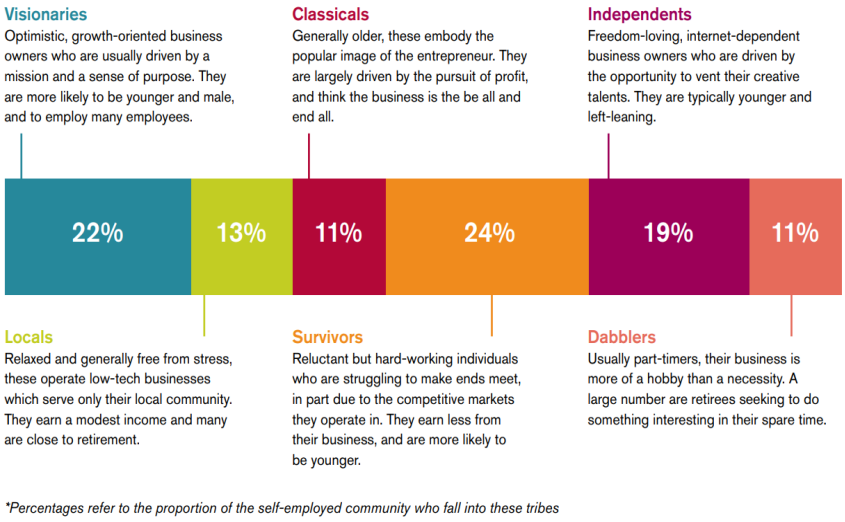

Figure 1: The six tribes of self-employment (Dellot, 2014)

2.4 Business Structures

In the United States, there are four common types of business structures: sole proprietorship, partnership, limited liability company (LLC), and corporations. Microenterprises typically operate as an "unincorporated entity"—either a sole proprietorship or general partnership. Depending on the state, locality, or industry, certain permits or licenses may be needed.

Sole proprietorships have one owner. Because they are easy to form, sole proprietorships are the most common type of business structure, and individuals have complete ownership of their business ("Sole Proprietorship", n.d.). Because there is no legal separation between an individual and his or her business, taxes are part of an individual's income statement and the owner is personally liable for debts and obligations of the business.

General partnerships are similar to sole proprietorships with the exception that they may have many partners. Partners have unlimited liability and the partnership should be formalized with a written partnership agreement.

Limited liability companies and corporations reduce an owner's personal exposure to liability but are more intensive to form. They require filing paperwork and drafting documents as well as various fees.

2.5 Digital Goods

Digital goods are "files that can be transmitted without a physical object" (Atasoy & Morewedge, 2017, p. 1343). They can be purchased online and used immediately without the need to worry about depreciation or loss. Examples of digital goods include e-books, music files, streaming media, fonts, cloud software, e-learning courses, digital subscriptions, virtual goods,

mobile apps, or digital files among others. The process through which digital goods are delivered to a consumer is called *digital distribution*. Due to their immaterial nature, digital goods are perceived as less valuable than physical possessions (Petrelli & Whittaker, 2010; Atasoy & Morewedge, 2017).

2.6 Customization and DIY

It can be said that "a closer fit between preferences and product attributes brings about increased benefits for the customer" (Franke, Keinz, & Steger, 2009, p. 104). If a customer has a clear insight into their preferences, they acquire additional benefits from customization. By participating in the creation process, the customer derives enjoyment. This can be also reflected in the case of handmade goods. Items created by individuals themselves have a high subjective value, regardless of quality of work (Franke, Schreier, & Kaiser, 2010). In fact, the designer does not need to participate in the designing process to value a product more greatly; the IKEA effect indicates that the impact of labor alone is enough to increase the customer's valuation of an object after it is made (Norton, Mochon, & Ariely, 2012).

2.7 Open Design

Open design involves the creation of physical products, machines, software, and systems though the sharing of public design information (Raasch, Herstatt, & Balka, 2009; Cruickshank, 2014). "Open design," as a term, emphasizes the democratization of the design and distribution processes, seen as a means for "alternative manufacturing or fabrication, a new way to organize and manage design, acts of prosumption or peer production, alternative material culture, and/or explorations in horizontal community organization" (Bakırlıoğlu & Kohtala, 2019, p. 390).

Examples of "openness" have been explored and documented in other fields like open-source for software development and Creative Commons for creative works. The emergence of open design can be considered to be influenced by open-source, as well as the trend towards do-it-yourself and a hacker culture. Regardless, open design suggests a "limitation-free 'design knowledge' sharing and calling for participation of people with varying backgrounds to develop and iterate design solutions" (Bakırlıoğlu & Kohtala, 2019, p. 394).

In the context of business models, digital designer makers are unconventional and not necessarily based on the traditional market economy. Those that participate in open design "includes models based on giving things away (free revealing), mass participation in design, co-creation and a range of other approaches that seek to develop new open methods of creativity" (Cruickshank, 2014, p. 23).

2.8 Intellectual Property and Attribution

The concept of collective invention was common in the 1800s, especially amongst the Cornish mining community. In collective invention settings, competitors share trade secrets with each other to help solve and improve technological designs (Nuvolari, 2004). While patents resulted in the disappearance of the collective invention, once again this notion of sharing ideas became prominent at the turn of the 21st century, in software, with "open source" in 1998. The term "open source" was formed in a strategy meeting in Palo Alto, CA, influenced by the release of the Netscape source code. Later that month, the Open Source Initiative, an organization intended to promote and advocate for open source software, would be introduced ("History of the OSI, n.d.). Inspired by the idea of creating open source licenses for creative works, Creative Commons (CC) released a set of copyright licenses free for public use in 2002. Influenced by the

Free Software Foundation's GNU General Public License, free software, and open-source initiatives, its singular goal is "to build a layer of reasonable, flexible copyright in the face of increasingly restrictive default rules" ("What We Do", n.d.).

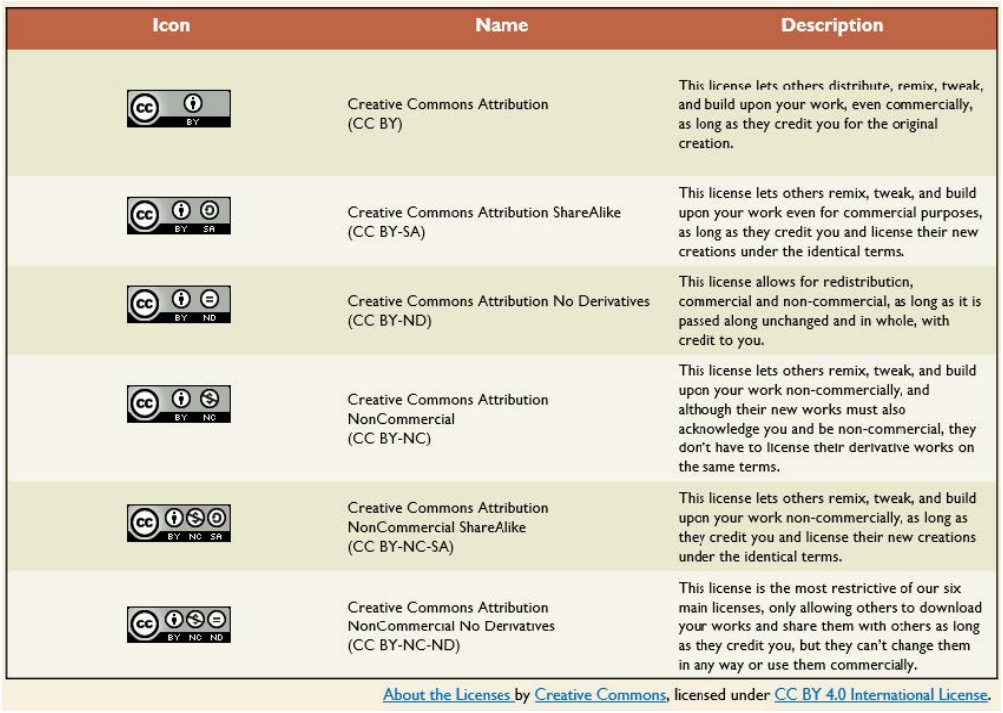

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Figure 2: Creative Commons Licenses

Shortly after the introduction of open source, Drs. Sepehr Kiani, Ryan Vallance, and Samir Nayfeh established the Open Design Foundation in 1999, with the aim to research further into open design. This idea would be taken up by various individuals in the future. In 2004, Ronen Kadushin would coin the term "Open Design" in his master's thesis and would later formalize it in his Open Design Manifesto in 2010 (Cruickshank, 2014).

The Open Design method, as described in Kadushin's manifesto (2010), consists of two preconditions:

1. An Open Design is CAD information published online under a Creative Commons license to be downloaded, produced, copied and modified.
2. An Open Design product is produced directly from file by computer numerical control (CNC) machines and without special tooling.

These preconditions infer that all technically conforming open designs and their derivatives are continuously available for production, in any number, with no tooling investment, anywhere and by anyone (para. 5).

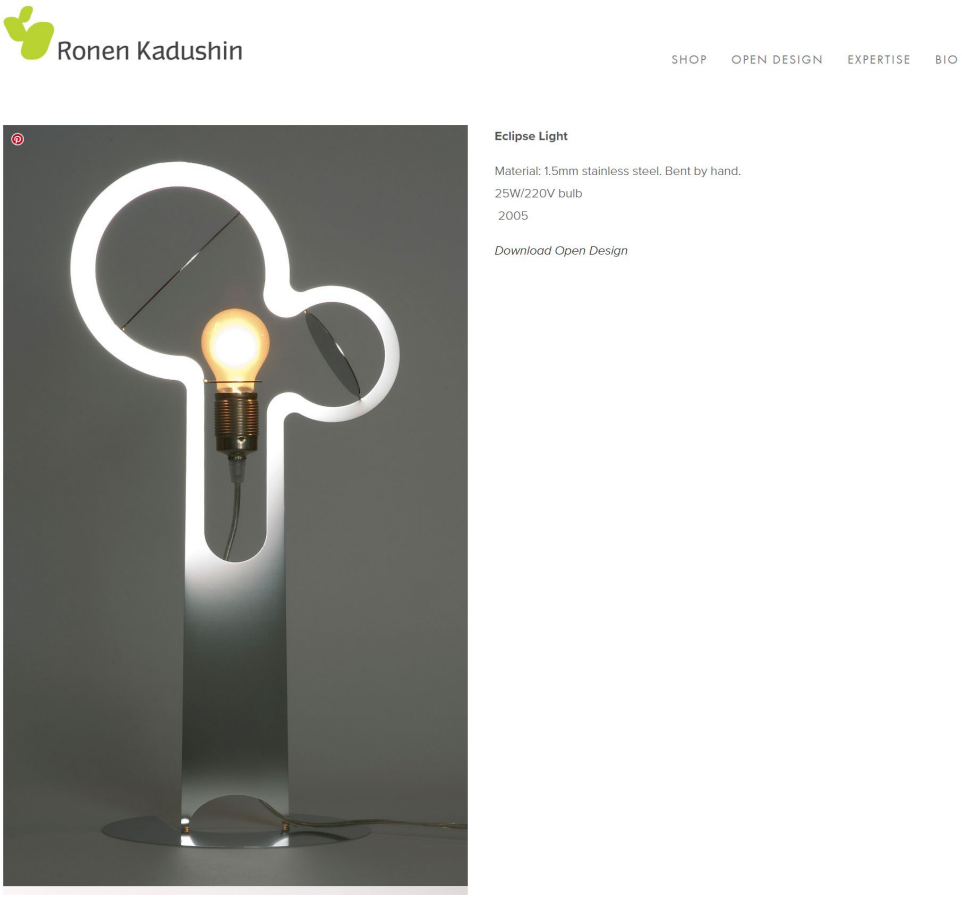
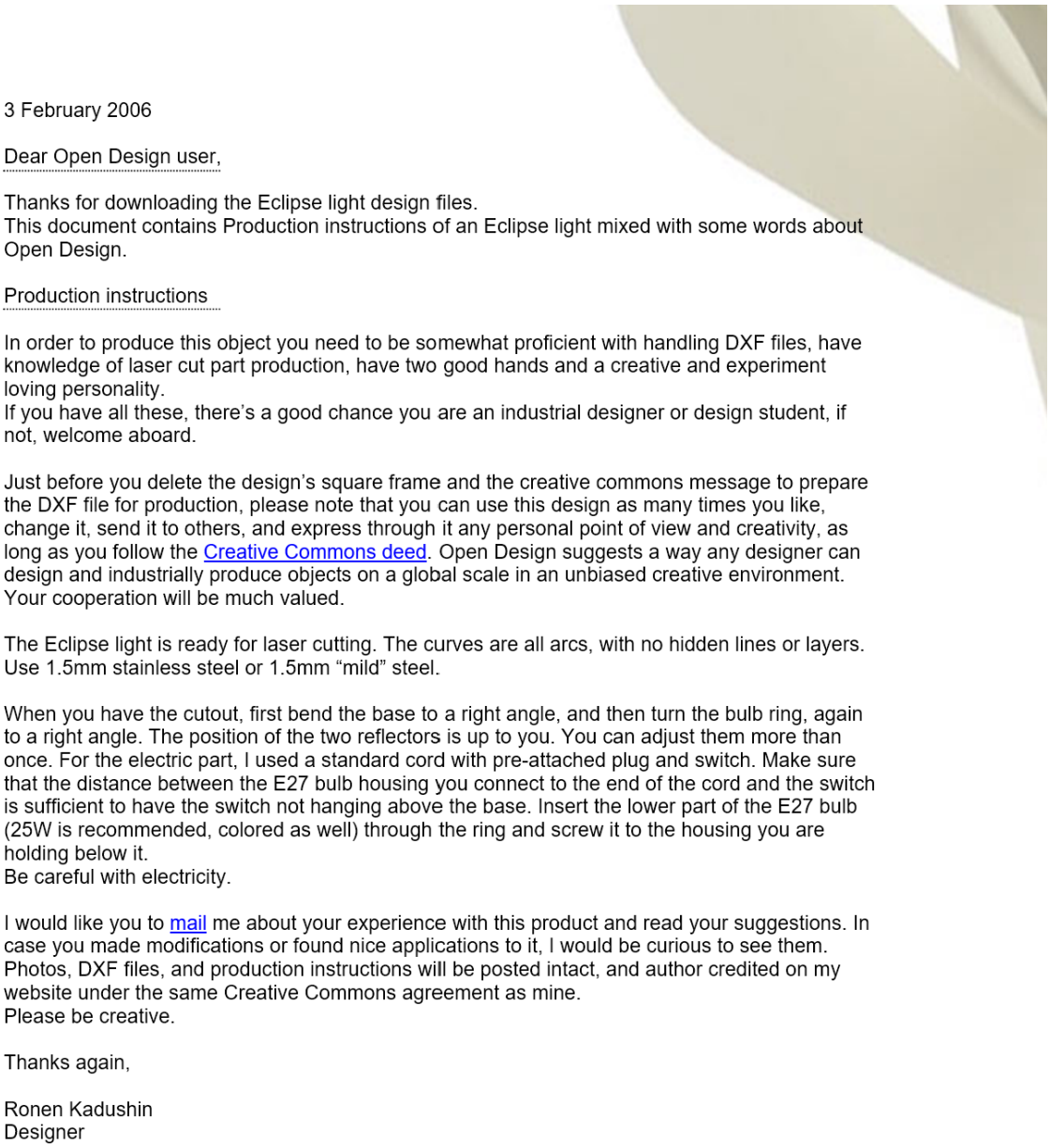


Figure 3: Eclipse Light, an example of an Open Design by Ronen Kadushin



3 February 2006

Dear Open Design user,

Thanks for downloading the Eclipse light design files.
This document contains Production instructions of an Eclipse light mixed with some words about Open Design.

Production instructions

In order to produce this object you need to be somewhat proficient with handling DXF files, have knowledge of laser cut part production, have two good hands and a creative and experiment loving personality.
If you have all these, there's a good chance you are an industrial designer or design student, if not, welcome aboard.

Just before you delete the design's square frame and the creative commons message to prepare the DXF file for production, please note that you can use this design as many times you like, change it, send it to others, and express through it any personal point of view and creativity, as long as you follow the Creative Commons deed. Open Design suggests a way any designer can design and industrially produce objects on a global scale in an unbiased creative environment. Your cooperation will be much valued.

The Eclipse light is ready for laser cutting. The curves are all arcs, with no hidden lines or layers. Use 1.5mm stainless steel or 1.5mm "mild" steel.

When you have the cutout, first bend the base to a right angle, and then turn the bulb ring, again to a right angle. The position of the two reflectors is up to you. You can adjust them more than once. For the electric part, I used a standard cord with pre-attached plug and switch. Make sure that the distance between the E27 bulb housing you connect to the end of the cord and the switch is sufficient to have the switch not hanging above the base. Insert the lower part of the E27 bulb (25W is recommended, colored as well) through the ring and screw it to the housing you are holding below it.
Be careful with electricity.

I would like you to mail me about your experience with this product and read your suggestions. In case you made modifications or found nice applications to it, I would be curious to see them. Photos, DXF files, and production instructions will be posted intact, and author credited on my website under the same Creative Commons agreement as mine.
Please be creative.

Thanks again,

Ronen Kadushin
Designer

Figure 4: "Read Me" DOCX file in the Eclipse Light folder

2.9 Design Thinking

Design thinking gained prominence in the latter half of the 20th century as a solutions-based creative problem-solving methodology. Buchanan (1992) suggests that there are four areas into which design thinking can be applied. They are as follows: the design of symbolic and

visual communication; the design of material objects; the design of activities and organized service; and the design of complex systems or environments for living, working, playing, and learning. It is important to note that design thinking should not be limited to just those who are specialized or traditionally associated with professions within this area (e.g. graphic designers with visual communication). The design thinking process can be applied to any sort of "design" project—including those by makers.

Stanford University's Hasso-Plattner Institute of Design at Stanford (d.school) which pioneered design thinking education, proposes a five-stage process: Empathize, Define (the problem), Ideate, Prototype, and Test (Ford, 2007).

Empathize: This first stage involves understanding the individual for whom one is designing for. In lieu of just asking questions and surveying them, which can produce faulty subjective results, observation of the subject as well as how they interact with their environment allows for the best insight into human behavior (Ford, 2007).

Define: This involves capturing the data and observations gathered in the empathize stage and processing them in order to "define" the challenge in a way that focuses on the human subject. This is called the "point of view" and should frame the subject and inspire the team (Ford, 2007.; Dam & Siang, n.d.).

Ideate: Ideation is the idea generation stage, which can involve a variety of techniques, like brainstorming, mind mapping, or sketching. The key to ideation is to refrain from judgment—this allows designers to think outside the box and stimulate the free flow of ideas.

Prototype: Prototyping is a method of communication. It should be quick, cheap, and easy—they are early working models of an idea, meant for experimentation and to

investigate the solutions created in the ideation stage. These are tangible models, they do not need to be physical models, though they often are, but embodiments of an idea (Kelley & Kelley, 2013). Prototyping allows for the rapid development of multiple ideas, as well as encourages testing and failure.

Test: Testing is typically done concurrently with the prototyping stage, where feedback is solicited from users. Furthermore, this is an opportunity to gain more empathy; to gain understanding through the observation of the product and its place within a user's life (Ford, 2007).

Brown (2009) describes design thinking, still human-centered, in a broader sense, with three stages of innovation: during the first, "inspiration", they experience a "'problem or opportunity' that sets them in motion; during 'ideation,' they generate and test ideas; and during 'implementation,' they move their innovation 'from the project room to the market'" (p. 16). This framework is subjected to three intersecting constraints: "'feasibility,' which is what can be done; 'viability,' what you can do successfully within a business; and 'desirability,' what people want or will come to want (p. 18). This study examines design thinking because it is inherently collaborative, which can be related to open design. Generally it is thought that designers and engineers think differently; however, this sort of integrative, and introspective method that designers use can be applied to any discipline, especially when pertaining to future scenarios. While designers do concept sketches and other iterations, even thinking of potential "What ifs?" is a method to which a marketer could apply this sort of design thinking (Kolko, 2014). The literature review will touch upon how a maker or designer can develop products for sale while utilizing a design thinking process.

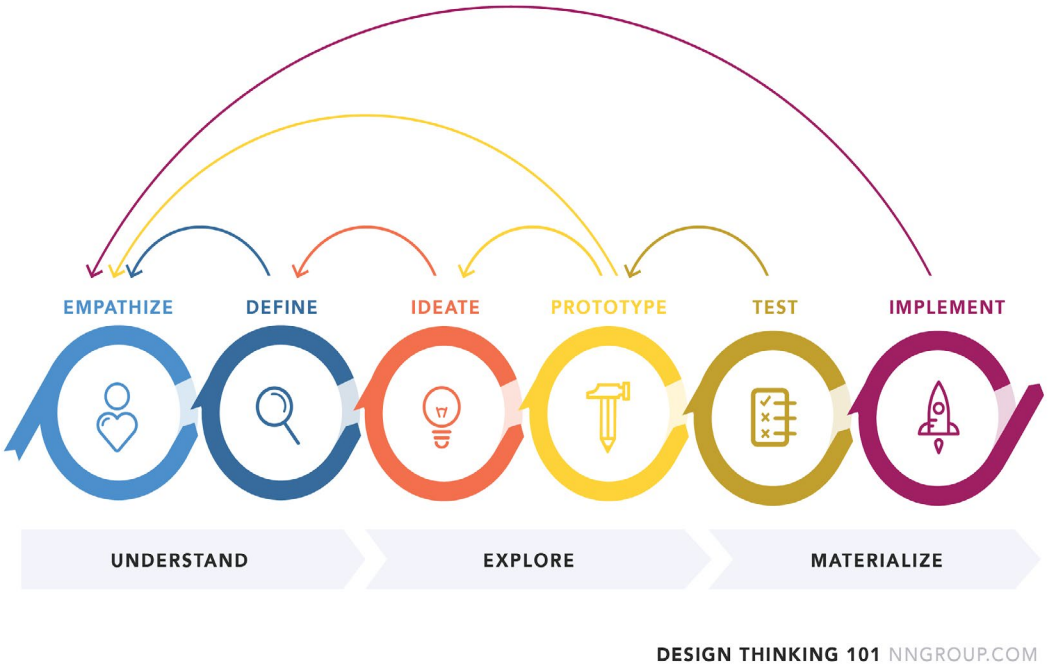


Figure 5: Design Thinking Process (Nielsen-Norman Group, 2016)

2.10 Design Theory

Many theoretical models exist when referring to design theory. Walter Schaer (1983), proposes a model where there are three functional dimensions for product design. The Human Function refers to the human needs to be fulfilled by the product, specifically how people react to products within socio-economic, cultural-aesthetic and physiological-practical parameters. The Production Function involves a production process that splits into planning and manufacturing. The Technical Function focuses on "... the artifact's syntactic relation to its own parts and to its external non-human physical environment" (Schaer, 1983, p. 206).

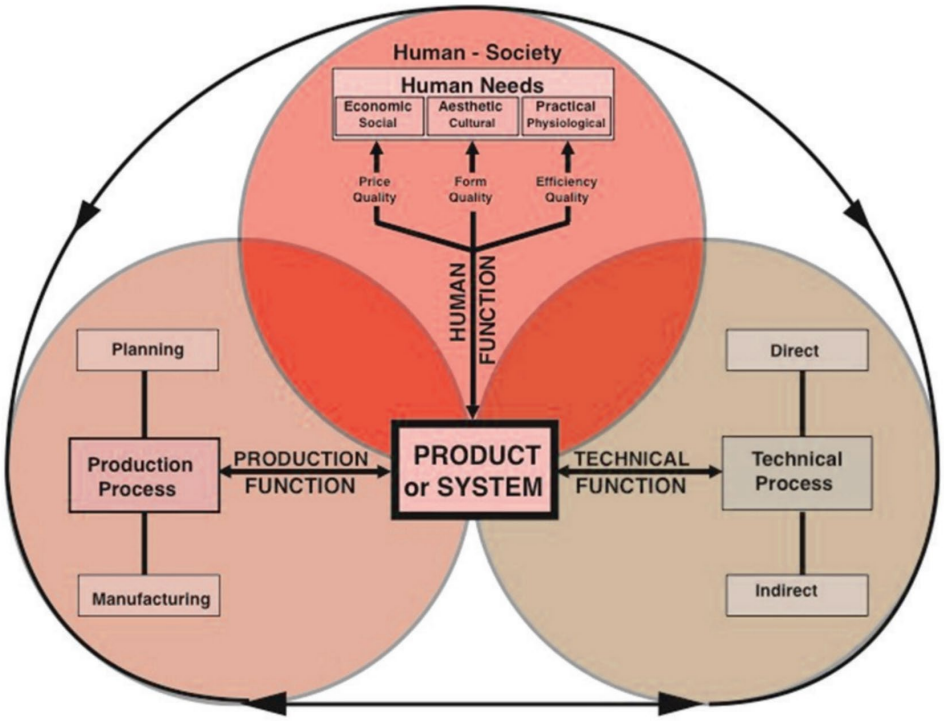


Figure 3: Schaer's Model for Designing Products

2.11 Computer-Aided Design.

Computer-aided design can be defined as, "the use of computers (or workstations) to aid in the creation, modification, analysis, or optimization of a design" (Narayan, Rao, & Sarcar, 2008, p. 3). This study relies upon the creation of objects that are digitally fabricated using computer-aided design (CAD) software packages for the intention of distribution.

Computer-aided design was invented in 1963, by an MIT graduate student, Ivan Sutherland, who developed Sketchpad, a graphical user interface, as his PhD thesis. The program allows designers to utilize a lightpen to generate engineering drawings with lines, corners, and joints, as well as indicate geometric constraints and duplicate sketch entities.

CAD software continued to develop, though primarily in the aircraft, automotive, and electronics industries that could invest in the computers that were capable of such computations. To ensure a neutral format for CAD files, the U.S. Air Force established the Initial Graphics Exchange Specification (IGES) format in 1980.

In 1982, Autodesk launched AutoCAD, the first 2D CAD program to be made specifically for personal computers, becoming an affordable option for design, engineering, and architectural firms to create technical drawings (Howitt, 1984). SolidWorks, the first significant 3D modeler for the PC, was released in 1995— the software was relatively easy to use and significantly more inexpensive than existing alternatives ($4,000 vs $18,000). This marked the beginning of 3D CAD development in the 1990s. In the years since, other file format standardizations like the STEP (Standard for the Exchange of Product Data) format have been implemented, as well as the introduction of free and inexpensive CAD modeling software for home consumers and students, like SketchUp, Tinkercad, Autodesk Fusion 360, among others.

2.12 Digital Fabrication.

Digital fabrication is a type of computer-aided design and manufacturing process wherein a computer controls a machine. Digital fabrication typically begins with the generation of a 3D model or 2D drawing, which is then interpreted by the tool—the most common tools being 3D printers, CNC routers, and laser cutters. Digital fabrication falls into two categories: additive manufacturing and subtractive manufacturing. Additive tools like 3D printing create parts by building them up, layer-by-layer. Subtractive tools like CNC milling begin with solid blocks of material that are then shaped by the removal of material.

2.13 Digital Fabrication Methods.

This study will be primarily looking at 3D printing, CNC milling, and laser cutting—the three processes which are most readily available to home consumers.

2.13.1 3D Printing

Chuck Hall developed 3D printing in 1984—specifically the process known as stereolithography (SLA), which utilizes ultraviolet technology to harden photosensitive polymers. The more common form of 3D printing, fused deposition modeling (FDM), where a filament is extruded through a nozzle to deposit layers, would be developed by S. Scott Crump in 1989 (Hessman, 2013). 3D printing became available for home consumers with the RepRap project launched by Dr. Adrian Bowyer in 2005, an open-source initiative to create a 3D printer that could print most of its own parts. This led to the democratization of manufacturing, and low-cost digital fabrication for the home consumer (RepRap, n.d.).

In order for a 3D file to be read by a 3D printer, it must be converted using a slicing software that will divide an object into layers. Cura (Figure 9), by Ultimaker, is the most popular slicing program, and operates by generating a G-code, which is the language that dictates the path, speed, and other functions of the tool.

	ABS	Flexible	PLA	HIPS	PETG	Nylon	Carbon Fiber Filled	ASA	Polycarbonate	Polypropylene	Metal Filled	Wood Filled	PVA
	Learn More	Learn More	Learn More	Learn More	Learn More	Learn More	Learn More	Learn More	Learn More	Learn More	Learn More	Learn More	Learn More
Compare Selected	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Ultimate Strength	40 MPa	26 - 43 MPa	65 MPa	32 MPa	53 MPa	40 - 85 MPa	45 - 48 MPa	55 MPa	72 MPa	32 MPa	20 - 30 MPa	46 MPa	78 MPa
Stiffness	5 / 10	1 / 10	7.5 / 10	10 / 10	5 / 10	5 / 10	10 / 10	5 / 10	6 / 10	4 / 10	10 / 10	8 / 10	3 / 10
Durability	8 / 10	9 / 10	4 / 10	7 / 10	8 / 10	10 / 10	3 / 10	10 / 10	10 / 10	9 / 10	4 / 10	3 / 10	7 / 10
Maximum Service Temperature	98 °C	60 - 74 °C	52 °C	100 °C	73 °C	80 - 95 °C	52 °C	95 °C	121 °C	100 °C	52 °C	52 °C	75 °C
Coefficient of Thermal Expansion	90 µm/m-°C	157 µm/m-°C	68 µm/m-°C	80 µm/m-°C	60 µm/m-°C	95 µm/m-°C	57.5 µm/m-°C	98 µm/m-°C	69 µm/m-°C	150 µm/m-°C	33.75 µm/m-°C	30.5 µm/m-°C	85 µm/m-°C
Density	1.04 g/cm³	1.19 - 1.23 g/cm³	1.24 g/cm³	1.03 - 1.04 g/cm³	1.23 g/cm³	1.06 - 1.14 g/cm³	1.3 g/cm³	1.07 g/cm³	1.2 g/cm³	0.9 g/cm³	2 - 4 g/cm³	1.15 - 1.25 g/cm³	1.23 g/cm³
Price (per kg)	$10 - $40	$30 - $70	$10 - $40	$24 - $32	$20 - $60	$25 - $65	$30 - $80	$38 - $40	$40 - $75	$60 - $120	$50 - $120	$25 - $55	$40 - $110
Printability	8 / 10	6 / 10	9 / 10	6 / 10	9 / 10	8 / 10	8 / 10	7 / 10	6 / 10	4 / 10	7 / 10	8 / 10	5 / 10
Extruder Temperature	220 - 250 °C	225 - 245 °C	190 - 220 °C	230 - 245 °C	230 - 250 °C	220 - 270 °C	200 - 230 °C	235 - 255 °C	260 - 310 °C	220 - 250 °C	190 - 220 °C	190 - 220 °C	185 - 200 °C
Bed temperature	95 - 110 °C	45 - 60 °C	45 - 60 °C	100 - 115 °C	75 - 90 °C	70 - 90 °C	45 - 60 °C	90 - 110 °C	80 - 120 °C	85 - 100 °C	45 - 60 °C	45 - 60 °C	45 - 60 °C
Heated Bed	Required	Optional	Optional	Required	Required	Required	Optional	Required	Required	Required	Optional	Optional	Required
Recommended Build Surfaces	Kapton Tape, ABS Slurry	PEI, Painter's Tape	Painter's Tape, Glue Stick, Glass Plate, PEI	Glass Plate, Glue Stick, Kapton Tape	Glue Stick, Painter's Tape	Glue Stick, PEI	Painter's Tape, Glue Stick, Glass Plate, PEI	Glue Stick, PEI	PEI, Commercial Adhesive, Glue Stick	Packing Tape, Polypropylene Sheet	Painter's Tape, Glue Stick, PEI	Painter's Tape, Glue Stick, PEI	PEI, Painter's Tape
Other Hardware Requirements	Heated Bed, Enclosure Recommended	Part Cooling Fan	Part Cooling Fan	Heated Bed, Enclosure Recommended	Heated Bed, Part Cooling Fan	Heated Bed, Enclosure Recommended, May Require All Metal Hotend	Part Cooling Fan	Heated Bed	Heated Bed, Enclosure Recommended, All Metal Hotend	Heated Bed, Enclosure Recommended, Part Cooling Fan	Wear Resistant or Stainless Steel Nozzle, Part Cooling Fan	Part Cooling Fan	Heated Bed, Part Cooling Fan

Figure 7: Common filament types and their properties ("Properties Table", 2019)

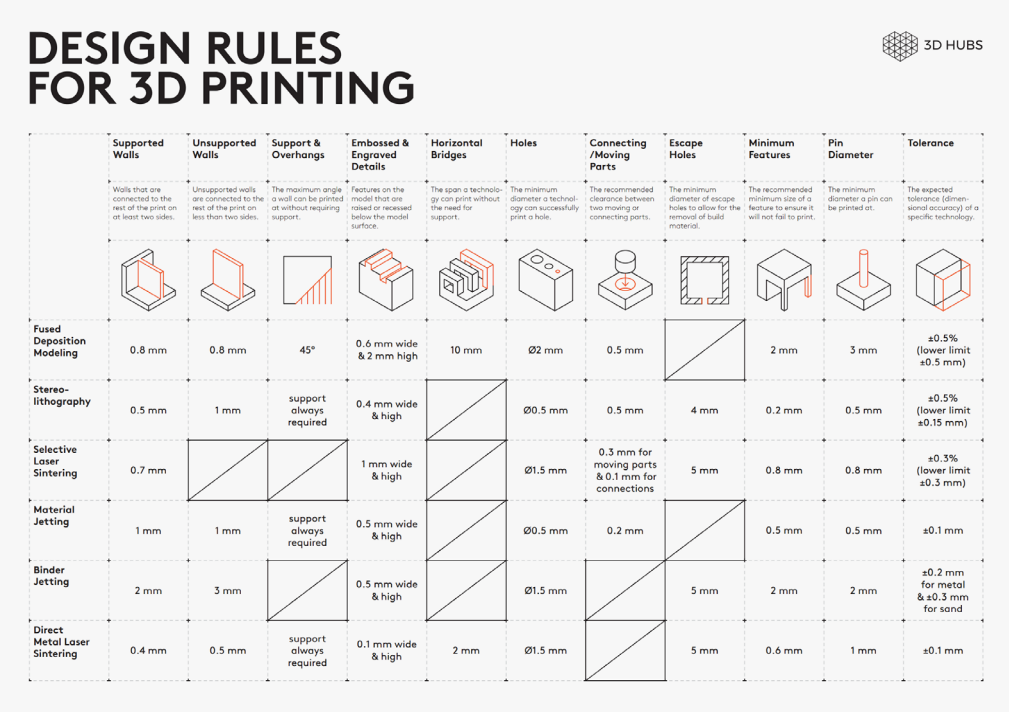


Figure 8: Design Rules for 3D Printing ("Key design considerations for 3D Printing", n.d.)

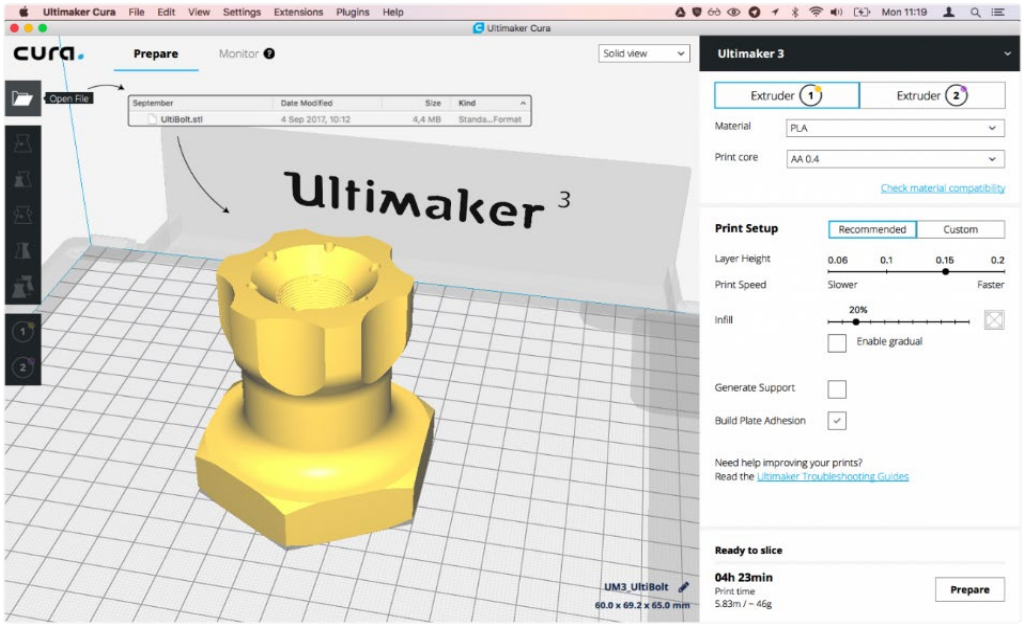


Figure 9: Ultimaker Cura slicing software

2.13.2 CNC Milling

CNC Milling, otherwise known as computer numerical control milling, is a subtractive machining process where a router is controlled by a computer to process a material—typically wood, plastics, or metals. Once a 2D or 3D CAD design has been created, it is converted to G-code.

Design considerations for CNC routing:

1. The most common toolings are cylindrical in nature with a limited cutting length
    a. Corners should have a radius
    b. Holes should use standard drill sizes
2. CNC tooling approaches the material from above, which means that features that are not accessible (with the exception of undercuts) are not machinable.
3. Parts should be machined in as few setups as possible, preferably one.

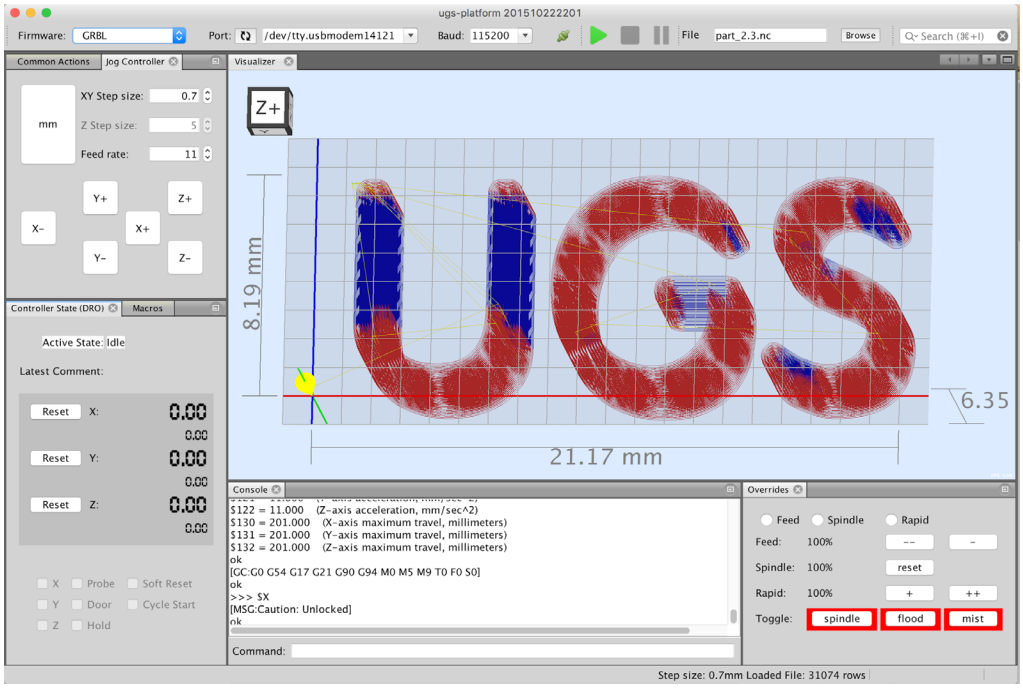


Figure 10: Interface for Universal G-Code Software (UGS)

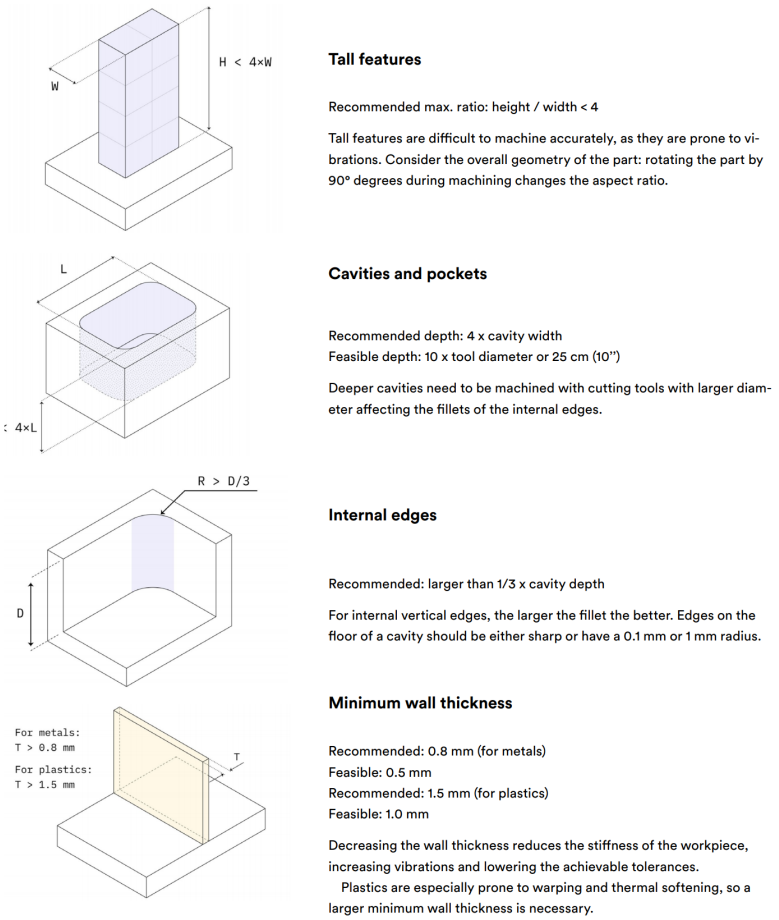


Figure 11: Design Rules for CNC ("CNC Machining: The Complete Engineering Guide", n.d.)

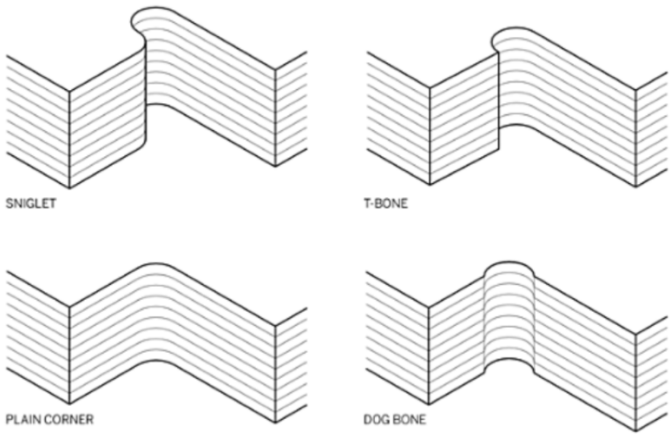


Figure 12: Demonstration of Fillets (Filson, Rohrbacher, & France, 2017)

2.13.3 Laser Cutting

Laser cutting uses a focused beam of light to cut or engrave materials. It is another form of CNC machine, meaning that it utilizes a computer-controlled laser to cut or etch materials. Laser cutting can achieve very high levels of detail and can be used on a variety of materials ranging from wood, paper, foam, acrylic, and more. Hobbyists tend to use low-power machines that are less than 100 W, but high power lasers can cut materials like metals or thicker pieces of material up to ¾".

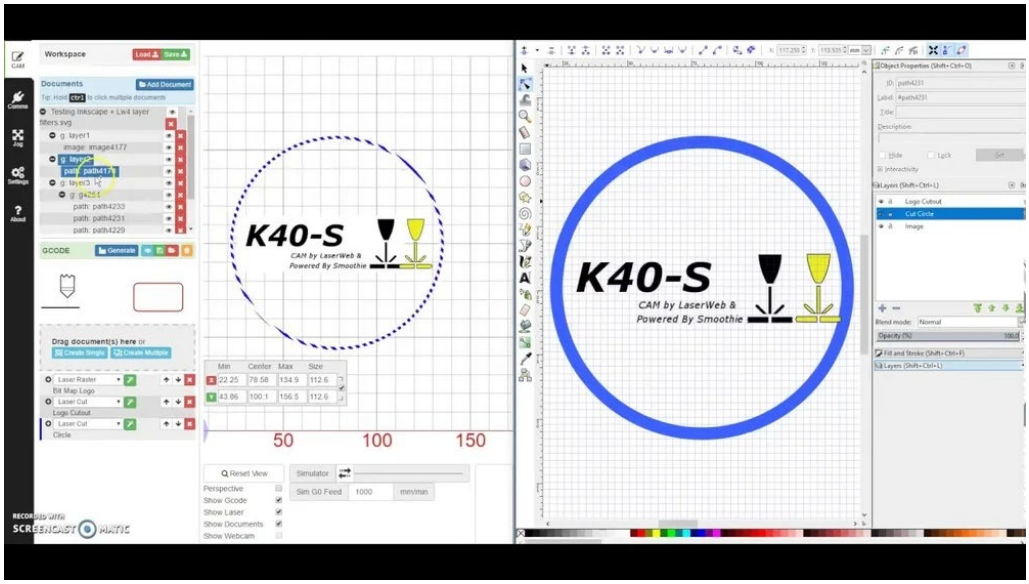


Figure 13: Interface for LaserWeb, a free open-source, laser cutting tool

2.14 Existing Commercial and Distribution Platforms - Case Studies

While there are a variety of online repositories for the distribution of 3D models, this study will primarily focus on those that are geared toward the sharing of 3D models or 2D models for intention of creating physical products through means of additive manufacturing (3D

printing), CNC milling, and laser cutting. Other options for the distribution of digitally fabricable models include the handmade marketplace Etsy, Sculpteo, MyMiniFactory, among others. With the creation of 3D objects becoming more commonplace, communities dedicated to the sharing of 3D models have emerged. This study will explore a few existing platforms in the CAD model sharing space.

2.14.1 Thingiverse

Thingiverse is an online community that supports the free sharing of 3D models for digital fabrication for everyone, regardless of expertise or experience (Thingiverse.com, n.d.). Launched in 2008 by Makerbot, Thingiverse encourages all designs to be licensed under a Creative Commons license, allowing anyone to use and create derivatives of existing designs. Thingiverse is the largest such repository of 3D printable items (though 2D designs that can be created using CNC mills and laser cutters can be shared as well) and is also identified as one of the most common resources for sourcing such files (Hudson, Alcock & Chilana, 2016; Baumann, 2018). As of 2018, over 3 million Things have been uploaded, downloaded over 340 million times ("MakerBot Thingiverse Celebrates 10 Years of 3D Printed Things," 2018).

Thingiverse is consumer-centric, particularly in that it has few barriers to entry—users can download files without signing up. Thingiverse offers "a number of abilities to upload, host, share, re-mix, discuss, and acquire objects via 3rd party providers" (Baumann, 2018, p. 84). These uploaded projects are called "Things," and can be placed into 10 categories: 3D printing, art, fashion, gadgets, hobby, household, learning, models, tools, and toys and games. Uploaded Things typically include the 3D files for fabrication, images of the design, and instructions for creating it, as well as references to sources–other Things that a design is "inspired by, derived

from, or a remix of" (Oehlberg, Willett, & Mackay, 2015, p.3). This reference to sources is referred to as a "remix." While remixing is encouraged, designers can choose how they license their Thing; to prevent derivatives, they can license it under a "Creative Commons - Attribution - Non-Commercial - No Derivatives license."

Upon upload, each Thing can be made public on a page that features images, data regarding views, downloads, references, licenses, tags, comments, likes, remixes, 3D print settings, and other metadata. While the majority of models are uploaded to be produced as is, a subset of authors upload parametric designs that can be adjusted by the end user. These parametric models are uploaded using Customizer, an in-website app introduced in 2003. Customizer utilizes files created from the script-based 3D modeler, OpenSCAD to create parametric, customizable designs. Most designs will be less than around $25cm^3$, about the size that an average 3D printer would be able to generate (Cruickshank, 2014). Alternatively, Thingiverse also allows the uploader to enable "Thing Apps", which offer an option to use an external service like Print a Thing, Treatstock, or NinjaPrototype. Print a Thing and Treatstock will automatically import the STL files for printing.

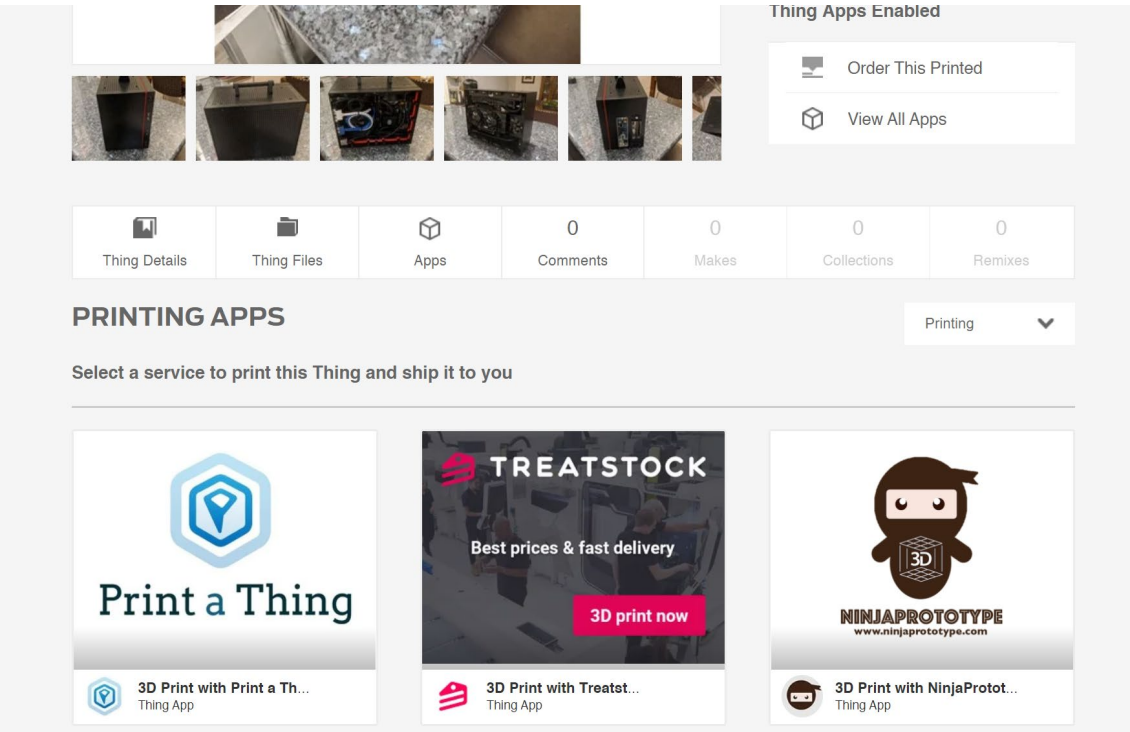


Figure 14: Thingiverse Printing Apps Example

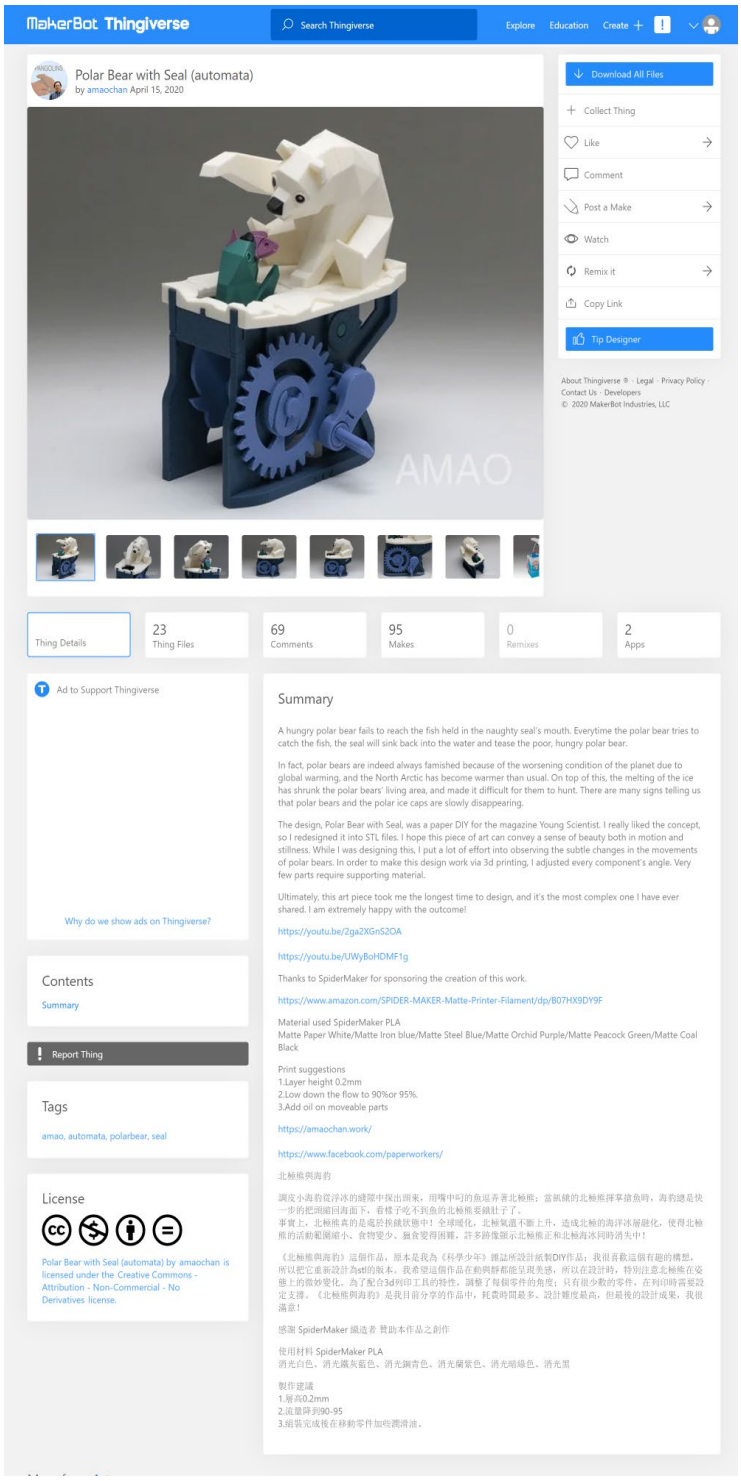


Figure 15: *Polar Bear with Seal (automata)* by user amaochan on Thingiverse

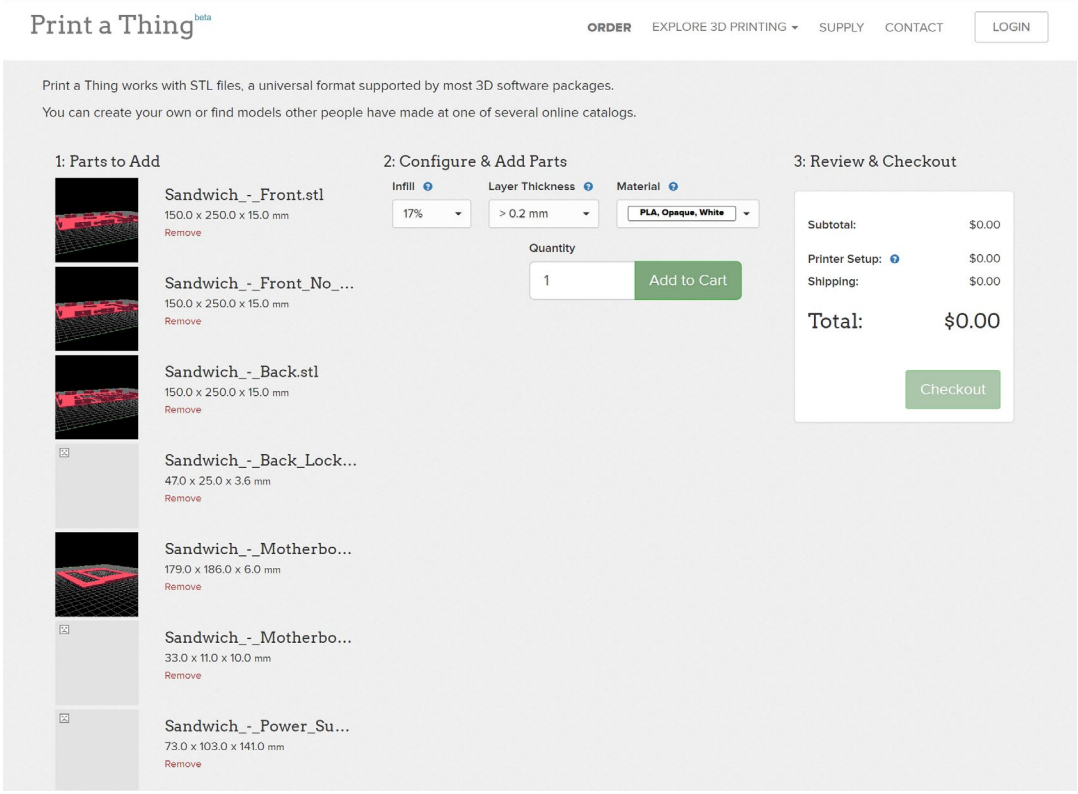


Figure 16: Demonstration of how Print a Thing imports files from Thingiverse

2.14.2 MyMiniFactory

Much like Thingiverse, MyMiniFactory is a community for the sharing of 3D printable objects, both paid and free. MyMiniFactory allows for a variety of licensing options, but digital files sold through the store have a strict non-commercial, personal use only license (“Object Licensing”, n.d.). Uploaded files are vetted through a software check and test printed by the community to ensure file quality before being published.

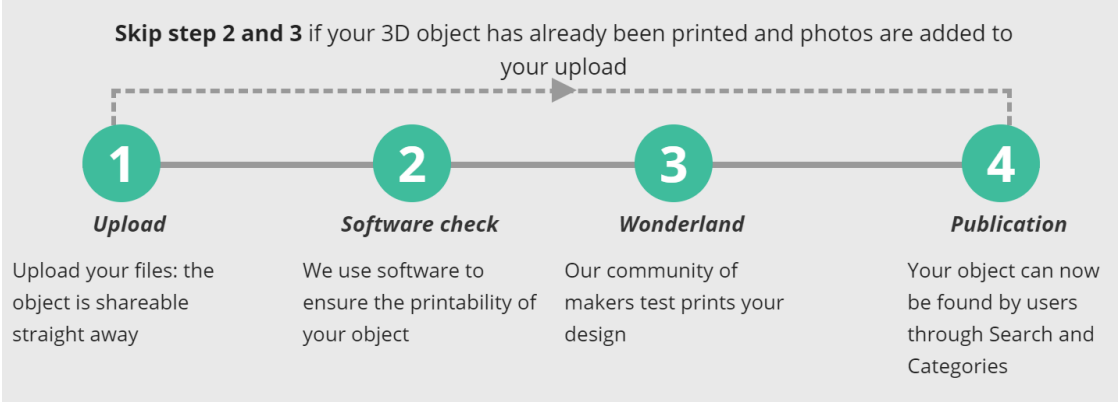


Figure 17: MyMiniFactory Printability Check Process

Users have the option to sell their files by either opening a "Store" at a cost of $24.99 a month, with an additional 10% fee on the selling price or by becoming a "Studio Designer." Studio designers act like content creators and make money through a revenue share option where they get paid per view or download, or through tips.

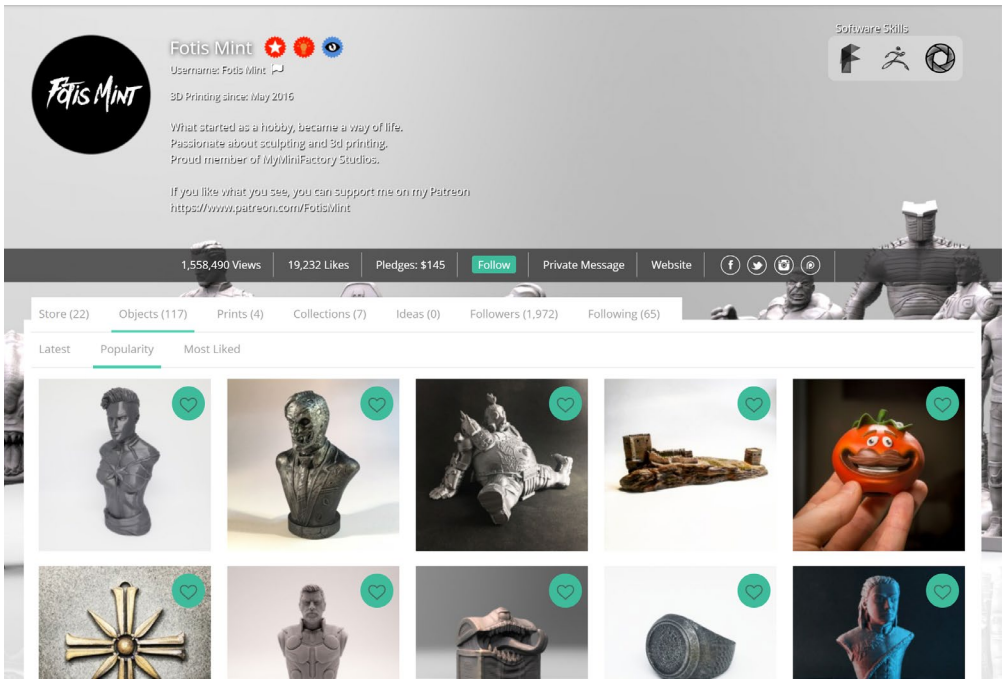


Figure 18: Profile for Fotis Mint, a MyMiniFactory studio designer

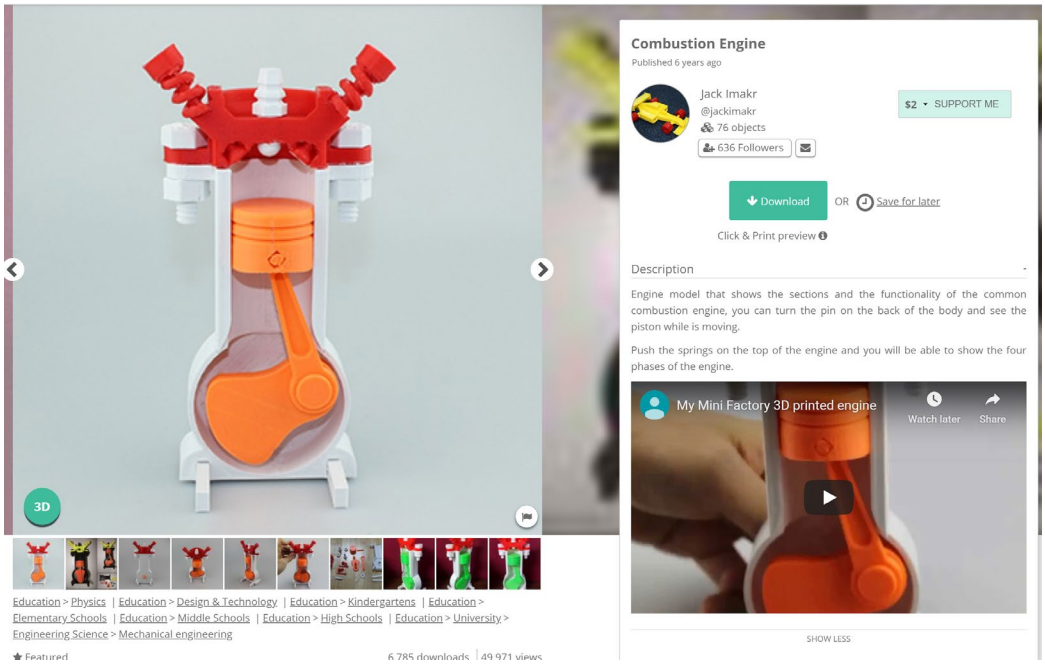


Figure 19: Combustion Engine by Jack Imakr

Name	Type	Compressed size	Password pr...	Size	Ratio	Date modified
balance	3D Object	9 KB	No	40 KB	80%	8/2/2016 12:43 AM
basis-holder	3D Object	1 KB	No	1 KB	76%	8/2/2016 12:43 AM
carter	3D Object	50 KB	No	159 KB	70%	8/2/2016 12:43 AM
distance	3D Object	4 KB	No	21 KB	82%	8/2/2016 12:43 AM
engine-head	3D Object	186 KB	No	443 KB	59%	8/2/2016 12:43 AM
part-1	3D Object	88 KB	No	214 KB	60%	8/2/2016 12:43 AM
pin	3D Object	2 KB	No	7 KB	82%	8/2/2016 12:43 AM
piston	3D Object	81 KB	No	230 KB	66%	8/2/2016 12:43 AM
piston-rod	3D Object	36 KB	No	106 KB	67%	8/2/2016 12:43 AM
piston-rod-pin	3D Object	50 KB	No	153 KB	68%	8/2/2016 12:43 AM
screw-MMF	3D Object	459 KB	No	998 KB	55%	8/2/2016 12:43 AM
spring-valve	3D Object	270 KB	No	645 KB	59%	8/2/2016 12:43 AM
valves	3D Object	20 KB	No	59 KB	68%	8/2/2016 12:43 AM

Figure 20: Contents of ZIP folder for Combustion Engine

2.14.3 Shapeways

Shapeways is a 3D printing marketplace and manufacturing service that offers professional-level printing services with 50 material choices ranging from plastics to metals. They primarily utilize selective laser sintering (SLS) to fabricate models, which entails using a

laser to sinter (make a powder merge into a solid) powdered material. Options like PolyJet and material jetting are available as well, depending on the material chosen. Shapeways provides specific design guidelines for each material and printing process. Pricing per model is based off of an algorithm that factors in material volume, machine space, number of parts, production costs, bounding box volume, and support volume (only for fine detail plastic).

Makers who wish to sell their products can upload their designs to the platform and sell them in the Shapeways marketplace, or integrate with Etsy, Shopify, or other APIs to have Shapeways ship directly to the consumer. "Shapeways sets a production cost, and you can mark it up as much as you want and that sets the final price. Depending on the material, customers will receive their items within 10-15 business days" (Smith, 2012, para. 5). Upon sale, Shapeways charges an additional 3.5% fee on top of markup to the seller.

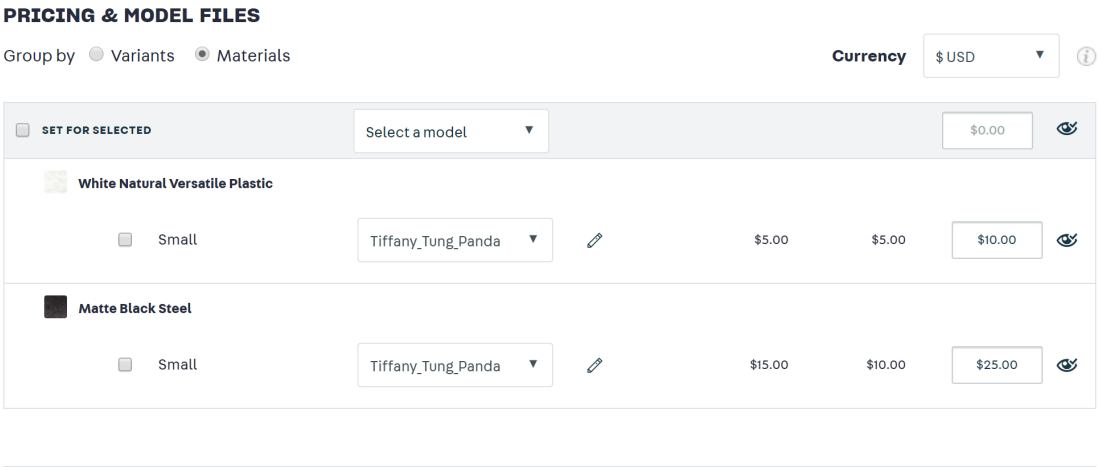


Figure 21: Shapeways' Marketplace Pricing

2.14.4 Pinshape

Pinshape is another online 3D printing community and marketplace, owned by Formlabs. Like MyMiniFactory, users are able to upload and share their designs for free or for sale. Pinshape does not take a cut of the designer's earnings; rather they charge an additional 30% on top of the markup. (For example, if a product is $1.00, the selling price would be $1.30.) While Pinshape does not do individual quality control for products listed on the marketplace, they do require that uploaders use Netfabb or Microsoft 3D Model Repair to check their STL files. For those looking for others to help them design models, Pinshape also has a forum for such requests.

In an analysis of their marketplace offerings, Pinshape (n.d.), determined that designs that cost less than $1 are 1.8 times more likely to be purchased than something that costs $2.50-$4.50. Furthermore, designers who printed their design and posted high quality photos were 7.3 times more likely to sell their designs ("3D Printing Design Guide", n.d.). Pinshape also offers the customers the ability to "stream" or "download" their purchases. Streaming a download involves using a cloud-based software called 3DPrinterOS which allows the customer to slice, scale, and print their model from within the browser.

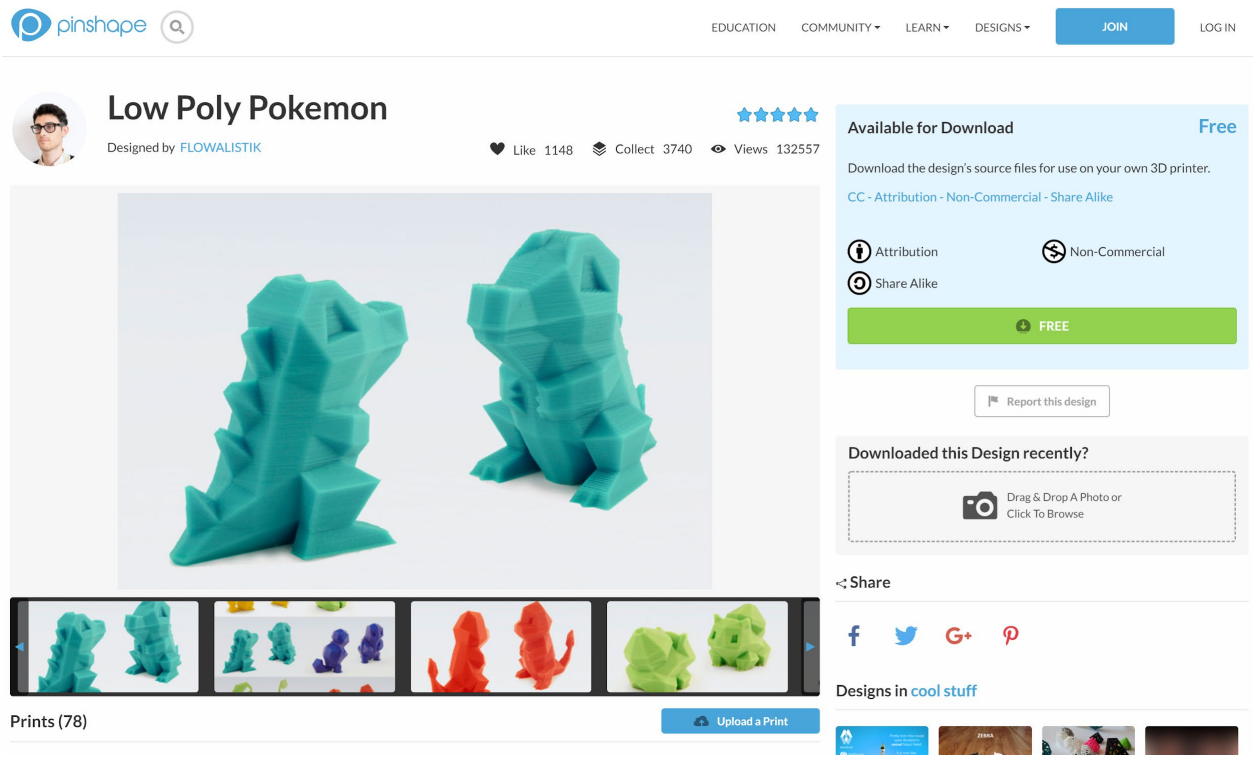


Figure 22: Low Poly Pokemon by FLOWALISTIK on Pinshape

Name	Type	Compressed size	Password pr...	Size	Ratio	Date modified
bulbasaur_starter_1gen_flowalistik	3D Object	7 KB	No	18 KB	61%	11/2/2015 1:23 PM
charmander_starter_1gen_flowalistik	3D Object	8 KB	No	18 KB	60%	11/2/2015 1:23 PM
chikorita_starter_2gen_flowalistik	3D Object	10 KB	No	26 KB	63%	11/2/2015 1:23 PM
chikorita_starter_2gen_flowalistik_body	3D Object	8 KB	No	21 KB	62%	11/2/2015 1:23 PM
chikorita_starter_2gen_flowalistik_leaf	3D Object	3 KB	No	6 KB	63%	11/2/2015 1:23 PM
pikachu_1gen_flowalistik	3D Object	9 KB	No	21 KB	56%	11/2/2015 1:23 PM
squirtle_starter_1gen_flowalistik	3D Object	8 KB	No	18 KB	60%	11/2/2015 1:23 PM
totodile_starter_2gen_flowalistik	3D Object	10 KB	No	23 KB	60%	11/2/2015 1:23 PM

Figure 23: Contents of the downloaded ZIP file for Low Poly Pokemon

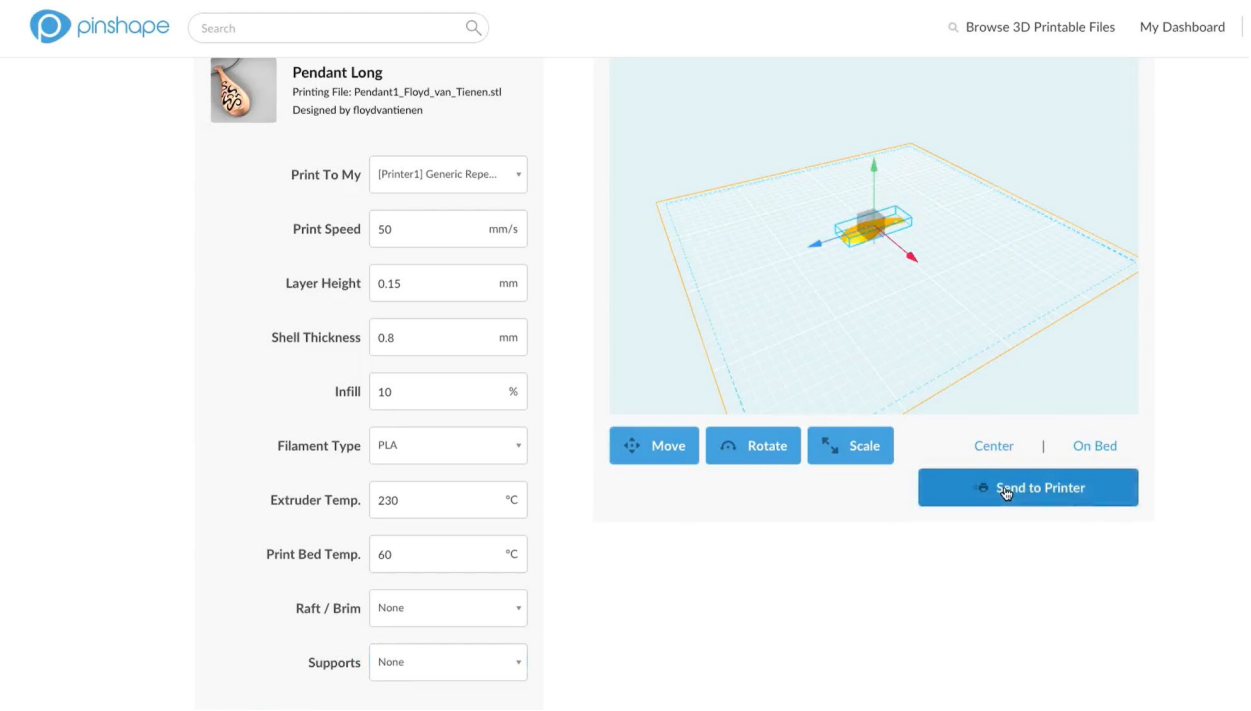


Figure 24: Demonstration of Pinshape's streaming functionality

2.14.5 Opendesk

Opendesk is a curated online furniture marketplace where anyone can download and fabricate non-commercially through creative commons licensing. While all furniture designs are free to download for individuals who want to "Make-It-Yourself," Opendesk offers a global distribution network for customers who do not have the necessary tools to fabricate the designs themselves, the platform will connect them with a local maker for fabrication (Opendesk also owns and operates the directory FabHub to find digital fabricators). Designers are only paid if the design is fabricated through the partner makerspace and do not receive any compensation when people directly download and create the item themselves ("From 'Business as Usual' to 'Business as Mutual'", n.d.).

Opendesk is fairly selective with the designs that they offer—they tend to be designed by professional designers and follow the rule of universal makeability—where common sizes, materials, and hardware should be used to ensure that no matter where an individual is, the product can be fabricated.

Make-It-Yourself downloads provide all DXF cutting files (already pre-nested), as well as an assembly guide, information regarding the Creative Commons - Attribution license, and a test cutting sheet.

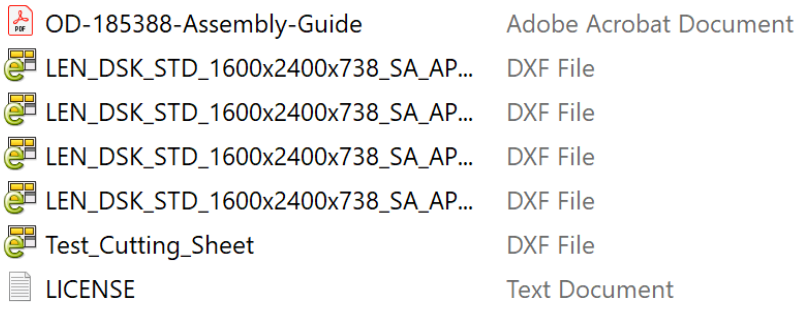


Figure 25: Contents of an Opendesk “Make-It-Yourself” folder

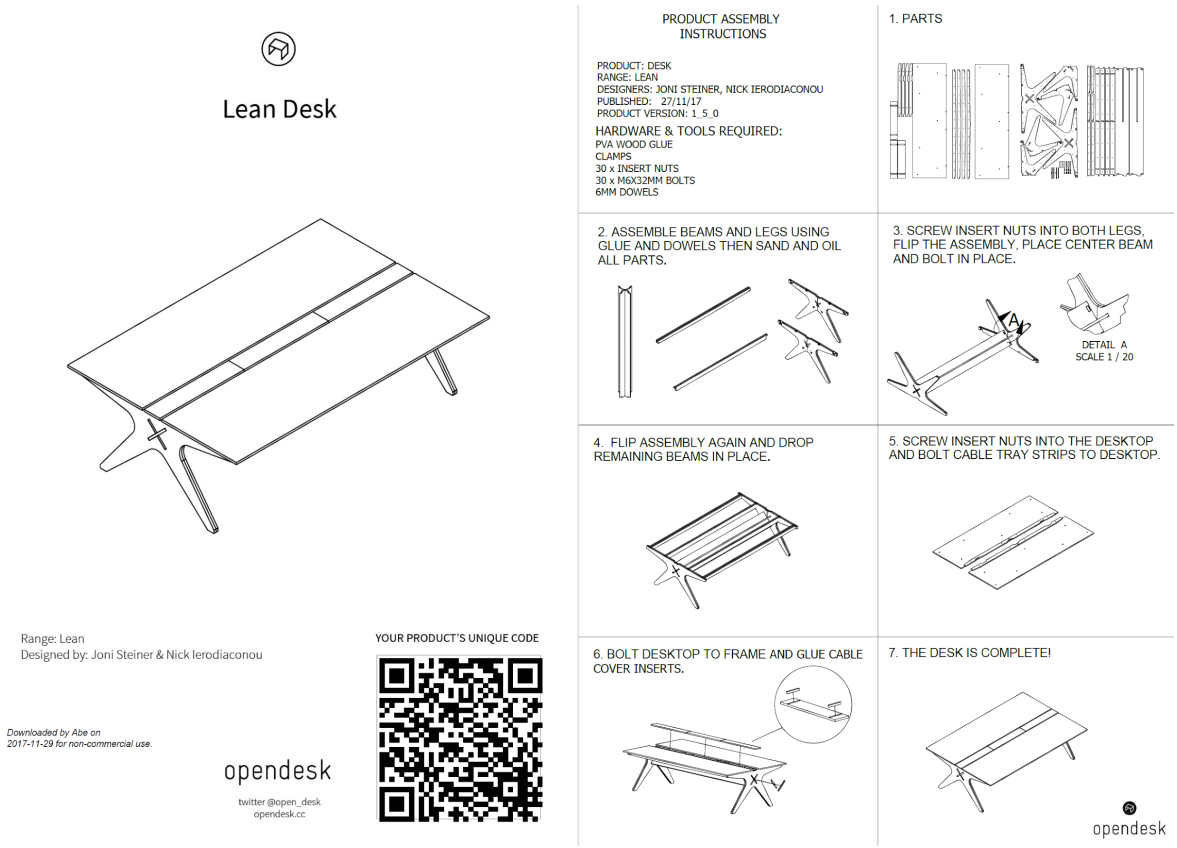


Figure 26: Assembly Guide for *Lean Desk* courtesy of Opendesk

2.14.6 FabHub

FabHub is owned and operated by OpenDesk, and is a "free listing and directory search service for qualified [digital] fabricators and a global maker map showing where they are located" ("FabHub", n.d.). Digital fabricators, individuals who are able to "make / manufacture / fabricate products that are designed for digital fabrication" create a profile where they provide a brief summary of their business and offerings as well as information regarding what services they provide and offer ("FabHub", n.d) . Interested parties are able to "Make an Enquiry" and give details of the project in order to receive a quote. Communications between the maker and client occur over email after the initial contact from the client.

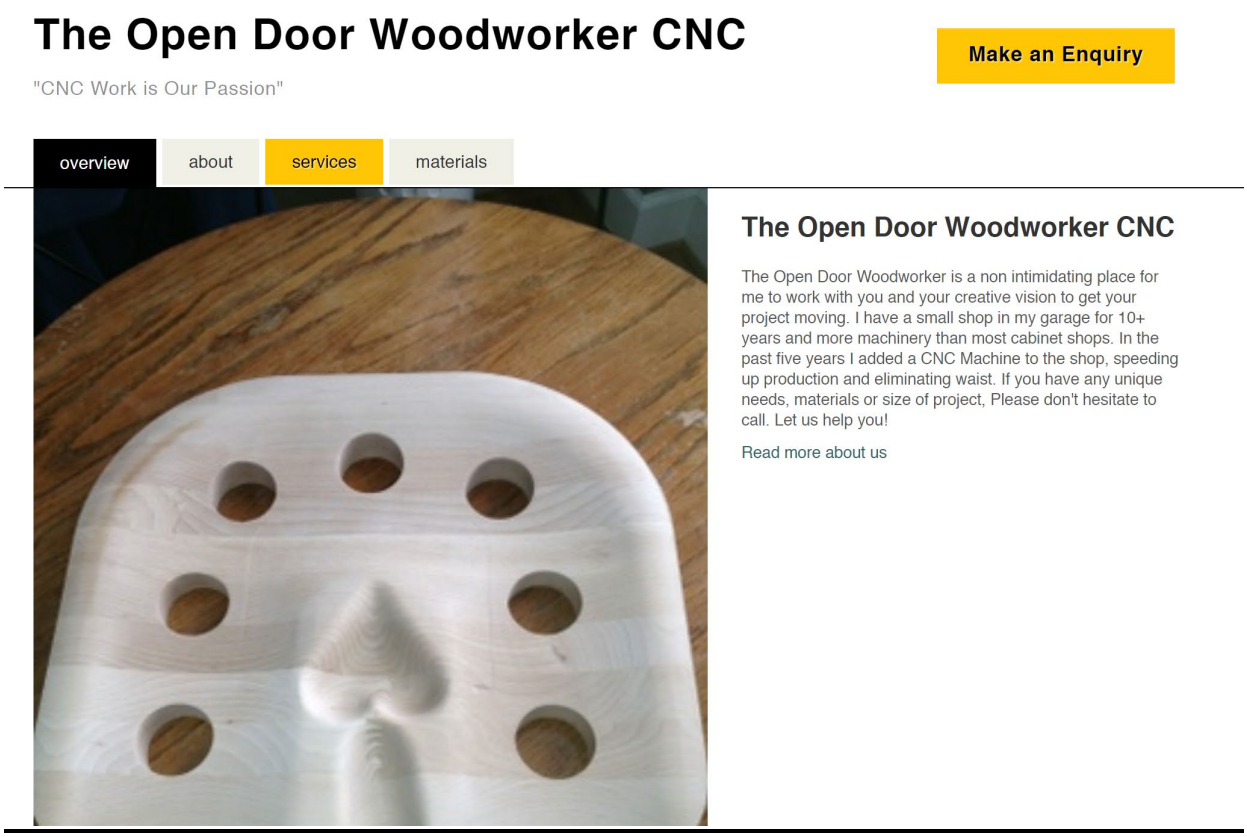


Figure 27: Sample Fabricator "About" Page on FabHub

2.14.7 Ponoko

Ponoko is a 3D laser printing (laser cutting and etching) service launched in 2007. Ponoko offers over 150 types of sheet materials for laser printing. Makers upload their vector files (in AI, SVG, DXF, and EPS formats) to receive an instant quote. Pricing per order is dictated by material type and order quantity, where bulk orders receive discounted pricing. Makers are also charged an additional $9 setup fee per project as well, which accounts for production costs. After the maker confirms the digital product visualization, it then gets confirmed by an in-house industrial designer and a production manager. It then goes through quality assurance to ensure the part and design match.

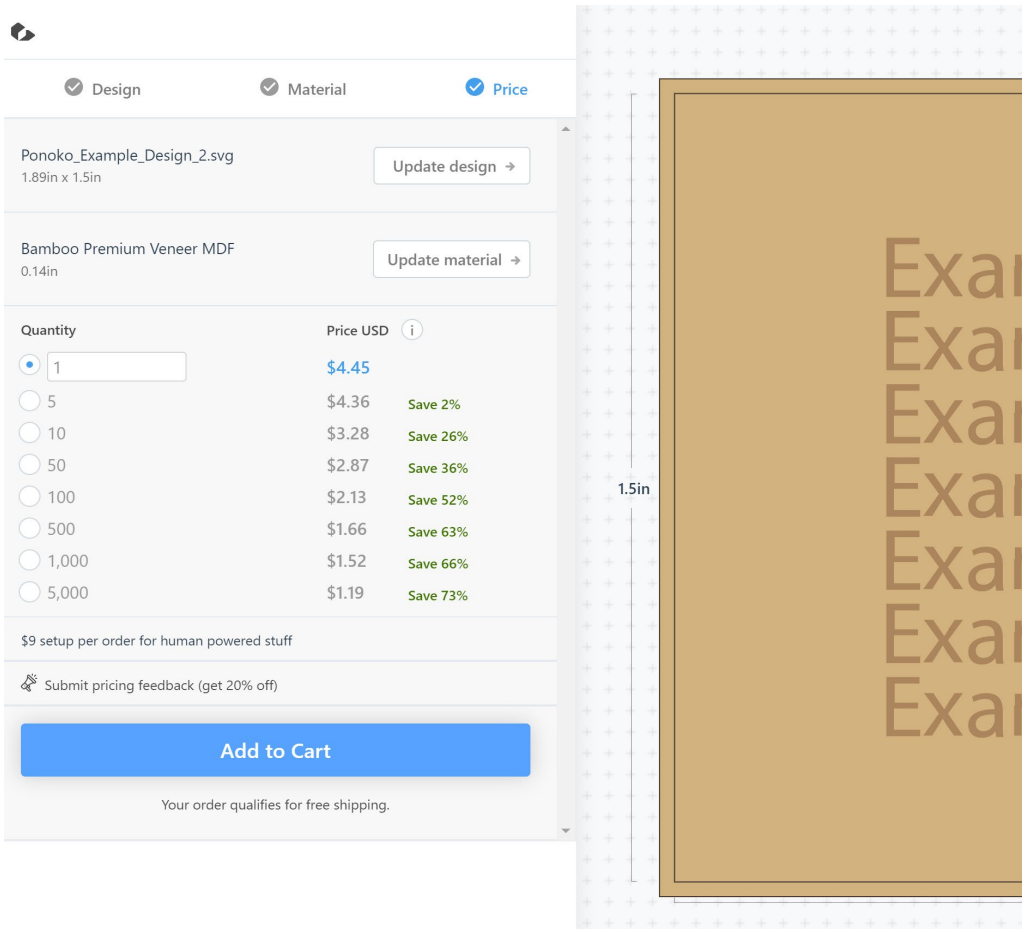


Figure 28: Example of Ponoko's Upload Procedure

2.14.8 Etsy

Etsy was founded in 2005 as a marketplace for handmade products, vintage goods, or craft supplies. According to the *Economic Impact of U.S. Etsy Sellers* (2019), Etsy marked more than $3.9 billion in sales in 2018, with more than 2.1 million sellers and 39.4 million active buyers. For 30% of these sellers, their creative business is their sole source of income.

While it is free to join and open a store, Etsy charges three fees: a 20-cent listing fee, a 5% transaction fee, and a 3 % + $0.25 payment processing fee. Listings last for four months or until the item is sold.

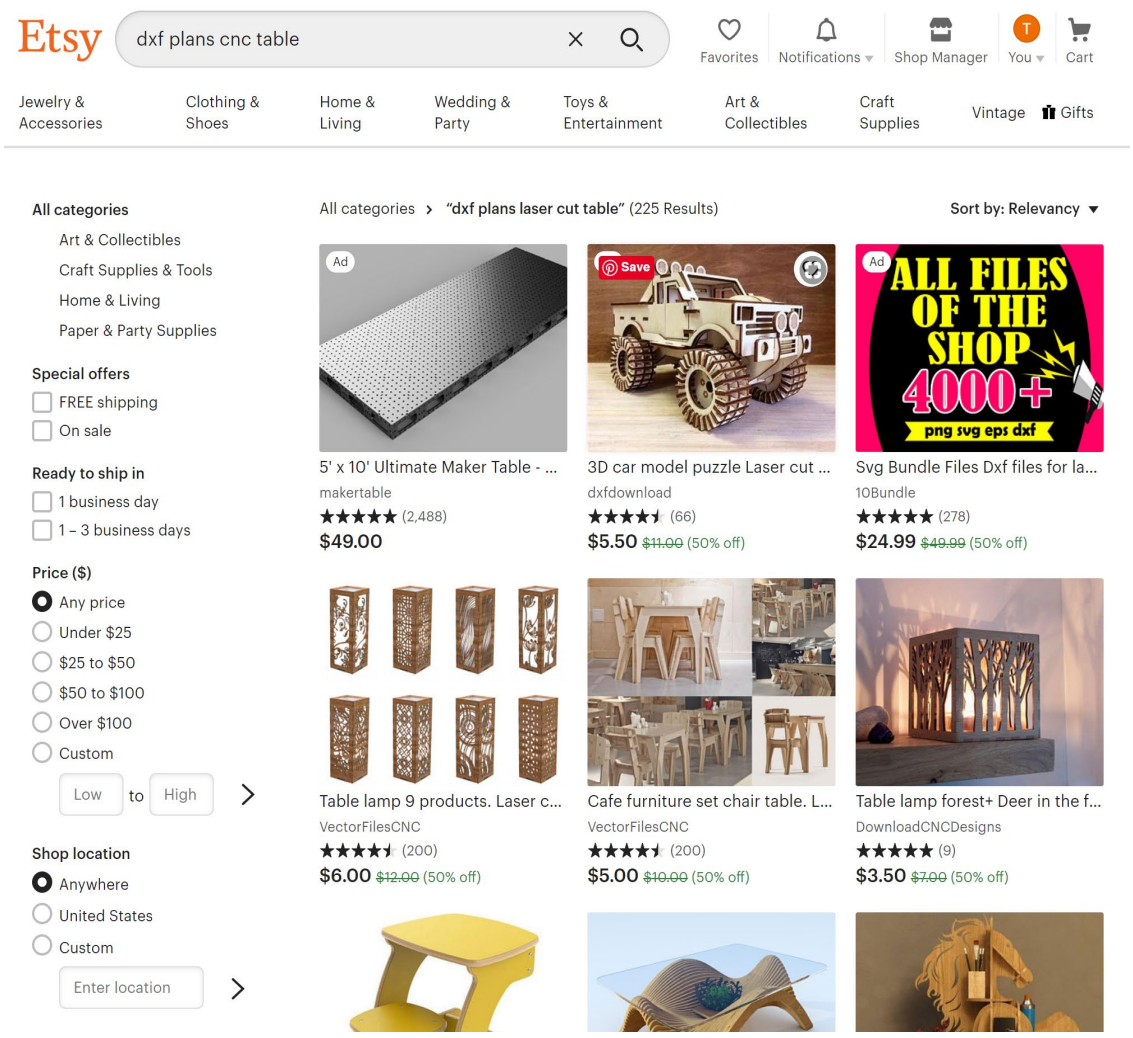


Figure 29: Example Etsy search for DXF plans for a CNC millable table

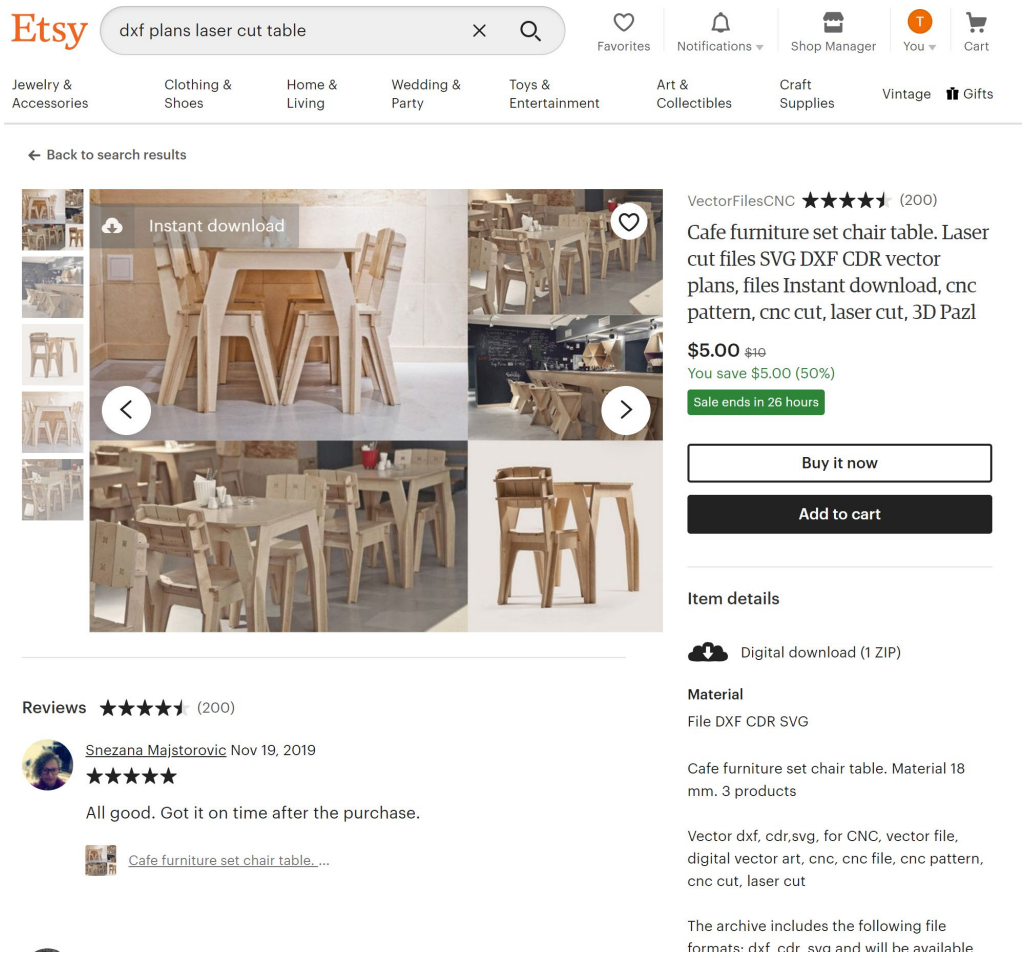


Figure 30: Etsy Product Listing for Cafe Furniture Set

2.14.9 Shopify

Shopify was launched as an e-commerce platform in June 2006 and as of 2019, hosts over one million businesses (“Shopify Announces Fourth-Quarter and Full Year 2018 Financial Results”, 2019). In 2009, they launched an App Store where developers can sell applications they develop for the Shopify platform. As a product, it offers businesses three plans to choose from to create their online storefront: Basic Shopify, which costs $29 a month, gives the business owner an online store with blogging capabilities, the ability to customize the theme and design, as well as an administrative portal to manage products, orders, and customer information.

Customers can choose to use a free myshopify.com domain name, or purchase their own. Selling fees using Shopify Payments is 2.9% + 30¢ per product. There are two additional storefront plans offered: Shopify ($79) and Advanced Shopify ($299). Each option offers various features, with the more expensive plans having advanced options like analytics, lower fees, and gift cards, among others (Figure 31).

For the distribution of digital downloads, Shopify has an app integration called “Digital Downloads” available for free download in their App Store (Figure 35). The application allows the seller to upload and distribute digital products, as well as indicate whether to manually or automatically fulfill orders in the form of a download or email link.

	Basic Shopify All the basics for starting a new business	Shopify Everything you need for a growing business	Advanced Shopify Advanced features for scaling your business
Monthly price	USD $29/mo	USD $79/mo	USD $299/mo
FEATURES			
Online Store Includes ecommerce website and blog.	✓	✓	✓
Unlimited products	✓	✓	✓
Staff accounts	2	5	15
24/7 support	✓	✓	✓
Sales channels Sell on online marketplaces and social media. Channel availability varies by country.	✓	✓	✓
Manual order creation	✓	✓	✓
Discount codes	✓	✓	✓
Free SSL certificate	✓	✓	✓
Abandoned cart recovery	✓	✓	✓
Gift cards	–	✓	✓
Professional reports	–	✓	✓
Advanced report builder	–	–	✓
Third-party calculated shipping rates Show calculated rates with your own account or third-party apps at checkout.	–	–	✓
SHOPIFY SHIPPING			
Shipping discount Competitive shipping rates from USPS, UPS, or DHL Express.	up to 64%	up to 72%	up to 74%
Print shipping labels	✓	✓	✓
USPS Priority Mail Cubic® pricing	–	✓	✓
SHOPIFY PAYMENTS			
Fraud analysis	✓	✓	✓
Online credit card rates	2.9% + 30¢	2.6% + 30¢	2.4% + 30¢
In-person credit card rates	2.7% + 0¢	2.5% + 0¢	2.4% + 0¢
Additional fees using all payment providers other than Shopify Payments	2.0%	1.0%	0.5%
POINT OF SALE			

Figure 31: Shopify Features

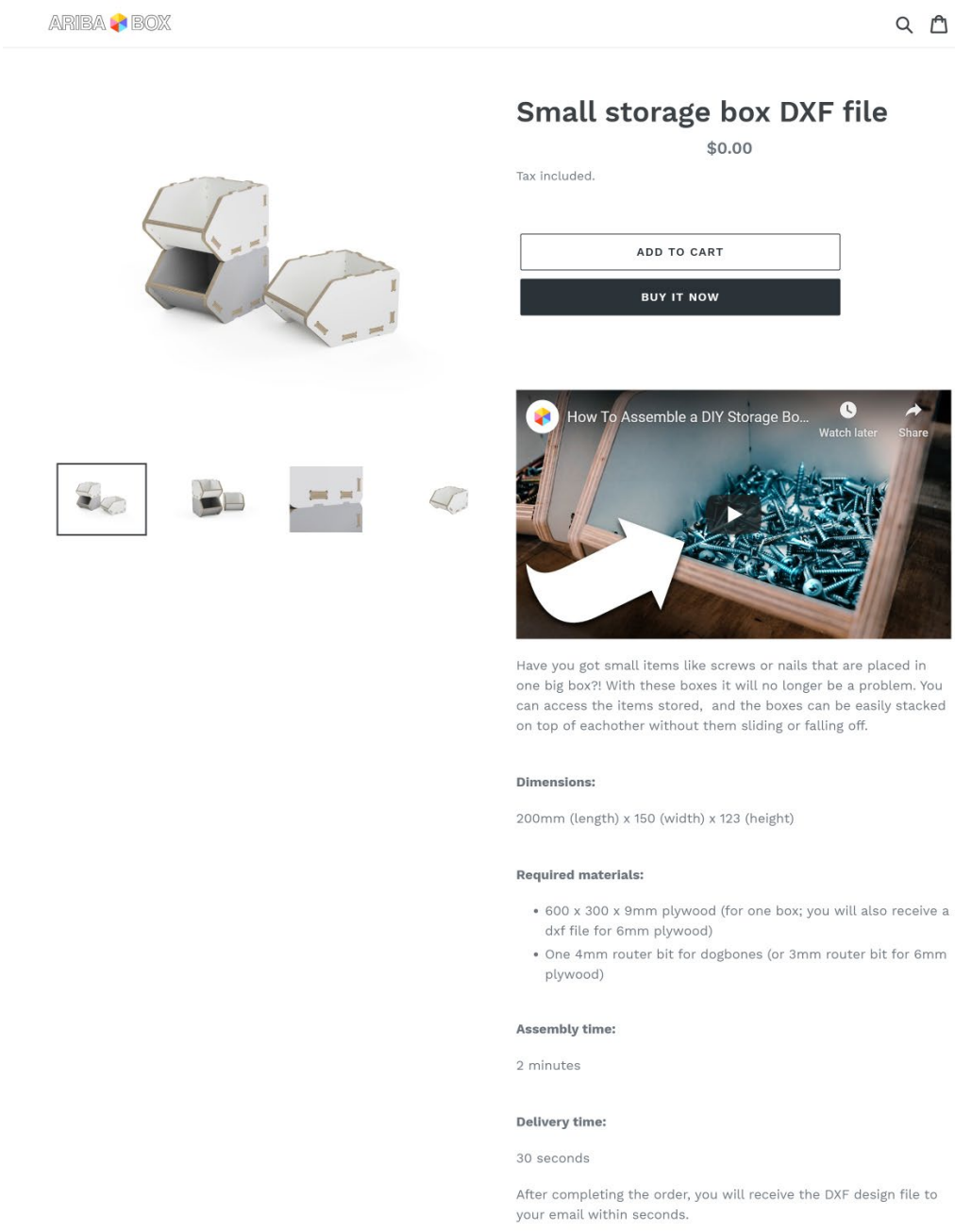


Figure 32: A product page from a webstore that utilizes Shopify's platform

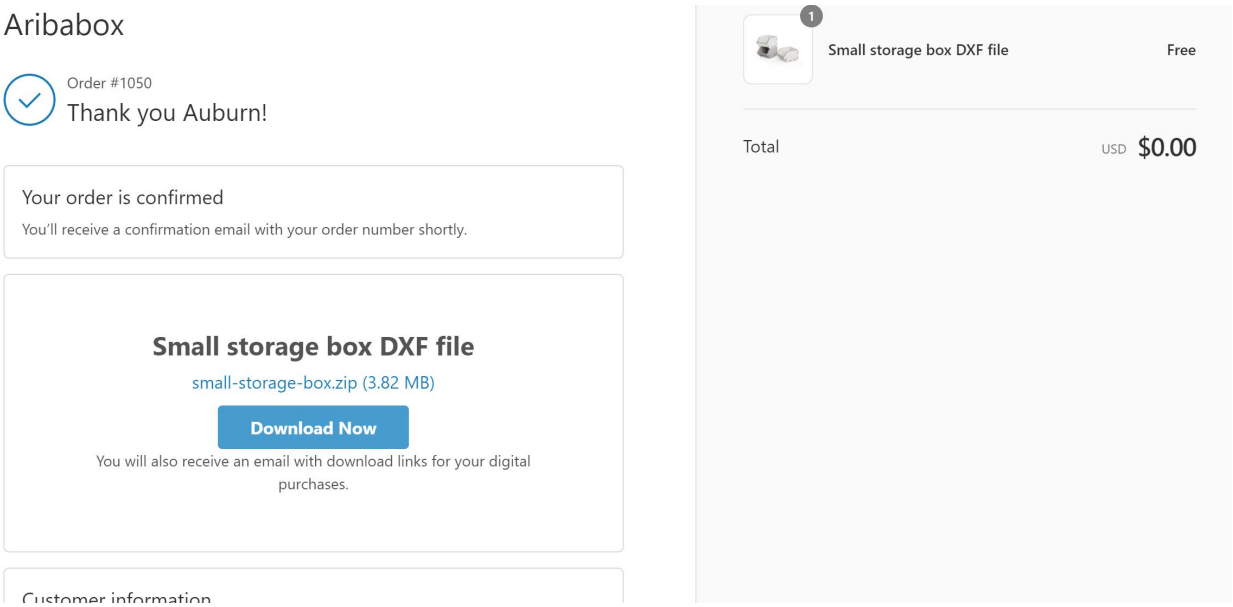


Figure 33: Shopify order confirmation page with link to download ZIP folder

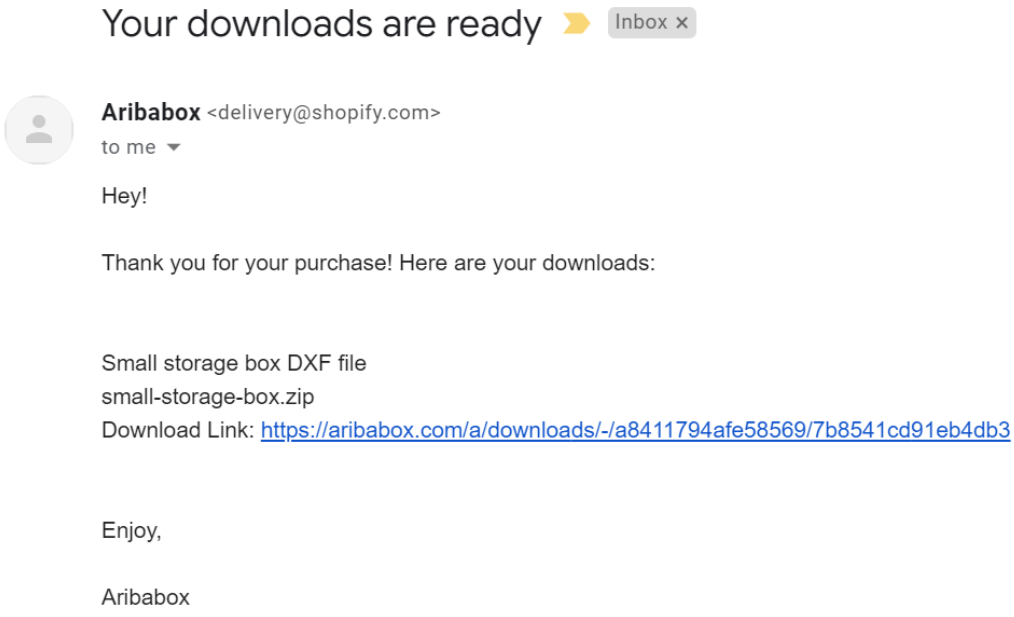


Figure 34: Email with link to download from Shopify

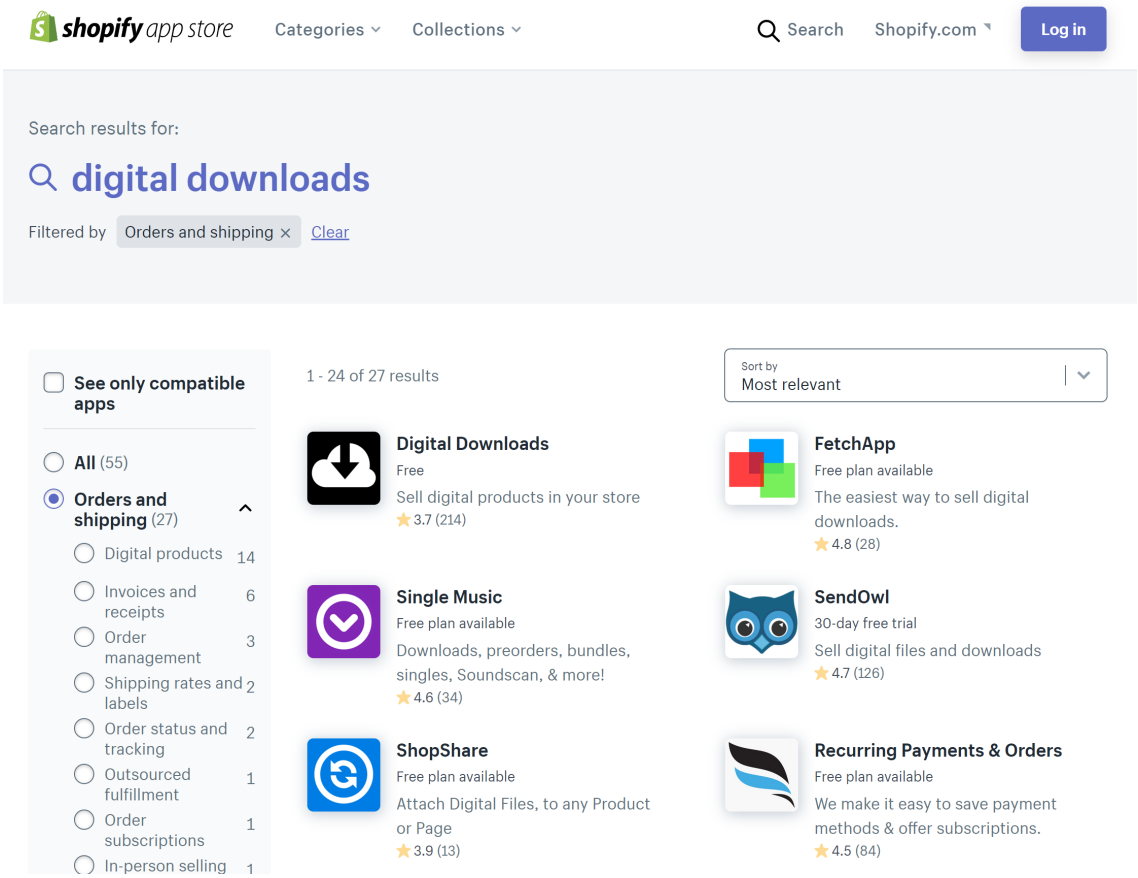


Figure 35: Example search for digital distribution integrations in the Shopify App Store

2.14.10 Big Cartel

Big Cartel is an e-commerce platform geared towards the creative industry, primarily artists, musicians, designers, and makers. Since 2005, the company has had over a million creators on the platform. Big Cartel offers one free plan, and three paid plans (Figure 36). The free Gold plan is limited in features— creators cannot use their own domain name and can only upload up to five products with one image each. Big Cartel does not charge their own processing fees on the sale of a product, but only gives the seller the option for two payment processing services: PayPal with a 2.9% + $0.30 fee and Stripe with a 2.75% fee on the selling price.

For digital downloads, Big Cartel developed an integration called Pulley (which can also operate as its own standalone service) that starts from $6 a month for 25 products and 100 MB of storage. Once a product is purchased, Pulley can automatically deliver the product to their email.

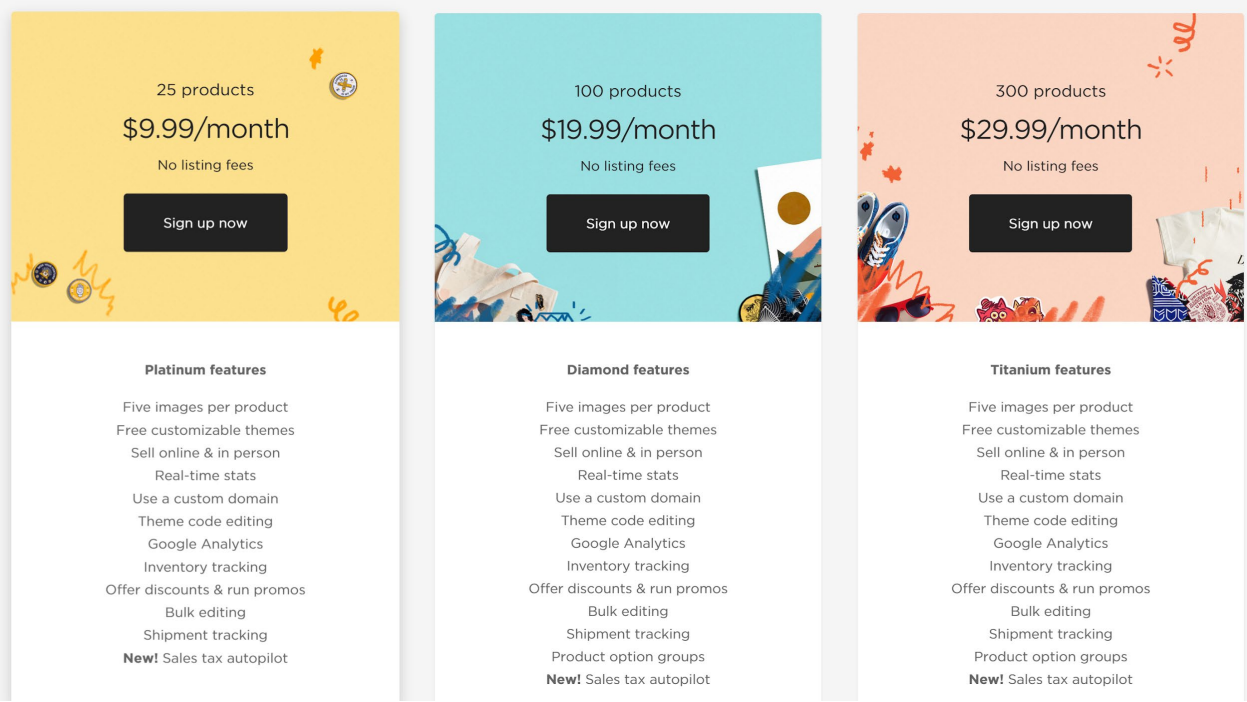


Figure 36: Big Cartel paid plan features

Figure 37: An example of a product listing on Big Cartel

2.15 Customization and Parametric Modeling

There are four approaches to customization: collaborative, adaptive, cosmetic, and transparent (Gilmore & Pine, 1997).

1. **Collaborative customization** entails working directly with the individual customer to create a product customized especially for them.
2. **Cosmetic customization** is when a standardized physical product is produced, but it is marketed or packaged specifically for different customers.
3. **Transparent customization** provides customers with a unique product without informing them that the product is customized for them.
4. **Adaptive customization** is a product that "offers one standard, but customizable, product that is designed so that users can alter it themselves" (Gilmore & Pine, 1997, para. 7). This is more commonly referred to as "mass customization." An example of this would be Hero Forge— a customizable character design application for tabletop figurines. Hero Forge allows customers to customize their character from head to toe, with options like faces, outfits, gear, and poses. After designing their character, customers can choose to download the STL file for $7.99 and 3D print it themselves or purchase a physical 3D model. Hero Forge partners with Shapeways for the production of 3D printed models.

Figure 38: Hero Forge Customizer Page

2.16 Pricing Designs

While a great number of 3D models are available for free download, it has become increasingly common to price more complex models for sale. Three factors are necessary in determining the price of a 3D model: understanding the market value, audience, and their purchase hesitations (Hazzard, 2015). Understanding the market value also involves not only knowing the available products, but also whether the product has the complexity to mark it as desirable for sale.

In a study conducted by Bashir and Thomson (2001), six factors are used to determine variances in productivity during the design process. These include: “product complexity, technical difficulty, severity of requirements, use of new technology, experience, skill, and

attitude of team members, team structure, use of design assisted tools, and use of a formal process" (p. 143). Though applied widely to design projects, these factors can be utilized to determine the time it takes to formulate and develop a design.

2.17 Distribution

There are two ways for designers to distribute their products: physical distribution, where the physical product ends up in the hands of the consumer or digital distribution, which is, as mentioned in section 2.5, the process through which digital goods are delivered to a consumer. Digital distribution can be separated into two venues: download and streaming. Downloads are the most common form of digital distribution on e-commerce platforms and occur when a file is stored onto a user's personal device (computer, mobile phone, etc). Streaming occurs when the digital product exists in the cloud (Figure 24) and cannot be stored on an individual's device, which helps the designer protect their intellectual property.

2.18 Digital Marketing and Social Media

Digital marketing has become more and more important for small businesses. In a survey of small businesses, the top 6 digital marketing channels were determined to be social media (73%), website (73%), email marketing (57%), SEO (49%), video (34%), and content marketing (32%) (Herhold, 2019). Benefits of digital marketing include the fact that it is relatively inexpensive compared to traditional advertising, and allows for experimentation.

Social media is defined as "a group of Internet-based applications that build on the ideological and technological foundations of Web 2.0 and that allow the creation and exchange of user-generated content" (Kaplan & Haenlein, 2010, p. 61). With over 3.5 billion users on

social media, advertising and marketing on popular social media websites, like Facebook, Instagram, Pinterest, and YouTube, has become necessary for online businesses. While businesses are able to purchase advertisements to target specific audiences based on location, interests, demographic, and behavior, for effective social media marketing companies need to move from trying to sell to consumers to forging relationships with them (Gordhamer, 2009).

To analyze how individuals, communities, and organizations can utilize various social media platforms to connect, monitor, and engage with each other, Kietzmann et al. (2011) developed a honeycomb framework (Figure 39) that organizes various facets (identity, presence, relationships, reputation, groups, sharing, and conversations) of the social media experience to determine the implications for firms and where they focus their marketing. Not all functions may be present in one platform; firms typically should focus on three to four blocks. The darker the block is colored, the more present the functionality in the social media site (Kietzmann et al., 2011).

Each section can be described as follows:

1. "Identity" is the center block in the honeycomb of social media and is "the extent to which users reveal themselves" in terms of age, gender, and other identifying information (Kietzmann et al., 2011, p. 243).
2. "Presence" refers to the ability to know whether or not another user is online and available. (For example, on Facebook Messenger, a user can be seen as "active".)
3. "Relationships" is how individuals are connected on each platform. On Facebook, friends can be identified as "family members" as well.

4. “Reputation” is “the extent to which users can identify the standing of other users and content” (Kietzmann et al., 2011, p. 247). This may be through the number of likes, follows, or engagement that a user has on the platform.
5. “Groups” is the ability for users to “form communities and sub-communities” (Kietzmann et al., 2011, p. 247). While some platforms may focus specifically on the community and sub-community formation, like Reddit, users with similar interests may “like” a page and also be in the same group.
6. “Sharing” is the exchanging of content with one another. These interactions can include engagements like posts, comments, re-shared content, likes, among others.
7. “Conversations” are “the extent to which social media users communicate with each other” (Kietzmann et al., 2011, p. 243). This can be as simple as how often the business posts, or how often consumers post brand-related comments.

In an example developed by Kietzmann et al. (2011), the honeycomb framework for Facebook shows while it may have elements of all the blocks, Facebook possesses a greater emphasis in building relationships, with a lesser focus in presence, identity, reputation, and conversations.

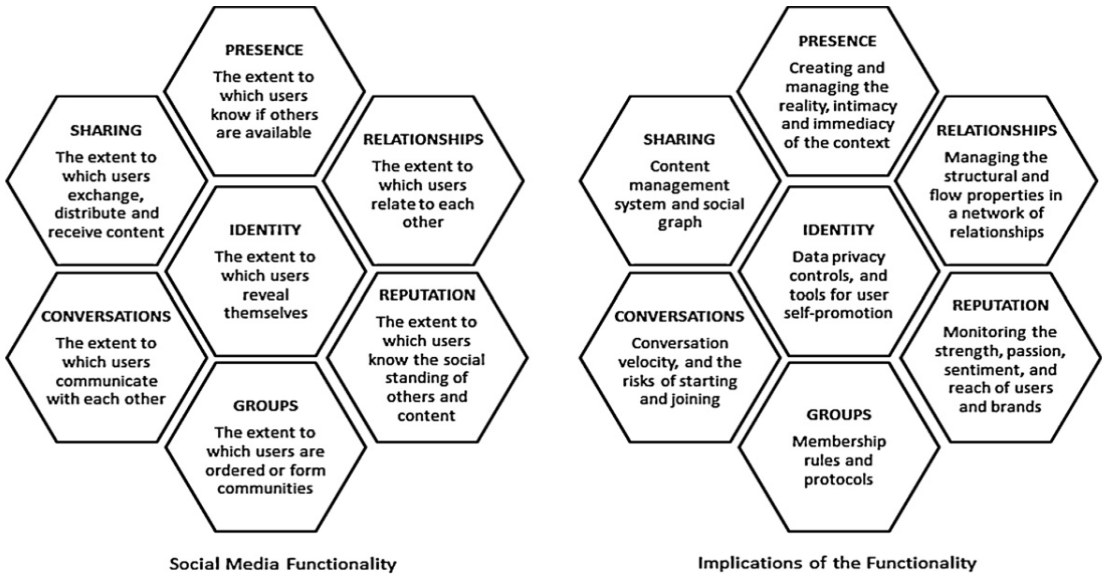


Figure 39: The honeycomb framework of social media (Kietzmann et al., 2011 p. 243)

Using this "honeycomb" framework, Kietzmann et al. also developed a guideline called the 4 Cs: cognize, congruity, curate, and chase - that a company should use to develop their marketing strategy for social media. Cognize is the recognition of a business's social media landscape primarily the available tools as well as how competitors may be using it. Congruity is the understanding that the firm's strategies and social media strategies are in alignment, as well as the determination of success metrics. Curate is as it sounds - the business must act as the curator of social media interactions and content by developing relationships and maintaining a consistent voice. The final C, which stands for "chase", is the chase for conversations and information regarding a brand, product, or individual.

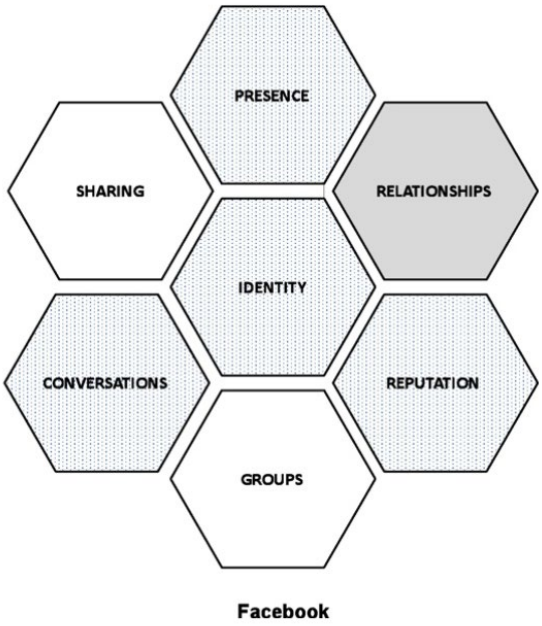


Figure 40: Facebook's honeycomb framework ((Kietzmann et al., 2011 p. 248)

Though Facebook has a greater user base, with about 2.45 billion monthly active users, Instagram has become a critical platform for microbusinesses. In fact, 90% of Instagram's one billion users follow at least one business on the platform, indicating that users actively seek out businesses to interact with ("Instagram Business", n.d.). In a study commissioned by Facebook IQ (2019), it was discovered that 54% of people surveyed made a purchase of a product after seeing it on Instagram. Instagram (2019), suggests that in order for a business to be discovered on Instagram, businesses must know how to utilize relevant hashtags and tags (Figure 41). Through the utilization of a variety of hashtags and tags, a business can increase their discoverability.

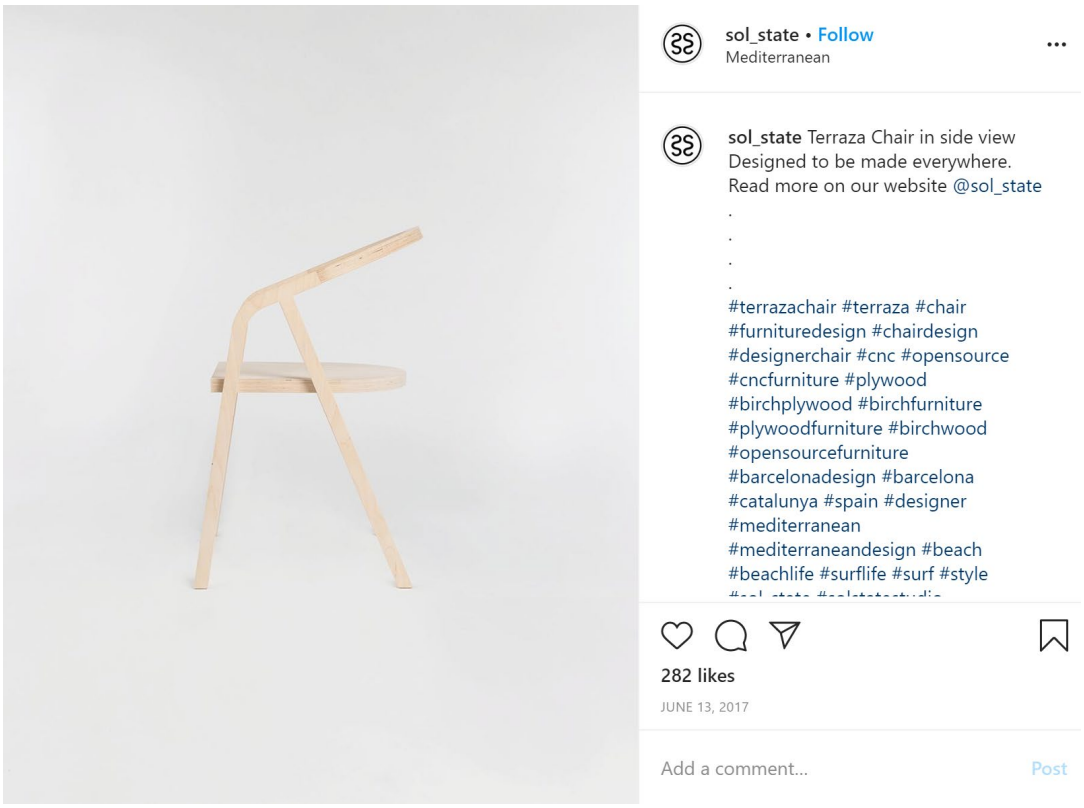


Figure 41: An Instagram post with too many tags

Businesses have the ability to track engagements in the form of likes, views, comments, follows, to assess the efficacy of posts on each social media platform.

Chapter 3: Guidelines

Overview

This chapter will provide a set of guidelines to help designers and makers determine how to design their digital CAD files for sale or distribution, with the intention of these objects becoming produced. The guidelines have been formulated in reference to the aforementioned case studies as well as observations from existing platforms and offer a suggestion as to best practices when developing CAD files for fabrication, as well as a step-by-step decision making process in order to assist the designer or maker in determining how best to distribute and create their CAD files.

Through following the flowchart (depending on the maker / designer's desire, the point at which a designer begins in the process may differ), and guidelines for monetization and marketing of their work, the designer will be able to evaluate how to proceed.

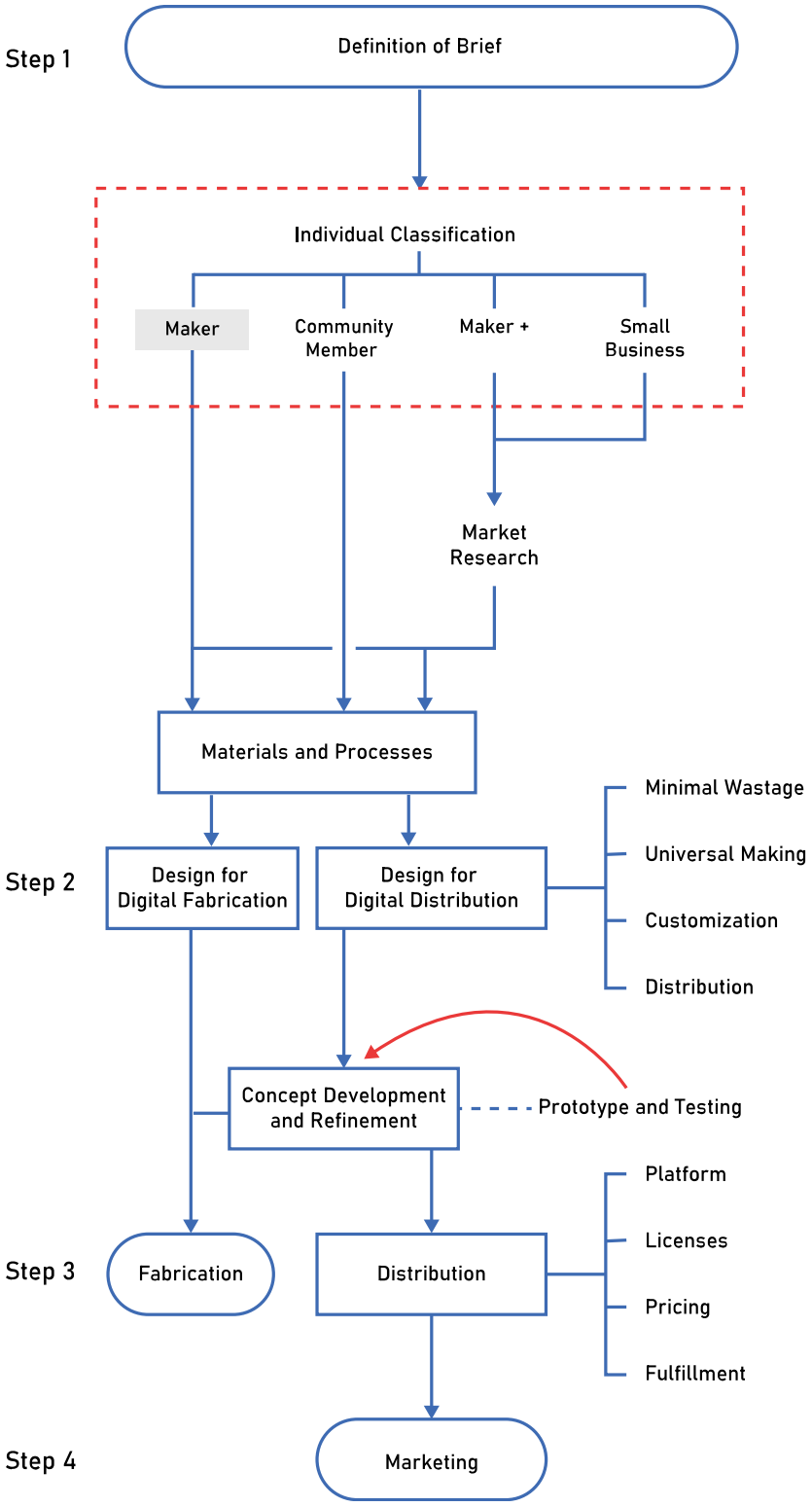


Figure 42: Design Process Flow Chart

Step 1: Definition of Brief

Design Brief and Objectives

Prior to designing the product for digital distribution, the designer or maker should determine the design brief and objectives regarding the product. This step requires the designer to assess their classification, as well as the needs and goals for the project.

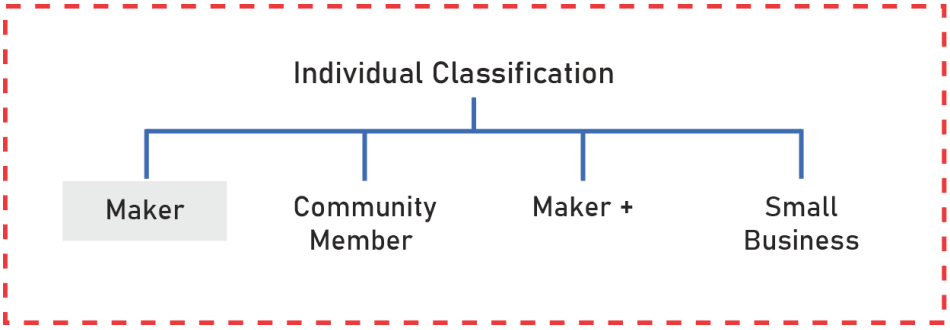


Figure 43: Classification of Individuals

Classification of the Designer Maker

While this guideline functions to help the designer or other interested parties to determine a process through which they can develop a product, it is important to classify them to determine the extent to which they should develop a 3D fabricable object. It is important to note that individuals can be classified in multiple types depending on the situation.

1. **Maker**: This type of individual develops a product that is solely for themselves. While they may upload this to an online community to share, the goal is to satisfy themselves rather than others.

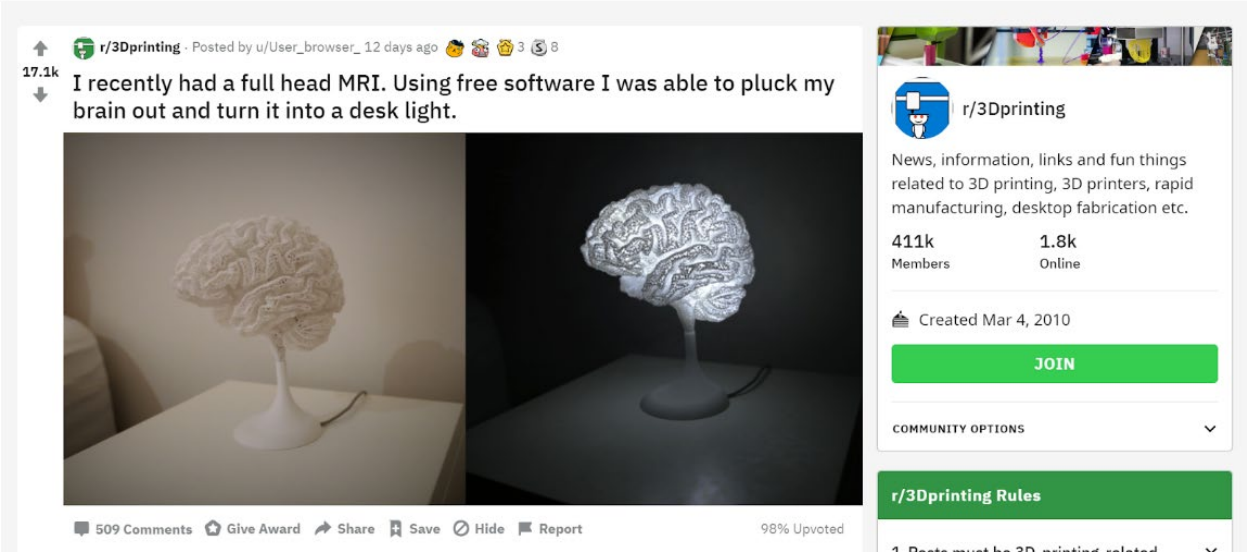


Figure 44: A submission to /r/3Dprinting on Reddit by /u/User_browser_

2. **Community Member**: A community member creates for the purpose of sharing with a community of like-minded individuals. They do not create with the intent of gaining profit, rather, derive satisfaction from knowing that others “like”, download, and produce their work.

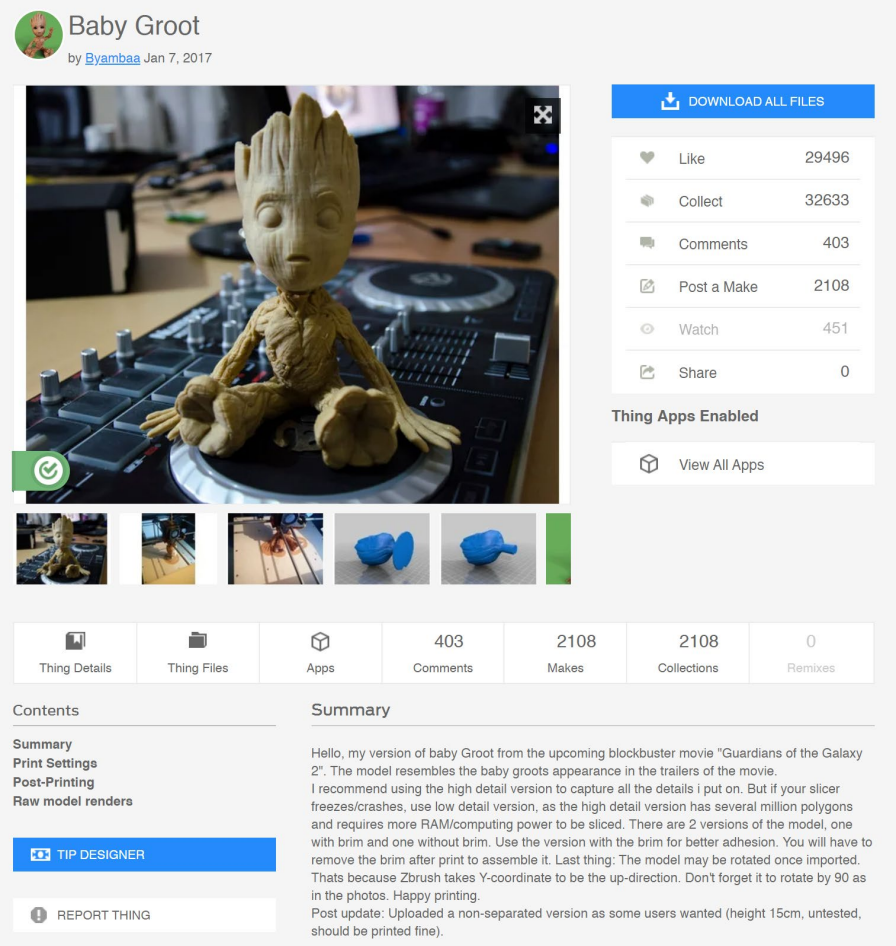


Figure 45: *Baby Groot* by user Byambaa on Thingiverse

3. **Maker +**: This individual designs with the intention of making a profit, though it may not be substantial. The object that they develop may relate to their interests and they passively seek to market and gain sales. This individual may also desire to have their side gig become a small business.

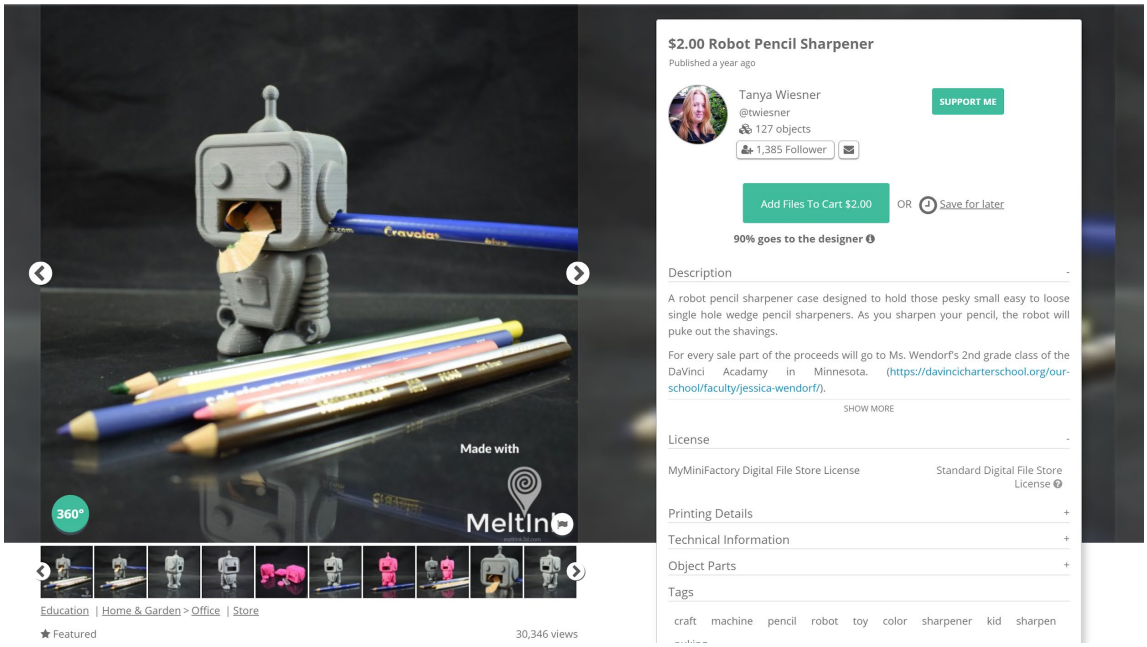


Figure 46: *Robot Pencil Sharpener* by Tanya Wiesner on MyMiniFactory

4. **Small Business**: This individual designs these products for a living. They are aware of other products in their field, and they actively seek to market their products and gain sales.

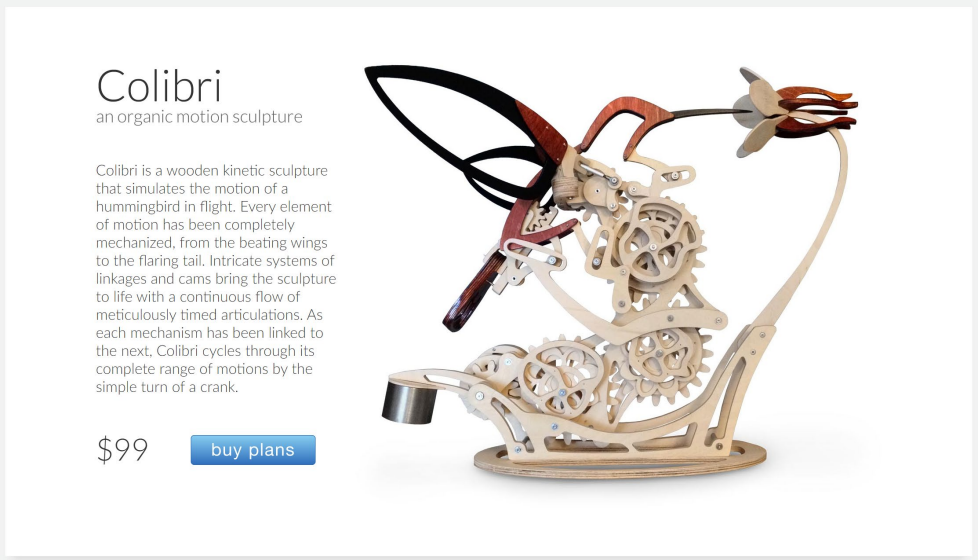


Figure 47: *Colibri* by Derek Hugger for sale on his personal webstore

Determining a designer's classification will dictate how they proceed in the design process. Many designers have "personal projects" that are based off of their interests, rather than referring to trends or gaps in the existing markets. In the case that the individual is developing a product for their own use, and not for sale, then the considerations would be lessor, as they need only to please the designer themselves. On the other hand, if a designer or maker is developing a product with an additional desire to sell or distribute the model, they should consider not only the consumer, but that of the potential fabricator as well.

Market Research

Prior to engaging in the actual design of the product, market research should be conducted. This involves understanding what other like products are on the market, as well as understanding what sort of processes that may be used. For products that are influenced by popular culture and media, it is imperative to note copyright and derivative laws.

Materials and Processes

Depending on the product to be developed, the designer should determine which process to use. CNC milling works for large pieces, but has limitations, like the inability to cut sharp inside corners. Projects that need a greater amount of detail, etching, or utilize thinner material, may use laser cutting. Objects with complex geometry should utilize 3D printing, which also comes with a slew of options. While FDM is the most popular, other processes like SLA printing have become more available to home consumers. Furthermore, 3D printing services like Shapeways, which specializes in SLS printing, are also readily available and provide design guidelines for each material. Prior to the design of the product, the designer should consider

potential suppliers or manufacturers. Design guidelines from fabricators should be referenced because technologies are evolving very quickly. If additional hardware is needed, the designer should also consider whether it's better to digitally fabricate the hardware or to find a readily available part.

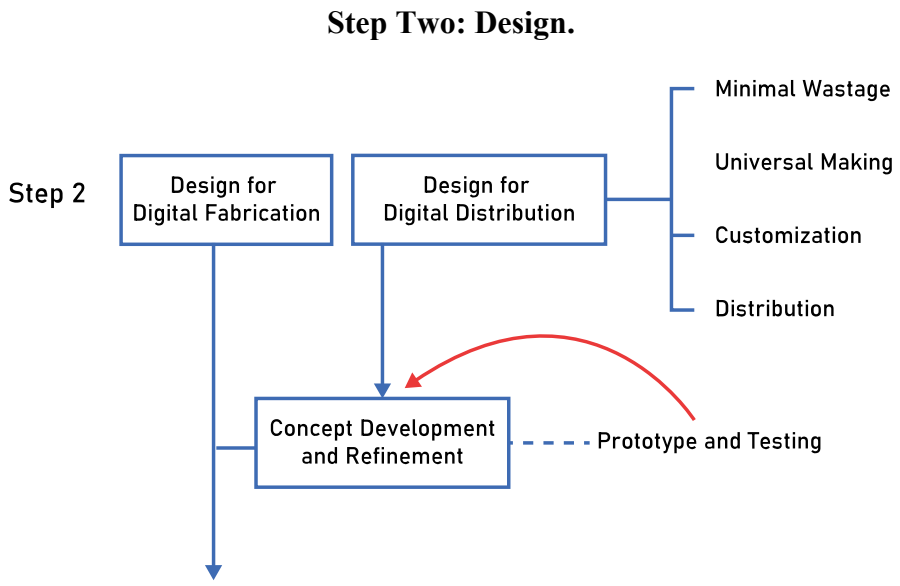


Figure 48: Step Two - Design

In the industrial design process, typically a designer will begin with iterative sketches before beginning the design of a CAD model. This allows for additional definition and clarity. While the use of a CAD modeling software like Fusion 360 can assist the designer in developing their product, in some 2D design cases, it may not be necessary. Based on the designer's capabilities and needs, they should be able to assess what tool best suits their situation.

Design for Digital Fabrication and Distribution

When designing a file for digital fabrication, the designer should consider a few factors depending on the manufacturing process being used. For digital fabrication, there are a few general rules that a designer can follow:

1. Design for minimal wastage
2. Design for universality
3. Design for customization
4. Design for distribution

Design for Minimal Wastage

When it comes to laser cutting and CNC milling, design for minimal wastage involves properly nesting the vector files on the material that is being used. While manual nesting is possible, software like SVGnest, an open source nesting program, is designed to assist the optimization of part arrangement on a sheet of material. This may lead the designer to modify geometry in a way that makes it easier to nest parts.

As referenced in Figure 49, designing for minimal material wastage for 3D printing involves fewer supports. In general, designers should limit overhangs to less than 45° to prevent the use of support material. While it is possible to adjust degree, type of support material, and extruder temperature to attempt to bypass this "rule," in order for others to replicate a design with maximum success, it is best to limit overhangs to 45°. Figure 49 also depicts how angles may affect support—on the letter "Y", because the angle is less than 45°, no support is needed, whereas it's necessary on the "H" and "T", both of which have 90° angles. Other options include printing multiple parts and assembling separately, reorienting the object so angles are less than

45°, chamfering edges, and adjusting slicer settings and speed, among others. Optimization of the design for the material and the process is necessary. For example, if designing for FDM printing, support is required in the case of overhangs. Designers should consider the model orientation and the design of certain details to minimize support materials. This may not be as much of a consideration if SLS is being used because the powder acts like a support for the object being printed.

Figure 49: Example of various overhang angles and support (Cain, n.d.)

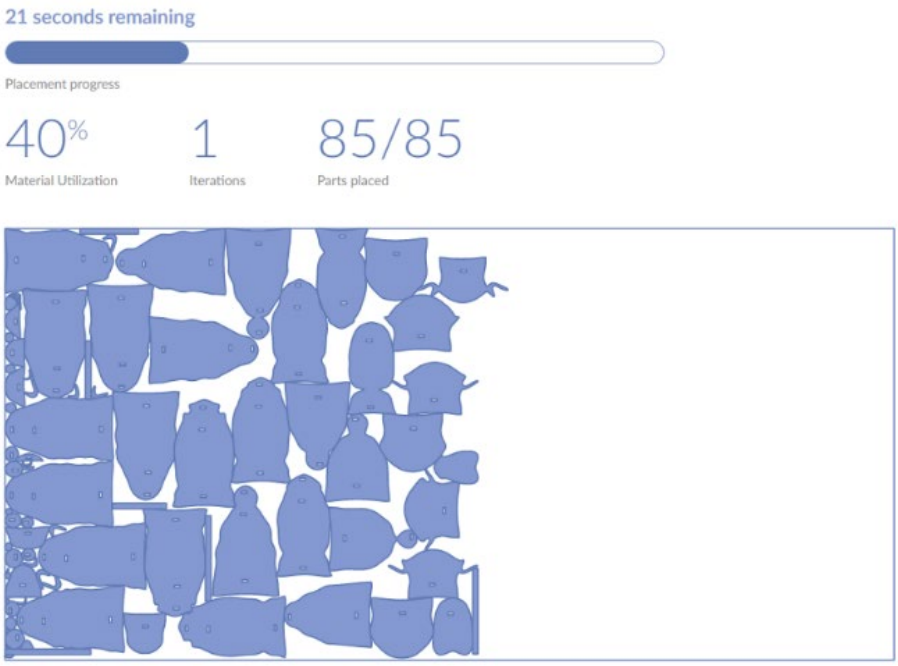


Figure 50: Example of a file nested with SVGnest

Design for Universality

For CNC projects, designs should be of a standardized material that is available all over the world, like plywood. Dimensions like 4’ x 8’ (1220 x 2440 mm) are common sheet sizes that are widely available, in thicknesses of ⅛” to 1 ¼”. However, one must consider the actual thickness of the wood as well—a ¾” thick piece of plywood would be 0.72 inches rather than 0.75 inches. It is important to consider choosing basic hardware components like nuts and bolts, which are available worldwide. Additional considerations would be drill bit size, among others. 3D printed projects should consider factors like common printing methods, printing bed sizes, and standard file formats (STL). Laser cut projects should consider common laser cutter bed sizes (12” x 24”) or sizes offered by laser cutting services like Ponoko (23.5” x 11.5” or 31.1” x 15.1”), as well as utilize common materials with standard sizes.

Design for Customization

The benefit of digital fabrication is that molds, jigs, or other tooling is not necessary—customizing a model does not require any additional tooling components. Creating a design for customization requires the maker to set parameters like sizing, material thickness, and dimensions that can be adjusted. This can be directly integrated into interfaces like Thingiverse's Customizer. Other options for customization are MyMiniFactory's Customizer which allows the customer to pick and choose different parts to integrate into a model.

Customization of CNC products tend to be more static; while it is possible to upload 3D models with parameters, it's often simpler for the maker to create a design and offer a few common sizes and variations in the form of incremental sizes and option that don't require the change of digital files, or a library of customized options and material options.

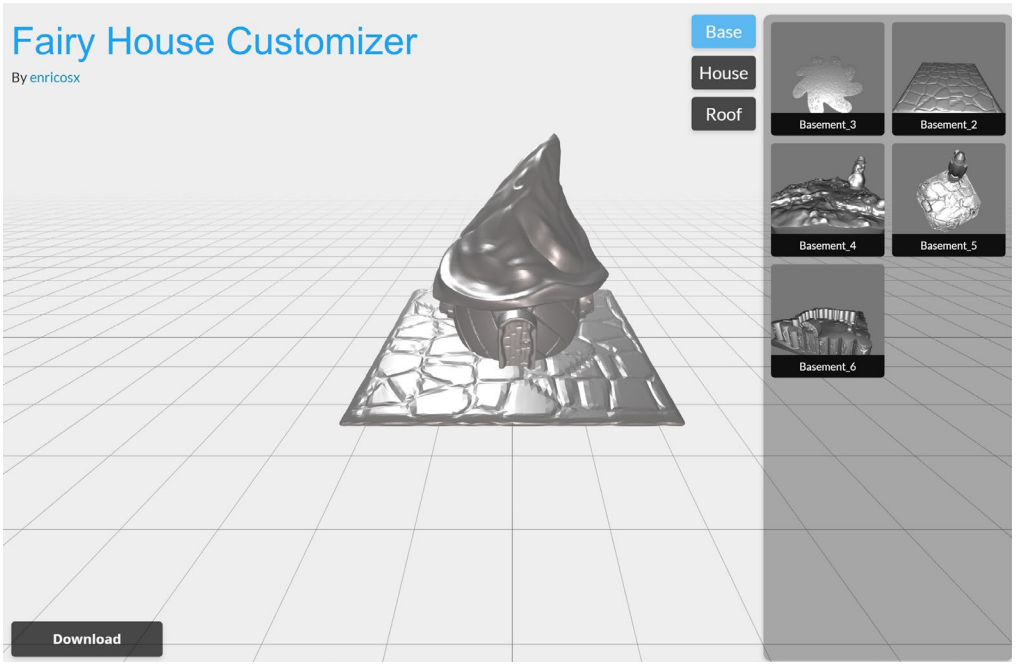


Figure 51: MyMiniFactory Customizer

Design for Distribution

Files should be shared in common vector formats for use by CNC machines, like DXF or AI. When uploaded to a repository, files should be compressed into a ZIP folder with files clearly labeled and organized. Upon extraction, each file should be immediately understandable. (Refer to Figure 25: Contents of an Opendesk “Make-It-Yourself” folder.)

Instructions and materials required should be clearly expressed without the need for words. Assembly should not be complicated—minimizing the diversity of parts, labeling parts, and using large pieces over many small ones all are ways to make this easier on the customer.

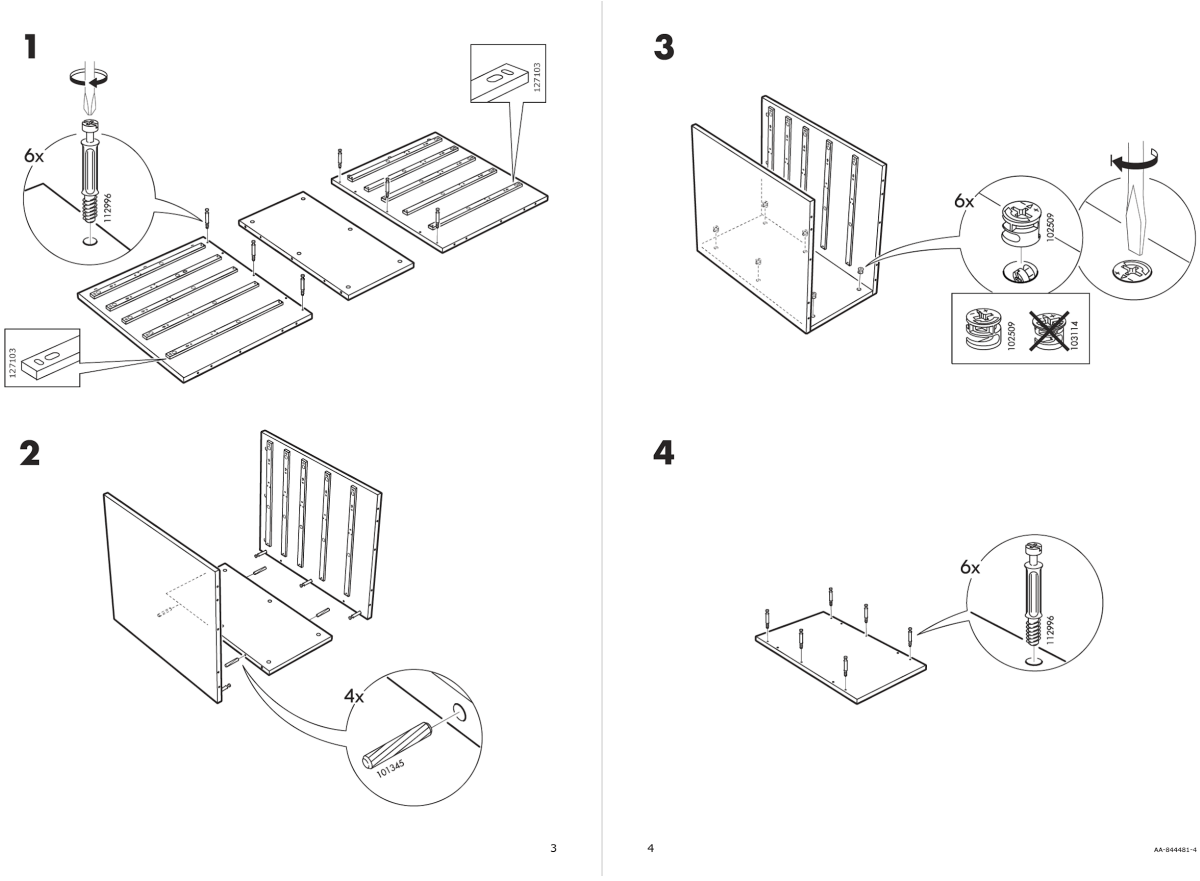


Figure 52: Assembly instructions for Linnmon / Alex desk from IKEA

3D printing projects should be tested for viability prior to upload. Recommended file formats for upload include STL, the standard format for 3D objects. For objects with a need for assembly, a step-by-step assembly guide featuring print settings is also suggested.

Concept Development and Refinement

In the design process, this would quantify as the prototyping and testing stage. The design has been fully fleshed out and should be fabricated in full scale with recommended materials and settings to ensure that it works and is feasible as a physical product. This stage offers the designer the opportunity to make additional modifications to the digital models and informs the design of the assembly guide. This phase also considers feedback from the buyer; because this is a digital file, the product can be continuously refined.

Step Three: Distribution

Figure 53: Step Three - Distribution

Step three is distribution, and involves the processes through which an individual may go through to list their "product" for digital distribution.

Platform

As depicted in the case studies in Chapter 2, there are a variety of online repositories and marketplaces where the designer can sell and distribute their digital files. Typically because production will utilize a third party software (like Cura, UGS, or LaserWeb), it will be downloaded onto an individual's computer prior to fabrication. Therefore, all files should be packaged into an easy to understand archive file format like ZIP.

Platform	Free / Hybrid / Paid	Digital Fabrication Type	Fees	Manufacture?	Marketplace search?
Big Cartel	Hybrid	CNC, laser cut, 3DP	Free option, then plans starting from $9.99 a month. No transaction fees other than those charged by payment provider	Shapeways integration	No
Etsy	Paid	CNC, laser cut, 3DP	20 cent listing fee, a 5% transaction fee, and a 3% + $0.25 payment process fee	3DP has option for Shapeways integration	Yes
GrabCAD	Free	3DP	N/A	No	Yes
MyMiniFactory	Hybrid	3DP	$24.99 a month, plus 10% fee on the selling price	No	Yes
Pinshape	Hybrid	3DP	Additional 30% on top of the markup	No	Yes
Shapeways	Paid	3DP	3.5% fee on top of markup	Yes	Yes
Shopify	Hybrid	CNC, laser cut, 3DP	Plans starting from $29, additional 2.9% + 30¢ on each item sold	3DP has Shapeways integration	No
Thingiverse	Free	Primarily 3DP, also CNC, laser cut	N/A	Partners with Print a Thing, Treatstock, and NinjaPrototype	Yes
Personal Website*	Hybrid	CNC, laser cut, 3DP	Depends on platform / payment provider	Depends	No

*Up to the discretion of the designer

Table 1: Common Marketplaces for Digitally Fabricable Files

3D Printing Service	Shipping	Materials
3D Hubs	Worldwide	PLA, ABS, ASA, TPU (FDM), Resin, Nylon (MJF/SLS/FDM), Nylon 12-GF (SLS/MJF), PA 12-FR, PA 11 (MJF), HST, PETG (FDM), PEKK, Stainless Steel, Aluminum, Titanium
3D Print-Au	Australia, New Zealand	Nylon (SLS)
3D Printing Ally	Worldwide	ABS, Polycarbnate PC (FDM), Ultem, Nylon (SLS), Resin
3D Systems On Demand	Worldwide	ABS, Nylon, PA 11 (SLS/MJP), Polypropylene PP (SLA/MJF/SLS), Resin, Titanium, Stainless Steel, Maraging Steel, Cobalt-Chrome, Aluminum, Nickel, castable Wax
3DExperience Marketplace Make	Worldwide	PLA, ABS, PC ABS, ASA, PEI, PET, TPC, HIPS, TPU (FDM/MJ/SLS), TPE (FDM/SLS), PETG, Woodlike PLA, PEEK, PEKK, Nylon (FDM/SLS), PA 12-GF (SLS), Resin, Tough Resin, Polypropylene PP, ULTEM, Steel, Aluminum, Stainless Steel, Steel, Nickel, Cobalt, Titanium, Zinc, Copper, Silver, Gold, Titanium, Platinum, Castable Wax, Synthetic Sand
3Diligent	Worldwide	ABS, Ultem, PC-ABS, Polycarbonate PC (FDM), Nylon (FDM/MJF/SLS), PA 12-GF (SLS), Resin, Aluminum, Stainless Steel, Titanium, Nickel, Inconel, Paper, Sandstone
AutotivMFG	USA	Nylon (SLA/SLS/MJF), PA 12-GF (SLA/SLS/MJF), PLA, Resin, TPU (SLS), Ultem, Aluminum, Titanium
Beta Layout	Worldwide	Nylon (SLS), PA 12-GF (SLS), PEE, Alumide, Stainless Steel, Inconel, Cobalt Chrome
Craftcloud	Worldwide	PLA, ABS, Nylon (FDM/SLS), PA 12-GF (SLS), Resin, Carbon™ Resin, Tough Resin, PETG (FDM/SLS), TPU (SLS), Polypropylene PP, Woodlike PLA, ULTEM, Steel, Aluminum, Alumide, Brass, Plated Metal, Copper, Silver, Gold, Titanium, Platinum, Wax
FacFox	Worldwide	PLA, ABS, TPU (SLS), ASA, Ultem, Nylon (FDM/SLS/MJF), PA 12-GF (SLS), Resin, Photopolymer PP, Stainless Steel, Bronze, Aluminum, Titanium, Maraging Steel, Cobalt Chrome, Sandstone
Fast Radius	Wordwide	ABS, PC, PC-ABS, ULTEM, ASA, PC-ISO, PPSF, Nylon (FDM), Resin (SLA, DLS), Nylon 12-PA (SLS), PP, Nylon 12-GF (SLS), Stainless Steel (L-PBF), Aluminum (L-PBF), Inconel (L-PBF), Titanium (L-PBF), Cobalt Chrome (L-PBF)
Fathom	Worldwide	ABS Ultem, Polycarbonate PC, ASA, TPU (FDM), Resin, Nylon (MJF/FDM), Acrylic, Nylon (SLS)
HK3DPrint	Worldwide	ABS, Nylon (SLS), Polycarbonate PC, Photopolymer PP, Resin
Jawstec	USA, Canada, Mexico	Nylon (SLS, MJF), PA 12-GF (SLS)
Kraftwurx	Worldwide	ABS Plus, Ultem, Polycarbonate PC, Photopolymer PP, Nylon (SLS), Gold, Aluminum, Stainless Steel, Bronze, Ceramic, Copper, Acrylic, Palladium, Casting Wax
Materialise OnSite	Worldwide	ABS, Polycarbonate PC, PC-ABS, Ultem, Nylon (SLS/MJF), Polypropylene (PP), TPU (SLS), PA 12-GF, PA 12-FR, Alumide, Aluminum, Stainless Steel, Titanium, Inconel
Protolabs	Worldwide	ABS, Nylon (SLS/MJF), Polycarbonate PC (SLA), Polypropylene PP (SLA), Digital Photopolymer, Aluminum, Copper, Stainless Steel, Titanium, Inconel
SD3D	Worldwide	PLA, ABS, PETT, PET+, PC-ABS, CF-PLA, CF-ABS, CF-PETG, CHETAH, PCTPE, FLEXSOLID, TPU, Nylon (SLS)
Sculpteo	Worldwide	Nylon (SLS/MJF), PA12-GB, PA12 Carbon, PEBA, TPU, Alumide, Resin, Stainless Steel, Aluminum, Titanium, Brass, Bronze, Silver, Plated Metal
Shapeways	Worldwide	Nylon (SLS/MJF), PA 11, PA 12-GB (SLS/MJF), Resin, TPU (SLS), Aluminum, Steel, Plated Metal, Brass, Silver, Gold, Bronze, Sandstone
Star Rapid	Worldwide	Titanium, Steel, Aluminum, Maraging Steel
Stratasys Direct	Worldwide	ABS, ASA, Nylon (MJF/SLS), PA 12-GF (MJF/SLS), PC, PEKK, PPSF/PPSU, TPE, ULTEM, Resin, Aluminum, Cobalt Chrome, Copper, Inconel, Monel, Steel, Titanium
Treatstock	Worldwide	PLA, ABS, Nylon (SLS/FDM), Stainless Steel, TPU, Titanium, Aluminum, Brass, Polycarbonate, Castable Wax, PETG, Resin, Cobalt-Chrome
Trinckle	Worldwide	Nylon (SLS), ABS, Acrylic, Plaster, TPE (SLS), Alumide (SLS), Silver
Voodoo Manufacturing	Worldwide	PLA, TPU (FDM), PETG, TPU
WeNext	Worldwide	Resin, Nylon (MJF, SLS) PA12-GF
WhiteClouds	No reply to our request	Nylon, Resin, full-color Sandstone
Xometry	North America	ABS, Nylon (SLS/MJF), PA 12-GF (SLS/MJF), Resin, Polycarbonate PC, Ultem, Stainless Steel, Aluminum
ZVerse	USA	Resin (SLA/DLS), Carbon™ Resin, Nylon CE (DLP), PA 2200 (SLS), Sandstone, Metal
i.materialise	Worldwide	ABS, TPU, Nylon (SLS/MJF), Alumide, Polypropylene PP, Resin

Figure 54: Platforms for Manufacturing 3D Prints (All3DP, 2020)

Licenses

A designer can choose from various types of licenses depending on how much ownership they would like to retain on their design.

For free, open designs, designers can choose from a variety of Creative Common licenses, depending on what sort of licensing conditions they would like to provide. Table 2 features the seven most common Creative Common licensing variations.

Icon	Description	Attribution Required	Remix?	Commerical use?	Free Cultural Works?	Meets OKF 'Open Definition?'
	Attribution alone	Yes	Yes	Yes	Yes	Yes
	Attribution + Noncommercial	Yes	Yes	No	No	No
	Attribution + Noncommercial + No Derivatives	Yes	No	No	No	No
	Attribution + Noncommercial + ShareAlike	Yes	Yes	No	No	No
	Attribution + No Derivatives	Yes	No	Yes	No	No
	Attribution + ShareAlike	Yes	Yes	Yes	Yes	Yes
	No restrictions	No	Yes	Yes	Yes	Yes

Table 2: Creative Common Licenses

Alternatively, if a designer wishes to sell their goods, they may want to retain ownership of their digitally fabricable design. In this case, it is recommended that the design be given a "non-commercial, personal use only license." This indicates that the customer is only given permission to create a physical end product, but not for resale or wholesale.

Pricing Digital Goods

While a great deal of digitally fabricable designs are available for free download, it is understandable that one may want to monetize their efforts. There are three factors that should be considered when it comes to pricing digital goods.

1. **What is available in the market?** It is important to price against the competition. Understanding the cost of other digitally fabricable items at similar complexities can help inform what to price at.
2. **Who is your audience?** Who are the potential customers and what are their considerations?
3. **What is the complexity of the object?** How much difficulty went into designing and fabricating the product?

Pricing for 3D files in general ranges from $1-10, with few willing to pay more than that. Colleen Jordan shares her 3D printable Bike Planter model for free on Thingiverse (Figure 55), but also sells the same planter as a physical model on Etsy for $45. These physical planters are printed through Shapeways.

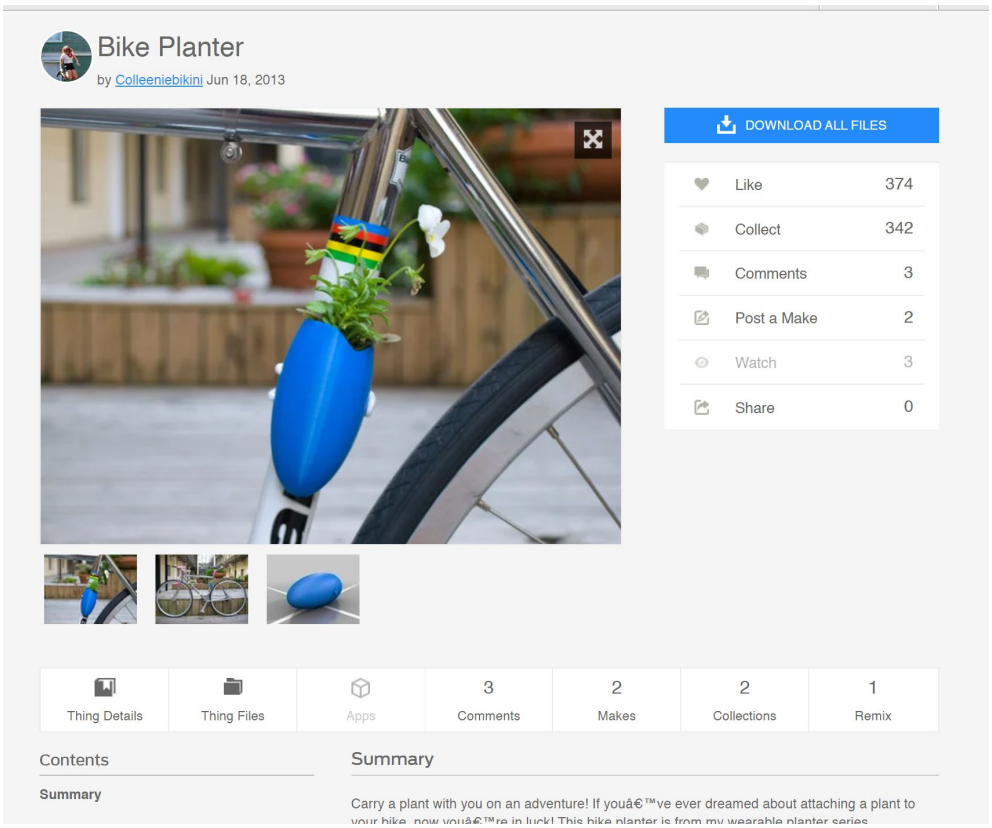


Figure 55: 3D Printable files for Bike Planter on Thingiverse

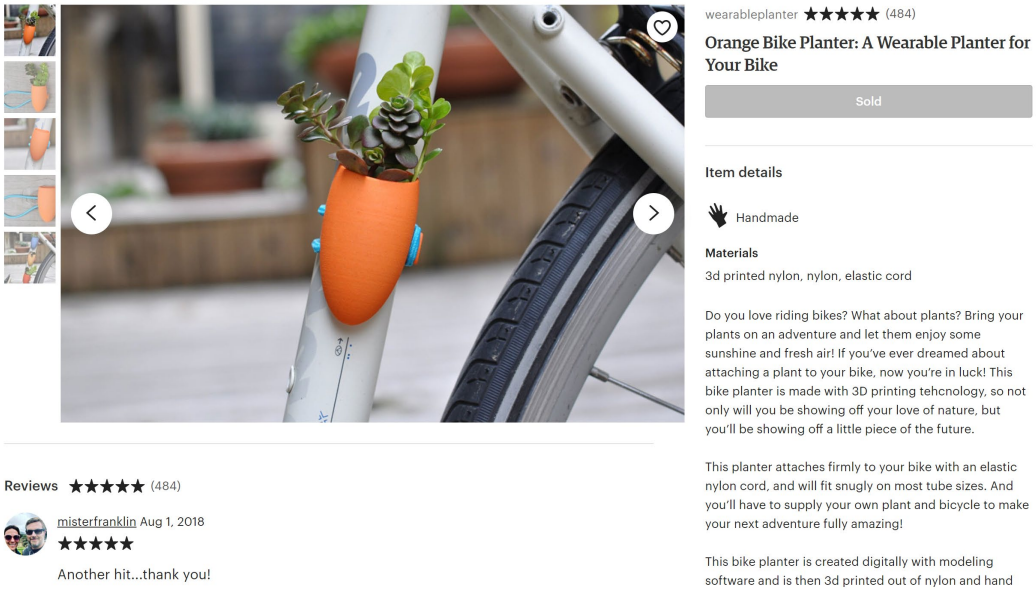


Figure 56: Listing for 3D Printed Bike Planter on Etsy

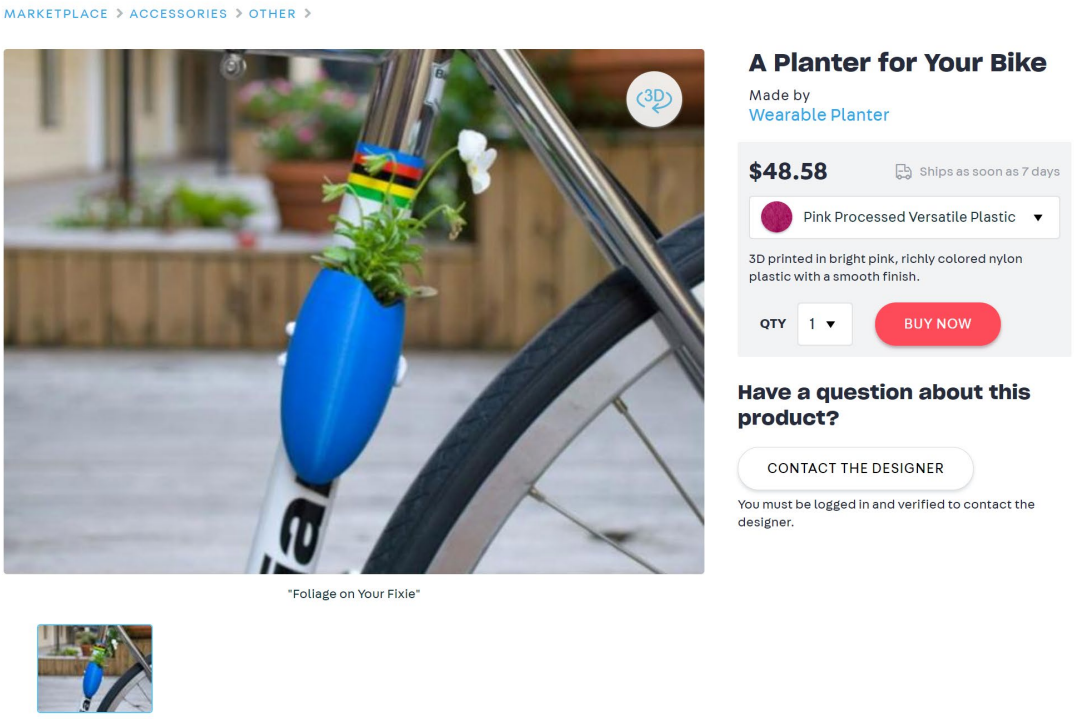


Figure 57: Listing for 3D Printed Bike Planter on Shapeways

Fulfillment

The product provided to the customer will ultimately be a compressed ZIP file with the model in the form of a STL file (Figure 25) or DXF/AI/vector file, an assembly guide (Figure 26), images, as well as licensing information.

Depending on the platform onto which the designer chooses to sell their product, the fulfillment process may be automated and as simple as a download button. Other alternatives are to email the customer a link to download the file or alternatively offer the option to purchase the physical model.

Step Four: Marketing

Figure 58: Step Four - Marketing

The final step is marketing, which sets the tone for how the product is perceived by potential consumers. This involves photography, product expectations, as well as how to determine what platforms to focus on for social media marketing.

Product Listings

Social media platforms and marketplaces are all visual platforms - photographs of the physical product—not renderings—at three or more angles, are more likely to be sold (see 2.14.4). In context photography of what the final product may look like gives the customer a better idea of what they are purchasing, and helps them alleviate risk.

In the item description, the product expectations and product dimensions (and potential customization) should be clearly stated. Because digital plans tend to be much more inexpensive in price relative to a physical product, the designer should explicitly mention that they customer will only receive digital plans, not a physical product.

It is important to note that product listings are an opportunity to utilize tags and keywords to generate traffic to one's products; the more products available in a store, the greater the probability it will be seen by a potential customer.

Social Media

While it's a good idea to have a presence on all social media platforms, it would be beneficial to determine which functional blocks of social media (see 2.18) are most relevant to the designer's brand and how they wish to portray themselves. The designer should utilize the honeycomb framework to help them determine which social media platform to focus their efforts on.

Because it is important for small businesses to forge a connection with potential customers, elements like sharing, groups, and relationships may be more prominent, so social media networks like Instagram may be recommended, and it may be beneficial to take a look at Reddit (Figure 44) or niche forums to see what other markets may be doing as well.

From there, a social media strategy can be developed featuring a consistent post rate, exchanges with potential customers, among others.

Summary

While the application of these guidelines cannot guarantee how successful a product may be in the market, it helps advise the designer through the development process of designing and marketing a digitally fabricable item. Through the assessment of each of the considerations, a designer should be able to classify themselves, and determine whether or not their product should be sold or offered for free. They should be able to design a product that is designed for both digital fabrication and distribution, and also be able to determine how best to distribute and fulfill their product for the consumer. The designer should also end up with a basic understanding of how best to market their product.

Chapter 4: Application

This chapter will examine the method derived from the flowchart established in Chapter 3 toward the design and marketing of a **nightstand or bedside table**.

4.1 Application of Method: Step 1 - Definition of Brief

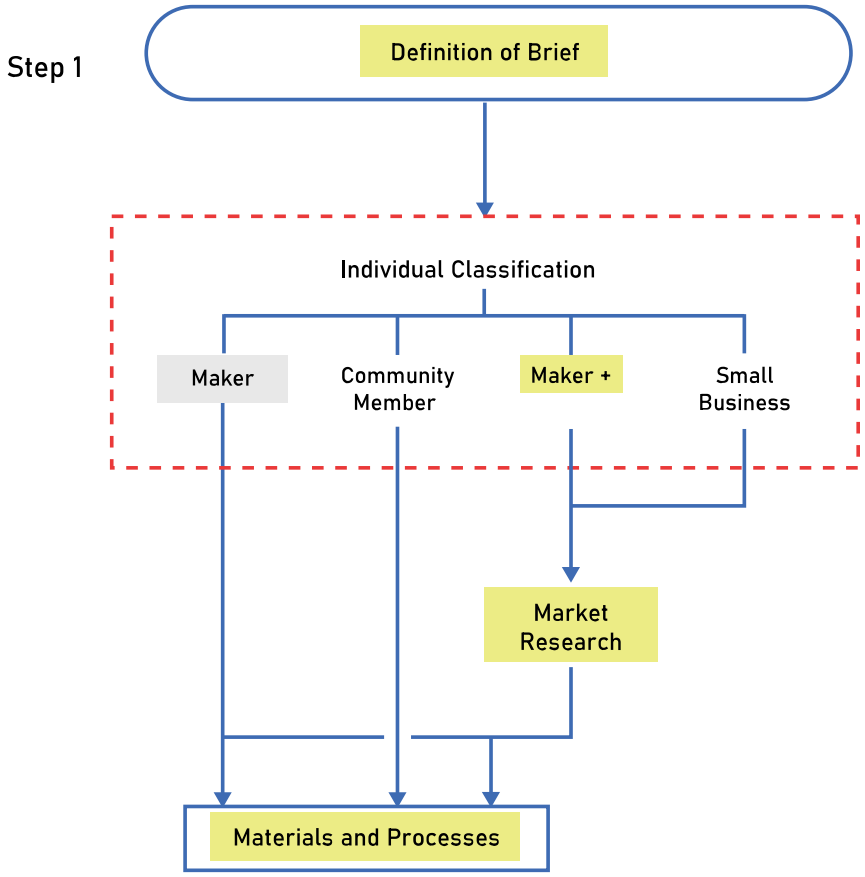


Figure 59: Application - Step 1

In this case, the individual classification is “Maker +” in which the designer develops the product initially for his or her own needs and interests, but also plans on making a profit from the sale of their design as well.

4.1.1 Definition of Brief

Based on the brief generated by the designer, certain criteria can be established and organized into the three dimensions established by Walter Schaer in 2.8. Because the design must be digitally fabricable, it is not unusual that the production function may be the most prominent and require the most criteria.

Human Function	Production Function	Technical Function
Design should be aesthetically pleasing	Can be created with a CNC router.	Feature an option to have a storage component
Design should be "makeable" in that others would want to replicate the project for themselves	Should be able to fit together with joinery or other readily available hardware components	Design should be a standard size, common to other nightstands
	Design should fit on one sheet of 4' x 8' plywood	
	Possesses 3D printable parts	

Table 3: Human, Production, Technical Functions

4.1.2 Market Research

Using the brief generated above, concepts can be developed. Market research can be conducted of existing options on the market. These options would be considered to be alternatives to a "digitally fabricable" nightstand that the target customer may consider. These may include pre-assembled or flat packed furniture pieces, CNC plans to create a nightstand, or free DIY tutorials on the internet.

Figure 60: Plywood Nightstand by Archivetica on Etsy

Figure 61: Bedside Table by MySAMshop

Figure 62: Retro Modern Eames-style End Tables Furniture Plan by plancanvas

Figure 63: DIY $12 Nightstand by The Definery Co

Figure 64: Bedside Robots by Make Furniture NZ

Figure 65: IKEA NORDKISA nightstand

Through research of available options and taking into consideration the criteria listed above, several concept sketches are generated.

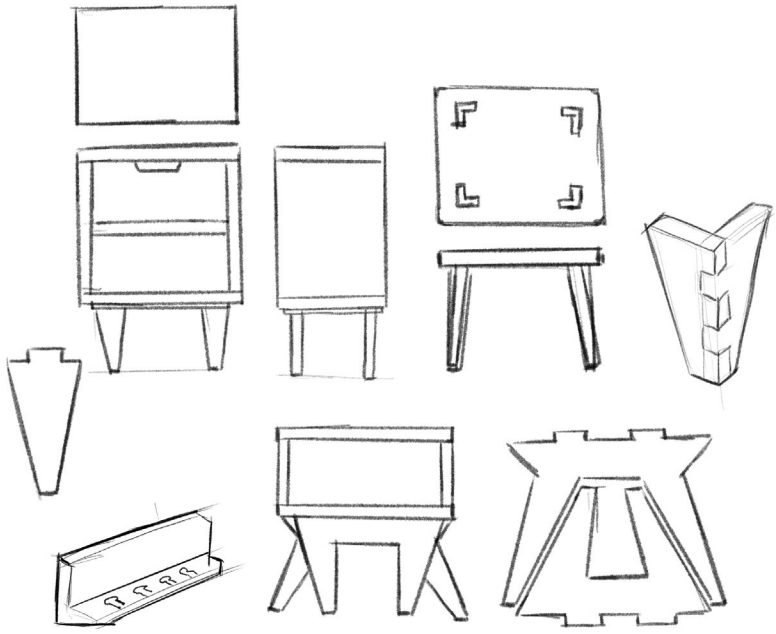


Figure 66: Initial concept ideation of nightstand

From these ideas, the following concept was chosen to proceed with. The nightstand has asymmetrical legs, giving the product an interesting form and silhouette. Because the design was already roughly decided, after drawing a more detailed concept sketch that showcased possible joinery and assembly, the design was moved into CAD.

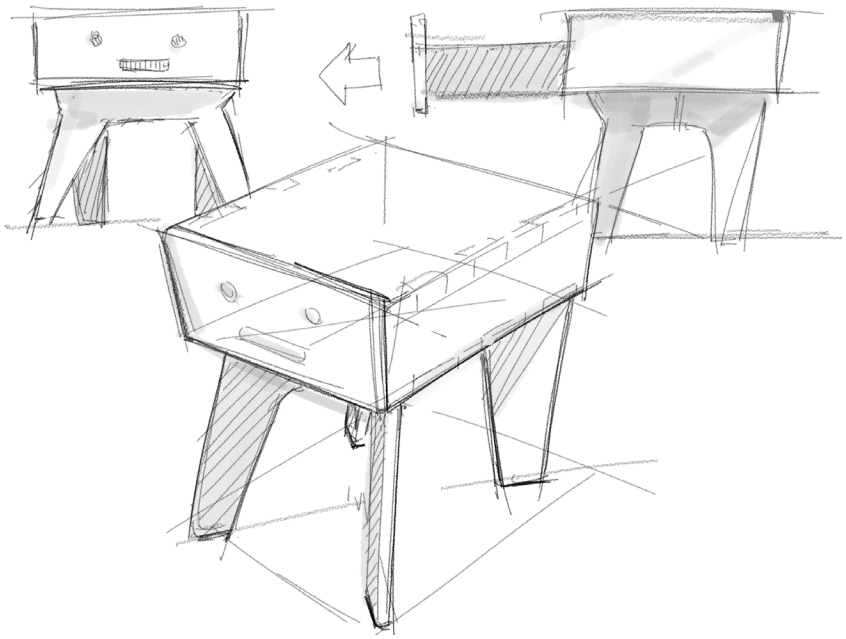


Figure 67: Developed nightstand concept sketch

4.1.3 Materials and Processes

Based on the concept sketch, the nightstand is a large furniture piece that relies mostly on pieces of flat material. In this case, it is deemed most pragmatic to fabricate it using CNC milling and plywood. Therefore, it is pertinent to consider the constraints of CNC milling, like the importance of dog bone fillets (because sharp corners cannot be routed). Furthermore, because there is the option to have a sliding drawer, it is necessary to choose drawer slides that are of common dimensions and can be purchased locally regardless of the customer's location.

4.2 Application of Method: Step 2 - Design for Digital Fabrication and Distribution

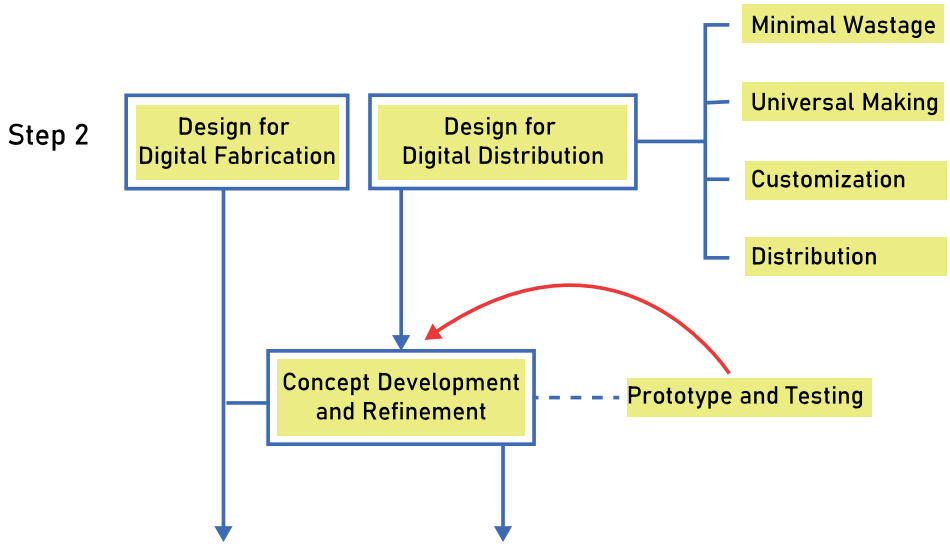


Figure 68: Application - Step 2

When bringing a model into a CAD software program, it is important to consider specifying parameters to allow for adjustment and customization of the model. While this can be added in later, it is more efficient to design with this in mind at the beginning. In the design of this model, parameters were given for the size of the “dog bone” fillets, the thickness of the wood, and the height of the nightstand.

Parameters

Parameter	Name	Unit	Expression	Value	Comments
Favorites					
User Parameter	TotalHeight	in	24 in	24.00	
User Parameter	DogboneFillet	in	0.26 in	0.26	
User Parameter	MaterialThickness	in	0.72 in	0.72	Nominal Thickness for 3/4" ply...
User Parameters					
User Parameter	TotalHeight	in	24 in	24.00	
User Parameter	LegHeight	in	TotalHeight * 3 / 5	14.40	
User Parameter	MaterialThickness	in	0.72 in	0.72	Nominal Thickness for 3/4" ply...
User Parameter	DogboneFillet	in	0.26 in	0.26	
User Parameter	PocketDepth	in	MaterialThickness / 2	0.36	
User Parameter	TableHeight	in	TotalHeight * 2 / 5	9.60	
Model Parameters					

Figure 69: Adjustable Parameters in Autodesk Fusion 360

4.2.1 Design for Minimal Wastage

When nesting the design on the plywood sheet, it is important to keep wastage at a minimum, while still keeping the direction of the grain into consideration. In this situation, the nightstand has the option to have a drawer made of the same material. Without a drawer, two nightstands can be fabricated on a 4'x8' sheet of plywood.

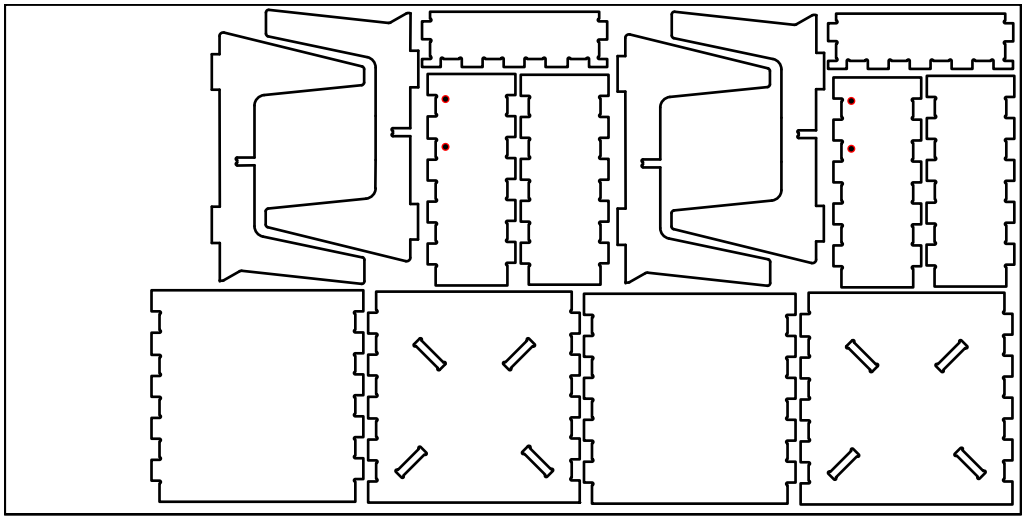


Figure 70: Example of two nightstands laid out on a 4' x 8' sheet of plywood

4.2.2 Design for Universality

The nightstand can be easily fabricated with common materials and standard dimensions. In this situation, the nightstand will be fabricated with ¾" plywood because it is a common sizing available worldwide. While it is tempting to rely completely on joinery to assemble the nightstand, because material thicknesses vary by millimeter, using wood glue or common hardware to support the build is encouraged.

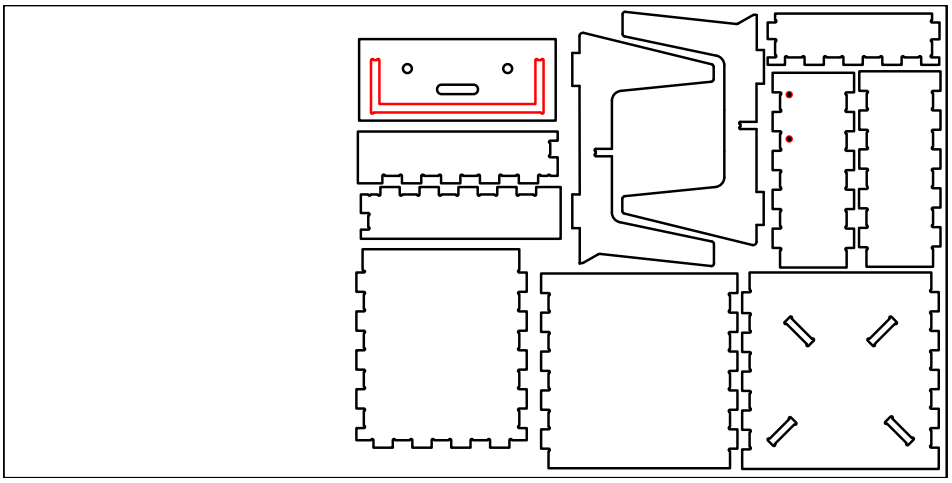


Figure 71: The cut file for one nightstand with an additional wooden drawer

4.2.3 Design for Customization

The nightstand will feature an option to add a drawer. The customer has the option to make a drawer from the same plywood used to build the nightstand. Alternatively, an option to laser cut a basket from felt is available. Further customizations include a 3D printable wire organizer which can be attached directly to the nightstand.

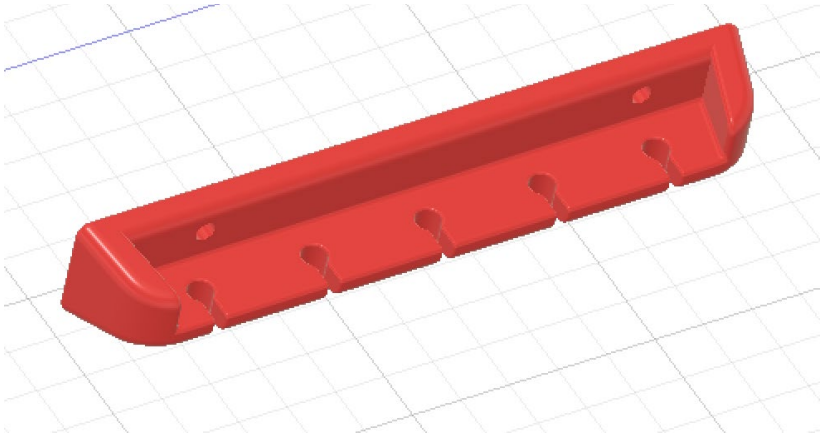


Figure 72: 3D Printable Wire Organizer

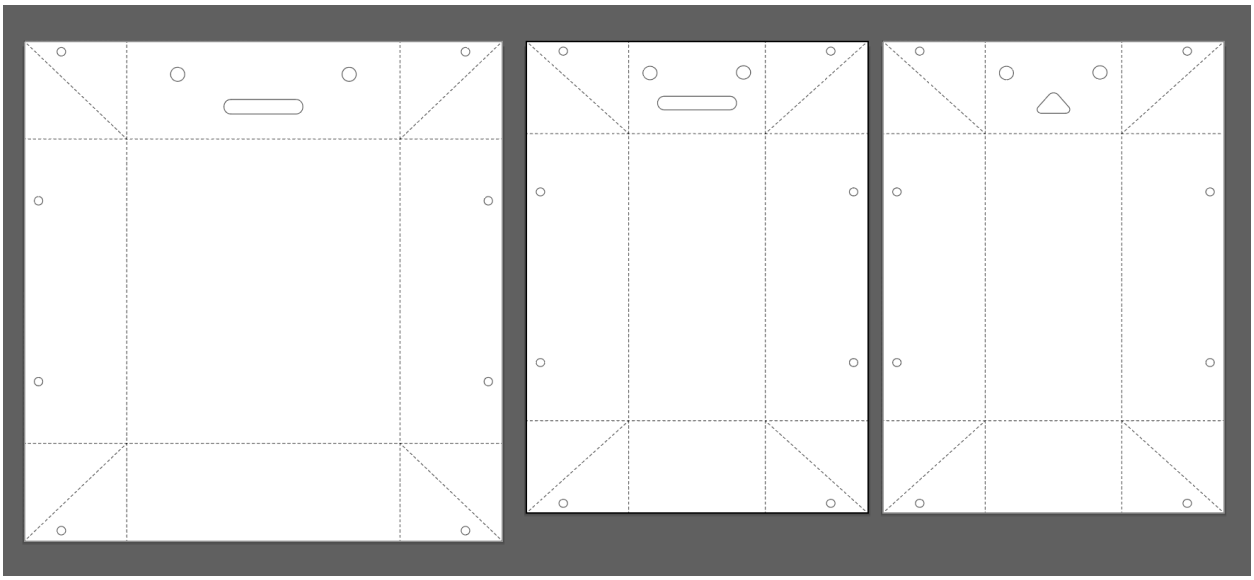


Figure 73: Cut File / Pattern for Felt Basket

4.2.4 Design for Distribution

The nightstand should be designed with the intention that others may intend to produce it. For the 3D printed components, STL files will be given. A DXF and AI file will be given for each of the CNC and laser cut components.

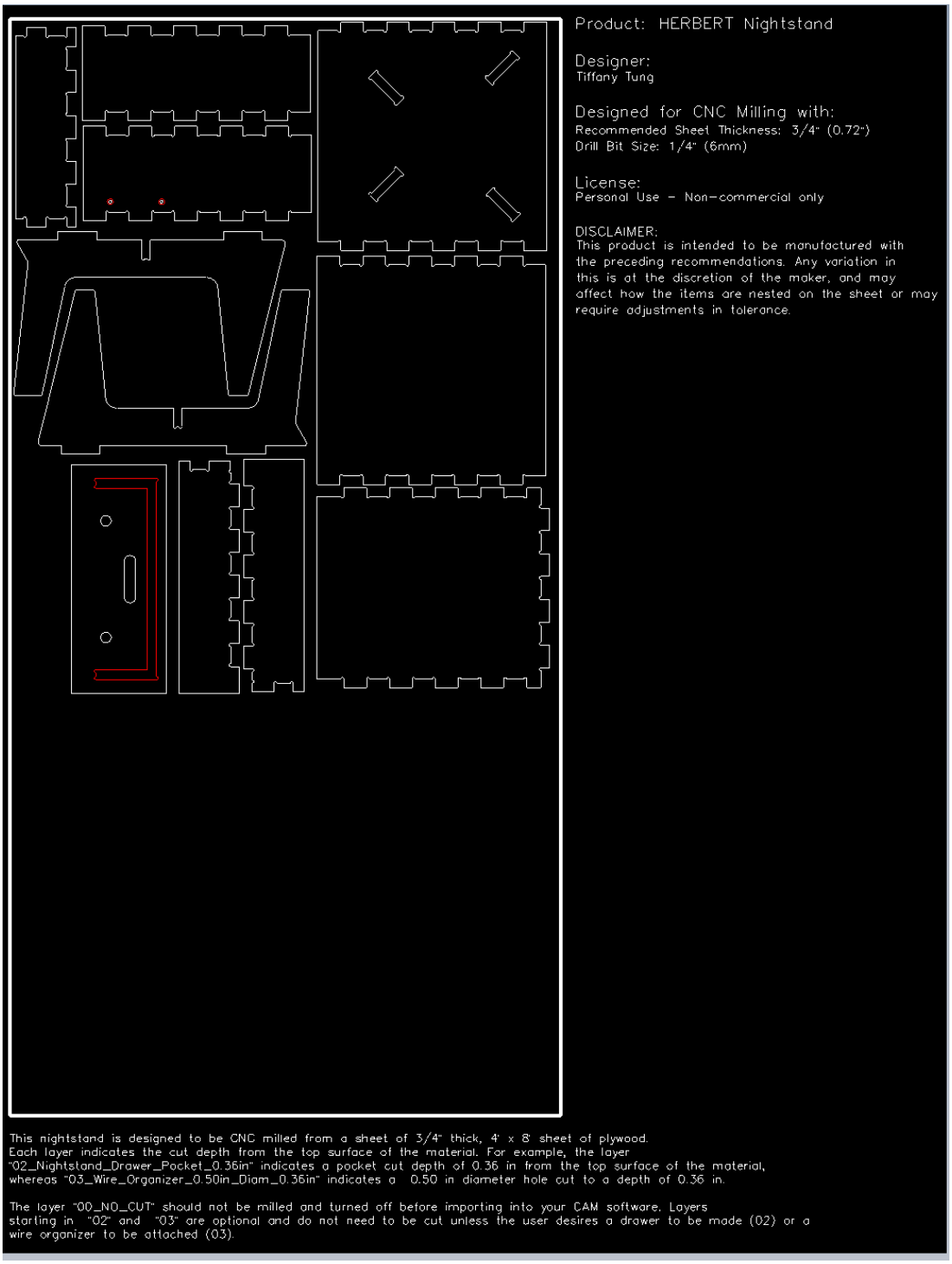


Figure 74: The DXF cutting file for the nightstand

In addition, an instruction assembly manual is generated that not only teaches the end user how to assemble the nightstand, but also gives information regarding recommended settings, materials, and hardware as well as where one can source them (see Appendix A for the full assembly manual).

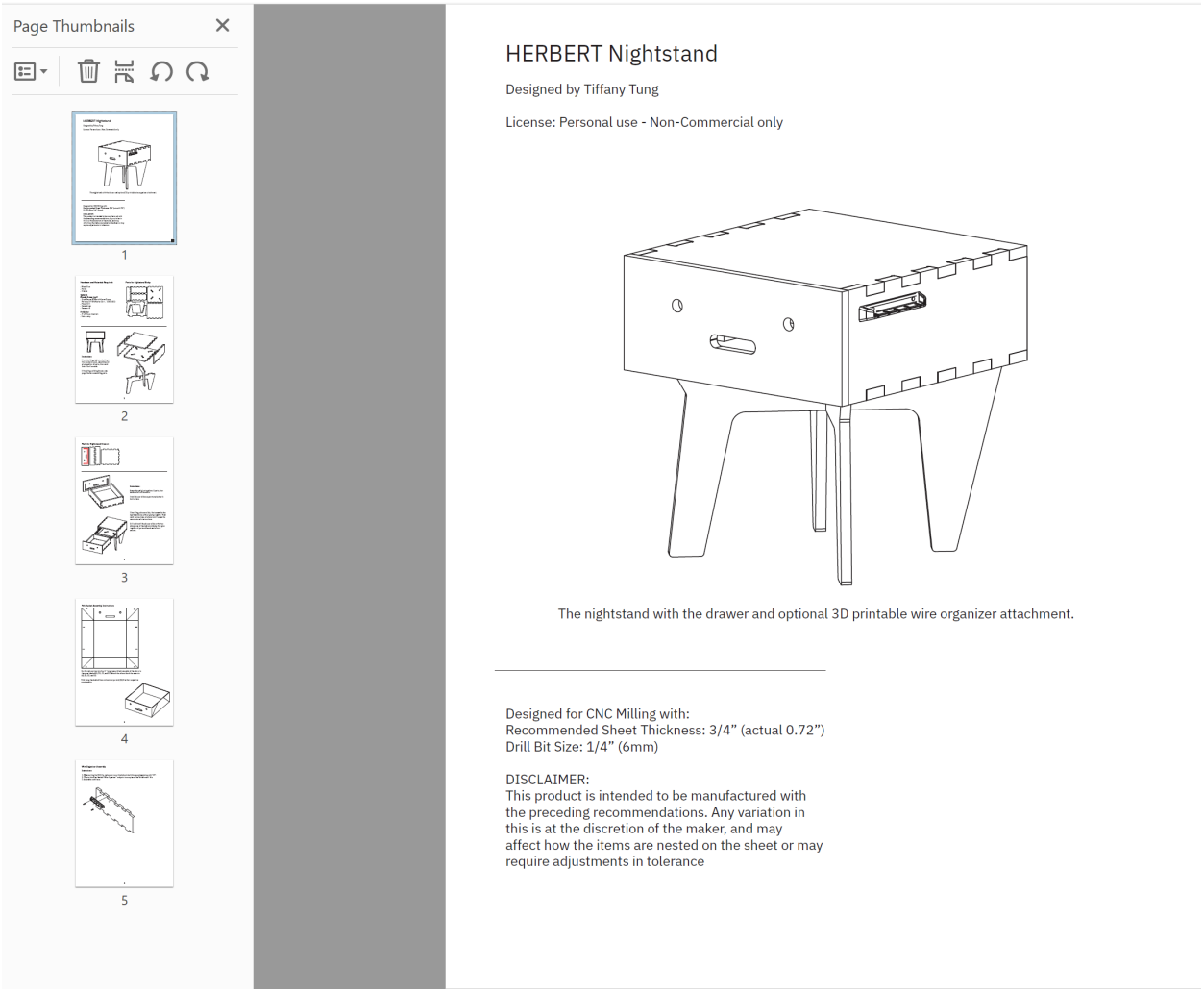


Figure 75: Nightstand Assembly Manual (see Appendix A for full manual)

4.2.5 Concept Development and Refinement

Figure 76: Rendered nightstand

The developed model is then converted to a DXF file (Figure 74) to create a full scale, physical model. It is CNC milled on a piece of 4” x 8” plywood, with a nominal thickness of ¾” a recommended drill bit of ½”, and assembled to test the structural integrity and feasibility of the design.

Figure 77: Full-scale model of the nightstand

4.3 Application of Step 3: Distribution

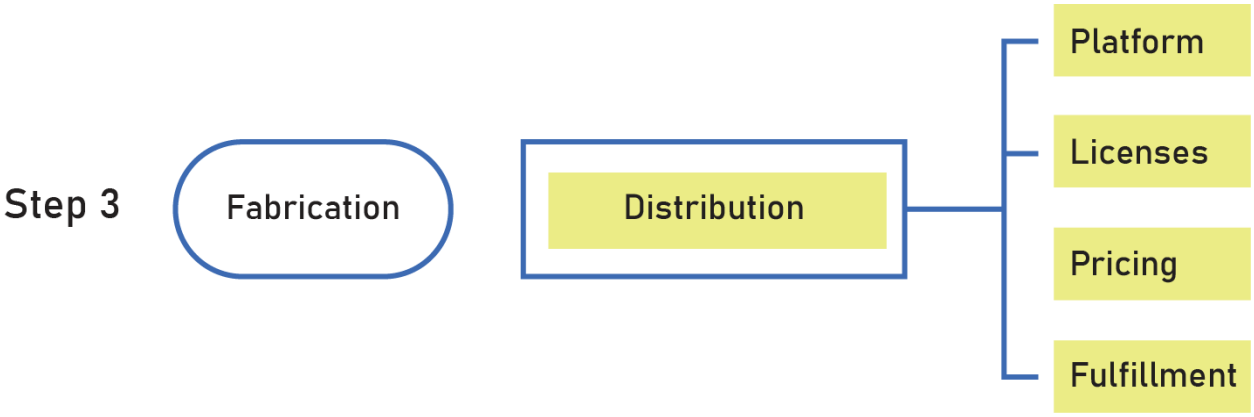


Figure 78: Application - Step 3

4.3.1 Platform

In the table below, based on the characteristics and considerations of the designer, platforms are assessed for certain qualities. Because the majority of this nightstand will utilize CNC milling (the customizable accessories can be 3D printed or laser cut), the available platforms for distribution are limited. As the characterization of the designer is “Maker +”, this indicates that this is just as a hobby or side business and the maker would not have too much time to manage marketing or to design their own personal website, nor would they be willing to spend a lot on a certain platform for just one or two products.

After assessing the qualities of each platform, there are two options that appear: Big Cartel and Etsy. While Big Cartel may be cheaper, it requires a paid integration for digital distribution, and does not have a marketplace option. This may be more cost effective for sellers, but without external marketing, it is difficult to make sales. On the other hand, Etsy may be more expensive, but it also has a marketplace. If a customer is looking for a specific type of item, like CNC plans, it can be easily found (Figure 29). A consideration for marketing is to offer the 3D

printable wire organizer as a free download on a website like Thingiverse or MyMiniFactory to bring traffic to the Etsy shop.

Platform	Products are Free / Hybrid / Paid	Digital Fabrication Type	Fees	Manufacture?	Marketplace search?
Big Cartel	Hybrid	CNC, laser cut, 3DP	Free option, then plans starting from $9.99 a month. No transaction fees other than charged by provider. Pulley is $6/mo.	Shapeways integration	No
Etsy	Paid	CNC, laser cut, 3DP	20 cent listing fee, a 5% transaction fee, and a 3% + $0.25 payment process fee	3DP has option for Shapeways integration	Yes
GrabCAD	Free	3DP	N/A	No	Yes
MyMiniFactory	Hybrid	3DP	$24.99 a month, plus 10% fee on the selling price	No	Yes
Pinshape	Hybrid	3DP	Additional 30% on top of the markup	No	Yes
Shapeways	Paid	3DP	3.5% fee on top of markup	Yes	Yes
Shopify	Hybrid	CNC, laser cut, 3DP	Plans starting from $29, additional 2.9% + 30¢ on each item sold	3DP has Shapeways integration	No
Thingiverse	Free	Primarily 3DP, CNC, laser cut	N/A	Partners with Print a Thing, Treatstock, and NinjaPrototype	Yes
Personal Website*	Hybrid	CNC, laser cut, 3DP	Depends on platform / payment provider	Depends	No

Red: No; Yellow: Maybe; Green: Yes

Table 4: Platforms for Consideration

4.3.2 Licenses

Because the nightstand is intended to be sold, a personal use only, non-commercial license is recommended. This means that the file can only be used by the customer who purchased it, and ensures that the files cannot be distributed, nor can the customer profit off the manufacture of the product. This license will be stated in a TXT file marked “License” (Appendix C) in the ZIP folder (Figure 80), on the DXF file, as well as on the assembly guide (Appendix A).

As for the wire organizer, because the design is fairly simplistic and is not particularly original, it will be given a “Creative Commons - Attribution Only” license. This means that it can be shared, remixed, or distributed (even commercially), but the designer needs to be credited.

4.3.3 Pricing

Pricing is made at the discretion of the designer based on the complexity of the design and other products on the market. While physical nightstands can retail from $50-$150 on the market, the plans are significantly less so. In this case, simple designs range from $3.95, with more complex ones at up to $30. Based on the complexity of the nightstand design, it is reasonable to price it from $7-$10.

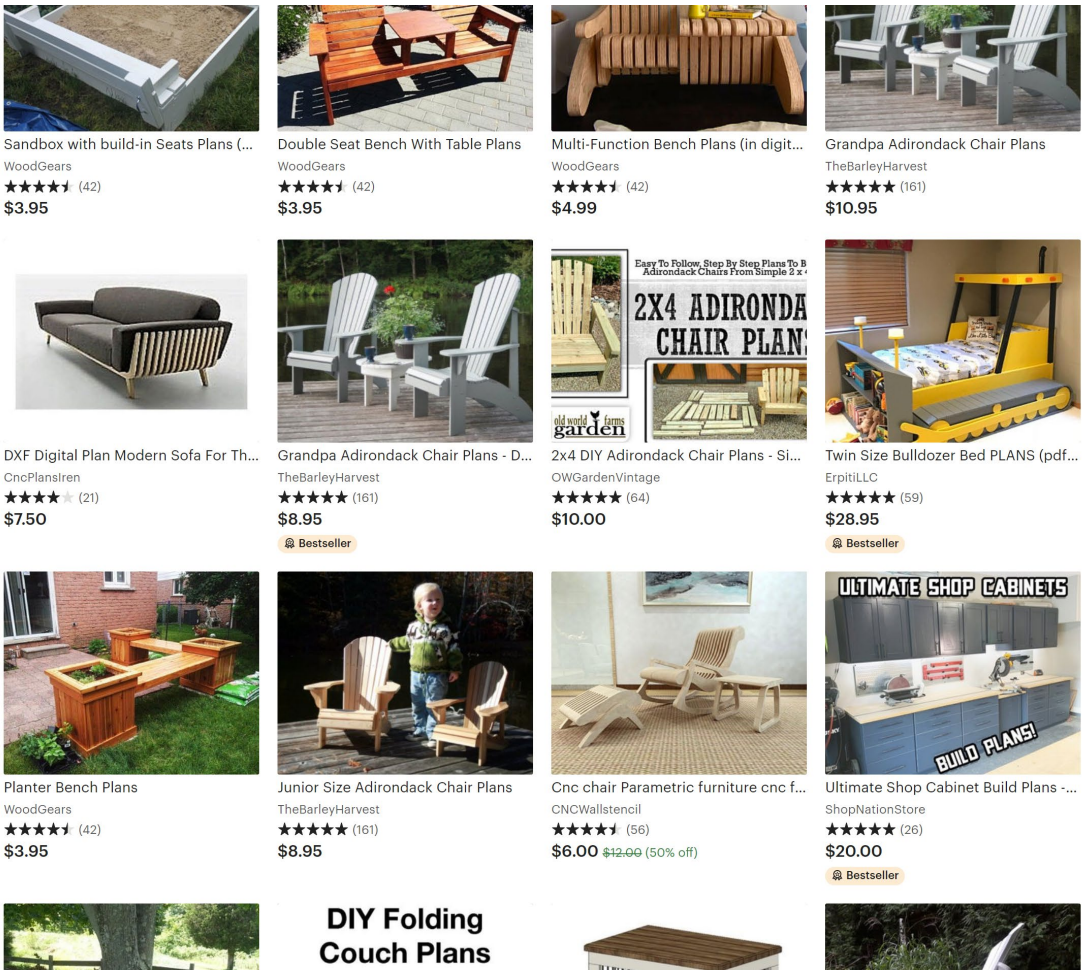


Figure 79: An Etsy search for “Furniture Plans”

4.3.4 Fulfillment

The customer will ultimately receive a compressed ZIP file with DXF/AI/EPS files (Figure 80), an assembly guide (Appendix A), appropriate STL files (Appendix B), licensing information (Appendix C), and images (Appendix D). This will be delivered to the customer in the form of a digital download.

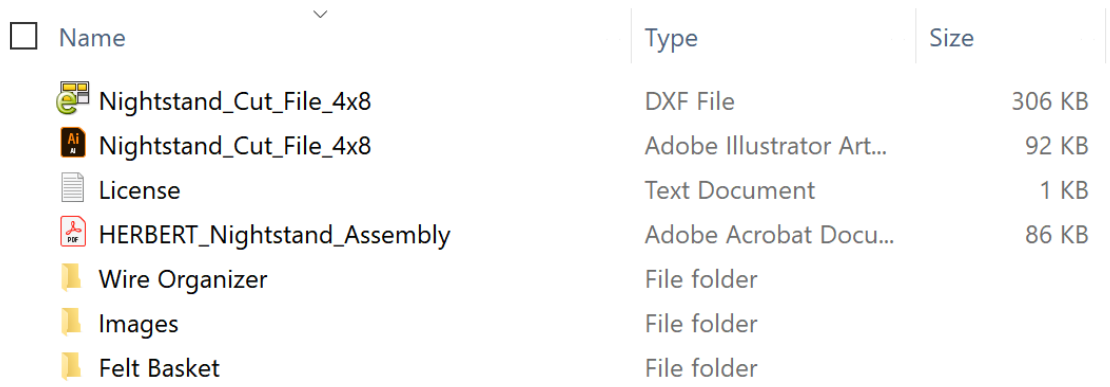


Figure 80: Contents of the ZIP folder

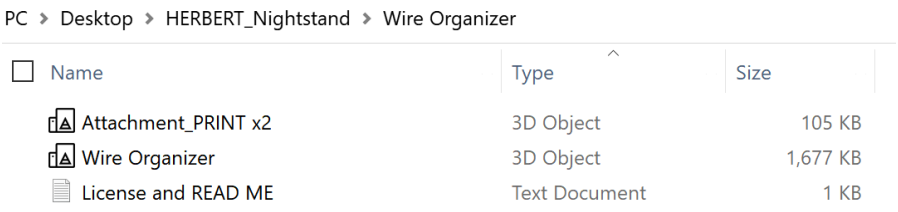


Figure 81: Contents of the Wire Organizer sub-folder

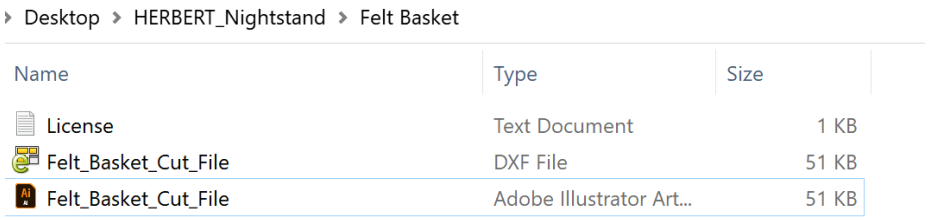


Figure 82: Contents of the Felt Basket sub-folder

4.4 Application of Step 4: Marketing

Figure 83: Application – Step 4

4.4.1 Product Listings

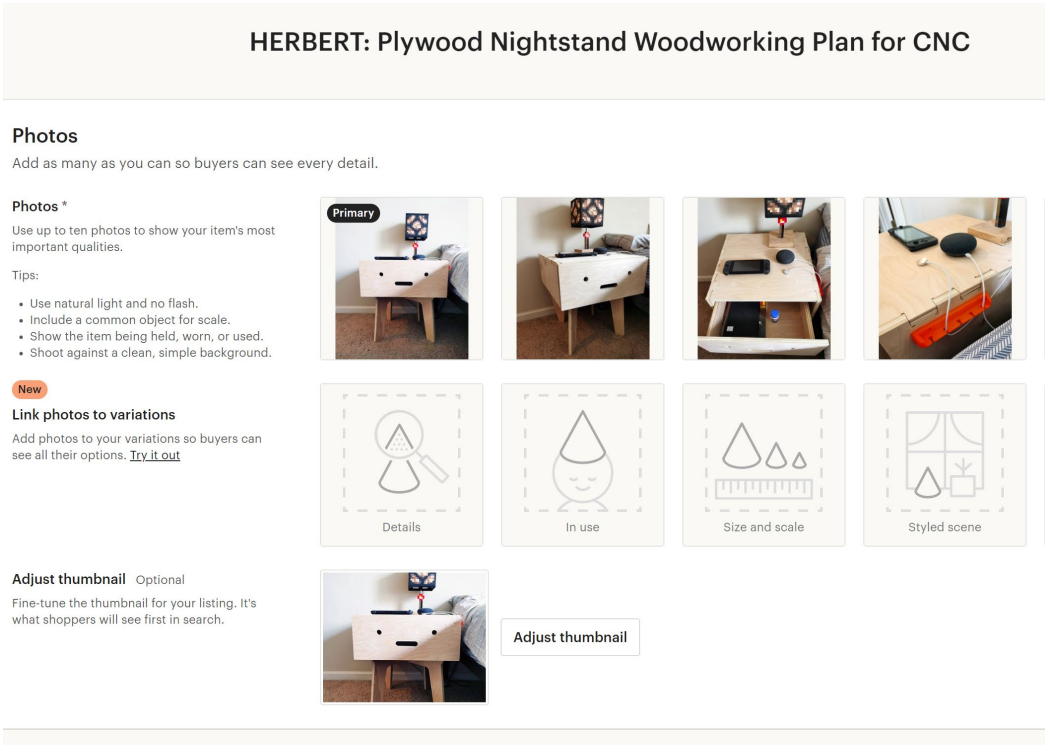


Figure 84: Choosing photos for an Etsy product listing

Multiple in-context, well-lit photos of the physical nightstand from various angles were taken and uploaded onto the Etsy platform. These photos feature various aspects of the design as well as how it can be customized.

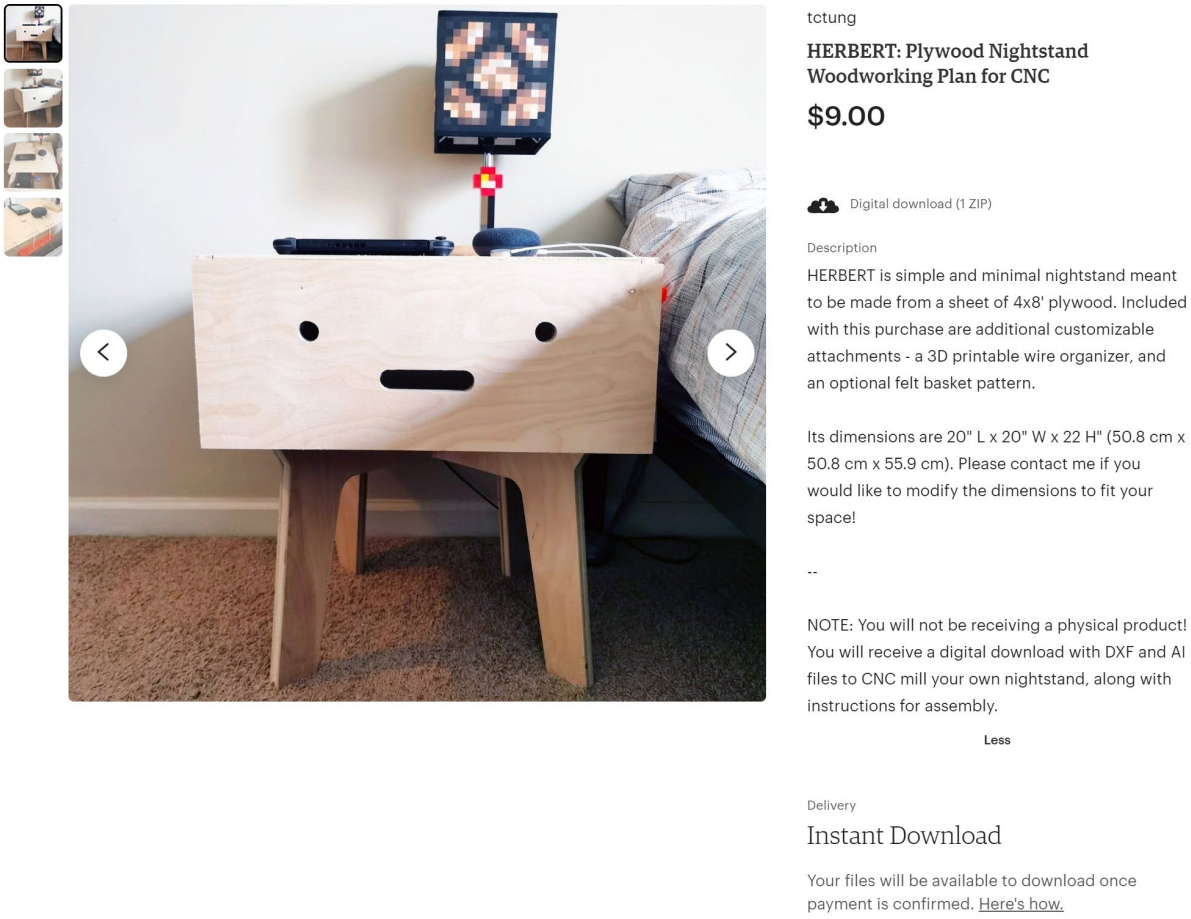


Figure 85: Nightstand product listing on Etsy

The product description follows suggested practices and sets the customers' expectations regarding the receipt of a digital file rather than a physical product, as well as product dimensions.

4.3.2 Social Media

As a Maker +, it is difficult to spend a lot of time on marketing a product. Utilizing existing social media platforms helps the designer connect to like-minded individuals while promoting their products.

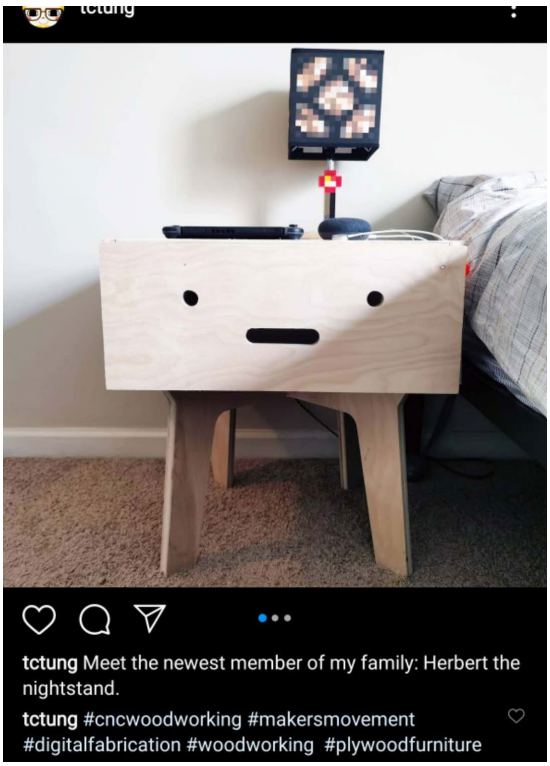


Figure 86: A social media post with tags made to promote the product

Application Summary

This project followed the design process of a nightstand from ideation to a product listing in a store. Through the guidelines defined in this chapter, a nightstand and accompanying downloadable digital files for distribution (including assembly instructions, digital files, and licensing information) were able to be produced, along with a product listing in a storefront and basic social media marketing approaches.

Chapter 5: Conclusions

Summary

This thesis was developed to create a guideline to help a designer develop designs for digitally fabricable products for production by a consumer or fabricator. This market only became significantly relevant in the past decade, and still lacks standardization and regulation. As digital fabrication tools become more attainable by home consumers, it can be anticipated that more and more designers will develop products for this purpose.

While it does assume that the designer has some knowledge of the design process, this thesis acts as a comprehensive guide to educate the designer-maker through the entire process of developing and selling a digitally fabricable product, and demonstrates such in design of a nightstand that utilizes multiple digital fabrication processes.

Further Research

Digital fabrication is an exciting and constantly changing field to be a part of, and therefore, further development can be conducted in a variety of areas:

1. Although this thesis covers three different types of digital fabrication, as more processes become more widely available, further research can be conducted regarding how they can be applied to the production of similar products.
2. Additional research into sustainability practices and how manufacturing locally, rather than shipping a premade product from across the globe, may affect the environment may also be of interest.
3. As more individuals choose to sell digital plans or 3D models, additional refinements can be made to the suggestions regarding marketing and pricing digital files.

4. Development into the creation of a marketplace that not only focuses specifically on the sale of digitally fabricable products, but also connects consumers to potential fabricators would also be relevant.

References

All3DP. (2020, March 27). 2020 Best Online 3D Printing Services (Spring Update). Retrieved from https://all3dp.com/1/best-online-3d-printing-service-3d-print-services/

Association for Enterprise Opportunity. (2013, November 10). The Economic Impact of Microbusiness In the United States. Retrieved from https://aeoworks.org/wp-content/uploads/2019/03/Bigger-than-You-Think-Report_FINAL_AEO_11.10.13.pdf

Atasoy, O., & Morewedge, C. K. (2017). Digital Goods Are Valued Less Than Physical Goods. *Journal of Consumer Research*, *44*(6), 1343–1357. doi: 10.1093/jcr/ucx102

Bakırlıoğlu, Y., & Kohtala, C. (2019). Framing Open Design through Theoretical Concepts and Practical Applications: A Systematic Literature Review. *Human–Computer Interaction*, *34*(5-6), 389–432. doi: 10.1080/07370024.2019.1574225

Bashir, H. A., & Thomson, V. (2001). Models for estimating design effort and time. *Design Studies*, *22*(2), 141–155. doi: 10.1016/s0142-694x(00)00014-4

Baumann, F. W., & Roller, D. (2018). Thingiverse: review and analysis of available files. *International Journal of Rapid Manufacturing*, *7*(1), 83. doi: 10.1504/ijrapidm.2018.089731

Brown, T. (2009). *Change by design: how design thinking creates new alternatives for business and society*. New York: Collins Business.

Buchanan, R. (1992). Wicked Problems in Design Thinking. *Design Issues*, *8*(2), 5. doi: 10.2307/1511637

Cain, P. (n.d.). Supports in 3D Printing: A technology overview. Retrieved from https://www.3dhubs.com/knowledge-base/supports-3d-printing-technology-overview/

Church, E. M., & Oakley, R. L. (2018). Etsy and the long-tail: how microenterprises use hyper-differentiation in online handicraft marketplaces. *Electronic Commerce Research*, *18*(4), 883–898. doi: 10.1007/s10660-018-9300-4

CNC machining: The Complete Engineering Guide. (n.d.). Retrieved from https://www.3dhubs.com/get/cnc-machining-guide/

Corcoran, E. (2008, August 13). Making Future Headlines. Retrieved October 22, 2019, from https://www.forbes.com/2008/08/13/diy-innovation-oreilly-tech-egang08-cx_ec_0813oreilly.html

Cruickshank, L. (2014). *Open design and innovation: facilitating creativity in everyone*. Farnham, Surrey: Gower.

Dam, R. F., & Teo, Y. S. (n.d.). 5 Stages in the Design Thinking Process. Retrieved October 1, 2018, from https://www.interaction-design.org/literature/article/5-stages-in-the-design-thinking-process

Dellot, B. (2014, September). Breaking the mould: How Etsy and online craft marketplaces are changing the nature of business. Retrieved January 12, 2020, from Breaking the mould: How Etsy and online craft marketplaces are changing the nature of business

Economic Impact of U.S. Etsy Sellers. (2019, February 27). Retrieved from https://dashboards.mysidewalk.com/etsy-economic-impact-1532038450/home

FabHub. (n.d.). Retrieved from https://www.fabhub.io/

Facebook IQ. (2019, February 6). How Instagram Boosts Brands and Drives Sales. Retrieved from https://www.facebook.com/business/news/insights/how-instagram-boosts-brands-and-drives-sales

Filson, A., Rohrbacher, G., & France, A. K. (2017). *Design for Cnc: furniture projects and fabrication technique*. San Francisco: Maker Media.

Ford, C. (9AD, October 2007). An Introduction to Design Thinking. Retrieved September 22, 2018, from https://dschool-old.stanford.edu/sandbox/groups/k12/wiki/c739e/attachments/5ba7d/An Intro to Design Thinking 07_10_09.pdf?sessionID=3d3a881db7041a8d8f943914d1a5df4678223b9f

Franke, N., Keinz, P., & Steger, C. J. (2009). Testing the Value of Customization: When Do Customers Really Prefer Products Tailored to Their Preferences? *Journal of Marketing*, *73*(5), 103–121. doi: 10.1509/jmkg.73.5.103

Franke, N., Schreier, M., & Kaiser, U. (2010). The "I Designed It Myself" Effect in Mass Customization. *Management Science*, *56*(1), 125–140. doi: 10.1287/mnsc.1090.1077

From 'Business as Usual' to 'Business as Mutual'. (n.d.). Retrieved from https://www.opendesk.cc/blog/from-business-as-usual-to-business-as-mutual

Gershenfeld, N. (2012). How to Make Almost Anything: The Digital Fabrication Revolution. *Foreign Affairs* , *91*(6), 43–57.

Gilmore, J. H., & Pine, B. J. (1997, January). The Four Faces of Mass Customization. *Harvard Business Review*. Retrieved from https://hbr.org/1997/01/the-four-faces-of-mass-customization

Gordhamer, S. (2009, September 22). 4 Ways Social Media is Changing Business. Retrieved from https://mashable.com/2009/09/22/social-media-business/

Hazzard, T. (2015, November 20). Accounting for Design – Pricing 3D Print Designs. Retrieved from https://pinshape.com/blog/accounting-for-design-pricing-3d-print-designs/

Herhold, K. (2019, February 27). The State of Small Business Advertising in 2019. Retrieved from https://themanifest.com/advertising/small-business-advertising-2019

Hessman, T. M. (2013, November 5). Take 5: Q&A with Chuck Hull, Co-Founder, 3D Systems. Retrieved from https://www.industryweek.com/technology/take-5-qa-chuck-hull-co-founder-3d-systems

History of the OSI. (n.d.). Retrieved from https://opensource.org/history

Howitt, D. (1984, December 3). One Company's CAD Success Story. *InfoWorld*, 39.

Hudson, N., Alcock, C., & Chilana, P. K. (2016). Understanding Newcomers to 3D Printing. *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*. doi: 10.1145/2858036.2858266

Instagram Business. (n.d.). Retrieved from https://business.instagram.com/

Kadushin, R. (2010, September). Open Design Manifesto. Retrieved from https://www.ronen-kadushin.com/open-design-manifesto

Kaplan, A. M., & Haenlein, M. (2010). Users of the world, unite! The challenges and opportunities of Social Media. *Business Horizons*, *53*(1), 59–68. doi: 10.1016/j.bushor.2009.09.003

Key design considerations for 3D Printing. (n.d.). Retrieved from https://www.3dhubs.com/knowledge-base/key-design-considerations-3d-printing/

Kietzmann, J. H., Hermkens, K., Mccarthy, I. P., & Silvestre, B. S. (2011). Social media? Get serious! Understanding the functional building blocks of social media. *Business Horizons*, *54*(3), 241–251. doi: 10.1016/j.bushor.2011.01.005

Kolko, J. (2014). *Well-Designed How to Use Empathy to Create Products People Love*. Boston: Harvard Business Review Press.

Menendez-Blanco, M., & Bjørn, P. (2019). Makerspaces on Social Media: Shaping Access to Open Design. *Human–Computer Interaction*, *34*(5-6), 470–505. doi: 10.1080/07370024.2019.1566000

Narayan, K. L., Rao, K. M., & Sarcar, M. M. M. (2008). *Computer aided design and manufacturing*. New Delhi: PHI Learning.

Nielsen-Norman Group. (2016). *Design Process*. Retrieved from https://www.nngroup.com/articles/design-thinking/

Norton, M. I., Mochon, D., & Ariely, D. (2012). The IKEA effect: When labor leads to love. *Journal of Consumer Psychology*, *22*(3), 453–460. doi: 10.1016/j.jcps.2011.08.002

Nuvolari, A. (2004). Collective invention during the British Industrial Revolution: the case of the Cornish pumping engine. *Cambridge Journal of Economics*, *28*(3), 347–363. doi: 10.1093/cje/28.3.347

O'Duinn, F. (n.d.). *Computers in Libraries 2012 Conference*. *Computers in Libraries 2012 Conference*. Washington D.C.

Object licensing. (n.d.). Retrieved from https://www.myminifactory.com/object-licensing

Oehlberg, L., Willett, W., & Mackay, W. E. (2015). Patterns of Physical Design Remixing in Online Maker Communities. *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems - CHI 15*. doi: 10.1145/2702123.2702175

Petrelli, D., & Whittaker, S. (2010). Family memories in the home: contrasting physical and digital mementos. *Personal and Ubiquitous Computing*, *14*(2), 153–169. doi: 10.1007/s00779-009-0279-7

Properties Table. (2019, May 30). Retrieved from https://www.simplify3d.com/support/materials-guide/properties-table/

Raasch, C., Herstatt, C., & Balka, K. (2009). On the open design of tangible goods. *R&D Management*, *39*(4), 382–393. doi: 10.1111/j.1467-9310.2009.00567.x

RepRap. (n.d.). Retrieved from https://reprap.org/wiki/RepRap

Rosner, D. K., & Fox, S. E. (2016). Legacies of craft and the centrality of failure in a mother-operated hackerspace. *New Media & Society*, *18*(4), 558–580. doi: 10.1177/1461444816629468

Schaer, W. (1983). Design interaction research. *Design'81 Conference on Design Integration*, 205–207.

Shopify Announces Fourth-Quarter and Full Year 2017 Financial Results. (2018, February 15). Retrieved from https://investors.shopify.com/Investor-News-Details/2018/Shopify-Announces-Fourth-Quarter-and-Full-Year-2017-Financial-Results/default.aspx

Smith, K. (2012, December 19). Now Anyone Can Use 3D Printing To Make Money. Retrieved from https://www.businessinsider.com/shapeways-3d-printing-2012-12

Sole Proprietorship. (n.d.). Retrieved March 3, 2020, from https://www.sba.gov/content/sole-proprietorship

The 3D Printing Design Guide. (n.d.). Retrieved from https://pinshape.com/3d-printing-design-guide

Troxler, P., & Wolf, P. (2017). Digital maker-entrepreneurs in open design: What activities make up their business model? *Business Horizons*, *60*(6), 807–817. doi: 10.1016/j.bushor.2017.07.006

Turner, F. (2018). Millenarian Tinkering: The Puritan Roots of the Maker Movement. *Technology and Culture*, *59*(4S). doi: 10.1353/tech.2018.0153

What We Do. (n.d.). Retrieved from https://creativecommons.org/about/

Wire, B. (2018, October 30). MakerBot Thingiverse Celebrates 10 Years of 3D Printed Things. Retrieved from https://business.financialpost.com/pmn/press-releases-pmn/business-wire-news-releases-pmn/makerbot-thingiverse-celebrates-10-years-of-3d-printed-things

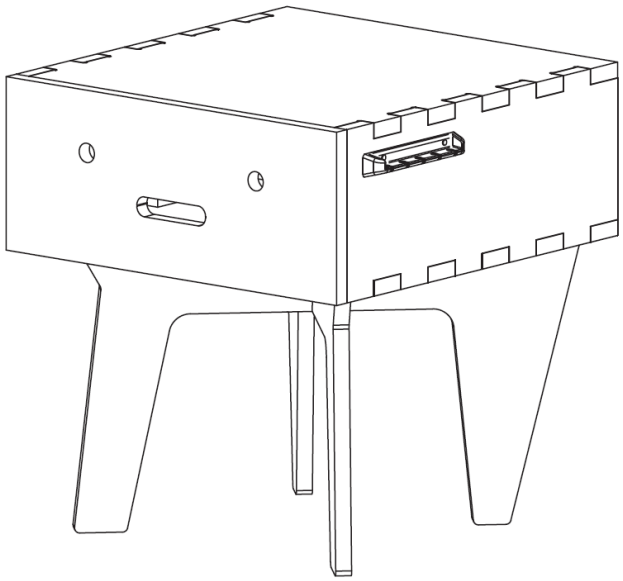
Wolf, P., & Troxler, P. (2016). Community-based business models: Insights from an emerging maker economy. *Interaction Design and Architecture*, *30*(1), 75–94.

Appendix A: Nightstand Assembly Guide

HERBERT Nightstand

Designed by Tiffany Tung

License: Personal use - Non-Commercial only



The nightstand with the drawer and optional 3D printable wire organizer attachment.

Designed for CNC Milling with:
Recommended Sheet Thickness: 3/4” (actual 0.72”)
Drill Bit Size: 1/4” (6mm)

DISCLAIMER:
This product is intended to be manufactured with the preceding recommendations. Any variation in this is at the discretion of the maker, and may affect how the items are nested on the sheet or may require adjustments in tolerance

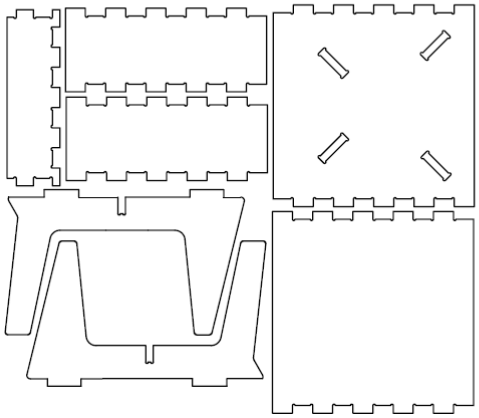
Hardware and Materials Required:

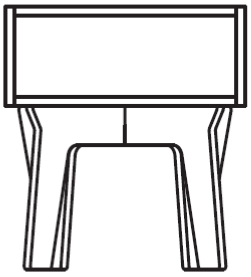
- Wood Glue
- Mallet
- Clamps

Optional
Wooden Drawer (pg 2)
- Steel Drawer Slides with Lever Drawer Release, 10" (McMaster-Carr - 11435A11)
- Power Drill
- Screwdriver
- Screws x 8

Felt Basket
- 3”x3” 3mm thick felt
- Velcro strip

Parts for Nightstand Body:

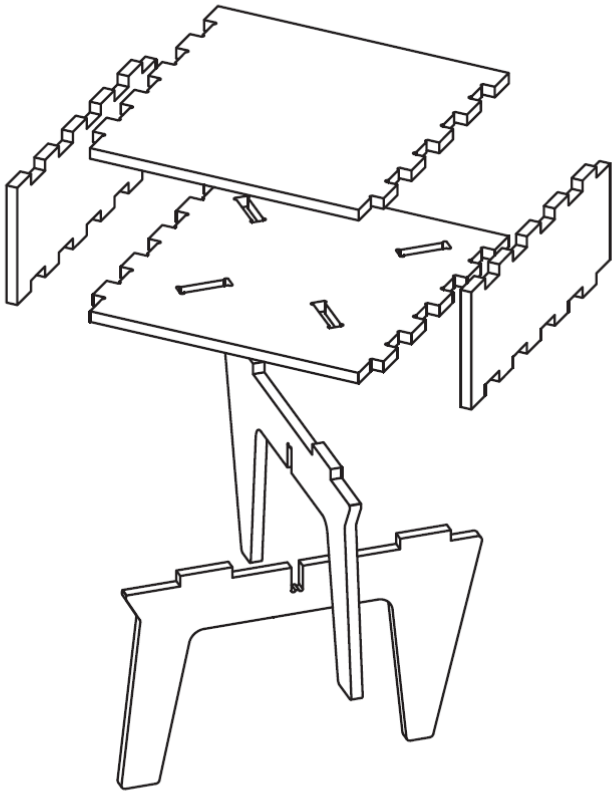




Instructions:

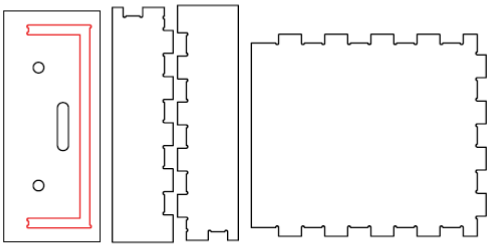
If only building nightstand without the wooden drawer, assemble and glue together all parts, then sand and oil until smooth.

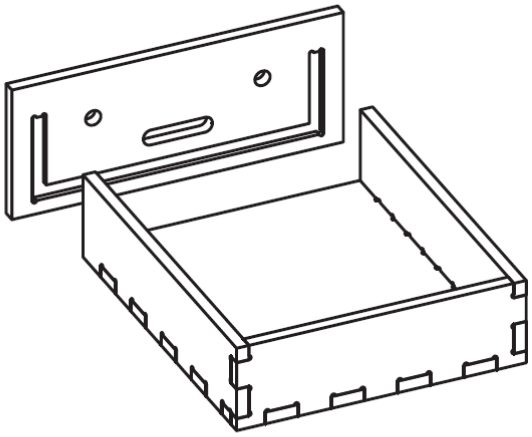
If installing a sliding drawer, see page 2 before assembling parts.



1

Parts for Nightstand Drawer:

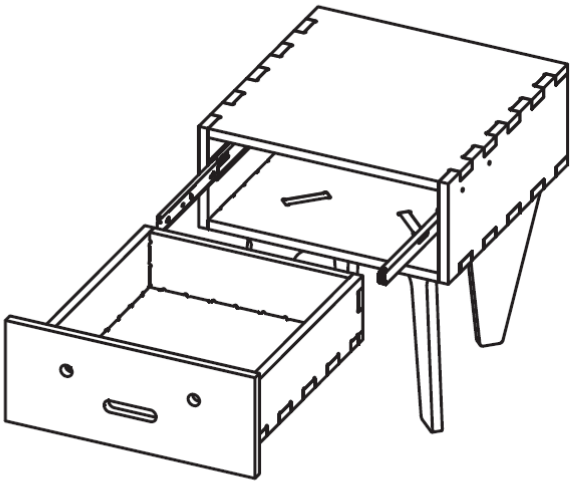




Instructions:

Assemble and glue together all parts, then sand and oil until smooth.

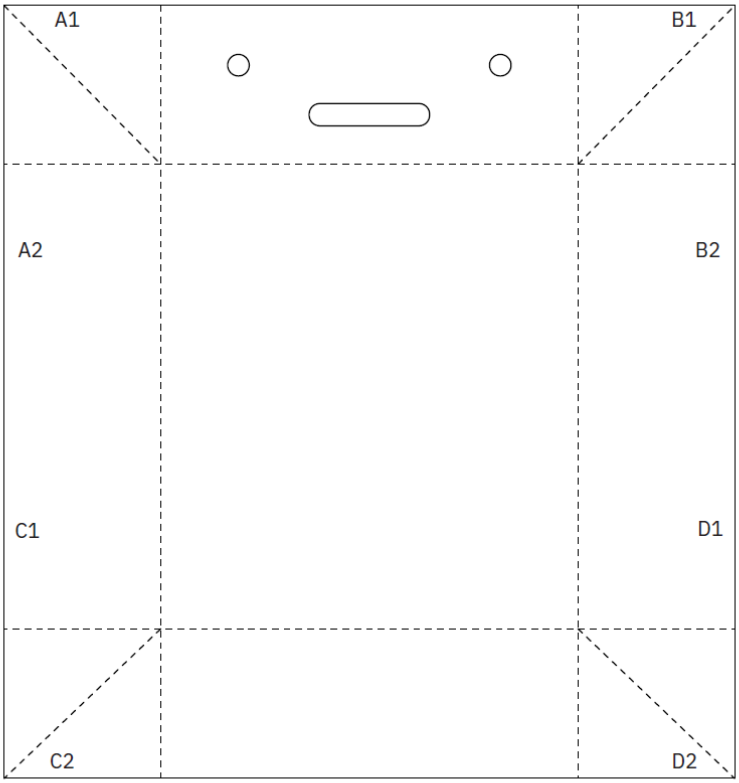
Install drawer slides as per manufacturer's instructions.



If installing a drawer slide, first assemble the nightstand body without gluing together. Then mark the locations of where to drill as per the manufacturer's instructions.

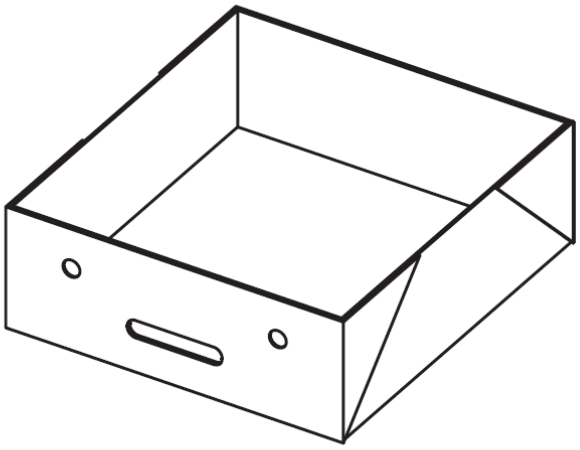
Drill and install the drawer slide on the two side pieces of the nightstand body, then glue together all parts and sand and oil until smooth.

Felt Basket Assembly Instructions



Cut the velcro strips into four 1” long pieces. Attach one side of the velcro to the areas labeled A1, B1, C1, and D1. Attach the other side of the velcro to A2, B2, C2, and D2.

Fold along the dashed lines and connect parts A,B,C,D to their respective counterparts.

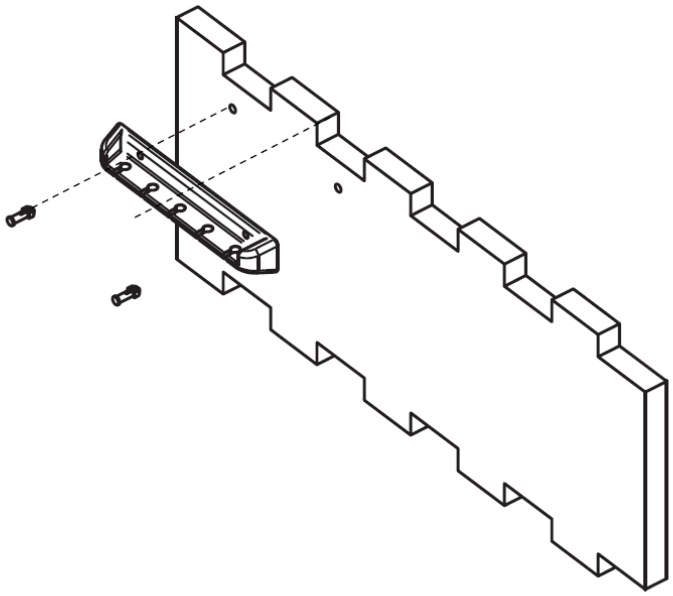


3

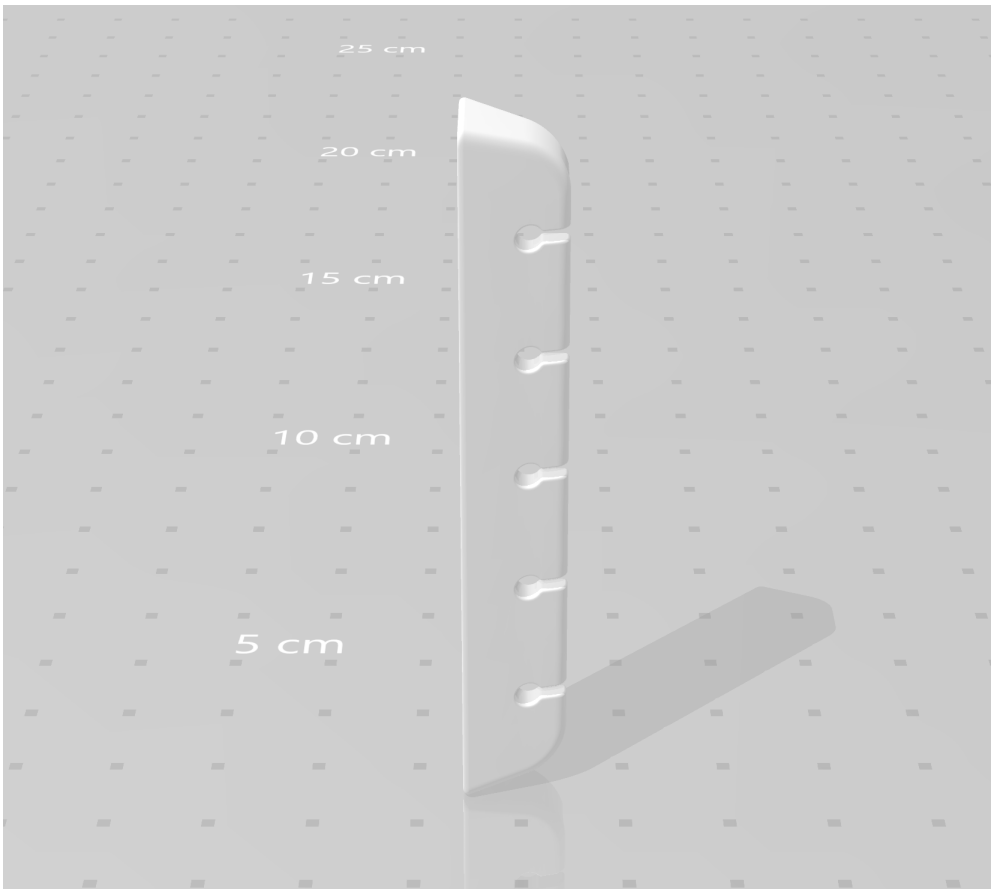
Wire Organizer Assembly

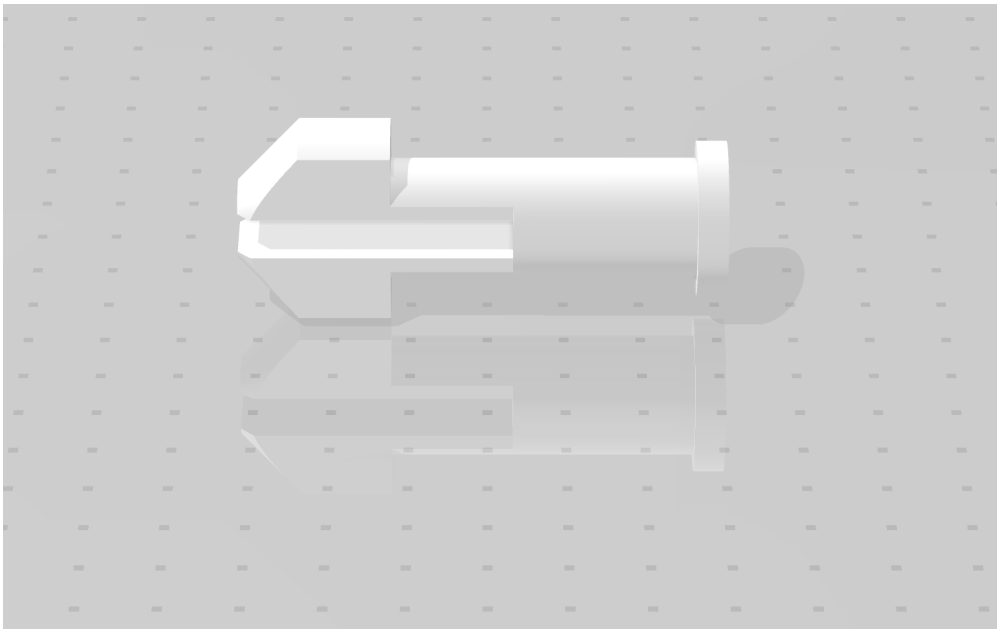
Instructions:

1. When cutting the CNC file, make sure to cut the holes in both the layers beginning with “03”.
2. 3D print the files labeled “Wire Organizer” and print two copies of the “Attachment” file.
3. Assemble as follows:

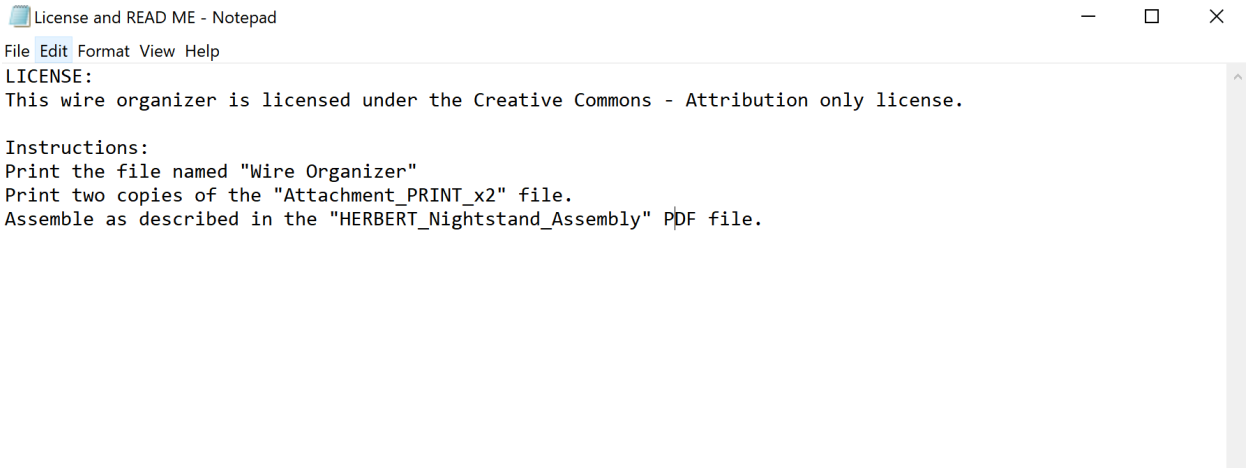


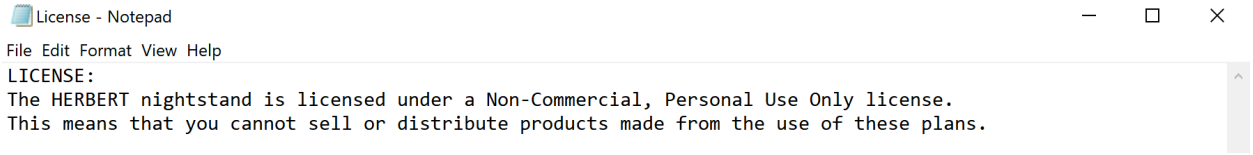
Appendix B: Wire Organizer STL Files





Appendix C: License Files





Appendix D: Product Photos