# Manufacturing at Home via 3D Printing

by

Michael Maffeo and Andrew Mularoni

An Interactive Qualifying Project

Submitted to the Faculty

of the

WORCESTER POLYTECHNIC INSTITUTE

In partial fulfillment of the requirements for the

Degree of Bachelor of Science

in Computer Science and Robotics Engineering

by

May 2022



APPROVED:

Smith, Therese

**Abstract**

This paper researches business models and manufacturing methods that can be used for additive manufacturing in a home setting, and explores the potential of this form of manufacturing. Practical business models are currently available that can leverage manufacturing at home effectively. A future where businesses harness the power of manufacturing from home is illustrated.

# Contents

# List of Figures

# Chapter 1

# Introduction

## 1.1 The Potential

3D printing is increasing in accessibility to the public, with new 3D printing technologies emerging and falling costs of consumer-grade 3D printers. Unlike the process of traditional manufacturing, 3D printing has the opportunity to create a new method of producing goods for consumers. Known as additive manufacturing, this field can improve the quality of life of both consumers and manufacturers in a sustainable way. By exploring the limitations and predictions of 3D printing, we can have a better grasp on the future of additive manufacturing, as well as opportunities for revenue within the field.

## 1.2 The Concept of Manufacturing at Home

As the concept of printing in 3 dimensions has expanded over the years, the desire to print goods at home has increased. Though some printable items are for personal use, others have been able to generate revenue off of low volume manufacturing of goods. Additive manufacturing is a fairly new business concept that has generated traction with the popularity of printing. There are several 3D printing based business models that are investigated in this paper; these are often utilized by individuals who spend a good amount of time at home, or who seek secondary sources of income. It is predicted that additive manufacturing will become a popular business model in the future, changing the customer's relationship with the producer and bringing some manufacturing from factories to homes.

## 1.3 Related Works

Research into methods to harness new 3D printing technologies in small businesses and home environments has been conducted by several researchers. The most relevant papers to the concept of manufacturing at home using 3D printers provide a few key insights into business models and specific applications that can be targeted using this technology. We have found research into a variety of entrepreneurial business models that are most effective when utilizing 3D printing to manufacture parts. The business models that were determined to have the lowest cost and highest number of customers are selling 3D printed parts, designs, services, and consultation over the internet[HBSS17]. Running services over the internet is highly beneficial to the number of customers a business can reach and allows a business flexibility to operate from home. Another paper illustrates how the use of 3D printing technologies has moved from rapid prototyping to rapid tooling to direct manufacturing to home fabrication[**?**]. Finally, one paper goes in-depth into the process of conductive material 3D printing with highly electrical conductive composite filaments[LCP+18]. This innovation dramatically increases the applications for 3D printed devices. Looking into business models that are similar to a home manufacturing yielded research on the average pay and other statistics for Amazon MTurk[HAM+18], By comparing and contrasting these business models, we can determine aspects from Amazon MTurk that a manufacturing at home business model should keep as well as aspects that must be avoided. By combining this research, this paper describes how 3D printing can be harnessed to create manufacturing from home jobs and businesses.

# Chapter 2

# The Reality of 3D Printing

## 2.1 Similar Business Models

The most important aspect of making 3D printing at home into a sustainable method for people to make money is to find a business model that both gives the consumer a product or service that they want and pays the manufacturer well for their time. This paper explores several business models that are currently being used for various industries and describes how they may apply to a 3D printing at home industry. Several business models explored have great applicability to 3D printing but not all would create positive results for the manufacturers. There are some business models that seem like they would work on the surface, but under a closer examination would cause home manufacturers to lose money.

### 2.1.1 Bitcoin Mining

Bitcoin mining is very similar to 3D printing in the aspect that both industries involve running several high-power, low-maintenance machines over a period of time. We can compare the power efficiency, amount of time spent monitoring the devices, maximum profitability, and cyclic costs for these two technologies to get a better idea of what 3D printing at home as a job would look like. To compare power efficiency, a comparison will be made between two standard systems for both tasks at around the $1000 price point. For bitcoin mining, an RTX 3090 will be used for comparison and for 3D printing the Prusa i3 MK3 will be used. The RTX 3090 GPU draws 285W continuously[rtx] to mine and is expected to generate $5 per day before accounting for power costs, needs daily monitoring that takes around 5 minutes, and the main cyclic cost is paying for power consumed by the device. The RTX3090 has a high power draw, and can cost more than $2 per day depending on local power prices. The Prusa i3 MK3 draws 120W[pru21] while printing ABS plastic and requires the user to slice and start new prints when the current print is complete, as well as monitor the printer to ensure it is error free. Running a 3D printer continuously takes approximately 30-45 minutes whenever a new print must be started on the printer as the model must be sliced, then the printer must be cleaned and prepared for the next print. Similar to bitcoin mining, monitoring the device should occur daily and take around 5 minutes per day to perform. 3D printing requires a cyclic cost of filament, which costs about $20 per kilogram of material. At a standard print speed, one kilogram of material takes about a day to print so the printer cyclic costs can be up to $20 per day. Quantifying the amount of money that can be made through 3D printing is difficult, so for this assessment we will assume that the 3D prints are selling for the same price that the WPI Innovation Studio maker space would charge for them which is $0.05 per gram. This results in a profit of up to $50 per day. The cyclic costs and profit generated from 3D printing can vary greatly based on customer demand for 3D printed parts.

Comparing these two technologies, it can be seen that there is a trade off between trying to make money with either technology. There are similar entry prices for both of these machines, but using either to generate a profit is a very different experience. Bitcoin mining is lower maintenance than 3D printing but is less profitable overall because of the lower net profit per day. 3D printing, on the other hand, is not a guaranteed source of income because it can vary based on customer demand. This model of a 3D printing business works best with a continuous stream of jobs to 3D print. For this extra time needed to run a 3D printer, the maximum profitability of 3D printers is much higher and from a power perspective 3D printers are eco-friendly as they draw less power.

### 2.1.2 Large Scale 3D Print Farms

One notable business that harnesses a large scale 3D printer farm for manufacturing is Prusa Research. This business manufactures their own 3D printer, may parts of which are 3D printed. Prusa Research runs a 3D printer farm which uses their prototype printers to manufacture the current generation of 3D printers. Utilizing 3D printing technology over injection molding allows Prusa Research to get valuable testing time on their newest prototypes and allows them to change mechanical components on their printers without having to re-tool new molds. Prusa Research has become a very successful 3D printing company, part of which is due to their innovative manufacturing method.

The low startup and change over costs inherent to manufacturing using 3D printers can be very beneficial to small businesses that require a low entry cost to production and must be able to pivot their designs quickly based on consumer demand for new features. Small businesses that are developing a new product can harness the power of 3D printing to rapidly fabricate prototypes and make small changes during low volume production that would otherwise require expensive retooling of an injection mold.

### 2.1.3 The Problem With Amazon MTurk

In a recent study data on Amazon MTurk workers was collected through the use of a browser plugin[HAM+18]. 2,676 workers were surveyed and data on each job that they completed was collected. It was discovered that the median wage for Amazon MTurk workers is below $2[HAM+18] per hour, far below the US minimum wage. There are two key reasons why this hourly wage is so low. First, the average requester on Amazon MTurk pays only $4.57[HAM+18] per hour, which is an incredibly low wage to start with. Often times a worker starts a task on MTurk but part way through the task the worker finds that they are unable to complete the task. For an unknown reason, the rate of tasks being cancelled due to the worker being unable to complete them is incredibly high. The study found that 31.8%[HAM+18] of time workers spend on Amazon MTurk is on tasks that will eventually be cancelled, meaning that the workers are not compensated for that time. The time spent for workers to look for new tasks also factors the low wage, but only accounts for 5%[HAM+18] total time spent looking for new tasks to complete.

For an ideal 3D printing service to be created that pays stay-at-home workers fairly, it is important to avoid the pitfalls of the MTurk business model. First, a fair price for 3D printed goods must be achieved to make this system equitable for people who manufacture at home. Following the concept of supply and demand, for a good to gain value the demand for said good can increase or the supply can decrease. Since the idea with this business model is to increase the supply of goods locally, the goods must reach a threshold of demand for them to have a high enough price to be worth printing. As 3D printing technologies advance, more intricate and new material goods may increase the demand, or people who 3D print at home can design new and innovative goods that have their own demand. The MTurk problem of cancellation is not as big of a problem when running a 3D printing business as goods that are no longer wanted by one consumer mid-production can be held in inventory to be sold to another customer at a later time.

### 2.1.4 Existing Infrastructure

Services currently exist that attempt to source 3D printing of models locally by connecting consumers who would like to 3D print a model with manufacturers that have 3D printing capabilities. Locally sourced 3D printing seems like a good idea as it can lower transportation costs and support local business. However, as the following experiment shows, locally sourcing a 3D printed design can cost more than having a design manufactured by a single large business that can take advantage of an economy of scale from having a high volume of similar parts to manufacture.

As an experiment, a sample 3D printable design was quoted using several services at different quantity price breaks. MakeXYZ is a service that consists of a network of people that own 3D printers and sends the design to the nearest person in the network that is capable of printing the design, while Hubs and Sculpteo are larger companies that perform the 3D printing of the design in-house. The sample 3D print is a simple NASA logo that should be simple for an FDM printer to make. All of the quotes were for the sample design to be 3D printed with an FDM printer with the cheapest available material. Shipping costs were not included in these quotations.

Price for sample 3D print with various 3D printing businesses

| Service | Price for 1 | Price for 10 | Price for 100 |
|---|---|---|---|
| MakeXYZ | $14.90 | $50.80 | $361.30 |
| Hubs | $7.27 | $13.10 | $83.00 |
| Sculpteo | $6.25 | $59.40 | $234.00 |

There are likely many factors that result in the larger businesses being able to manufacture 3D printed designs at a lower cost. These larger 3D printing businesses are the go-to for prototyping and small-scale manufacturing because they have the lower cost. The same sample design only needs 2.83g of filament to print so if somebody was to have a 3D printer and only pay for material costs, the sample design would cost $0.06 per part. There must be a significant profit margin on these parts so it is still possible for a new service to compete with these larger companies. One possible reason for the higher manufacturing prices for the MakeXYZ service is that the service is not streamlined enough to take full advantage of the location of manufacturing. There is potential for new services to drive down the cost of 3D printing in the future.

## 2.2 Current Business Models

### 2.2.1 Centralized Manufacturing

Centralized manufacturing is a business model where the manufacturing of a product happens in one centralized location and is then shipped from the central location to the consumer. One good example of a centralized manufacturing business model for 3D printing is Shapeways. This company hosts a marketplace where designers list their models. When a customer purchases a product from the Shapeways marketplace, a royalty is paid to the model creator and the model is printed by Shapeways and shipped to the customer. In this centralized model consumers do not need to own a 3D printer in order to get the product and product designers are paid for their time designing the product.

### 2.2.2 Distributed Manufacturing

Distributed manufacturing is where there are several small manufacturing centers distributed around where customers are and when a customer orders a product it is manufactured at the manufacturing center that is closest to them and shipped locally. This distributed manufacturing approach creates local jobs and reduces the amount of shipping that is required for a product to get to the customer. Distributed manufacturing centers benefit from the smaller entry costs involved in running a smaller manufacturing center and can be done in a home with just one or two printers. A good example of a distributed manufacturing business is MakeXYZ. MakeXYZ takes parts that a customer wants to be 3D printed and finds the closest manufacturer in the network that can manufacture the part. The part is then locally manufactured and shipped to the customer.

### 2.2.3 Consumer Manufacturing

Consumer manufacturing is a business model where the consumer owns a 3D printer and purchases a 3D printable design from a business. The consumer then 3D prints and manufactures the product themselves based on the purchased design. This business model does not require any shipping of the product or external labor so it is both more environmentally friendly and lower cost for the consumer in exchange for some of their time. As consumer level 3D printers reach higher levels of automation this consumer manufacturing business model becomes more appealing as the cost savings from this business model are the same but it requires less time of the consumer. One example of a business that uses a consumer manufacturing business model is 3D Lab Print. This RC airplane company sells designs for 3D printable aircraft that the customer then prints themselves.

## 2.3 Printing at Home

### 2.3.1 Technologies for Printing at Home

#### Printer Technology

FDM 3D printers extrude molten plastic onto a plate to form a model layer by layer. FDM printed parts often have layer line artefacts from the thickness of the layers that are used to build a model. The main limitation of FDM 3D printing is that each layer must be supported by the layer underneath it. Unsupported floating geometry will fall while being printed and cause the print to fail. FDM 3D printed parts can have a variety of physical properties based on the material being printed. and are often relatively durable. The time it takes to print a part using FDM printing is proportional to the volume of filament that is needed to make the part and inversely proportional to the layer thickness.

SLA 3D printers create a part by exposing a UV sensitive resin to UV light in certain areas using an LCD screen. Like the FDM 3D printer the model is created layer by layer but with SLA 3D printers using LCD screens, the entire layer is exposed to UV light at once. This means that the time it takes for a part to be printed using SLA printing is inversely proportional to the layer height and proportional to the height of the tallest part being printed, regardless of the volume or number of parts being simultaneously printed. The layer thickness on SLA prints is often much smaller than FDM printing, resulting in higher detail parts that do not show layer lines. However, due to the currently limited selection of SLA resins and the fact that it must be a UV curable resin, most SLA prints are relatively brittle and break easily.

Currently, most home 3D printers are FDM printers because they are available at the lowest price. With low-cost LCD screens and increasingly available resin SLA printers are rapidly gaining traction as the price for an entry-level SLA printer is dropping. Innovations in consumer-level FDM 3D printers are becoming less common. An FDM printer that was new 3-5 years ago is still competitive with new consumer-level 3D printers. However, consumer-level SLA printers are rapidly changing with new innovations frequently being released that increase 3D printer speed and resolution while decreasing cost. In the near future a current-day SLA printer will likely be much worse.

When planning to manufacture at home with a 3D printer it is important to consider the technology that the 3D printer is based on. If the higher detail of SLA printers is not currently needed, FDM printing technology is recommended as FDM printers are not changing as fast. It is possible that with new SLA printer developments a good current day consumer SLA printer may not be as good as a future consumer SLA printer. With developments in SLA resins, it also may be harder or more expensive to run should future SLA printer resin be incompatible with current day printers.

### Automation Technology

There are not many consumer-level 3D printer automation technologies even though they are becoming available for commercial applications. Consumer-level automation technologies could be key in reducing the amount of time that must be spent for a person or small business to manufacture goods at home in a low-volume production setting, which could make a consumer manufacturing business model more practical. Higher levels of consumer 3D printing automation also make a business model that sells designs for a product more viable as more consumers would be able to own and operate a 3D printer to manufacture their products.

One notable 3D printing automation technologies is the application of a continuous belt 3D printer. These FDM 3D printers print their parts onto a rolling conveyor belt that the material sticks to. Eventually when the part reaches the end of the conveyor belt the 3D printed part is separated from the belt and falls off the printer. This technology is not common in consumer printers but is popular enough that there is enough support for an experienced user to setup and use this type of printer.

### Design Technology

With high quality cameras becoming more common in phones as well as the introduction of LIDAR in new IPhones, 3D scanning technology has taken off and become both simple to preform and highly accurate. One interesting use case of this technology is to scan broken parts to reverse engineer the part and 3D print a replacement. Many consumers have camera-equipped smartphones that are capable of 3D scanning parts so a business model could be created where a consumer sends a scan of a broken component to a business and the business sells the consumer a complete design for a replacement part.

### Power Technology

As 3D printers are relatively low power consumption devices, solar power can be considered as a viable power source for a 3D printer. To illustrate the size of solar panel system that would be required to run a 3D printer, it would take approximately a 1 square meter solar panel in Massachusetts to continuously power a Prusa MK3s 3D printer which draws 120W of power while printing[pru21]. The current market price of a 1 square meter solar panel is around $1400[322]. For a little more than the cost of a high-end consumer 3D printer a solar panel array that can power it year-round can be purchased.

### 2.3.2 Benefits to Printing at Home

Depending on the business model implemented, 3D printing at home can have benefits over a large business manufacturing and shipping products to consumers. Two different business models that have significant benefits over a centralized manufacturing and shipping model are: a model where designs are sold to a consumer who prints the product and a model where the product is 3D printed at a home locally and shipped to the customer.

In the consumer manufacturing business model 3D printable designs are created by a business and are sold over the internet. The consumer who buys the design 3D prints the design themselves. There are two main benefits to this business model: there is no shipping involved in getting the product to the consumer and the material and manufacturing costs are significantly lower for the consumer because they preform the manufacturing themselves. The only shipping involved in this business model is from the consumer buying the material to manufacture the design with. The distribution of material to consumers can be done with a much lower carbon footprint because fewer unique items need to be distributed.

In the distributed manufacturing business model a product is manufactured closer to the consumer in a home and is then shipped a shorter distance to the consumer. This business model reduces the amount of shipping that is needed as the product only needs to be shipped locally instead of regionally and creates local jobs that can be done at home. The distributed manufacturing business model is more expensive than the consumer manufacturing model because a worker must manufacture the product and the product still must be shipped to the consumer.

Overall, both of the explored business models reduce the amount of shipping that is required for a product to reach the consumer in comparison to centralized manufacturing methods that are currently being used. The distributed manufacturing business model has a smaller shipping component and creates local manufacturing jobs while the consumer manufacturing method completely eliminates shipping a product and passes labor and shipping savings on to the consumer.

## 2.4 Developments in 3D Printing

There are some notable advancements in 3D printing that while they are not currently being utilized in a consumer manufacturing setting have potential in this space.

### 2.4.1 Conductive Filaments

Polymer conductive FDM printing filaments have been around for some time, but the main limiting factor of this technology has been the resistivity of the filament. Higher resisistivity means that a conductor is less efficient at conducting current and can cause undesired hearing of the conductor. Especially with 3D printed materials, undesired heating can cause the material fail and the 3D printed object to break. Some recent research has been conducted into lowering the resistivity of 3D printed materials and with an new polymer 3D printed material, lower resistivity materials can be printed and be used to create more effective electrical devices.

### 2.4.2 Metal Printing

Metal 3D printing has existed in industrial environments for a few years, and this technology is starting to trickle down to consumers. Filaments have been developed[**?**] that carry a metal powder inside of them and allow consumers to print their part out of this material then through a heating process melt the plastic that carries the metal powder then sinter the metal powder into a continuous part. This allows consumers to produce metal 3D printed parts if they can get access to an ceramics oven for the debinding and sintering process. Someday, with a cheaper consumer level ovens and sintering metal filaments, metal 3D printed parts could become more common for consumers and open more opportunities for distributed and consumer manufacturing of more products.

## 2.5 Open Source Development

One of the greatest driving factors pushing 3D printing technologies to the consumer market is the presence of open source projects. These projects are a key source of free tools for consumers who are interested in 3D printing and designs for machines that can be kitted and sold by larger manufacturers. Further, availability of consumer 3D printers has accelerated the quantity and quality of these open source projects as components that would otherwise have to be machined by a manufacturer can be 3D printed by hobbyists for a far lower price. The Open Source Initiative[ope] is an organization that supports open source projects through education and advocacy. Supporting this organization and others like it is important for consumer 3D printing to continue to advance through open source projects.

### 2.5.1 Developing an Open Source Project: Prusa Print Remover

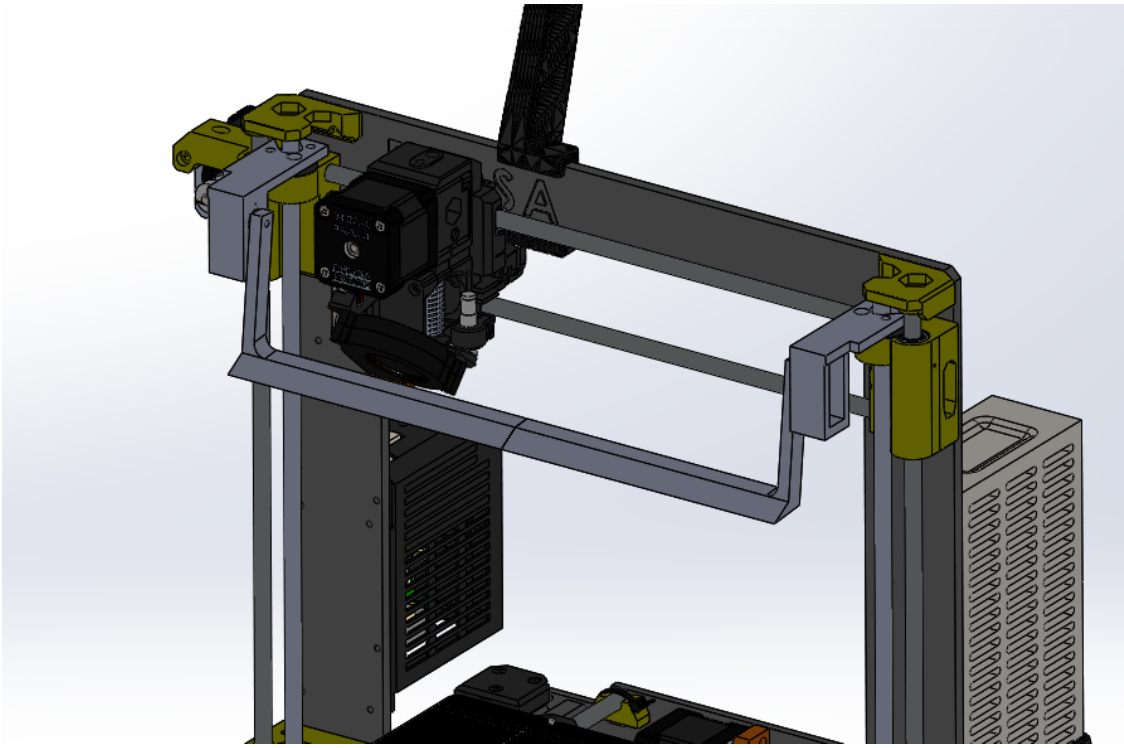
To further investigate how open source projects are developed and can help others, one of the authors will attempt to create an open source project that can aid others in automating their 3D printers at home. The process to create a small open source project will be to design the components, test the system, then distribute the source to other people who can utilize it.

## Project Goals

For this project, the goal will be to create an automatic part removal tool that can be attached to the Prusa MK3s printer that automatically removes the parts from the printer when the print is complete. If this project can be designed to be easily printable and cheap, it can benefit people who currently own a 3D printer and would like to begin automating their home manufacturing.

## Design

The mechanical design concept for the print removal tool is shown below. It can be installed onto a printer with only 4 screws and uses cheap off-the-shelf components to rotate the scraper beam into place. The intention for this design is that the scraper beam will be held above the print head while parts are being printed and at the end of the print the scraper beam will be lowered into the displayed configuration and used to scrape all of the printed parts off of the print bed.



The design for the automatic Prusa printer bed removing tool.

There is an additional software and electronic component to this project that is responsible for moving the motors that hold the scraper bar when the print is complete. This electronics component consists of a microcontroller, two remote control servos, and a connection to the printer itself for signaling. The software for this project is written using the Arduino IDE, which is another open source project that is easily accessible to other people who would like to extend the functionality of this project in the future.

**Testing**

To test this project, it was installed onto the Prusa MK3s printer that it was printed on and the servos to actuate the scraper were wired to a microcontroller to command the servos to move when needed. By writing a few lines of G-code that are placed at the end of each print, the printer alerts the microcontroller when the print is done which causes the servos to rotate and lower the scraper bar. The printer then moves the bed backwards and the scraper arm causes all of the printed parts to peel off of the bed.

### Distribution

Distributing an open source project in an effective manner to people who can utilize it is paramount to this project. The project source will not be helpful to anybody in the future if they cannot find and access the necessary files and documentation. To begin, the project was first uploaded to Github. This platform allows other users to download, edit, and share the modifications that are made to the project as it progresses. After creating and naming the project, there is an important decision that the user must make: the type of license that is assigned to the project. There are a multitude of different licenses to pick from depending on how the project owner feels about the project being redistributed and used in closed source projects. For this project, one of the simpler licences was chosen that allows almost unlimited access to whoever receives the project files: the MIT license. This license allows others to create closed source versions of this project and sell them as well as redistribute the files however they want. I believe that this license falls closest to the beliefs of an open source software ecosystem.

Next, the project was uploaded to Thingiverse. Thingiverse is a website that hosts 3D printable files for anyone to download and print. For this project, Thingiverse acts like a distribution or advertising service to get other people with 3D printers to learn about the project and possibly print and use it if they are interested. Distributing this project to people who would like to utilize it is very important for an open source project so that it can benefit the largest amount of people.

# Chapter 3

# 2122, The 3D Future

## 3.1 The 3D Printer of the Future

Hypothesizing about the future is not an accurate endeavour, but an examination of what might come. A vision of a world where 3D printing expands from its niche corner and enters our everyday lives. This world is no utopia, as it would be silly to predict that 3D printing could save human kind. Rather, it is an exploration that combines the technology of today with a prediction of the future. By combining information from studies, predictions from experts, and our own hypotheses, we will be able to examine how additive manufacturing might change manufacturing and consumerism in our daily lives.

For this thought experiment, the life of a hypothetical subject, Michael Mann, will be utilized for some examples. How he might use 3D printing in his day to day life, and how it has changed the manufacturing industry will be explored in depth. This hypothetical character might provide some insight and provoke further exploration about the possibilities of this technology. The year is 2122, one hundred years from present day.

In this future, we hypothesize that 3D printers have expanded, in both popularity and size. Much like many different appliances in our homes, the printer has achieved a commonplace status as a household item. Rather than being placed on a table or bench, the printer now acts as its own bench, taking up a space about the size of a horizontal refrigerator. As 3D printing expanded as a technological powerhouse, the demand to be able to print items larger and faster increased. Companies responded to this demand by offering printers with larger print beds, and the race to build bigger began. It was this drive that allowed the printer to become the very workbench it had once laid on.

As a technology expands in popularity and usability, it can quickly become an essential part of everyday life. Microwaves, for example, were first designed by Raytheon for industrial kitchen use. In time, the microwave became smaller and more affordable to the public. Now, almost 70 years later, it is quite uncommon for a home to not have a microwave in the kitchen. Likewise, the Global Positioning System was used by the military when it was created. Nowadays, our phones have GPS capabilities, and using it to navigate the world has become an afterthought to our generation. Although this future might seem like a giant technological leap for our time, it might just be a way of life for that generation.

## 3.2 The Design of the Printer

Whereas our current printers only have one printing head and a bed around the size of a square foot, we hypothesize that the 3D printer of the future might be built like a table, around the size of a horizontal refrigerator. In fact, it might be more accurate to refer to it as a printing table, rather than merely a printer. Because of the size, it often can be found in garages or basements, where it can be used when necessary without having a constant presence.

But what might drive a printer to increase to such a size? Although there are plenty of smaller printers now that can print objects that might be larger than expected, they are often limited to the size of the printing bed. Likewise, when the refrigerator first became commercially viable, it was the size of a small cabinet. As the benefit of the refrigerator became apparent, the size and features increased. We expect this trend to translate to 3D printers. As the popularity of printing larger and more useful items increases, the size of the printing platform would also increase as well. This, of course, would also be boosted by the inclusion of multi-material printing. The ability to use multiple materials would result in more common household items being printed, increasing the versatility of the printer.

The printing times have also advanced over the years. Rather than a single head having to handle the entire print, the printing table might have sections and systems to increase the speed and quantity of the prints. A printer could work on a single item, building it rapidly with mathematical precision. If multiple items were required, each section of the printer could focus on an item of a different material. Because they can work independent of one another, identical objects can be printed at the same time, on the same table. Print times for larger and more complex items would have drastically decreased, as this has a direct impact on the speed at which a print is completed.

The ability to print in multiple materials is crucial in cementing itself as a manufacturing competitor. Currently, there are various methods of printing that are being utilized to print in different materials, but none yet exist that can print with any degree of materials. As the technology improves over the years, we believe that such a printer would be created. The physical processes of printing, however, remain to be seen. Whether it is a powder or a filament, we are confident that the printer of the future would be able to create objects using a variety of raw materials. By examining the latest advancements in printing technology today, we can better predict the materials that might be available in the future.

## 3.3 Printing Materials

### 3.3.1 Metals, Ceramics and Alloys, Oh My

Advancements in printing will allow for a large variety of materials to be used in additive manufacturing. While organic materials, like plants or complex biological structures, cannot be exactly replicated on commercially available printers, substitutes are popular. This is akin to today's printers using wood composites and resins, which are alternatives to wood and rubber. Ceramics, composites and metals have become more mainstream, along with plastics and other polymers. Most importantly, like with every technology, the materials have become much more affordable by today's standard.

Another important aspect are the alloys and composites that can be used in printing. Different materials, like aluminum and silicon, can be combined to strengthen the printing material, which can increase an object's versatility and durability. As this combination of materials can only be done in high-end printers today, it would be reasonable to expect that this would become more commonplace in future printers. A 2017 study found that "...only a few alloys, the most relevant being AlSi10Mg, TiAl6V4, CoCr and Inconel 718, can be reliably printed; the vast majority of the more than 5,500 alloys in use today cannot be additively manufactured because the melting and solidification dynamics during the printing process lead to intolerable microstructures with large columnar grains and periodic cracks. Here we demonstrate that these issues can be resolved by introducing nanoparticles of nucleants that control solidification during additive manufacturing." [MYH$^+$17]. With the right focuses today, more printable alloys and metals are almost guaranteed to emerge in the additive manufacturing market.

Alloys aren't the only material expected to advance over the years; ceramics, though printable now, still have a ways to go. "...(D)imensional accuracy and surface finish still remain crucial features in today's AM due to the layer-by-layer formation of the parts.[Tra] With the right research and development occurring, advancements in ceramic printing will help further additive manufacturing as an industry. With a larger variety of materials to print with, more items will be able to printed, and the market for additive manufacturing will expand as well. These materials, though emerging advancements today, could be reasonably expected to have developed to the point of commercial usability over the next century. The successful utilization of these materials in a multi material printer will be assumed when discussing the implications of additive manufacturing.

### 3.3.2 The Waste of the World

One of the benefits of additive manufacturing is a potential in reduction to material waste. "In addition, in contrast with subtractive processes that lead to excessive use of material, AM can reduce material waste (Tuck et al., 2007). Baumers et al. (2016) also explain that the cost reduction in AM may contribute to the minimization of process energy consumption, mainly due to the feasible optimization design. Research has also demonstrated the ability of AM to simplify the supply chain because it helps produce small batches economically (Berman, 2012) and does so on-demand, with shorter lead times and, thus, lower inventories (Petrick and Simpson, 2013)." [CG] Rather than tossing unused or overproduced product away, additive manufacturing might help ensure that the product wasn't created in the first place. By building what is needed, less waste will be produced. However, additive manufacturing still has challenges ahead when it comes to reusability.

In its current state, printing is not an eco-friendly system. Prints cannot be repurposed, and if a print is defective, it is usually discarded. As 3D printing is still in its infancy, this is to be expected; generally, concerns of recyclability come after the problem has been created. However, solutions to this problem are being explored. If the ideal world has an economy that reuses materials to reduce waste, 3D printing might be the solution to achieve that milestone. According to a recent paper, "additive manufacturing (AM) -also known as 3D printing- and its direct (or distributed) manufacturing capabilities is becoming a key industrial process that could play a relevant role in the transition from a linear to circular economy" [CBCP20]. The ability to reuse product is crucial, considering that the consumer is also the producer. This study found that though "few works have been done for the recovery and preparation stages ... a great progress has already been done for the other stages in order to validate the technical feasibility, environmental impact, and economic viability" [CBCP20] of reusing and recycling printing material.

The research suggests that while a great effort has been put forth into researching recycling printed materials, more time and experimentation are needed to develop the methods and materials needed to create a circular economy. If additive manufacturing becomes a true alternative to traditional, it has the potential to create a less wasteful society. We hypothesize that recycling printing material in the future might look similar to bottle and can recycling centers in supermarkets. Programs could be created to recycle old, broken, or unwanted prints, with incentives such as discounts towards future purchases of material. For the examples examined in this paper, this will be the status quo assumed in the future. With additive manufacturing becoming an eco-friendly, circular economy, it would be a welcome companion and occasional competitor to traditional manufacturing.

# Chapter 4

# Manufacturing Comes to Us

## 4.1 Conflicting Approaches to Manufacturing

In a world where 3D printing can create items using different materials, it would make sense that the process of consumerism might change drastically. In fact, with additive manufacturing poised to become the next giant step in manufacturing, the production of goods will shift from factories to printers. Rather than assembly lines pumping out product, a machine that could print the appropriate items necessary would shift our economy from a products standpoint to a materials standpoint. With the right technology, we could see the end of inhumane factories and giant warehouses. In fact, it would be reasonable to believe that raw materials, in powder or filament form, would become the most important aspect of our economy.

Let's examine some common items of our world, and how they might be transformed in the future. Something simple and basic, like a set of silverware. Presently, there are two mainstream options for creating cutlery. They are either stamped out in a factory, or crafted by hand or machine, in traditional manufacturing (TM). Both require the same raw material to be formed, but not everyone has the skills or tools required to make a spoon by hand. Since spoons will always be in demand, there exists a need for a production line of spoons, and subsequently, factories for cutlery.

However, with 3D printing, spoons could be made right in our backyards, at a fraction of the overall cost. Although the ideal printing materials are not easily accessible at the moment, it is not unreasonable to assume that they would become commonplace in the future. With additive manufacturing, money and time could be saved, as seen in a study examining the cost of building ice cream scoops. "For instance, according to Zonder and Sella (2013), it takes 30 days and $1400 to build an aluminium mould enabling to mass manufacture a set of six ice-cream spoons by injection moulding. Instead, the exact same mould (albeit in polymer) can be 3D printed in less than seven hours and about half the cost ($785)." [RS16] Right off the bat, 3D printing has led to a cheaper and faster alternative to TM. Building the physical mould costs about as much as printing 12 scoops.

This isn't a guaranteed win for AM, however. The method of the mould might be able to create spoons faster than AM in the long run, depending on the amount of scoops within the mould, and the time it takes to create them. One study concluded that "AM becomes less competitive for higher production volumes, since the cost per unit of mass production decreases. The findings of this research lead to a conclusion that in general AM can be a suitable alternative to conventional manufacturing for low-volume production, i.e. less than 40 parts. However, it can be depend on the capacity of machine, material properties and required quality levels." [KNNPT19]. When it comes to traditional manufacturing, the ability to produce a specific amount of product is difficult to match. However, in this example, the expensive mould can only create one specific type of object: scoops.

With a physical mould, the creativity and customizability reduces drastically. If someone wanted a scoop with a smaller handle, or larger volume, a different mould would have to be produced. This would lead to more initial up-front costs and more space required for storage. Every slight change that might be thought of after the mould had been created would have to wait until a new mould was created. Additive manufacturing solves this problem entirely by removing the concept of moulds. ”Hence, instead of producing tens of thousands of identical ice-cream spoons, it is economical to produce smaller series that are particularly fit for a dedicated market segment (e.g., for toddlers, to eat ice-cream safely on the go). In fact, many objects can be better tailored and render ergonomically fitter and, hence, address the needs of potentially largely heterogenous(sic) market segments.” [RS16] The aspect of customizability and versatility will be a huge drive in the switch from traditional to additive manufacturing.

The current method of storing products until they are sold might also work against traditional manufacturing. As briefly mentioned above, storing scoops after they are produced carries a risk. They require physical storage until they are sold, which costs money, and the company is counting on customers to purchase the scoops. However, additive manufacturing creates items as they are needed, which eliminates both of these issues. ”Furthermore, parts can be produced on demand, reducing the inventory of spares and decreasing lead time for critical or obsolete replacement components. For these reasons, AM is now widely accepted as a new paradigm for the design and production of high performance components for aerospace, medical, energy and automotive applications.”[DWZ+18] Although spoons are vastly different from aerospace parts, the analogy can still translate.

## 4.2 The Spoon of the Future

A hundred years from now, we revisit the basic concept of the spoon. With 3D printers able to print out multiple materials, including metals like stainless steel, the need for someone else to construct a spoon has been eliminated. Michael, our subject from the future, has decided that he has a need for a new set of silverware. At the moment, he has nickel and stainless steel filament ready to use in his home. Using his iPad, he scrolls through various designs of different cutlery; there are hundred of different designs, sizes and composites that he can choose. He chooses one that is 15 percent nickel, 85 percent stainless steel, and uploads the schematics to the printer. No mold is needed for each piece, and no factory is required to produce each one. Within hours, they will be ready, and only at the cost of the material and plans.

One aspect that drives this future is the option to customize the things that are built. The size, weight and design of the object now play much more of a factor. If Michael wants his cutlery to feel heavier, he can change how large the size of the handle is, or what material it is made out of. If he wants his cutlery to have a cat face at the end of each handle, he can find a model that has this, or even create his own. If he has children, he could print out cutlery out of a kid-friendly plastic that has the same design, but smaller in size. Customization becomes a key aspect in manufacturing at home, and companies have an opportunity to take advantage of this. "One manner to address this need is the paradigm of co-creation. Broadly, co-creation is the joint creation of value by the company and the customer [299]—essentially, it is providing the opportunity for a customer to influence the design of an artifact based on his/her specific needs. Within the context of CAD and AM, co-creation will take the form of a web-enabled software tool that will allow users to modify the dimensions of a pre-designed part." [GZR+15]

Finding the right storage for everything also becomes much easier. Instead of purchasing a generic cutlery holder, one could be designed or modified to fit the ratios of the home. "Further to the cost reduction, designers will have the chance to share the prototype of the final product in each step of the product development process with their customers in order to involve them in the process and to reach higher levels of customer satisfaction. This is the point that the producer and the consumer can cooperate effectively in making a product, which is known as prosumer rather than being only a consumer."[KNNPT19] Returning to our example, Michael is looking for a holder that can hold up to 12 different types of cutlery. He picks a model that only has room for 10, but adds two other slots to hold the rest of his collection. He is easily able to replicate the style of the holder, which consists of a white plastic outline, 4 silicone feet, and a silicone base in each slot. To ensure a snug fit, he extends the model both length-wise and width-wise to the dimensions of the drawer. A few hours later, Michael has a silverware tray that has been tailored for him, designed by a company.

When it comes to 3D printing, imagination is now the limiting factor in what can be made. A teaspoon and tablespoon measurement combination, with one on either end? It's not something that is sold in stores, and the process to make it might not be worth the effort. If a mould is made, and the product either doesn't work as intended, or doesn't sell well, the company would be at a financial loss. However, it costs nothing but time and a computer to create a 3D model of an object. If it doesn't work as intended, then the losses are much less than with TM.

## 4.3 The End of Warehouses?

While the example of spoons might be smaller in scale, there are a good deal of objects that could be created using additive manufacturing. Every object that can be printed is one less that needs to be stored and transported by larger manufacturers. With AM, companies have the option to downsize a portion of what they use for assembly, storage, and transportation. From a study in 2015: "In the future, the industrial production could revolutionize in the medium and long term through the wider use of 3D printers by no longer selling the physical product, but only the product data. The transport of products could be replaced in the future via the data transfer of the print data according visionary approaches.” [MRD15] Companies might be able to save in various aspects of the manufacturing industry by removing storage and transportation costs altogether. How might they be able to make money from products they no longer produce? The answer might come from the schematics of the object itself.

For example, in today’s age, it is not uncommon to find furniture that was purchased and assembled in the owner’s home. With a futuristic 3D printer being able to print out larger objects in multiple materials, it might be easy to see how this analogy would apply. Lets’ use a generic TV stand, for example, that is currently sold by Target. A stand comes with the bases, shelves, supports, nails, screws, dowels, and cams, all packaged and contained within a cardboard box. The box is transported and stored in large warehouses until it is ready to be sold and assembled by the owner. Every stage up until assembly could be bypassed if the owner could purchase the blueprint for the object instead. Revisiting our subject, Michael, will provide a glance into this future. After ensuring he has the proper filaments for the print, Michael purchases the plans for the stand. The parts begin printing out simultaneously, with each printing head working on the different components of the stand. A printing head loaded with a stainless steel alloy prints out the nails, screws, and cams, while other heads print the reinforced wood shelving, bases and dowels. After the parts finish, the item can be assembled, and Michael can enjoy a TV stand that never sat in a factory or a store. Packaging, labor, transportation and time were all saved by the company in this process, and they were still able to make money off of the blueprints.

Though it might seem contrary, there will most likely be objects that are both traditionally and additively manufactured. The Target TV stand is actually a good example of how this comparison might work in the future. At the moment, Target sells the "assembly required" TV stand, but more expensive, professional, handmade options are available as well. Thus, it is probable that AM will replace the assembly version of the stand, but not necessarily the TM version. Customers who are willing to pay extra for the quality and handmade feel would most likely stick with that version, whereas customers who are happy with a cheaper, DIY version would find the benefits in the cost saved and customizability. It is, with this in mind, I believe that AM wouldn't replace TM, but rather it would cement itself as it's own category of manufacturing.

Along with this, not everything is going to be printable. Fabrics, such as cotton, wool, and polyester would still be required to be created in a more traditional method. Without a doubt, however, there will definitely be combinations of the two coming together. A chair with a cushion, for example, could be sold as just a cushion, along with the rest of the materials needed to be printed.

A similar design aspect might also occur with items that have electronics. A standing lamp, for example, can be printed, but the cord and socket might have to be traditionally manufactured, and physically sold along with the necessary filament. Items might also be rethought and redesigned for a 3D printed world. Perhaps, rather than using a cord at all, a new type of conductive material will be printed into the lamp to allow power to flow from the base to the socket. Even more complex electronics might be printed as well. If the components of a gaming console could be printed out, that could solve supply and demand problems that often plague releases. Let's examine some popular printing options of today and hypothesise what the future might hold.

## 4.4 What the Hell Are They Printing Over There?

Given these benefits of printing at home, it seems to be obvious that manufacturing will be gradually heading to a more individual scale for some objects. Based on the trends of printing today, we might be able to gather a better understanding of what will be created in the future.

### 4.4.1 Medical Advancements

Even with today's technology, 3D printing plays a role in the medical world. The company Sonova has been producing 3D printed hearing aids for several years now. "Today, 3D printing has long been the standard at Sonova: All the shells for custom in-the-ear hearing aids as well as various custom earpieces for behind-the-ear and receiver-in-canal hearing aids are produced using 3D printers. This enables the shape of the shell to be tailored optimally to the wearer's individual ear canal and degree of hearing loss." [**?**] Scanning the ear and canal allows the expert to create the perfect fit for each person. Although the printing and modeling is done on site, it can give an idea of what the future might hold. With printers a commonplace item in each household, the models could be sent directly to the customer to be printed at home. Although they may still have to go in to have the model created, they can also pick up the inner electronics, which might be tougher to print out. If the hearing aid is cracked, broken, or worn down, printing out a new version is easy enough, as long as the inner electronics are not damaged.

Similarly, eyeglasses could be printed out using AM. Frames for glasses can be quite expensive, whereas lenses can be much cheaper. Being able to model out and print eyeglass frames would save customers money and stress. If the frames crack or snap, then printing out another just takes a simple push of a button. Although this might come at a cost to the eyewear monopoly, it wouldn't hurt them permanently. They will still be able to sell models to print out, and, as mentioned before, 3D printing wouldn't outright replace the eyeglass industry. Rather, it becomes a more affordable alternative to those who want it.

Affordability becomes a factor when the medical industry is created via additive manufacturing. Probably the most cost effective model that comes to mind are 3D printed artificial limbs. At the moment "...prosthetics can cost anywhere from $3,000 – $100,000" [HSE21], which can be a rather costly procedure following a traumatic event. "Ultimately, the scientists concluded that by removing the necessity for an expensive manual fitting, their 3D printing production line could dramatically reduce the cost of artificial limbs for those in need. Although the team didn't put an overall price on their production pipeline, they concluded that the overall concept could "provide a much-needed leap in the field." [HSE21] The need for prosthetics increases every day, and people's lives can change drastically with them.

Innovation in artificial limbs can also occur with additive manufacturing. Not only could one get creative with the designs of the limb, but the parts can also be modified to reduce the price. "The original design for the wrist consists of three plates, three standoff posts, and two adapters, for a total of eight parts, not including the screws. With additive manufacturing, that assembly is combined into a single part; a part that would be impossible to make with traditional CNC or molding methods. Additive manufacturing eliminated tooling for those eight parts, and the bill of materials is reduced by seven parts." [?] This ability to reduce costs while improving quality of life is a huge aspect of additive manufacturing. Bringing manufacturing to the individual could help provide a better quality of life to certain groups. Artificial limbs aren't a one-time purchase either. Much like shoes, a child would need a larger hand or foot to match their body as they grow older. Printing the next size up, or even new parts to replace broken ones, would be less of a hassle and much less expensive if the technology was available in our own homes.

### 4.4.2 A Handy Printer

Although these advancements in the medical sector seem like an amazing leap, the true potential of the 3D printer is almost limitless. With the right materials, the imagination becomes the limiting factor. Many different aspects of our lives today could have 3D printed alternatives in the future.

One major area being explored currently is using 3D printed parts in airplane engines. "Comprising around 300 3D printed parts, these come together to make up a total of seven multi-part components. This includes the famed GE 3D printed fuel nozzle. Additional components, including temperature sensors and fuel mixers, and larger parts, like heat exchangers, separators and foot-long low-pressure turbine blades, helping to reduce the weight of the engine." [**?**]. Reducing the weight of an engine is important in flight, as it allows the plane to carry more people, and thus make more money. However, there is a much more important aspect that relates to our daily lives. If the technology can be used in airplane engines, why couldn't it be used in car engines? Quite often, cars need repair, and new parts can be expensive or hard to acquire. Using the right materials, 3D printed parts could be beneficial in making repairs cheaper and easier, whether in the interior of a car or the engine bay. This could be especially useful if the part or the car is no longer in production, as it would provide a path of repair even if the part isn't physically around anymore.

3D printing could also change the market for games and toys. In 2014, the toy company Hasbro developed a line of My Little Pony toys that were designed to be 3D printed. "Hasbro decided to embrace the fan designs and partner with Shapeways, a website where people can share blueprints that are entered into 3-D printers"[nbc14]. Though this might appear to be for children, the designs had mostly been created by "guys who just really loved the show"[nbc14]. Allowing each user to be able to print their own designs gave Hasbro a chance to truly connect with their fan base. Only a few of the designs might have been created, if they had gone through the traditional toy designing process, and the success would have been judged on the sales in stores. However, with additive manufacturing, these "bronies" were able to create and design the toys they wanted, with almost no cost to Hasbro. This doesn't have to stop at Hasbro, however. With an increase in popularity, additive manufacturing has the capacity to customize many of the games and toys that we love today. Whether board game pieces or LEGO parts, printing would allow for customizability for a variety of different pieces, within a matter of hours. Imagine a world that allowed for a better version of a toy to be built, if you disagreed with how it had been originally designed. Without a doubt, more 3D printed versions of games and toys are sure to follow as printing becomes more popular.

However, the greatest aspect to the 3D printer is that it is not limited to any one type of object. Thus, the possibilities are literally limitless. If a piece of moulding comes loose, and it needs to be nailed in, a 3D printer could solve that problem by printing the nail. Don't have a hammer? 3D print it. An earring goes missing? Print another one. A foot breaks off of a piece of furniture? Print it. We enjoy convenience, and additive manufacturing provides the convenience to print out almost anything we could need in the span of minutes.

# Chapter 5

# Modeling (But Not With Our Bodies)

With the expansion of 3D printing in our everyday lives, the current industry of printing individual objects out and selling them online might be hurt. People might still have a need for printing, but it would have such a wide range of influence that there would be options for those without. Printing cafes, printers in libraries and campuses, and other forms would allow printing to anyone with a varying degree of age and experience. It wouldn't be infeasible, however, to believe that a source of income is impossible to achieve through 3D printing. The virtual creation of the models themselves is a process that all 3D printing depends upon, and it is from these models that a source of revenue can be generated.

## 5.1 Modeling the Future

Often, the object that is being printed does not exist in anything but the imagination. Bringing that model to the virtual world would take some design skills that might not be as common, even in a world that utilises printing. Much like an artist that paints or an architect that designs, the creator of the models can implement their own style into the model.

Generating consistent revenue might be tricky, especially if selling a model equates to becoming TikTok famous. However, it can be a creative way to still earn money, as well as functioning as a secondary job or a hobby. Rather than focusing on the quality of the print, a creative individual would be able to focus their attention on the minute details of the print. For example, Disney adults have become a niche demographic in recent years. There are successful business opportunities for those who are able to design common 3D printed household items to that target audience. With the ability to be printed in different materials, the objects themselves wouldn't just be for decoration, but for functionality. Who wouldn't want spoons with Mickey Mouse's face engraved on the handle?

This wouldn't be a market for everyone, but it would provide everyone who had access to 3D printing software a chance to earn money from home. In fact, if a company decide to create a line of 3D products, it would create opportunities for individuals to design said line. Working as a 3D designer might even become a full time job; as more objects become printable with additive manufacturing, more variations and models might be sold. Figuring out how to minimize material usage and print times would be an aspect that companies might want to consider. This would make models easier to print, and allow companies an advertising advantage to their products.

## 5.2 A Return of Inventors

The ability to translate dreams and imagination into pixels might also allow creative and scientific-minded people to work on creating the next big idea. The ability to create what you can imagine, without being limited to physical items around, might give those who are of the inventor mindset a place to flourish. Working with computer programs to design 3D printed objects would create an environment to solve problems in real time. "Current AM technologies provide the most freedom to a designer in the realization of complex geometric shapes. When employing AM, this complexity comes at no additional cost, as there is no need for additional tooling, refixturing, increased operator expertise, or even fabrication time. While complexity can be achieved in traditional manufacturing processes such as injection molding (especially if it is justified via the profits found in a large production quantity), there is a direct relation between geometric complexity and the mold cost." [ZJYB18] If these problems are properly fixed, selling the solution as a model might generate the owner some revenue as well. Instead of pitching the idea to a few people for funding, like Shark Tank, the creator could post his design or model online, and the revenue generated would be the sign of his success.

# Chapter 6

# In A World...

When writing about the future of technology, it is pretty easy to assume that the next great leap will be able to solve the world's problems. Although it has great promise, additive manufacturing has the potential to backfire and create more problems than solutions. Additive manufacturing is about creating something with minimal waste, but if that object cannot be properly repurposed or reused, it might wind up creating more plastic waste. However, if methods for reusing and recycling printing materials are developed today, 3D printing will be able to create a less wasteful and more efficient economy tomorrow. Although this future might still be considered a dream, it is achievable if attention and interests are focused on the right areas of our lives.

## 6.1 Teaching the Children

The future belongs to the children, and giving them the proper tools that they need to succeed in a technology-centered world is going to be crucial. Although it is not uncommon for elementary and middle schools to have some form of coding or computer science related class, we believe that it should be a more fundamental part of a child's education. From personal experience, the emphasis on cursive should be decreased, and replaced with basic lessons about computer science. Programming is a language in itself, and teaching it early on might make it easier to use and more approachable later in life. With 3D printing and modeling becoming as popular as predicted, it would be beneficial to be able to easily use a computer modeling software. With an early start to programming, children could choose to advance their learning with classes in high school, rather than learning it from scratch. However, it appears that today, most students begin learning about tech while they are in high school. "High schools are at the early stages of learning and adoption of 3D printing technologies in their informal programs such as first robotics and formal technology oriented electives. Training programs for high school teachers including examples of curricular uses of it through potential integration of courses with design as well as informal opportunities through programs such as first robotics can be used as channels for exposure." [GZR+15] This is less than ideal. "Education and training in 3D printing will be critical for the future customer to adapt and innovate in AM... " [GZR+15], and starting their education in technology as a child will give them the best chance of success in the future.

## 6.2 Recycling Plastics, Resins, and Other Materials

In its current state, additive manufacturing cannot be considered an efficient form of manufacturing. Compared with traditional manufacturing, it has the advantage of minimizing waste while creating the object desired. However, after the object has been printed, there isn't an easy solution to reusing or recycling the material. This is especially important if the object does not print correctly. Deformed prints are generally thrown away, abandoning any opportunity to repurpose that print into a usable material. Thus, if additive manufacturing is to achieve its potential, systems need to be properly developed for recycling different printed materials. "Based on the results, it is concluded that the recovery and preparation stages are less studied.

Research efforts need to be taken in the pre-treatement of the recycled material, including efficient models to collect waste material, technology and methodologies to develop quality indicators of the waste material." [CBCP20]. Investing the necessary time and effort into the development of recycling systems for printing materials is a necessity for the future. As mentioned before, a recycling program, similar to that of cans and bottles at grocery stores, would be an effective strategy to recirculate used material. With the proper incentives, additive manufacturing could reach its potential, reducing the amount of waste created, and helping to further a circular economy.

"However, the question that remains unclear is about the willingness by users to use recycled 3D objects and eventually to become 'prosumers' in the recycling process (Kreiger et al., 2014). Educational courses on distributed recycling are perceived as a means to encourage students to think about the access to the digital manufacturing capabilities and their sustainability-related issues (Jaksic, 2016; Schelly and Pearce, 2019)." [CBCP20]. If these methods are developed, and no one wants to use them, then the problem hasn't changed. Awareness is key in this aspect; spreading information about recycled materials and promoting the use of them, especially among us youth, is crucial. Given the current viewpoints on recycling, we believe that the idea of recyclable printing would be able to sell itself, especially among the youth. However, it would also benefit from influential figures or campaigns raising awareness of the new abilities of this product.

## 6.3 Promotion of 3D Printed Items on Social Media/IRL

Without a doubt, the popularity of 3D printing will rely on newer generations finding interest and use out of additive manufacturing. One of the easiest ways to drive this popularity would be over social media, especially with the newest apps. TikTok, the latest popular video sharing platform, has creators that post about the items that they print. The posts vary from initial designs of products to current prints in various stages of completion. Often, the product is shown on the app to then be sold online, but the designs and prints can be just for fun, as a hobby. If 3D printing is to expand to the general public, it is going to require an initial exposure for each person, and media-sharing apps can accomplish this easily. If creators focus on creating and spreading more additive manufacturing content on a variety of platforms, then the usefulness and attractiveness of printing will naturally increase. Its popularity among the youth will also be important; as printing becomes more common in their world, it will make the idea of owning and using a 3D printer less foreign, and provide an easier transition to additive manufacturing in our daily lives. Though the important changes to printing haven't yet occurred, this boost of popularity in the public eye will help to spur these changes, and help additive manufacturing reach its true potential alongside traditional manufacturing.

# Bibliography

[322] Kyle BrowningFeb 3. 1kw solar panel (ultimate guide to a 1kw solar system), Feb 2022.

[CBCP20] Fabio A. Cruz Sanchez, Hakim Boudaoud, Mauricio Camargo, and Joshua M. Pearce. Plastic recycling in additive manufacturing: A systematic literature review and opportunities for the circular economy. *Journal of Cleaner Production*, 264:121602, 2020.

[CG] Damien Chaney and Julien Gardan. A framework for the relationship implications of additive manufacturing (3d printing) for industrial marketing: servitization, sustainability and customer empowerment.

[DWZ+18] T. DebRoy, H.L. Wei, J.S. Zuback, T. Mukherjee, J.W. Elmer, J.O. Milewski, A.M. Beese, A. Wilson-Heid, A. De, and W. Zhang. Additive manufacturing of metallic components – process, structure and properties. *Progress in Materials Science*, 92:112–224, 2018.

[GZR+15] Wei Gao, Yunbo Zhang, Devarajan Ramanujan, Karthik Ramani, Yong Chen, Christopher B. Williams, Charlie C.L. Wang, Yung C. Shin, Song Zhang, and Pablo D. Zavattieri. The status, challenges, and future of additive manufacturing in engineering. *Computer-Aided Design*, 69:65–89, 2015.

[HAM+18] Kotaro Hara, Abigail Adams, Kristy Milland, Saiph Savage, Chris Callison-Burch, and Jeffrey P. Bigham. *A Data-Driven Analysis of Workers' Earnings on Amazon Mechanical Turk*, page 1–14. Association for Computing Machinery, New York, NY, USA, 2018.

[HBSS17] Patrick Holzmann, Robert J Breitenecker, Aqeel A Soomro, and Erich J Schwarz. User entrepreneur business models in 3d printing. *Journal of manufacturing technology management*, 28(1):75–94, 2017.

[HSE21] Paul Hanaphy, Kubi Sertoglu, and Hayley Everett. Scientists create fully-automated 3d printed prosthetic production line, Mar 2021.

[KNNPT19] Mojtaba Khorram Niaki, Fabio Nonino, Giulia Palombi, and S. Ali Torabi. Economic sustainability of additive manufacturing: Contextual factors driving its performance in rapid prototyping. *Journal of manufacturing technology management*, 30(2):353–365, 2019.

[LCP+18] Zuomin Lei, Zhenxing Chen, Huan Peng, Yuqiu Shen, Wenchao Feng, Yi Liu, Zhuo Zhang, and Yan Chen. Fabrication of highly electrical conductive composite filaments for 3d-printing circuits. *Journal of materials science*, 53(20):14495–14505, 2018.

[MRD15] Dominik T. Matt, Erwin Rauch, and Patrick Dallasega. Trends towards distributed manufacturing systems and modern forms for their design. *Procedia CIRP*, 33:185–190, 2015. 9th CIRP Conference on Intelligent Computation in Manufacturing Engineering - CIRP ICME '14.

[MYH+17] John H. Martin, Brennan D. Yahata, Jacob M. Hundley, Justin A. Mayer, Tobias A. Schaedler, and Tresa M. Pollock. 3d printing of high-strength aluminium alloys, Sep 2017.

[nbc14] Brony? 'star wars' fan? 3-d printing can make a toy for you, Jul 2014.

[ope] About the open source initiative.

[pru21] Prusa knowledge base, 2021.

[RS16] Thierry Rayna and Ludmila Striukova. From rapid prototyping to home fabrication: How 3d printing is changing business model innovation. *Technological Forecasting and Social Change*, 102:214–224, 2016.

[rtx] Leading cryptocurrency platform for mining and trading.

[Tra] Nahum Travitzky. Additive manufacturing of ceramic-based materials.

[ZJYB18] Yuan Zhang, Stefan Jedeck, Li Yang, and Lihui Bai. Modeling and analysis of the on-demand spare parts supply using additive manufacturing, Nov 2018.