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An Examination of the Influence of Sustainability on Business Strategy in the Three-Dimensional Printing Industry

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AN EXAMINATION OF THE INFLUENCE OF SUSTAINABILITY ON BUSINESS STRATEGY IN THE THREE -DIMENSIONAL PRINTING INDUSTRY

by

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ABSTRACT

3D printing, also known as additive manufacturing, is an emerging field that has yet to find its place in society. Research and development in the 3D printing industry spans a vast range of technologies, materials, and applications. Many say that it is still in search of its "killer app," a tool or capability that will lead to mass popularity the way the internet and personal computers played an essential role in the exponential growth of the computer industry (Kurman & Lipson, 2013; Misek, 2013). New entrepreneurs and established business executives involved with the 3D printing industry are scanning the field for areas this technology can benefit. In search of key market targeting and positioning these executives must ensure that their businesses remain financially sustainable. Some companies are looking to reduce the environmental impact of 3D printing by creating 3D printing materials made from recycled plastics or that have biodegradable properties, or minimize the impact on the environment in other ways. For some companies this is a key piece of their business model. The commonly used definition for eco-sustainability is, "development which meets the needs of the present without compromising the ability of future generations to meet their own needs" (Drexhage & Murphy, 2010). The literature review reveals common themes around the sustainability and the 3D printing industry. This research brings up several questions: How do executives sustain their 3D printing businesses in this emerging and volatile industry? What are the trade-offs in pursuing a sustainability-focused business strategy vs. a more traditional business model? Where does social and environmental sustainability fit into the 3D printing industry and how does it influence other businesses?

These questions have driven the research in this paper. 3D printing startups and end-users were interviewed to explore to what extent sustainability is a priority and which types of sustainability are manifested within their businesses.

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INTRODUCTION

Many industries have recognized the growing importance of becoming sustainable (Ortiz, Castells, Sonnemann, 2009; Yip Robin & Poon, 2009). Businesses are adapting to new policy changes that push for increased environmental or socially sustainable standards (Ortiz, et al., 2009; Yip Robin & Poon, 2009; Harman, 2013). At the same time new technologies are emerging and companies developing around these new industries sometimes see a trade-off in profitability vs. sustainability. The 3D printing industry is one of these new industries with companies that span a wide variety of product and service options. The companies also pursue different types of sustainability to varying degrees. It can be hard to map out an industry early in its life cycle, but it provides an important way to see to what degree sustainability is prioritized in the industries and lead to potential insights for the future development of the industry. I interview participants in the 3D printing industry to learn about their business practices and the degree to which sustainability is pursued.

From an environmental perspective the awareness of the negative effects of pollution and the implications of climate change on our future is growing. World conferences are being held to curtail our bad habits and invest in more responsible habits ("UNFCCC – 20 Years of Effort and Achievement," 2014). Trends like "buy green" or "buy local" are ways that society is working to improve these situations on the consumer level. Consumers are becoming concerned about what materials and chemicals are used in their products and where they are sourced.

Separately, 3D printing has been developing over several decades. However, it is only in the past 10 years or so that people have started to hear about this technology

(Bergl et al., 2013). And it has only really gained media coverage within the past five years. Since then 3D printing experimentation and development has spread to a variety of fields (Huang, Liu, Mokasdar, and Hou, 2013; Kurman & Lipson, 2013; Winnan, 2012). However, this industry is still in its forming stages and has yet to really find its place in society. The media coverage has helped expedite some areas of development as tinkerers work to improve various aspects of 3D printing. "Makers," as many fans on the consumer level like to call themselves, work on developing many aspects of 3D printing from material strength or elasticity, to creating more efficient software, working out bugs in the design stages, or improving the speed of printing ("Leading the Maker Movement," 2016). There are many facets of additive manufacturing that still need refining.

3D printing has grown with the help of Makers. Adoption into the manufacturing field, using 3D printing for prototyping, and integrating this technology into school curricula has also contributed to the growth of the 3D printing industry. This raised awareness around 3D printing technology and its rise in popularity has incited people to ponder its potential issues.

Recently, articles on 3D printing have begun to focus less on trinkets that can be created out of plastic and more on the amount of waste produced from failed plastic prototypes, scrapped for a superior iteration (Gebler, Schoot Uiterkamp, & Visser, 2014; "3D Printing: Sustainability Opportunities and Challenges", 2015; Sreenivasen, Goel, Bourell, 2010). Another issue is the large amount of energy used to create objects made out of metals and other materials requiring high heat or pressure (Gao et al., 2015; Gebler, et. al., 2014). It seems that an increased concern about environmental consequences and developing concerns about 3D printing processes, lines up in a way that could lead to the

development of ecologically conscious and sustainable 3D printing processes in the future.

Purpose

The purpose of this thesis is to examine the business sustainability strategies of 3D printing companies and end-user businesses that integrate 3D printing into their strategy. The role of social and environmental sustainability will be discussed in relation to these businesses and how it is prioritized by businesses in the industry. Businesses need to be economically viable to thrive. Many 3D printing companies follow the example set by traditional manufacturers, using non-sustainable materials such as ABS plastic and various metals ("Clearing the air about 3D printing emissions, 2015; Rayna & Striukova). Other business look for environmentally friendly alternatives when they are developing to minimize or eliminate negative effects on nature, while others have adapted sustainable practices over time (Weller, Kleer, & Piller, 2015; Marien, 2012). Looking at the different motivations and goals of a cross section of companies can help provide insight into the 3D printing industry. Through a series of interviews the research goal was to explore motivations of business leaders and see if there was a social or eco-sustainability element to the business.

Significance

Businesses are starting to recognize the need for sustainable products and processes. Major players are making changes to their business models and mission statements. If companies incorporate the 3 R's (reduce, reuse, recycle) into their business models this may reduce pollution that harms the environment, reduce health risks and disease, prevent drastic effects of climate change, and other potential consequences.

The additive manufacturing industry is now becoming a part of this problem. As an emerging industry about to hit the growth phase, it is positioned to expand well into the future. It is still in the formative stages as there is no one main application, but many niche markets have been targeted (Huang, et al., 2013; Kurman & Lipson, 2013; Winnan, 2012).

Moving towards a sustainable future is key. Not only will environmentally responsible products and manufacturing reduce the negative effects of pollution on the world we live in, but it will also increase efficiency, decrease production costs, which could save money for business and could also open up new markets focused on sustainability.

LITERATURE REVIEW

Sustainability

Types of Sustainability

Sustainability can be a complex topic to discuss, because it can be manifested in many different ways within an industry (Lewis, 2005). There are also different degrees to which sustainability can be pursued. Sustainability is generally considered to be composed of three parts: economic, social, and environmental (Labuschagne, Brent, and van Erck, 2005).

Economic sustainability has multiple definitions depending on the article or organization defining it. (Labuschagne, et al., 2005) notes that the Global Reporting Initiative (GRI) defines it as ‘‘an organisation’s impacts on the economic circumstances of its stakeholders and on economic systems at the local, national and global levels.’’ The GRI is externally focused whereas the United Nations and Wuppertal Institute focus internally, calculating contribution to gross national product and gross domestic product (Labuschagne, et al., 2005). Some indicators of economic sustainability include financial health (profitability, liquidity, and solvency), company’s perceived value by its shareholders, potential financial benefits (ex. subsidies for pursuing sustainable business initiatives), and trading opportunities (Labuschagne, et al., 2005). A firm needs to generate enough revenue to offset its costs and stay in business.

Environmental sustainability involves reducing or eliminating impact on the quality of air, water, land, mineral, and energy resources Labuschagne, et al., 2005). Companies could track this in a variety of ways from product life-cycle impacts, to air emissions, or reducing energy and material waste within the business (Labuschagne, et

al., 2005; Veleva, Hart, Greiner, and Crumbley, 2003). There are many ways companies can reduce their impact on the environment. For example, they could use raw materials from renewable resources or utilize more efficient processes and technology to reduce energy use and emissions.

A firm can pursue social sustainability internally and externally. Some internal elements include employee job stability, fair compensation, non-discriminatory business practices, and proper health and safety standards within a business (Labuschagne, et al., 2005). Externally, the company's impact on the community is factored in. This includes the impact a business may have on the community's health as well as educational and training opportunities to share information (Labuschagne, et al., 2005). The second social impact is calculated by "the strain placed on these assets and infrastructure availability by the business initiatives" (Labuschagne, et al., 2005). The third social impact involves relationship of the business and community (Labuschagne, et al., 2005). This involves potential impact of the community's security, job opportunities, impact on poverty, social cohesion, etc. (Labuschagne, et al., 2005). One way to track these elements is called the triple bottom line (TBL), used by accounts to calculate a firm's impact on these three areas of sustainability (Flint, 2013; Labuschange, et al., 2005, Stead & Stead 2014). Like other ways of calculating sustainability this has its flaws and is often biased towards economic sustainability over social or environmental aspects (Flint, 2013). The intent behind social sustainability is to engage equitable practices that can benefit company employees and the greater community.

Sustainability Barriers and Drivers

After reviewing literature on sustainability there is evidence that some industries show a measurable shift towards social and environmental sustainability. However it seems that some industries might need a strong incentive to change, such as regulatory changes. A review of the construction and restaurant industry in the UK revealed that both were reluctant to change unless policies required they comply with certain standards (Revell & Blackburn, 2007). Restaurant owners seemed to lack knowledge of sustainability standards and regulations and they believed changing their business to be eco-sustainable would be costly (Revell & Blackburn, 2007). Small and Medium-Size Enterprises (SME's) paradoxically stated that they believe the only way to ensure businesses adopt better practices is to impose government regulations (Revell & Blackburn, 2007). They also claimed that if there were no regulations owner-managers often assumed that there were not any environmental issues (Revell & Blackburn, 2007). Similarly, a study of the pharmaceuticals industry revealed regulation as the main driver for sustainability (Blum-Klusterer & Hussain, 2001). The second biggest factor was new technology development (Blum-Klusterer & Hussain, 2001). From the construction industry side they were mainly concerned with cost and the time projects took to complete over environmental concerns (Revell & Blackburn, 2007). However, it also seems that the construction industry is working towards better sustainable practices (Ortiz, Castells, Sonnemann, 2009; Yip Robin & Poon, 2009). Additionally, low profit margins were a contributing barrier to sustainable investment in the construction industry. This review reveals that many industries face a variety of barriers to sustainability. Some of these are linked to misperceptions or lack of knowledge on sustainability. However

others are more constraining barriers like financial constraints that prevent investment in sustainability.

One article states, “SMEs contributes up to 70% of industrial pollution and there is a need to increase the modernization of industrial process in developing countries and promote best practices engineering” (Ortiz et al., 2009). This shows a valid reason for concern since they are responsible for a substantial amount of industrial pollution. Some studies have attempted to map out levels of sustainability and performance indicators. (Veleva, et al., 2003) map out five levels of sustainability. At the lowest level (level 1) firms comply with current standards (Veleva, et al., 2003). Level 2 involves further social and environmental tracking such as emission and waste generation as well as occupational injuries (Veleva, et al., 2003). Level 3 involves whole facility impact and worker health and safety standards (Veleva, et al., 2003). Level 4 tracks the life cycle of product development from raw material extraction, to production, to disposal across the supply chain and all the way to the end users (Veleva, et al., 2003). Lastly, Level 5 is a commitment to being a partner in the global eco-system (Veleva, et al., 2003). This illustrates the levels of commitment a company can have for pursuing sustainability.

The GRI is another way to track performance measures. It has been established as an attempt to set a uniform set of global sustainability standards (Veleva, et al., 2003; Jenkins & Yakovleva, 2006). (Labuschagne et. al, 2005) claims that the “GRI [is] the only recognized international initiative that focuses on reporting the sustainability of the entire organization.” This organization collects submissions of sustainability reports. Their current website shows that 9,501 organizations to date have made submissions (Sustainability Disclosure Database, 2016). These organizations are located around the

world. This is just one of many initiatives to create standards and indicators that contribute to sustainability.

While reporting and creating sustainability indicators contributes to the shift toward sustainability there are still many barriers. Additionally, there are downsides to regulation as well. Lack of education about issues around sustainability and new policy changes are a barrier to adopting sustainable practices (Lewis, 2005; Revell & Blackburn, 2007). Also, some people perceive that it rests upon the government to take action and impose policies especially (Lewis, 2005). Another insight revealed that people meet government standards, but rarely see incentive in going beyond them (Revell & Blackburn, 2007). Across these industries there are common themes that crop up as drivers and barriers of sustainability.

Benefits of Investing in Sustainability

Scott, Martin, & Schouten (2014) make the argument that integrating sustainability into business makes logical sense. They discuss short and long-term gains such as lower cost, energy savings, and reduced waste (Scott, et al., 2014). It is also pointed out that waste streams can still be profited from (Scott, et al., 2014). This could refer to a closed-loop system for the business where the raw material is derived from the waste of discarded end products produced by the company. Using renewable resources could also lower insurance rates (Scott, et al., 2014). These are a few of the benefits to switching to a more sustainable process. “Accountants have a particularity unemotional argument for moving towards sustainability. Cost and risk equations are dynamic, and the long-term shifts clearly favor sustainable production and sourcing” (Scott, et al., 2014). To back this up they cite PricewaterhouseCoopers warning carbon-intensive businesses

that they will continue to face stricter regulations and modify their business practices. This argument is also supported in another article (Webster, 2007).

> "Businesses and innovators who are leading the way to a 'bright green future' (Anderson 1999; Steffen 2007). They will be the beneficiaries of this new worldview—they will thrive in a carbon-constrained world of limited resources. They do it because it makes sense, not because they particularly want to do their bit 'for the planet', but because they know they have a working relationship *with* the planet."

This line of thinking points at a shift in perspective and how people view their relationship with the planet and realizing the bigger impact that our actions can make. Additionally, (Harman, 2013) illustrated the impact that pursuing sustainability can have. He highlights the Energy Star program which, "saved enough energy in 2010 alone to avoid greenhouse gas emissions equivalent to those created by thirty-three million cars – all while saving nearly $18 *billion* on their utility bills." These actions benefit the environment and the consumer. (Harman, 2013) states, "In both government and industry, the economic benefits of sustainable products and alternative energy are proving their worth. Clean tech is less than ten years old as a recognized market sector, but it is the fastest growing venture capital investment market." He has identified that at least in the short-term there is great growth in this area. Clean tech could include 3D printing companies if they chose to pursue such a strategy.

Sustainability and the 3D Printing Industry

(Cohen-Rosenthal, 2000) writes about the need for people to take the initiative to develop sustainable technologies. "A society sitting on the sideline waiting for technology to solve its problems is waiting for Godot" (Cohen-Rosenthal, 2000). This implies that no change will ever come if we expect it to happen, but do not invest in research and development to make this so. In addition to this (Cohen-Rosenthal, 2000)

suggests that partnerships are one way to achieve these initiatives. “Networks of businesses brought together to seek common benefit will uncover possibilities that preordained pathways will miss” (Cohen-Rosenthal, 2000). Additionally, 3D printing experts (Kurman & Lipson, 2013) clearly state, “3D printing won’t be an innately green manufacturing technology unless we actively seek to make it one.” The general sense from these books and research papers is that sustainability will only emerge if it is actively integrated.

The 3D printing industry could lead to more sustainable manufacturing in several ways. (Kohtala, 2015; Stephen, 2015; Tyl, Lizarralde, & Allais, 2015) highlight the potential benefits of localization. They argue that 3D printing enables in-country, local production, which could provide local lobs to the community, reduce the distribution chain, and reduce transport emissions. The cost savings for the technology and the shortened supply chain could make in-country production favorable to invest in compared to outsourced production. According to (Kohtala, 2015) personal or collaborative fabrication facilitates sustainable practices. (Kohtala, 2015) also cites sources that highlight co-production as a way to “empower local communities and encourage responsible use of local resources (physical and social)” by taking responsibility for the resources used communities may manage them more responsibly. “For all papers explicitly mentioning ‘local’ issues, the main sustainability benefit was avoidance of environmental impact related to transport” (Kohtala, 2015). In this way localization could be one way that 3D printing enables sustainable practices to develop.

The manufacturing process for 3D printing is one area of concern when it comes to sustainability. (Sreenivasan, Goel, & Bourell, 2010) is one study that aims to create an

assessment of environmental impact based on energy consumption. (Sreenivasan, et. al., 2010) created what they call "Eco-indicators." The higher the eco-indicator the greater the environmental impact a specific printing process has. Their model goes over use of resources, land, and emissions released. This is further broken down into damage incurred on resources, ecosystems, and human health (Sreenivasan et al., 2010). This eco-indicator is factored into their overall energy consumption formula to create a total energy indicator. While the Selective laser sintering (SLS) rating was 8.3 Stereolithography (SLA) and Fused Deposition Modeling (FDM) ranked 12 and 13, showing a higher environmental impact and energy consumption (Sreenivasan et al., 2010). Studies like this one are a start in the development of performance indicators, but there is still more that can be done.

The 3D Printing Industry

3D printing has increasingly gaining attention around the world. While there are a few major companies there are also a myriad of start-up companies and Do-It-Yourself (DIY) tinkerers who participate in the development of the field. It is a volatile environment due to the rapid changes in technology capabilities and the diverse range of 3D printers, materials and other differentiators.

History

The idea for 3D printing started earlier than most people realize. The process of layer-by-layer fabrication was proposed as early as 1951 by Otto John Munz (Weber, Peña, Micali, Yglesias, Rood, Scott, & Lal, 2013). Chuck Hull received the first patent for a 3D printing process in 1986. That same year he founded 3D Systems, one of the

main corporate players in the 3D printing industry today. Hull is seen as a figurehead of 3D printing technology. There are many different types of 3D printing processes today, but the core concept behind 3D printing remains consistent (Kurman & Lipson, 2013). 3D printing is commonly referred to as additive manufacturing, because it "adds" a layer of material every time the printer head makes a pass over the base platform of the printer or when a laser or digital beam of light hardens liquid resin or fuses powder into a layer (A. van Wijk & I. van Wijk, 2015).

In 2007 the startup company Shapeways came to the scene. This online platform allows people to design and sell their products and has become hugely successful since its inception (Bergl et al., 2013). This was also one of the first steps towards open-source sharing (Bergl et al., 2013). In 2008 the recession hit as the U.S. housing bubble burst. People started losing their jobs and their financial resources dwindled. In an effort to keep stay afloat more and more people were using ingenuity to create and sell products that would provide temporary income. Crowd funding helped people finance many of these early 3D printer projects (Bergl et al., 2013). MakerBot was one company that helped facilitate the rise of 3D printing. In addition, Quirky, an online platform, aided consumers by manufacturing the products they designed. Quirky then gave consumers part of the profits (Bergl et al., 2013). Each of these companies came at a time when consumers and business people were looking for ways to sustain themselves financially during tough times. For some, these platforms provided them with an answer.

3D printing has grown since then and people are realizing that its capabilities surpass printing out small, plastic trinkets (Conner, Manogharan, Martof, Rodomsky, L., Rodomsky, C., Jordan, & Limperos, 2014; Huang et al., 2013). Rapid prototyping,

creating product design prototypes quickly, was an easy first connection with this technology (Berman, 2012; Rayna & Striukova). Additive manufacturing means that parts can be printed out cheaply in plastic and examined for design flaws to help engineers reach their final design faster. The cause for concern, however, is that these plastic prototypes and trinkets create a lot of waste that will end up in our landfills, depleting already limited resources. There have been other inventions that were well intended, to help reduce waste and production time frames, that have backfired. A prime example of this is the invention of K-cups and single serve coffee makers. John Sylvan, inventor of the single serve coffee K-cup wanted to give customers increased convenience and customization without foreseeing the potential negative consequences (Baer, 2015). While this product does achieve its goal and is massively popular it also creates a huge amount of waste and the K-cups are not recyclable (Baer, 2015). Lately, however, a shift towards sustainability has started to enter the minds of 3D printing companies, consumers, and media critics alike (Sreenivasen, et. al., 2010; Gao et al., 2015; Gebler, et al., 2014; Huang et al., 2013).

There has also been a rise of 3D filament companies, (the material used in the products that are created through extrusion methods) that focus on using sustainable materials or materials with biodegradable properties. As the industry continues to develop and grow who knows what new innovations we will see and what 3D printing will be used for in the future.

Overview of 3D Printing

This section is a brief overview of the 3D printing process, software, and materials. The capabilities and drawbacks of 3D printing will also be discussed. This is

by no means comprehensive, yet will hopefully give some background for those unfamiliar with this topic.

3D printing processes. (A. van Wijk & I. van Wijk, 2015) have composed a chart of 3D printing processes (Appendix A) that define the different technological capabilities between printers. As there is a wide range of 3D printing technologies this paper mainly discusses 3D printing in regards to Fused Deposition Modeling (FDM). FDM is a process where material is warmed to a specific temperature and then extruded (A. van Wijk & I. van Wijk, 2015). This part of the process is similar to a glue gun that heats up material and then pushes it out of a nozzle. The material is then laid out in a specific pattern. When one layer is complete the printer platform is lowered or the printer head is raised. Then the second layer is started. The process repeats, layer by layer, until the final object is fabricated (Kurman & Lipson, 2013). Some objects require support material. This material is different from the main product material and can be printed by a different printing nozzle (A. van Wijk & I. van Wijk, 2015). According to (A. van Wijk & I. van Wijk, 2015) "The FDM method is one of the cheapest 3D printing methods and most often used in 3D printers at home." Commonly, ABS or PLA is used to print with. These materials will be explained in the 3D printing materials section.

3D printing software. Several types of 3D printing software exist. These are either closed source software or open source software. Open source software enables any person with access to the Internet to download the software for free. Once downloaded the user can use the software as is or modify it (Winnan, 2012). They can then share the modified version online with other users if they so choose. Open source software can

advance faster than some standard 3D printing software due to this model (Winnan, 2012).

Design files can be made using a Computer Aided Design (CAD) file. Adobe also has several programs that can be used for 3D printing. Files can also be created by scanning objects. (Winnan, 2012) claims that 3D scanners are the best way to obtain data, but they are cost prohibitive to the average user. Once a design file is created it is sliced into digital layers and sent to the 3D printer in a command file (A. van Wijk & I. van Wijk, 2015). Ultimaker's software, Cura, is an example of open source software that slices design files (Wittbrodt et al., 2013). This software can be downloaded for free. In addition to slicing and modeling software, 3D printer's have their own built-in software. This is also known a "firmware" (Kurman & Lipson, 2013). This type of software tells the printer specific x, y, z coordinates and how much material should be released. (Kurman & Lipson, 2013). This also means that across different types of software there can be parts of the design files that need "cleaning up" according to (Kurman & Lipson, 2013). This process of cleaning up means altering design files so there is not excess material added on or missing parts of the object.

3D printing materials. There are an increasing variety of materials used in 3D printing. Material selection depends on a variety of factors. Certain products may need a certain level of strength or flexibility, for example. Some materials are better for producing products that are highly detailed while others may have a high melting point (Kurman & Lipson, 2013). These materials come in several forms. As listed in the 3D printing technologies processes chart (A. van Wijk & I. van Wijk, 2015) these materials

can be resins, powders, or solid material spun into a spool to be fed through the machine, melted and extruded. The last form is commonly referred to as filament.

Filament is used for FDM style printing. Thermoplastics are used in this type of 3D printing, because they melt and then solidify without changing their composition (Kurman & Lipson, 2013). ABS is one type of thermoplastic that is commonly used in manufacturing. It is often cited as the material used to make LEGOs (Kurman & Lipson, 2013; Winnan, 2012). PLA is the other common printing material. It is based from sugar in beets, sugarcane, and corn according to (A. van Wijk & I. van Wijk, 2015). This material crystallizes slower and has a lower melting temperature. Often additives are used with PLA to better adapt it to certain print jobs such as "UV stabilizers, impact resistance modifiers or flame retardants" (A. van Wijk & I. van Wijk, 2015). This could have an impact the end products biodegradability or the percentage of environmentally friendly materials used. (A. van Wijk & I. van Wijk, 2015).

There is also a post-processing stage for 3D printing. Support structures need to be removed. The 3D printed object usually has a rough texture after fabrication that could require sanding, chemicals, or a variety of other post-processing steps to get to the finished format (Gao et al., 2015).

Commonly Used Terms

There are a few terms that will be mentioned throughout this thesis. Makers are how individual tinkerers refer to themselves ("Leading the Maker Movement," 2016; Kurman & Lipson, 2013). This group of people is categorized by having a DIY mindset. They like to create things themselves and modify existing technology. These people are

the early adopters of the industry. Sometimes this trend is categorized as the Maker Movement ("Leading the Maker Movement," 2016; Kurman & Lipson, 2013).

Crowd sourcing and crowd funding are two common terms used in the 3D printing industry as well. Many startups have gained funding from online platforms (Winnan, 2012). These websites allow startups to share their ideas and their goals. Other people are encouraged to donate to their cause and help fund their project. This is why the term "crowd funding" is used to define this type of fundraising strategy. Some campaigns have turned into successful companies (Bergl et al., 2013). Crowd sourcing is more involved than crowd funding (Nakrani & Tovey, 2004; Huang et al., 2013). This involves combining skills from several areas. The person with an idea for a 3D printed object could get design advice from one person and another person could advise them on materials. There is a more involved network, in this sense.

Open source design and open source sharing is similar to community collaboration. Designs files can be uploaded online and anyone can access and download these files. From there these files can be used as is or modified and shared again. The designs are then open source designs involving and open source sharing process ("Coining 'open source,'" 2012). Open source sharing can enable open source software to develop more quickly, than company-owned software (Winnan, 2012).

Capabilities of 3D Printing

There are a lot of reasons that 3D printing has captivated so many people. The capabilities of 3D printing give it a unique advantage over traditional manufacturing.

> "The 3-D process allows the porosity and mixture of plastics to vary in different areas of the [ear piece] frame… No assembly required. Printing parts and products also allows them to be designed with…geometries previously too fine to mill" (D'Aveni, 2015).

The ability to create complex products allows for technology developments that were not previously possible without access to industrial equipment. 3D printing can also produce products that mimic organic forms better than traditional manufacturing. It also allows complex customization down to the level of only a few microns (a couple diameters of a red blood cell) (DeSimone, 2015). The hearing aid industry benefited because hearing aids could be created that fit the individual patient's ears (D'Aveni, 2015). The design files created for the hearing aids can be kept indefinitely, decreasing inventory needs and overhead costs (D'Aveni, 2015). It also shortens the process of hearing aid creation and allows reprints to be made as needed in the future. Medical device companies can also provide these products at a lower retail price because it does not cost exorbitant amounts of money to produce highly customized items (Kurman & Lipson, 2013). A company can still benefit from high margins while also reducing the cost to the customer.

Another important advantage includes the ability to cut down production costs through the design process. "[3D] printing technology allows a nozzle that used to be assembled from 20 separately cast parts to be fabricated in one piece. GE says this will cut the cost of manufacturing by 75%" (D'Aveni, 2015). In addition to cutting manufacturing costs less waste is created through the additive process. Traditional manufacturing uses a subtractive process, which in some companies results in up to 90% of materials to be wasted (Millard, 2015). The aeronautics industry, for example, has seen benefits in lighter, efficient, 3D printed parts. Lighter parts have meant less gas consumption. "For every kilogram that's shaved off of the weight of an airplane the plane will burn approximately 600 fewer liters of fuel per year" (Kurman & Lipson, 2013). And less gas consumption, whether intended by the company or not, means lowered carbon

emissions. 3D printing can have many benefits due to advanced technological capabilities.

I believe that with a certain focus 3D printing could have a major application that has widespread appeal and the market could grow exponentially. If you look at Apple, a well-known innovator, the company's success is clear. Apple products are known for having an easy-to-use interface. These products are also appealing because they enable users to utilize a wide range of applications. This means Apple's customer base can be very broad, capturing a larger market share due to increased utility for users. 3D printers could see a similar type of progression. 3D printers will become more straightforward to use. The filament and resolution will improve over time to create higher quality products (Halterman, 2015). The amount of training needed may decrease with an easy to use printer and computer software. Thus more businesses may invest in the technology.

Drawbacks of 3D printing

While many people have referred to 3D printing as the new industrial revolution (Rethink everything: 3-D printing and the product design revolution, 2015; Berman, 2012; D'Aveni, 2015; Smith, 2015; Stephen, 2015). This technology has a lot of useful capabilities, as previously mentioned, but there is room for it to develop into other, unique directions. For some industries this technology could be a game changer, but oftentimes the flaws of 3D printing are not highlighted. A few areas for improvement will be mentioned below.

Zero-lead time critique. Some sources like (Kurman & Lipson, 2013) mention that 3D printing has zero-lead time. This claim that often repeated, however, lead-time varies depending on the type of 3D printing process, the skill level of the 3D designer and

machine operator, the material used, and the resolution (level of detailed) of the printed product ("3D Printing: Sustainability Opportunities and Challenges", 2015; Weller et al., 2015; Rayna & Striukova). Each product starts as a design file. If the customer downloaded a design that was popular and used frequently it might not need any modification. However, if they picked or created a complex design then it could take a lot of prep time and testing. Even then a design could be formatted on the computer and then the file sent to the 3D printing software, requiring additional adjustments before the printing process can start, increasing the overall production time. Following this step the printing process itself will take time. Depending on the size of the object and the properties of the 3D printer and printing material this could take several minutes or several days to print (Wittbrodt, Glover, Laureto, Anzalone, Oppliger, Irwin, and Pearce, 2013). This is excluding issues like incorrect settings, adjusting the printer to print too fast or having issues with pressure through the FDM extrusion method could cause filament jams. Post-processing can also take days or weeks to give the product the proper high-quality finish (Connor et al., 2014; Lindemann, Jahnke, Reiher, & Koch, 2014). It is true that these products can be made in the business, office, or at home, which does cut out the need for shipping, shortening the supply chain and carbon footprint. However, every point in the process has such high variability and those investing in this technology should be sure they know about the technology they are investing in and a realistic timeframe and budget for production work and maintenance (Wittbrodt et al., 2013). Lead times may generally be shorter than traditional manufacturing, but not for every product (Wittbrodt et al., 2013). And the price of certain filaments, resins, or powders could be more costly than traditional raw materials (Allen, 2013; Price compare – 3D

printing materials – Filament, 2015; Thomas, 2013). Overall, there are many factors that inhibit users from making accurate assumptions about lead times. While the overall process may be more efficient in most cases it is hard to generalize across the 3D printing industry. The possibility for drawn out printing and post-processing times should be taken into consideration when fabricating a product.

The technology hurdle. Depending on the industry, managers may be more or less willing to adopt the 3D printing technology. In Fabricated: The New World of 3D Printing by Hod Lipson and Melba Kurman one of the authors ("I" is used for both authors without differentiation) lobbied for 3D printing while serving in the military. They talked about the pushback against introducing this technology and how they eventually convinced them of the technological advances in terms of efficiency. "Design iterations aside, it had a built-in capacity for making calculations and predictions that no human draftsperson could touch" (Kurman & Lipson, 2013). People are generally resistant to change, especially when it means re-training employees, investing in the expense of a new technology, and the other modifications a business or organization must make to adapt it to their processes. Introducing new technology can be a huge risk. The more done to prove that the technology will create value and increase efficiency will decrease the uncertainty and resistance to investing in the new technology. In regards to (Kurman & Lipson, 2013) adoption was successful, but it required a lot of dedication and time to convince everyone to invest in the technology. 3D printing has issues between the large variety of 3D printing methods, materials, and software programs, which add to the confusion and perceived risk of the investor. Having proper guidance, potentially

advising services could help decrease this. Also general advancements in 3D printing will help curb this issue.

Another concern is the quality of materials. The manufacturing industry has specific guidelines and regulations they must stick to. As part of this it is important to ensure that theses companies use materials that meet industry strength standards, have the proper level of heat resistance, or meet other specifications. The general perception of 3D printing materials is that they are weaker than current materials used in the manufacturing industry (Berman, 2012). It is true that photopolymers are not stable under UV and that PLA can melt or warp in hot climates ("Choosing the Right Material for Your Prototype," 2013). However, there are also materials that do stand up against industrial standards (Gao et al., 2015: Conner et al., 2014). This will continue to grow as more research and development is done. In particular hybrid materials have perhaps the best chance of proving this (Conner et al., 2014). The needs will change depending on the product needed. The focus might be on maximizing detail over high strength or heat resistance. Filaments, resins, and powders have been created from a wide-ranging spectrum of materials. Metal, mud, glass, salt, paper, coffee grounds, wood, human cells, and sand are only a portion of the ever growing list of materials. The fast-paced and volatile nature of this field make it hard to predict what will come next.

Current State of the Industry

Crowd Funding. A growing trend that has helped 3D printing gain traction is crowdsourcing. The public comes together to support good ideas, providing a significant portion of the funding for various emerging technology projects. Key influencers in the 3D printing field built their foundation through crowdsourcing include: Makerbot,

Ultimaker, and Formlabs (Formlabs, 2015; Gordon, O'Meara, Troutwine & Lopez, Tweel, 2014; All3DP, 2016). Ben Kaufman is the founder of Quirky -- an online platform that connects inventors, designers, etc. to help in product development and sales. Quirky, Kickstarter, Indiegogo, GoFundMe, and many other platforms provide means of financial support for project development, aiding their customers in similar ways (Barnett, 2013).

Social media sites like Facebook and Twitter gained traction online before the 2008 recession. People were excited to share their ideas online, which facilitated a shift in in mentality when it came to doing business. The inception of internet platforms like Quirky and Kickstarter came around at a key time, while people were looking for new ways to support themselves financially. In the words of Kaufman, "They realized that sharing ideas isn't scary! It's the way of the future…I credit the market. It was finally the right time" (Bergl et al., 2013). Those in the business world should know that a great product or service, with the right advertising, investment, etc. may still fail if there is no demand. As illustrated in this example, sometimes it comes down to timing. The importance of timing impacts the receptiveness of the consumer or business and how likely they will be to invest in the technology.

Of course in the realm of additive manufacturing there is much development that still needs to be done to make the process more simple, consistent, and reliable. A major drawback of current 3D printers is that they are slow and have limited production capabilities. However, D'aveni points out that,

> "Some may forget why standard manufacturing occurs with such impressive speed. Some may forget why standard manufacturing occurs with such impressive speed. Those widgets pour out quickly because heavy investments have been made up front to establish the complex array of machine tools and equipment required to produce them" (D'Aveni, 2015).

His point is that while the actual printing process may be slow now it will increase in speed in the future. Over the past few years competitors like Formlabs and Carbon3D have created printers up to 25-100 times faster than previous 3D printers (DeSimone, 2015). While many 3D printing companies focus on fused deposition modeling (FDM), an extrusion technique, Formlabs is a clear example of a company with a unique position in the 3D printing field. Their printers use a technology called stereolithography or STL. The printers are much faster using this method, have higher resolution, and the 3D printer has a clean, sleek design.

Some people get very excited when they see a 3D printer at work for the first time. They say they are witnessing a technology that will lead to the next industrial revolution. Several journal articles that optimistically make the same claims, like the one quoted in the previous paragraph. Connecting back to crowd funding I would argue that this is why support from the community is and has been so important to 3D printing. The tinkerers and entrepreneurs that developed 3D printing to where it is today started with similar optimistic ideas. And starting as a largely U.S. based phenomenon it appeals to a shared, cultural value of self-reliance. Emerging 3D printing startups used crowd funding as a short-term way to get the money they needed to invest in the first steps of their project. After that a lot of hard work was invested in developing their products and delivering the end product to their supporters. Bre Pettis, founder and former CEO of Makerbot, is an example of someone who pursued their dreams and rose through the ranks to success (Gordon et al., 2014). Eventually, Makerbot rose to become one of the most well-known 3D printing companies. That idea of working hard and rising through the ranks appeals widely to the American population. Considering the recent U.S.

recession, it was encouraging to witness an inspiring story and technology emerge during this period of economic downturn. Unfortunately, in the long-term his business model changed dramatically away from open source, leaving the founding community feeling betrayed. Nonetheless, before that turning point Makerbot was an inspiring story.

Crowd funding has also showed an interesting shift towards collaboration and open-source sharing. These partnerships improve organizational capabilities and technological advancements (Gao et al., 2015; Conner, Manogharan, & Meyers, 2015). Without input from its customers Makerbot would not have had the growth and success that it has (Gordon et al., 2014). Again, there were issues when the company values shifted away from this open source model to a proprietary one. I believe that supports the case that customer input and involvement is crucial when growing a business. This is especially important when customers helped create the business foundation.

The 3D printing is still in an early stage of industry development. Many investors are hesitant to fund a company when there is not enough evidence compiled yet to ease the risk of investment. This is the reason crowd funding has been successful to help launch tech startups. There are of course other alternatives. Some companies fund themselves entirely on their own financial resources and potential business, technology, or related competitions. On the other side larger companies sometimes buy out the smaller startups to gain their intellectual property (IP). Another method, however, is to partner with companies that are either internal or external to the additive manufacturing industry. D'Aveni conjectures,

> "Power will migrate from producers to large system integrators…They'll foster innovation through open sourcing and acquiring or partnering with smaller companies that meet high standards of quality. Small companies may indeed continue to try out interesting new approaches on the margins—but we'll need big

> organizations to oversee the experiments and then push them to be practical and scalable" (D'Aveni, 2015).

Partnership and acquisition based strategies will help drive innovation by providing small startups with the financial backing they need to further develop their ideas. The route they pursue, however, will determine the degree of control they have with this development.

Globally, 3D printing is spreading to many different countries. The 3D printing industry used to be almost exclusively U.S. based. 3dhubs.com contains a list of these 3D printing communities The U.S. still tops the charts. Most 3D printers are located here than anywhere else in the world. However Europe seems to have a high density of 3D printer locations especially in the U.K., France, Germany, and Poland. India and South Korea also seem to be latching onto this technology too. Since the nature of 3D printing is to be customizable it will be interesting to see which areas of development these countries focus on as they further develop and utilize this technology.

METHODS

The Sample

CEO's and top executives from 3D printing companies, startup businesses, and non-profit organizations were contacted for this research. A list was compiled based on personal research – looking up company contact information mainly through company websites. My thesis committee members also had personal contacts that were added to the candidate contact list. During the research period I contacted reached out to numerous companies. In total, 38 candidates were contacted to participate. Out of this group 10 candidates were interviewed between March 8th, 2016 – March 30th, 2016.

Interviews were set up in person, when candidates were located within the state of Maine. Other interviews were conducted over the phone or via Skype. The range of interviews lasted between 27-64 minutes. Eight out of ten interviews were audio-recorded. Technical issues prevented recording of the first two interviews. The audio recordings were also supplemented with notes in a field journal. When necessary for quotation, interviews were transcribed verbatim into Microsoft Word.

Questions were in a semi-structured, open-ended format. The framework of questions was reviewed by the University of Maine International Review Board for Protection of Human Subjects (IRB). The finalized application and questions were reviewed and approved by the IRB Committee. Following protocol all candidates were given the general consent form with information about the research, data collection, and researcher contact information. The interview questions were modified slightly for a few of the interviews when the business was not primarily a 3D printing company or developed enough to answer all questions accurately.

Interview-ees	Affiliation	Company size	Year Founded	Product/ Service Offerings	Interview Date & Duration	Audio-Recorded (Y/N)
Interviewee #1&2	Manufacturer 1	100 employees	2011	FDM desktop 3D printers, printer parts & filament retailer, support services, free open-source software	3/25/16 (45 min)	Y
Interviewee #3	Manufacturer 2	180 employees	2011	FDM desktop 3D printers, free open-source software, printer part and filament retailer	3/10/16 (50 min)	Y
Interviewee #4	Manufacturer 3 & Filament Producer 1	11-50 employees	2014	FDM desktop 3D printers, conductive filament	3/8/16 (60 min)	N
Interviewee #5	Filament Producer 2 & Educational Services Provider	1-10 employees	2014	*Recycled waste filaments, educational & training services, 3D printer leases, spare parts, 3D printing services	3/10/16 (27 min)	N
Interviewee #6	Filament Producer 3 & Educational Services Provider	1-10 employees	2014	Educational & training services, 3D printing services, *recycled waste filaments	3/17/16 (40 min)	Y

Interview-ees	Affiliation	Company size	Year Founded	Product/ Service Offerings	Interview Date & Duration	Audio-Recorded (Y/N)
Interviewee #7	Filament Producer 4	1-10 employees	2013	*Recycled plastic filament	3/25/16 (29 min)	Y
Interviewee #8	Filament Producer 5	17 employees	2010	Biodegradable filament	3/17/16 (40 min)	Y
Interviewee #9	Filament Producer 6	1-10 employees	2015	Compostable filament	3/30/16 (28 min)	Y
Interviewee #10	End User 1	201-500 employees	1980	Window shade component and operating system manufacturer (uses 3D printing for prototyping)	3/14/16 (46 min)	Y
Interviewee #11	End User 2	1-10 employees	2005	Architectural planning, industrial design, & consulting (uses 3D printing for prototyping & some end products)	3/16/16 (52 min)	Y

*Recycled waste: covers a variety of recycled materials including (but not limited to) plastic bottles, coffee grounds, yogurt containers, automotive plastics, etc.

Each candidate was asked about motivation and perceptions of their business and where they see 3D printing headed in the future. They were also asked about their company's specific strategy to sustain their businesses into the future. Through this research the information was analyzed to see to what extent sustainability played a role in

the 3D printing industry. The information also revealed whether sustainability was pursued purposefully or incidentally.

RESULTS

Over the course of this study I set out to answer two main questions about the 3D printing industry. The first question was: To what degree is sustainability a priority for businesses in the 3D printing industry? 3D printing has been touted in the media as a "green" or sustainable technology, but in recent years critics are starting to question and investigate the validity of these claims (Gebler et al., 2014; "3D Printing: Sustainability Opportunities and Challenges", 2015; Sreenivasen et al., 2010). There are also very few articles that have been written pertaining to sustainability in the 3D printing industry. My second question was: Which types of sustainability are pursued within the business? The 3D printing industry is still forming and thus has a multitude of different businesses within it. So, there are many ways that businesses could pursue sustainability.

There were eleven candidates from ten different companies who agreed to be interviewed. They represented businesses in the U.S., the U.K., the Netherlands, Austria, and India. Three of the companies manufactured 3D printers, six created their own filament, two provided educational services, and two were 3D printer end-users. From these ten businesses there were two that provided both educational services and created 3D printer filament. There was also another business that created 3D printers and 3D printer filament. Due to the many types of 3D printing processes only businesses using the FDM printing process were interviewed. It is also important to note that eight out of the ten companies were recent startups (founded between 2010 and 2015) and were in various stages of business development. Since some of these startups were pre-revenue financial figures were not analyzed and the economic side of sustainability was not

explored. It was too early to draw conclusions about economic sustainability from the study sample.

The eleven people interviewed came from a variety of backgrounds. Five out of the eleven had a background in environmental or biological sciences. Two of the eleven had a background in engineering or architecture. And four had a background in business. Six out of the ten candidates interviewed were CEOs and/or founders of the company they represented.

Although only two 3D printing end users were interviewed there were several areas of overlap in the discussion, despite being involved in very different businesses. Both end users considered themselves to be first-movers in their industries for investing in 3D printing technology. They highlighted the need for businesses to invest in new technology to stay ahead, especially in mature industries. This process is cost effective allows them to come up with prototypes quickly for their customers. One interviewee stated, “Before 3D printing came along [a prototype] was probably like three times the expense or even more than that depending on what material you use” They both mentioned that the ability to customize products adds value to their business and helps them stay competitive in the market.

When asked about open source sharing and design all respondents had positive remarks. Even those who do not make use of it commented that it can provide some of the best software on the market. One candidate mentioned that more filaments are compatible on open source 3D printers than 3D printers that are not. One startup member mentioned that open source has fostered a sense of community and that small startups with similar businesses are more likely to work together to grow awareness for their

niche of the market. Additionally, online platforms like crowd-funding websites are also beneficial to small startup growth. While one startup failed to meet their fundraising goals they mentioned that many people reached out to them from magazines, online channels, and blogs. They gained awareness for their business as a byproduct of their campaign on an online fundraising platform.

There were four main drivers of sustainability mentioned during the interviews. Seven out of the ten interviewed mentioned that sustainability was at least partially company-driven. Nine out of the ten companies believed that sustainability is or should be at least partially driven by the consumer. At least three of the respondents mentioned that education drives the shift towards sustainability. Education can increase awareness around social and environmental sustainability issues in a variety of ways. One candidate suggested that 3D printers could be used as a tool to demonstrate recycling. Teachers could explain that a recycled filament originated from what was once a yogurt container, for example. Other interviewees added that shift towards sustainability might also be driven by concerns over chemicals used during the printing process especially if used in unventilated areas. As people start using these machines in their homes and in schools more education about these potential issues could lead customers to demand safer material alternatives or ventilation systems incorporated into 3D printers. Lastly, government was directly cited by three candidates as a sustainability driver. However, it is noteworthy to mention more than three of the ten companies mentioned adhering to government regulations or receiving government funding for their businesses, especially in regard to pursuing sustainable initiatives.

Detailed below in Table 1 are the different groupings of the ten businesses explored in this study.

Table 1. Groupings of the Businesses Participating in this Study.

	Cumulative %	Frequency
Social/Environmental Sustainability as core to the business model	30%	3
Social/ Environmental Component complimentary to business model	60%	3
Social/Environmental technological benefits as byproduct of business model	100%	4

Of the ten businesses three had a clear focus on social or environmental sustainability as the core of their business model. A quote from each of these startups illustrates this point. One respondent explained how their business targeted environmental sustainability,

> "Our main goal is to solve two environmental issues: the plastics pollution problem, you hear about the ocean plastics …we want to find a way, …if things end up in the ocean, [to provide] an alternative out there that is degradable so it does not persist in the environment…We're making this bio-digestable, bio-degradable material that's a plastic substitute. The second [environmental issue] is that of methane gas…Methane [gas] generation, if admitted into the atmosphere, is pretty bad. So therefore by capturing that methane and converting it into the plastic substitute we are then kind of embodying our mission in trying to capture and solve those two big environmental issues."

This business develops bio-plastic material at an affordable cost as a solution to these issues. Organisms break down the bio-plastic naturally and do not need a sterile environment to do so. By developing bio-plastic they ensure that their material will breakdown instead of accumulate in the ocean like traditional plastics. They also reduce methane emissions by converting the gas through the stages of matter to create a solid filament product. The respondent explained that this product can then degrade in the

environment and then be reused through this process, in a way that has the potential to create a closed-loop cycle.

The second respondent discussed their bio-plastic. Their advantage is in the chemical composition of their filament. Their filtration process is not only cheaper, reducing overall costs, but it also helps reduce carbon emissions. They are also proud of their products compostability. The respondent mentioned, "With our bio-plastics you can just throw it in your compost pile and it will degrade within half a year." This meets their business goal of creating non-toxic, biodegradable plastic. These two startups are clearly targeting environmental issues and working towards providing solutions for them.

The third respondent had a startup centered mainly on social sustainability, while also impacting environmental sustainability as well. They explained,

> "At our core we're a social enterprise…what we're trying to do …is primarily, to generate additional income for the waste pickers. And the idea is to add value at the grassroots, so a lot of that value can be captured, at the grassroots."

A fellowship they received provided a write up of the organizations founder and explained that this startup enable waste pickers in India "to earn over fifteen times more for [collecting] the same amount of plastic" (Echoing Green, "Our Fellows," 2014). This is a direct added value to waste pickers looking to earn more money for their efforts. This startup also has the ability to have an environmental impact as well.

> "Right now the filament that we produce is made out of this plastic called HTPE. And the reason that we chose HTPE is because it's the second most abundant type of plastic in the area that we work in, and it lends itself decently to being extruded into filament."

They are finding an opportunity to use collected plastic waste as raw material for filament development. HTPE is being recycled, adding an environmental sustainability component to Filament Producer 4. As the respondent explained, though, this has more to do with the

abundance of HTPE, which provides convenient source material for the social enterprise. As explained by the three interviewees of the companies in the top tier of the matrix in Table 1 these businesses are focused on environmental or social sustainability as the core of their business model.

The second tier in Table 1 groups together three businesses that are pursuing sustainability initiatives as one part of their business strategy. One company in this study pursues social sustainability as one component of its business. The interviewee explained,

> "We work closely with e-NABLE. We print, sponsor, and help companies printing prosthetics for children. We're very close with the Red Cross as they are setting up fab lab makerspace-like environments in, for example, Nairobi or Afghanistan to print medical applications or prosthetics for people."

While social sustainability is not at the core of this 3D printing manufacturer's business it is pursued through these partnerships.

Another 3D printer manufacturer is pursuing social sustainability through their open source model. They share 3D printing information on their online platform as well as free 3D printing software downloads, as does the previous company. Aside from the monetary cost of the 3D printer itself this provides information customers may need to design 3D printing objects in a way that is free and easily accessible. Additionally, they explained that open source 3D printers can be improved and developed through this community collaboration between the business and its customers.

The other company in this category is an organization that provides educational services and business trainings in regard to 3D printing and it develops offers recycled filaments. The recycled filament is a new addition to their already new startup (established in 2014). Their main business model is centered around providing training and educational services and the recycled filament is a new component that they have

incorporated into their business. The filament brand clearly targets an environmental concern by finding ways to recycle plastic objects and turning them into 3D printer filament. This business has been in talks with the Green Alliance in the U.K. and the British Plastics Federation to discuss bio-plastics. The respondent explained, "Recycled materials within 3D printing is yet a further niche, and we don't see that taking off anytime soon, necessarily, but we do see lots of interest in it… I think it's about big businesses, local councils, governments, and educations, catching up with the fact that we can make a huge impact with 3D printing when we're using recycled filaments." The team at this startup sees value in pursuing sustainable filament development to proactively position themselves for the future. The firm even received an award for "best recycled product of the year" a feat when this small startup has had its product compared to products produced by "industry behemoths from the plastics industry." This component of the business intentionally aims to make an impact on environmental issues. However, the other portion of the business, the educational component seems more centered around 3D printing education and not about sustainability. When asked directly if there was a sustainability component to the educational services offered the discussion went back to the recycled filament. They explained that since the filament component is very new and requires them to pursue a different strategy than their education services model and they are still trying to find a way to integrate the two into a strategy that works for both parts of the business.

The last tier comprises the remaining businesses. These businesses are not intentionally pursuing sustainability, but are involved in 3D printing in some capacity. As stated before 3D printing has benefits that make the process generally less

environmentally harmful compared to traditional manufacturing methods. It is arguable that the additive manufacturing process generally saves time, reduces waste, and energy consumption compared to traditional methods like subtractive manufacturing or injection molding process, for example.

To further explore these three main differences between the companies studied Table 2 was created. This table breaks down the three categories by 3D printer manufacturers, filament products, educational service providers, and end users. Due to some overlap in business product and service offering the sum of this chart comes to a total of 13. There were three businesses that are responsible for this overlap.

Table 2.

	Core	Component	Byproduct
Manufacturing	0	2	1
Filament	3	1	2
Educational services	0	0	2
End users	0	0	2

The end users and educational services providers did not have distinguishable sustainability components or initiatives that could be measured. For this reason both groupings are sustainable only as a byproduct of the 3D printing process. Both end users interviewed for this study thought environmental sustainability was an important issue, but mentioned that generally government and sometimes education were the drivers of change. One end user also said that for the business to invest in sustainable alternatives their business customers would need to be responsible for pushing sustainability. In terms of educational services, these two companies focus more on how to operate a 3D printer and design objects, at least currently, and do not offer services concerning sustainability in the 3D printing industry. Therefore both end users and educational service providers in

this study had a low sustainability priority. They pursued sustainability only as a byproduct of the 3D printing process

The 3D printer manufacturers show a partial shift towards sustainability. Two out of the three manufacturers interviewed took further steps to pursue some aspect of social sustainability. Manufacturers 1 and 2 both follow an open-source business model whereas manufacturer 3 relies on its 3D printer and 3D printing material IP to provide a strategic advantage. Manufacturer 3 claimed that by the nature of additive manufacturing this technology is more sustainable than traditional methods. Since the exact amount of material needed to produce a product is used during creation it can be argued that this process is better than methods like subtractive manufacturing, for example, which can result in up to 90% waste from raw materials in some cases (Millard, 2015; Kurman & Lipson, 2013). Manufacturer 1 pursues social sustainability through open source sharing and making 3D printing knowledge readily available. This includes information on how to operate and assemble the printers as well as design file sharing and free software downloads. This free and easy access to information has the ability to provide social benefits. The scope of possibilities is huge with 3D printing technology. You could 3D print a product prototype, a replacement part for something broken, or even a medical model customized to the patient to help doctors perform a difficult procedure. As previously noted, manufacturer 2 has worked towards social sustainability as part of its business strategy. They help by donating printers to these causes and the e-NABLE community adds value by improving and tailoring these prosthetic designs. Their open source model also aids in the development and production of prosthetics through design file sharing and free downloadable software.

The final grouping is the filament manufacturers. These companies spanned the three different degrees of sustainability pursuit. Filament Producer 1 is also Manufacturer 3 is creates its own filament and remains in the "sustainability as a byproduct" category for this grouping as well. Filament producer 2 has developed a filament from product waste and thus is more sustainable than traditional materials such as ABS and PLA. However, they are not motivated by sustainable goals for the production of this filament. As previously mentioned in the results section, they believe the success of these filaments is due to their novelty in the market. Filament producer 3 is also an educational service provider. While they focus on environmental sustainability as a core value in developing filaments this same focus is not incorporated into their educational services. For this reason they are placed in the middle category, since only part of their business prioritizes sustainability. As previously discussed this business has been in talks with the Green Alliance in the U.K. and the British Plastics Federation. However when asked about a sustainability component within their services they went back to talking about the accolades their recycled filament has received. This seems to stem from the fact that filament producer 3 is a recent startup and has yet to figure out a business model that accommodates for both parts of their business. They explained in the interview,

> "We have got several mission statements we're playing with at the moment…And not so oddly, they do differ between [the product and services offerings]. [One] is about knowledge dissemination within the additive manufacturing world, research and development, knowledge sharing, while [the other] is all about making sure we can be sustainable…In that respect they're both different mission statements."

They then further discussed how this factored into how their business would be shaped in in the future. "Are we going to be this 'green' type of business… or are we just going to be knowledge-based? There's no kind of mutual exclusivity there to be honest."

Currently, at least, sustainability is not pursued to equal extents in both portions of this company. The last three companies have centered their business strategy on social or environmental goals. These companies seem more concerned about fulfilling these goals and acknowledge that in some cases this means accepting lower profit margins. Filament producer 4 aims to meet social sustainability goals by helping waste pickers generate a better income. To meet these goals the respondent acknowledged that accepting a lower profit margin is necessary to sell the ethically-sourced filament at a competitive price. (cite) Companies pursuing sustainable values must offer products that are on par with other available options. To reach a wider customer base they cannot put a "green premium" and price above the market, especially when the 3D printing industry is still considered a niche market. However, the respondent believes that customers will choose a more sustainable or ethically sourced filament if it is priced the same as typical 3D printing filament. Filament producers 5 and 6 focused on environmental sustainability as the driving factor for their business strategy. The interviewee for filament producer 5 mentioned,

> "A lot of the time you have to give up economics for sustainability…So you need to find a way to be economical and [environmentally] sustainable at the same time… You have to think a little bit outside the box for that, but it can be done, as hopefully, we're proving."

This business receives its raw material for free, but has factored in a pricing system for the future that still makes it possible for them to produce the filament cheaply. This will allow them to price competitively in the future. They see this pricing strategy along with increasing consumer education around environmental issues as driving factors that will sway consumers to choose their products over their competition. Near the end of the interview they reiterated that they want to "make sure consumers make the right choice

for the environment and the future.” Their products provide a starting point for this change. They along with filament producer 6 both plan to expand from the 3D printing industries to other areas that could benefit from their bio-plastics.

DISCUSSION

Based on the conversations with candidates involved with various facets of the 3D printing industry social and environmental elements exist presently in this industry. It appears that some of these recent startups could become part of the shift towards sustainability. From this research a few interesting propositions can be formed.

Proposition #1 Businesses focused on open source are more likely to pursue sustainability

Manufacturer 1 and manufacturer 2 both pursued sustainability to some extent and were both using an open-source model. Manufacturer 3 was pursuing a proprietary model and was only sustainable by the nature of the 3D printing process. Open-source online platforms make it easy to share and improve on product designs and also allows users to download free software. This helps make new technology more accessible, which in turn can be used to pursue social sustainability. Libraries and educators can make use of 3D printers to make this technology available to the general public, as mentioned by manufacturer 1. Additionally, manufacturer 2 entered into a partnership with an organization that creates prosthetics, because it complemented their open source model (Van Geelen, 2014). Users can upload a design for a prosthetic and these designs can and have been improved by other users until the final product is ready. Then these design files can be retrieved anywhere that has an access to the online platform. Then the final product can be printed off and the end user gains a prosthetic limb. Other projects that contribute to social good can benefit from this model. There are well-known examples of open-source outside of the 3D printing industry as well. Mozilla Firefox and Facebook are both part of this open-source sharing (Haigh & Hoffman, 2014). Arguably, these two

companies promote social sustainability. They both provide free platforms that share knowledge with the public. Facebook also allows for groups and events to be created that can bring awareness to social issues. Open-source also reduces or sometimes eliminates issues like scalability since the software and design files are widely accessible (Wittbrodt et al., 2013). This also contributes to their popularity. For example, schools benefit from open-source sharing by being able to download and print out educational models and devices for in-class demonstrations (Wittbrodt et al., 2013). The average household could also potentially benefit from open-source sharing by printing off general household items instead of going out to purchase them (Wittbrodt et al., 2013). These benefits make open-source models appealing to consumers and thus an appealing model for companies to pursue. Whether intentional or not, this widespread availability of software and design files can be seen as a contributor to social sustainability.

Proposition #2 Businesses founded by people with a core focus on sustainability choose markets based on their perceived viability to pursue these goals

This proposition adds to the debate on entrepreneurial discover theory. (Murphy, 2010) discusses whether opportunities are created or sought out. There are two main distinctions from entrepreneurial research. Some research suggests that entrepreneurial discovery is the product of a deliberate search for opportunities (Murphy, 2010). The other conjecture is that entrepreneurial discovery is serendipitous and unplanned (Murphy, 2010). From my own research it appears that the filament producers pursuing sustainability at the core of their business intentional selected the 3D printing industry. They saw opportunity in a new and growing industry. These companies knew they wanted to pursue sustainability and saw 3D printing as a promising starting point for their

endeavors. Filament producer 4 is a social enterprise. Their founder is committed to helping the local Indian community. They explained how,

> "3D printing was more, just a conduit, to that end - [to generate additional income for waste pickers], but it seemed like a really good way to add value. We're not really a 3D printing company. We're not really a manufacturing company. At our core we're just looking for ways to add value at the base of the pyramid."

Filament producer 4 sees the potential of the 3D printing industry to help support waste pickers by creating 3D printer filament. The producer also made sure to emphasize that this started out as an initiative to promote the livelihood of waste pickers by being able to offer them higher wages for the same waste picking work they did before. This startup is pursuing a social sustainability mission and has chosen the 3D printing industry as its vehicle.

Filament producer 5 also saw the potential in the 3D printing industry. They are exploring many different areas for bio-plastic application, however they are still working on scaling up production. They cited 3D printing as a high priority for the business, however. Filament producer 5 expressed that they believe 3D printing is going to become a big industry and that both bio-polymer producers and those involved with 3D printing could have a mutually beneficial relationship. From a business model standpoint filament producer 5 explained how 3D printing has synergies with their model. They both can benefit from locally based production and reduced transportation distances. Both bio-polymer production and 3D-printed object production can be carried out in-house. These similarities attracted filament producer 5 to the 3D printing industry and incited them to develop an environmentally sustainable filament.

> "I don't personally have a background in 3D printing either. As my team and I are learning more there's so much waste that's generated, because people want to [rapidly prototype]… and that's really going to move our world forward, but what

> do they do with it once they're done with it? … there's a lot of waste that could potentially be generated. Instead of adding to the plastics problem why not choose a polymer that can then degrade and you can have this really cool thing, but it won't have this other, kind of, backlash to it."

They have seen the potential for bio-plastic filament to play a role in the 3D printing industry though they realized this has not quite been established yet. They are taking steps to be one of the few biodegradable filament producers in the industry.

Lastly, filament producer 6 was the third business to pursue sustainability at the core of its business. They also started with the development of a bio-plastic and found potential in the 3D printing industry. "Our business mission is to produce these bio-plastics and sell it… so we start with 3D printing, in the first place, and move then on to packaging, agriculture, and final stage, to licensing of our technology." They realize that entering an emerging industry comes with risks and challenges.

> "I think…the sustainable solutions are mostly a bit more expensive than the conventional solutions …and since it's not really an option to be a bit more expensive you have a lower profit margin if you want to produce sustainable 3D printer filament."

They acknowledge this fact and still choose to pursue it, because they see the potential for an environmentally friendly filament to be produced and sold in the 3D printing industry.

The decision by these three startups to pursue sustainability shows a deeper commitment and connection to sustainability as illustrated in the levels of sustainability mapped out by (Veleva, et al., 2003). (Webster, 2007) also discusses that new businesses and innovators that take the lead in pushing sustainability "know they have a working relationship *with* the planet" (Webster, 2007). Additionally, they have chosen 3D printing as their vehicle to pursue these goals. They have further recognized that they can play a

part in shifting 3D printing in a more socially responsible and environmentally friendly direction.

Proposition #3 The kind of business established will influence the type(s) of sustainability that is likely to exist

When looking at the businesses that provide educational services it is hard to say that they could pursue an environmentally sustainable strategy. They could focus on social sustainability and provide information on educating consumers on environmental concerns, but there will likely not be a measurable environmental impact from a services business. The filament businesses, on the other hand, are creating a tangible product that can be regulated or produced to meet certain environmental standards or combat environmental concerns. There is also the potential for filament producers to make a social impact as seen by filament producer 4. Filament producer 4 has waste pickers collect plastic bottles that it then uses as a raw material for filament production. Waste pickers continue to collect waste as before, however, filament producer 4 can offer them higher wages for their work. This provides them with a social benefit. Organizations like the Red Cross are working with 3D printing companies to source printers in under-served areas of the world to print out useful medical devices. For 3D printer manufacturers environmental sustainability seems less likely to happen for the most part. Of course, there is Markus Kayser who created a 3D printer that fabricated product using desert sand and solar power (Kurman & Lipson, 2013). His experiment is inspirational and likely causes innovators to contemplate the future of 3D printing. However, while researching 3D printing manufacturers I did not come any that could claim a core or partial focus on

developing a printer that runs on renewable energy or is made of compostable or recycled parts. No one, to my knowledge is making a 3D printer out of recycled plastic or compostable parts. This is not to imply that this would be an easy endeavor. While there is current research for developing compostable electronics ("Compostable Electronics for Printing," 2015) this technology is not developed enough to be incorporated into end-user products. As has already been demonstrated socially sustainable elements have already been pursued by some 3D printing manufacturers. This proposition can be extended to other businesses outside the 3D printing industry.

Proposition #4 When dual businesses align in their degree of sustainability it will reduce cost to the organization

Three of the businesses selected for this research had dual businesses in the 3D printing industry. One candidate represented a business that manufactured 3D printers and produced their own 3D printing filament. The other two candidates represented businesses that offered 3D printing educational/training services and produced their own 3D printer filament. 3D printer manufacturer 3/filament producer 1 pursues the same degree of sustainability for both sides of its business. Filament producer 2 also provides educational services. This business is also fairly well aligned. They do not focus on promoting social or environmental sustainability through their services, however their filament is more environmentally friendly than conventionally used materials. However, the interviewee was clear to mention that this was driven by the aspect of novelty and not one rooted in a desire to produce an environmentally friendly product. The filament is inherently better than conventional materials because it makes use of beer and coffee

waste and recycles it into 3D printing filament. For this reason there is some difference in alignment since, as far as could be deciphered, the services offered do not focus on sustainability in the 3D printing industry. Lastly, and perhaps most interesting, is filament producer 3. This company offers educational services on 3D printing and they produce filaments from a variety of recycled materials. There is a pretty stark difference between the two sides of this business, which the interviewee was clear to point out. The results section highlights a few of these comments about having two different mission statements, in a sense, to explain the two sides of the business. The interviewee also discussed the conflict over whether the business should orient itself fully towards a sustainable image or not. These two sides pursue sustainability to varying degrees. The services side does not incorporate an element of sustainability education, however it seems like they have considered that as a future option going forward.

> "We should be looking at this as the industry grows rather than ten years down the line when it might be hard to actually cross everything over and buy different technology and try to cope with it."

They acknowledge that pursuing sustainability now makes more sense than in the future, however they are still working out a way to integrate recycled filament and educational services together. Since the services side is not currently incorporating sustainability there is a discrepancy. Maintaining two very different sides of a business over the long term could be difficult to do. It makes more sense for the firm to look for a way to pursue sustainability to the same degree for both. By doing so they differentiate themselves from other 3D printing educational services while also optimizing firm resources. Their filament uses recycled waste. This knowledge is still part of a niche within the 3D

printing industry and educating consumers about this would be an easy extension of the business, for example.

Proposition #5 The amount of infrastructure a business has can limit the ability of the firm to invest in sustainable development

Among those interviewed for this study it was interesting to discover that while half of the filament producers pursued sustainability as a core component of their business none of the 3D printer manufacturers pursued sustainability as a core component. It is difficult to know what is preventing manufacturers from seeing an opportunity in investing fully in a sustainability-oriented strategy. One conjecture is that the two types of businesses deal with different types of infrastructure, which can help or hinder the ability of the firm to invest in sustainable development. Filament producers create their product in-house. On the other hand, 3D printer manufacturers deal with a more complicated supply chain. They must source their parts for their 3D printers as well as assemble and distribute the end product. They also need to continuously update their printer models and software, which takes time and resources to stay ahead. A 3D printer is easy to create compared to the production of a 3D printer filament that performs up to certain printing expectations. It appears that the investment of 3D printer manufacturers could be greater than that of the filament producers. Filament producers pursuing sustainability as a key component to their businesses also benefit from free or low cost raw materials, reducing or eliminating current business expenses. This also helps them benefit from a larger profit margin in the short-term, allowing them to invest their earnings in the company to work on scaling up production. These benefits are simply not

the same for 3D printer manufacturers who need to source their raw materials from a variety of places, committing financial resources to production instead of research and development. Though this is conjecture it may explain why 3D printer manufacturers have yet to pursue a business strategy fully focused on sustainable goals. While these manufacturers may be able to pursue social sustainability to some extent investing in environmentally conscious practices may be more difficult.

CONCLUSION

This study has explored sustainability by focusing on the 3D printing industry. 3D printing technology is not new, but this industry is only recently starting to emerge. Many conjecture that 3D printing could become prevalent in many industries in the future. There are already many useful applications for it across many fields.

Through this research I have examined companies (mainly recent startups) that are involved in the 3D printing industry. These companies prioritized sustainability to various extents. Additionally, the ability to examine the mindset and motivation of business executives helped categorize the prioritization of sustainability from company to company. From this information it can be inferred that those committed to pursuing sustainability at the core of their business may be responsible for the shift towards sustainability in the future. This research provides evidence that sustainability already exists to an extent in the 3D printing industry. Companies, customers, government, and education are all drivers of change that will be responsible for this shift going forward.

For future research these various degrees of prioritization could be explored on a larger, more in-depth level. This categorization could be used to explore other industries as well to reveal business leader's perceptions and attitudes towards sustainability.

Exploring the differences amongst 3D printer manufacturers and filament producers could be another area for further study. Though it was explored on a small scale a larger study could uncover information to explain why a discrepancy exists between the two types of businesses (3D printer manufacturers and filament producers) and the priority they give to sustainability goals. Developing performance metrics may also help quantify differences in the industry to create more meaningful data.

Due to the small sample size it is hard to create propositions that characterize the whole industry. However, emerging themes have revealed some insights into the 3D printing industry and how business leaders try to provide solutions to improve social and environmental issues. It will be interesting to see how the industry grows and changes in the future.

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Appendix A

APPLICATION FOR APPROVAL OF RESEARCH WITH HUMAN SUBJECTS
Protection of Human Subjects Review Board, 114 Alumni Hall, 581-1498

PRINCIPAL INVESTIGATOR: Yvette Alexandrou
EMAIL: yvette.alexandrou@maine.edu TELEPHONE: 207-631-6251 CO-INVESTIGATOR(S): N/A
FACULTY SPONSOR (Required if PI is a student): Terry Porter
TITLE OF PROJECT: Researching Business Sustainability Strategy Motivations in the Three-Dimensional Printing Industry

START DATE: 2/25/16 ~~02/18/16~~ PI DEPARTMENT: Business
MAILING ADDRESS: University of Maine, 5733 Hart Hall, rm 103, Orono, ME 04469
FUNDING AGENCY (if any): N/A
STATUS OF PI:

FACULTY/STAFF/GRADUATE/UNDERGRADUATE Undergraduate

1. If PI is a student, is this research to be performed:

X for an honors thesis/senior thesis/capstone? ☐ for a master's thesis?

☐ for a doctoral dissertation? ☐ for a course project?

☐ other (specify)

2. Does this application modify a previously approved project? N (Y/N). If yes, please give assigned number (if known) of previously approved project: N

3. Is an expedited review requested? (Y/N). Y

Submitting the application indicates the principal investigator's agreement to abide by the responsibilities outlined in Section I.E. of the Policies and Procedures for the Protection of Human Subjects.

Faculty Sponsors are responsible for oversight of research conducted by their students. The Faculty Sponsor ensures that he/she has read the application and that the conduct of such research will be in accordance with the University of Maine's Policies and Procedures for the Protection of Human Subjects of Research. REMINDER: if the principal investigator is an undergraduate student, the Faculty Sponsor MUST submit the application to the IRB.

Email complete application to Gayle Jones (gayle.jones@umit.maine.edu)

****

FOR IRB USE ONLY

Application # 2016-02-10 Date received 02/10/2016 Review (F/E): E

Expedited Category:

ACTION TAKEN:

X Judged Exempt; category 2 on 2/12/16 Modifications required? Y

Accepted (date) 2/25/16

☐ Approved as submitted. Date of next review: by Degree of Risk:

☐ Approved pending modifications. Date of next review: by Degree of Risk

Modifications accepted (date):
☐ Not approved (see attached statement)
☐ Judged not research with human subjects

FINAL APPROVAL TO BEGIN Date 02/25/2016 08/2015

Appendix B

Interview Questions*

1. At (company xyz) what is your business mission?
2. How do you express that through your business model?
3. What is exceptional about your company?
4. Where is there room for improvement within the business process?
5. Who do you see as your biggest competitors?
6. What is your pricing strategy?
7. In such a diverse field, who do you target? (i.e. consumers or businesses?)
8. What do you consider your competitive advantage to be?
9. How competitive is this industry?
10. How does open source design share help/hurt your company? Do you make use of open source sharing or not?
11. Do you have any community-based projects?
12. Where do you see the future of the company headed? (ex. towards what tech developments or industries?)
13. What current or developing technologies do you believe will have an advantage in the future of 3D printing? Additionally, which filament materials do you see have the highest growth rate (plastic, metal, high grade metal, plant-based, bio-degradable, hybrid materials, etc.)?
14. Where do you see 3D printing headed in the future?
15. What are your environmental, sustainability goals currently and for the future?
    a. What are tradeoffs for 3D printing companies pursuing sustainable product development and initiatives?
    b. Are these goals company or consumer driven?
    c. Has your work impacted other businesses that you work with or consumers you sell to?
    d. What have you done to date to meet these goals?

* Some questions were modified for interviewees representing 3D printing end-users

Appendix C

3D PRINTING TECHNOLOGIES PROCESSES [3] [9] [12]

PROCESS (ASTM PROCESS)	TECHNOLOGY (SOME EXAMPLES)
EXTRUSION	Fused Deposition Modelling (FDM)
(MATERIAL EXTRUSION)	A material is melted and extruded in layers, one upon the other *(This technique is normally used in 3D printers at home)*
DIRECT ENERGY DEPOSITION	Electron Beam Direct Manufacturing (EBDM)
(DIRECT ENERGY DEPOSITION)	An electron beam melts a metal wire to form an object layer by layer
SOLIDIFICATION OF POWDER	Selective Laser Sintering (SLS)
(POWDER BED FUSION)	A bed of powder material is "sintered" (hardened) by a laser, layer upon layer until a model is pulled out of it
SOLIDIFICATION OF POWDER	3D Printing (3DP)
(BINDER JETTING)	Powder is bond by a binding material distributed by a movable inkjet unit layer by layer
PHOTO-POLYMERIZATION	Stereolithography (SLA)
(VAT PHOTO-POLYMERIZATION)	Concentrating a beam of ultraviolet light focused onto the surface of a vat filled with liquid photo curable resin. The UV laser beam hardening slice by slice as the light hits the resin. When a projector beams the UV-light through a mask onto the resin it is called Digital light processing (DLP)
PHOTO-POLYMERIZATION	Polyjet Process
(MATERIAL JETTING)	A photopolymer liquid is precisely jetted out and then hardened with a UV light. The layers are stacked successively
SHEET LAMINATION	Laminated Object Manufacturing (LOM)
(SHEET LAMINATION)	Layers of adhesive-coated paper, plastic, or metal laminates are glued together and cut to shape with a knife or laser cutter

(A. van Wijk & I. van Wijk, 2015)

Appendix D

Manufacturer 1 Represented by Interviewees 1 & 2

March 24, 2016

Interview: duration 45 minutes, audio recorded, interview notes were recorded in a field journal during the interview

Business Overview:

"We believe you should be free to use, learn from, and improve the machines you use, and share that with the community."

Manufacturer 1 focuses on giving freedom to the users. They provide free, open-source software to their customers. Everything is pre-licensed and all the models are online. This enables it to change and grow without the restriction of patents. They mentioned that occasionally, Ultimaker's Cura software is used. At their headquarters, they currently have 140 3D printers that produce parts for additional 3D printers. While their software offerings are free the printers themselves are sold for a profit. Interviewee 1 mentioned that one of the perks of open source printers includes filament compatibility. He said that generally, there are more filaments that are compatible with open source printers. Manufacturer 1 produces 3D printers, however, they do not create their own filaments. They also draw from their customer base through an online forum for product decision feedback and future product development.

Competitive Advantage:

Their company has seen drastic growth. They make sure everything is tested in-house including filaments. Testing ensures that they are providing a quality service for their customers. They also provide support via phone or email. Interviewee 1 stated, “We can’t keep [our products] in stock fast enough.”

Interviewee 1 explained that Manufacturer 1 has built a reputation for its quality and support. A testament to this is their ranking on Aniwaa’s “2016 meta-list of the best 3D printers” (“The 2016 meta-list of the best 3D printers,” 2016). Aniwaa is a company that focuses on creating a database of information around 3D printing and provides reviews. Their printer is #1 out of 980 3D printers. Closely following in 4th place is the smaller version of their 3D printer. Their strategy is to appeal to a large variety of consumers. They mentioned businesses like NASA and Caterpillar were using their printers as well as home users, schools, and startups. They attribute this success to the open source hardware and software. The open source model eliminates restrictions and has the potential to develop and improve quickly. They noted that the collaborative work lends itself to creating higher quality hardware and software. Their customer service base is very responsive as well. The people that they employ, Interviewee 2 mentioned, take pride in their work and some have even relocated to work at the company.

Areas to Improve

While they already draw from their customers for ideas, Interviewee 1 noted that they could always do a better job listening. They could also work with their customers more to

incorporate feedback into their decisions. Communications within the company could be improved as well. Of course, this will be a challenge as they scale up.

Sustainability

Interviewee 1 noted that the company offers a variety of filaments to meet customer needs. They look to see what consumers are responsive to. Interviewee 1 talked about push and pull for materials coming from both the business and consumer sides. They are partnered with a chemical company and "push" the customers towards certain products that are low emission by suggesting certain filaments and focusing on customer education. They even provide safety data sheets and important chemical and product information to help customers make informed decisions. From the "pull" side customers will sometimes recommend that they test certain filament materials.

They also mentioned that producing 100% recyclable filament would be ideal, but that it has not developed enough to be reliable. Recycled materials are also harder to work with compared to virgin plastics. They said that the interest for sustainable materials is driven from both sides. "There's really strong consumer and company appetite for [sustainability] definitely…[but] it's not inevitable: consumers have to choose, companies have to choose. It's not just going to happen, but I think there's very good momentum."

Industry Competition

Interviewee 1 mentioned that competition could examined from the angle of open software and hardware. He also discussed how anyone looking to do business with them in such a way could be a “friend” or “collaborator.” They said that any companies restricting this sharing strategy could be considered competition. From the prototyping angle there are many of ways to make things. CNC, desktop 3D printers, injection molding, foam, and paper maché are only a few of the ways prototyping can be done. Within the 3D printing industry Interviewee 1 mentioned that there are over 980 3D printer models and over 300 manufacturers competing in this industry. And they highlighted the fact that companies will have regional advantages, like a Dutch company in Holland will likely have more ease gaining market share than a company that is based in a different country.

They talked about filament producers who generally price just to offset their own costs. They also mentioned that some filaments could be highly priced if they are rare. Manufacturer 1 works with these suppliers and discusses pricing and whether they believe prices are set appropriately for the market.

The Future

Company

The company plans to continue to increase sales and “ride the wave of the explosion of the 3D printing industry.” They also hope to expand into industries that have yet to recognize the benefits that 3D printing could bring. They would also like to increase their

range of filament options. Interviewee 1 said that he wished he knew where the future would lead. He joked, “I wish we did… I might not be talking to you. I might be out getting some investors.” This remark shows the nascent state of the industry and unpredictability that surrounds its development.

Industry

These are the early days of the industry, according to Interviewee 1. Lots of companies are pursuing similar business models as Manufacturer 1 and succeeding. They also mentioned that “hostile” companies that follow traditional tactics may have trouble in the future.

Interviewee 1 noted that he believes innovative development will come from outside the realm of the 3D printing industry. They mentioned that chemical companies may be the ones contributing to the development.

Manufacturer 2 Represented by Interviewee 3

March 10, 2016

Interview: duration 50 minutes, audio recorded, interview notes were recorded in a field journal during the interview

Business Overview:

Mission: To empower makers around the world by developing the best open tools for creating physical objects ("Mission, Vision, Brand, Values," 2016).

Manufacturer 2 has built its business on the Maker community. They are committed to cooperative collaboration using open source sharing. Interviewee 3 explained, "We strongly believe in co-development, co-creation, in a more professional way." This open-minded approach fosters a company-community relationship. Input and development happens from both sides. This open-source oriented strategy aids the company in generating new ideas. Their company values are preserved, because they have built their mission and vision around collaboration with their customers.

Recently, the company has started to investigate who their customers are and where they come from. When Interviewee 3 joined the company in 2015 he asked, "Who's buying our printers?" He admits, "We didn't know… How can you be successful and think of what the next wave of development should be, not knowing where your printers are and what they are being used for?" They realized that their customer base of "tinkerers" was

composed of students (Phd and masters) studying chemistry, engineering, and electronics. They tinkered with these machines on the weekends and eventually started introducing them to the workplace. Interviewee 3 explained,

> "They were persistent in using the machine to showing what the capabilities are of 3D printing. And now we are working with big multinationals installing printer walls, which means, one hundred machines in a row, working on, or being used for sort of small scale production, in a manufacturing environment… as it turned out by accident and that we have a direct sales force in place approaching all those companies and [telling them] what the advantages are of 3D printing."

The customers experimenting with 3D printers were the ones proving the advantages of the machines to resistant management members. They raised awareness and demonstrated the capabilities of Manufacturer 2's desktop 3D printer, in a sense, becoming part of Manufacturer 2's sales force.

Interviewee 3 also highlighted the importance of customer relationships. Manufacturer 2 is built from its foundation of customers. This collaboration influences what Manufacturer 2 develops and produces based on customer feedback. To take it a step further, long-term relationships are important to Manufacturer 2's business model. During the interview Interviewee 3 discussed research and development. He mentioned,

> "In terms of customer research it's very hard to ask the customer what they want to have… When they printed for four and a half years, then they start to ask for, '…reliability…[a] bigger printer, faster, more [sic] safe…and so…If you [ask], and this is one example, of course, my mother, 'what do you want to do with a 3D printer?' You won't get an answer... And that's why you see 3D systems and the others not focusing on the mass market, because it doesn't exist yet. There is no consumer market at this moment in time for 3D printing."

He emphasized the fact that this is a very immature industry, in his opinion. While tinkers have helped create Manufacturer 2's base they do not constitute the mass market. The development happens over time as customers experiment with 3D printers and then learn

the technology well enough to know what they want improved. Interviewee 3 explained that this is why experienced consumers help Manufacturer 2 figure out the next steps that the business will take.

Competitive Advantage:

According to Interviewee 3, Manufacturer 2's advantage lies in their quality printing capabilities. He stated, "I believe we have the best FDM printer in its segment." The open source machine also sets the company apart from most of its competitors. He noted, "Apple, or Tesla, Boeing, Airbus, BMW – All those big companies are using [our printers], because the engineers in those companies love the machine, because they can do whatever they want to do and it still prints properly." The company also has invested in software development. Their software is open source 3D printing, slicing software. "But for the time being now, ensuring that you can print your Solidworks design or your AutoCAD design properly using [our software] that's also a big advantage." Software is more difficult to replicate compared to the printer's hardware. The unique open-source style printers along with company produced software helped distinguish Manufacturer 2 from the other 3D printing companies in the industry.

Areas to Improve

Manufacturer 2 is continuously testing 3D printing filaments. This testing in turn will develop into a sort of certification system to ensure filaments are compatible with Manufacturer 2's 3D printers. Software is the other component that Manufacturer 2 will

continue to work on and improve. Interviewee 3 emphasized that ease of use is the main goal for future software development.

Sustainability

Manufacturer 2 contributes to sustainability in more ways than one. From a social sustainability viewpoint its community-based projects help serve medical needs with 3D printing technology. They have worked with Enable to create prosthetics. Additionally, they collaborate with the Red Cross to develop makerspaces in Nairobi and Afghanistan for medical applications and prosthetics.

Interviewee 3 mentioned the trade-offs of sustainable materials. Virgin plastics are of a higher quality than recycled plastic. This could mean, for example, that a recycled plastic might not have the same level of strength or heat resistant capabilities. In regards to their makerspace projects he mentioned issues with PLA. This material is corn based and more eco-friendly than alternative 3D printing filaments ("3D Printer Filament Comparison Guide," 2016). However, the downside is that it has a very low melting temperature. In areas with high temperatures products printed in PLA are susceptible to melting in the sun. Interviewee 3 explained that Manufacturer 3 has developed a UV resistant material, chuckling as he said, "And that's a great example of working with your customers… When you start to work with customers or users you start to learn what you need to develop. In this case, being able to print properly prosthetics from UV resistant material." Eco-friendly materials help reduce negative impacts on the environment, however they still need to be functional. Interviewee 3 did indicate that he is looking for a 3D printing

filament made out of bio-degradable material. He also emphasized the fact that while he does consider sustainable materials the company does not aim to advertise themselves as "the most sustainable 3D printing company."

He also said that sustainability is currently company driven, not consumer driven. The companies doing this are developing eco-friendly materials because they believe the environmental impact of plastic and chemical waste is negative and that our products and processes need to change. They are not doing it for advertising, but because they are driven by core values.

Interviewee 3 also commented on Manufacturer 2 specifically and working to minimize the impact the company has on the environment. This includes waste management and ensuring they ask their suppliers about their values and practices. While sustainability is not the core focus of their business Interviewee 3 explained, "Not to say that [sustainability] isn't important. But the focus now is on making sure we have our business in place… We're just too young and [have] other challenges to face and tackle…" While Interviewee 3 does ask suppliers about their practices and looks for eco-friendly filaments the main goal currently is to continue to grow their profits and expand the business.

Industry Competition

Large companies are the main concern for a company like Manufacturer 2. The company started up in 2011, relatively young compared to some of the major players in the 3D

printing industry. Interviewee 3 explained, “For the short-term it’s of course our 3D printing, printer builder or designer companies like Makerbot, and LeapFrog, and XYZ.” Interviewee 3 also mentioned the risk in focusing solely on hardware development. He noted software and material development will grow in the future. “The thing is it’s not difficult to design and build a printer. What is difficult is what [our company] did, establish a brand name, and have support in place, … And dealers in place, …[etc.] being able to send out thousands of machines every month.” The founders of Manufacturer 2 had to take time, money, and effort to build up the company to what it is today. Anyone can figure out how to assemble their own 3D printer with the right resources, however there are many pieces involved in establishing a business and creating a brand image.

The Future

Company

Manufacturer 2 is looking to move toward professional users over the tinkerers. “I see us moving out of the tinker space…to the more professional user. In due course, as that’s a complete new segment, moving into the manufacturing space.” Additive manufacturing has already started to change the manufacturing space. Manufacturer 2 plans to move into this area of development.

As they grow they will face internal challenges as well. Interviewee 3 stated, “We’re growing like crazy. We’re doubling our revenue every year... We have a lot of new influx of ideas and experienced people.” He mentioned that the company grew from a small team working “at the kitchen table” to a fast growing company. Interviewee 3 explained,

"It's a challenge: how to grow this fast, and how to make sure you build a proper business without throwing overboard your original plans, ideas, DNA." As the business expands the core values it may be important for upper management to examine their growth and how the structure changes over time. He also mentioned that they are working to prove to the chemical industry that 3D printer material development is worth investing in. As sales increase chemical companies may take notice. Interviewee 3 conjectured that chemical companies make "work with us closely to ensure that their material prints properly on our printer." Chemical companies may see the benefit in being the company that can demonstrate they produce better quality plastics or other materials that print consistently with Manufacturer 2's printers, for example.

Industry

Interviewee 3 described the industry as very driven towards technical features. However he pointed out that 3D printing needs to be more consistent and reliable to gain a larger customer base. Usability may also develop further in the future. Manufacturer 2 compared the creation and production of a document in Microsoft Word to 3D printing, "In Word, for example, you hit the print button and the printer, it starts to print. That's not the case with 3D printing yet." Moving forward he sees 3D printing turning into a technology that allows everyone to customize the items they have. He also noted that 3D printing organic shapes will be easier to print as experts create better algorithms. He claims it is just a matter of time and processing power. "The more processing power as there always is, the better the shape gets."

This technology may also help localize production, bringing it back to the country of origin. Interviewee 3 highlights the elimination of stock with the increase of manufacturing through 3D printing.

> "Spare parts for cars, for example (not all of them of course), are made out of ABS. Wouldn't that be for great for every dealer to have a good ABS printer and you print on demand the spare parts you need? So, no warehouses anymore (or less). No mass production anymore somewhere in South Korea, or China, or wherever. No transportation anymore. That's the real change."

Interviewee 3 agreed that this means there could be a shift away from outsourcing towards in-country production. He also mentioned at least 10-15 years in the future that the focus will be centered around design, not the physical end product.

Manufacturer 3 & Filament Producer 1 Represented by Interviewee 4

March 8, 2016

Interview: approx. one hour, not audio recorded, interview notes were recorded in a field journal during the interview

Business Mission and Model:

"To make functional electronic parts without factory constraints"

Currently, Manufacturer 3 expresses its business mission through its model by creating a desktop printer that allows for prototyping. Interviewee 4 explained that the business plans to expand beyond this in the future. The product pieces created by Manufacturer 3 are modular and add-ons can be incorporated to create a customized end product. Their products are especially unique, because their production process enables them to print with a conductive ink, incorporating the electronic element into the product itself.

Competitive Advantage:

The 3D printing material does not use heat during product creation. The deposition technique is utilized cutting out the need for higher energy consumption during the fabrication process. The material used by Manufacturer 3 contains unique properties, which gives them a competitive edge. Their patents and employee knowledge in material science aids in the growth and development for this company

As testament to their startup success they were listed among the “50 Smartest Companies” of 2015 by the MIT Technology Review. They ranked #17 just below Apple at #16 and above companies like Facebook, 3D Systems, and IBM (“50 Smartest Companies 2015,” 2015). They have also received a “Gold” rating for the 2015 Edison Awards for their innovative technology (“2015 Edison Award Winners,” 2015). Among other awards and recognition the company has clearly established that it has IP that sets it apart from others and gives it a competitive advantage over competitors.

Areas to Improve

The company recognizes that software is challenging to design especially when multiple materials are being used during the fabrication process. Further development in software technology could help make the design process simpler and quicker. There are also challenges when using a conductive ink. One drawback includes extra planning in the product development stage to ensure the path of conductive ink remains intact so as not to break the connection.

Industry Competition

In a general overview of the 3D printing industry Interviewee 4 stated that he perceived the industry competition ranged from medium to high. He also noted the increasing overseas competition and especially in regard to rising 3D printer hardware manufacturers in China.

In a break down hardware and software he claimed that the competition for hardware was high. This is further highlighted by a ranking list of 3D printing hardware (the printer's themselves). This list included 980 different types of 3D printers ("The 2016 meta-list of the best 3D printers," 2016). Software he noted was less competitive and still more in a research and development mode.

Large 3D printing companies are obviously a direct concern to Manufacturer 3, because they have a larger base of financial capital to draw from among other things. There are also startups such as Carbon3D and Desktop Metal that are important to watch as Manufacturer 3 continues to grow.

Their development towards company versus individual consumer preferences clarifies its position among competitors and supports their pricing strategy.

The Future

Company

Manufacturer 3 will continue to develop and grow, hopefully leading to a leadership position in the industry.

Industry

When talking about the future of the industry Interviewee 4 mentioned a few key areas that may change in the future. He predicted 3D printing speed will continue to increase. Metal based 3D printing involving jet engines, car parts, etc. will continue to be a fast

growing segment of the industry. He conjectured that hardware development will start to taper off and software development will be a long-term factor in the 3D printing industry development. And lastly, he mentioned that filaments are only one portion of the 3D printing industry. He mentioned that different deposition techniques will likely develop and grow in the future.

Sustainability

Manufacturer 3 is more sustainable than traditional manufacturing methods that require a subtractive process. The 3D printing process allows producers to create objects that only use the exact amount of material needed. This is more sustainable compared to traditional practice where the excess material is discarded.

Future sustainability will come from "The Nike's of the world," that consumerize products. Companies that are well established and backed by large financial capital could be influencers in the shift toward sustainability, Interviewee 4 conjectured. Such companies will make mass customized products – if we use Nike as an example this could mean shoes customized to every customer's foot scans. In addition a large company could invest in R&D and incorporate sustainable materials into their end product. The combination of customization and sustainability could put the product at a premium position in the market. The higher than average costs could offset the investment in R&D and result in a profit for the company.

Filament Producer 2 & Educational Services Provider 1 Represented by Interviewee 5

March 10, 2016

Interview: duration 27 minutes, not audio recorded, interview notes were recorded in a field journal during the interview

Business Overview:

The mission: "help people get printing and change the world"

Interviewee 5 runs two complimentary businesses. One part of the business provides customer service and educational services around 3D printing. It also includes spare part production for replacement 3D printer parts. The second business Interviewee 5 runs, develops 3D printing materials. These 3D printing materials are derived from innovative sources such coffee bean hulls and beer waste. The novelty of these unique filament materials has caught the media's attention, raising awareness of the filament production side of the business.

This company is moving away from selling 3D printers. The focus now shifts towards 3D printer training sessions and supplying spare parts for a variety of 3D printers. They serve both individual customers and businesses. Interviewee 5 noted that many businesses have been buying spare parts from the company. There is convenience in buying a spare part over fixing the actual 3D printer problem. This practice extends to the academic realm as well. Interviewee 5 explained that the company works locally with various universities

and robotics teams. He says they provide materials for free and can provide parts if a printer is broken.

Overall, these businesses do not generally make use of open source design. If a customer needs design work they generally do not intend for it to be open source. His opinion is that open source can only help the growth of the 3D printing industry. It builds awareness, which then leads to increased demand. There are also more designs available to 3D printing customers.

Competitive Advantage:

Interviewee 5 and his coworkers see their experience with 3D printing as part of their competitive advantage. The products that Interviewee 5 and his colleagues sell are products that they use on a daily basis. They have a thorough understanding of 3D printers and the technology used.

Their filaments are also unique within the spectrum of 3D printing materials. Interviewee 5 explains that these materials like beer and coffee waste and bio-composites capture the consumer's imagination. They also have the benefit of getting their raw materials from waste left over in the coffee making process and grains that would not be used otherwise.

Areas to Improve

Interviewee 5 stated that the business needs to work on systemization. They also offer custom 3D printing. He mentioned that some customers will walk in with a file they

would like printed out, but the company may be unable to print it out for them. They also provide a lot of support over the phone, which ties up the time they could be investing in other things. Thus, productivity is not always as high as it could be.

Sustainability

The filament side of the business has a material selection that provides some options that are inherently more eco-friendly. The filaments made from waste byproducts are produced because they are innovative. They were not intentionally created to combat environmental concerns. Interviewee 5 mentions that such actions are “nice to think about” but that such a strategy may not be a sustainable for the business. The fact that some of the filaments they produce come from waste is “nice that the products go hand in hand,” but the decision was not made with sustainability as the driving force. The company delivers what customers want and need to be successful, according to Interviewee 5.

An eco-sustainable solution may not be profitable. The decision to pursue eco-sustainability must be in line with the business strategy. Interviewee 5 explained that the filament they produce is successful because it is a novel product and it catches people’s attention. He also noted a new hemp based material that they recently produced. This material led to another company producing pen bodies with this material. So, in a way they have impacted other business by enabling them to create such products.

Industry Competition

For 3D printer hardware (the printer itself) there is intense competition, according to Interviewee 5. However, he noted that the 3D printer repair and spare parts services have minimal competition. The custom 3D printing arena also has lots of competition, so while it is a part of the business, it is not the focus. And lastly, the material sector of the 3D printing industry also contains lots of competition.

The company sets itself apart with 3D printing repair services and providing spare parts. This decreases their direct competition in the 3D printing industry. Interviewee 5 mentioned, “Nine times out of ten we’re the only person that provides those spare parts.” The industry is extremely competitive and Interviewee 5 discussed that desktop 3D printers, especially, seem to only have small shares of the market as well as 3D printing materials. The upside to the fast growth of the industry is that there are lots of opportunities to find ways to differentiate.

The Future

Company

Interviewee 5 sees the company sticking with FDM printers for the long-term. He said they might bring in an SLA machine, but again emphasized they would not be focusing on selling 3D printers. The business will continue to serve its existing customer base. Interviewee 5 also mentioned that it will be up to the customers to determine how the business will change the world.

Industry

In Interviewee 5's opinion bio-degradable 3D printing materials will continue to grow and materials will become safer in the long term. From his viewpoint this will be a customer driven change as customers demand for material that is easy to print with, safe, and environmentally sustainable. However, he admitted that environmentally sustainable attributes are likely the last thing consumers may be thinking about when choosing a 3D printing filament. He also mentioned that such products would need the right kind of market as well. The change will not happen solely from consumer demand.

He also discussed that PLA may remain popular as it has a low warp and is easy to print with. ABS may also remain in the market, as it is one of the original 3D printing materials. Niche markets may also contribute to the development of new materials. This could include materials that have a specific level of flexibility or are self-insulating, for example. However, Interviewee 5 made a point to say that such niche products will never overtake the market.

Apart from materials Interviewee 5 explained that the industry is continuing to grow even though the hype is dying down. The benefit, he states, is that the increase in media coverage has helped raise awareness of 3D printing. This has then lead people to buy into the hype and discover that 3D printing can have useful applications. Schools may start expanding with 3D printing as well. They have been "dipping their toes in" and now are starting to scale up. Interviewee 5 conjectured that 3D printers have the potential to

become an item “on the desk of every engineer [to] kick out prototypes as needed.” Interviewee 5 stated that schools might even invest in large printers for detailed work.

Filament Producer 3 & Educational Services Provider 2 Represented by Interviewee 6

March 17, 2016

Interview: duration 64 minutes, audio recorded, interview notes were recorded in a field journal during the interview

Business Overview:

Filament Producer 3/Educational Services Provider 2 is a very young company and has yet to formulate a concrete mission statement. Interviewee 6 offered some insight, explaining that knowledge dissemination is a key component of their business. Filament production is a dual part of the business that focuses on development of sustainable 3D printing materials. This is meant to target both open and closed loop systems as part of the circular economy.

As the company develops it will be focused on expanding education and promoting innovation and creativity. As this is a growth industry everything is currently about selling and sharing knowledge, according to Interviewee 6. Consultancy services can be used for large businesses, where the cost will seem minimal for the education they receive. On the other side, services can be tailored and modified to suit small business needs as well. Currently, Interviewee 6 sees the educational component being pushed by businesses rather than being consumer driven.

Interviewee 6 talks about the challenge of open-source knowledge. It is important to share information as a means of raising awareness. Interviewee 6 does this by attending talks and conferences. He says he tries to share as much information as possible, yet this is tricky, because he does not want to compete with their business model.

Competitive Advantage:

At the moment Interviewee 6 highlights the business and education cross-over as a source of their competitive advantage. Their target market includes businesses and colleges.

Instead of competing for customers within the 3D printing industry the company is aiming to attract those who are outside of it. Interviewee 6 explains how people are starting to pay for the knowledge by enrolling in training courses and learning about filaments. An example of a potential growth area could include architects and aiding their draft designs.

A general competitive advantage that Interviewee 6 sees for 3D printers over more traditional machines (like laser printers) is that they are much simpler. He says he hopes they do not get too complex to fiddle around with and that smoother designs foster a false sense of security.

Areas to Improve

Interviewee 6 highlighted several areas where the 3D printing industry could be improved. He mentioned that 3D printing needs to coexist with other business. He

commented on how they have been “shoe-horned into plastics and metals” in terms of 3D printing materials. He also talked about the lack of communication between industries. Cross-over communication would help each area improve and develop more innovative solutions. One suggestion Interviewee 6 had involved coordination with plastics testing to establish a certification system for 3D printing materials.

Sustainability

The filament production side of the business has caught the attention of the U.K. organization Green Alliance. This organization has been discussing bio-plastics with their company. Filament Producer 3’s goal is to be the leader in the field of innovation and sustainability. Interviewee 6 emphasized the importance of examining issues now instead of ten years down the road.

Eco-builders have consulted Interviewee 6 to ask about additive manufacturing and create decorations within buildings. The company even encourages customers to use the recycled filament that they offer. He also mentioned that easy to print objects do not need to be supplied, thus localizing material and putting power back into the consumers hands, so to speak.

Fila-cycle is the filament side of the business. Interviewee 6 describes it as a “niche within a niche.” 3D printing is still considered a niche market in of itself. He explains that recycled filament has yet to take off, but that there is lots of interest in the material. “[Our company is] flying the flag for recyclable materials, for biomaterials, and sustainability.”

This differentiator, Interviewee 6 stated, has helped them get in the door of big industries and associations. He also claimed that he believes there is a bigger place for bio-plastics in the industry especially if more people start demanding such materials. He also believes that incorporating sustainability solutions into products will help businesses like his get their foot in the door of big companies and industries. He also highlighted the evolution of recycled paper to address concerns of weaknesses in recycled 3D printing filaments. Interviewee 6 talked about how at first recycled paper was low quality, but research and development led to recycled paper that is now on par with virgin materials.

Industry Competition

Currently, Interviewee 6 sees other startups as their biggest competition. Some of these new businesses are also working towards offering services with an educational component. And some of them, Interviewee 6 notes, are very good at marketing. The second type of competitors is the 3D printing material producers. However that competition is less intense, as he listed there are only one or two other business out there producing or developing bio-plastics.

Interviewee 6 broke down the industry into lower end of the market, where he states there is high competition. He also distinguished an upper-end and medium-end where there is minimal competition.

The Future

Company

In the short term (perhaps over the next 12 months) the company plans to focus on developing educational services over product development.

Industry

Interviewee 6 noted that short-term growth for the 3D printing industry lies in material development. In the long term growth might come from 3D printing software development. Software developers will likely simplify this software. Interviewee 6 mentioned that even though the industry has been around since the 1980's it has only really taken off in the past 3-4 years. He also conjectures that interest in 3D printing sustainability will increase amongst big businesses, government, and education. He sees the potential for major growth to occur in the next 12-24 months compared to the previous growth rate in the past few years. He also noted that larger 3D printing companies may have trouble adjusting to a faster growth pace in the future.

There is lots of room for industrial plastics to grow, according to Interviewee 6. However he believes there will be a shift away from ABS towards PLA (starch-based and materials that are bio-degradable under industrial conditions). One development of bio-plastic could combine rubbish with plastic. Another solution might include recycling plastics for filament.

Within the next five years, Interviewee 6 imagines there will be massive growth in education around 3D printing. From that he sees potential for adoption into educational institutions. The exposure of 3D printing could start to occur sooner, as young kids are exposed to the technology. In addition to education, the general rising concern over pollution and consumption waste could drive change.

Filament Producer 4 Represented by Interviewee 7

March 25, 2016

Interview: duration 29 minutes, audio recorded, interview notes were recorded in a field journal during the interview

Business Overview:

Filament Producer 4 is a social enterprise. The mission is to generate income for waste pickers by creating and capturing value at the grassroots.

Filament Producer 4 is still in its pilot stage, but is working with 3D printing distributers and manufacturers in the meantime. Interviewee 7 is aiming for open source filament distributers of HDPE plastic. He explained that HDPE is the 2nd most abundant plastic in India.

He does not plan to be a direct seller, but rather to work through a distribution network. He also hopes that his filament can be priced competitively instead of putting an "ethical premium" on it. The company has been fortunate to have ground funding, along with funding from MIT. Their process is financially lean. Interviewee 7 explained that much of the expenditure occurred in the technology and the filament production process. There is little cost for management.

Filament Producer 4 is not making use of open source sharing, however Interviewee 7 mentioned that it is a good way to create global feedback and communication. While he

is very busy currently, documentation might improve. He did make a point to say that he is will to talk to people who reach out to him about setting up an organization like his. He sees the sharing of knowledge gained from trial and error as mutually beneficial.

Competitive Advantage:

They have supply from all the plastic waste. Filament Producer 4 also ensures that profits go to the waste pickers and give them empowerment. In addition there are benefits to the company throughout the supply chain that can give the company a competitive advantage. The “raw material” comes directly from the grassroots, so it is essentially free, according to Interviewee 7. In addition to this, the wages for waste pickers enables the end product to be priced lower. The fact that this will be an ethically sourced filament could give them consumer preference if they are priced competitively. Interviewee 7 discussed how consumers were becoming more environmentally and socially concerned. He conjectured that perhaps millennials will be the ones to take interest in this product offering.

He also attributed his unique product and mission to the startups success thus far. Interviewee 7 believes that his company would not have gained the same support for a “run-of-the-mill” product. He says that many companies have reached out to Filament Producer 4 and discussed sustainable business practices. While the business has had help so far, he stated that it will be a challenge as the business scales up.

Areas to Improve

Currently, Filament Producer 4 is working out filament issues. Since recycled HTPE is not as good as PLA Filament Producer 4 will need to fix issues with warping and crystallization. Interviewee 7 is working with national chemistry labs in India to develop an additive to prevent warping.

Sustainability

The process that Interviewee 7 would like to work towards is a closed loop supply and demand. Filament Producer 4 pursues sustainability in a few ways that are core to the business process. Filament produced is created from recycled plastic. It is also sustainable in that it promotes ethical sourcing. According to the Echoing Green Fellowship page, Filament Producer 4 pays its waste pickers fifteen times more than the average waste picker in India (Echoing Green, "Our Fellows," 2014). Interviewee 7 has also conducted market research and discussed product distribution with some large 3D printing companies. He said there was definitely some interest in his recycled filament however it is hard to quantify that until Filament Producer 4 has established sales data. "I have received a lot of interest and a lot of distributers organically, which I think is definitely not the case if you were just doing a run of the mill product." He also explained his choice to use HTPE plastic for the 3D printing filament. "The reason we chose HTPE is because it is relatively abundant…it will actually make an environmental impact when you recycle it." However he also mentioned that purely profit driven entities do not face the same constraints as Filament Producer 4. "We have these social constraints and environmental constraints that we've imposed on ourselves, because it's a core part of

our mission." He mentioned that for-profit companies have an advantage because it gives them more flexibility if they do not establish and pursue these constraints.

Industry Competition

Those competing in economies of scale may be challenging to compete with in terms of pricing. Companies producing filament out of virgin materials may also be competing with Filament Producer 4. To maintain filament quality, Interviewee 7 mentioned the need to price competitively. He said he believes it will all come down to price sensitivity. As of now he does not see the industry as being very competitive and that the current prices are highly inflated.

The Future

Company

In the short-term Interviewee 7 will be focused on fixing the warping issue that his filament has. However, his organization already has pre-orders from many distributors and he has even received some consumer feedback as well. His plan is to grow organically.

Industry

In the short term, Interviewee 7 said that demand is increasing more than supply in the short-term. Over time the highly inflated prices of filament will decrease, according to Interviewee 7. In his estimation prices will plummet over the next ten years as the industry starts to become more competitive.

He predicted that SLA will be the cheapest printing technique to use and will be the most widely used. FDM printing will have its place, too, however. There are capabilities FDM has that SLA cannot compete against. He explained how FDM is a low-tech process that is not as costly as SLA and does not deal with resins. Schools may invest in low-end 3D printing because it is a fun and engaging tool that will help students visualize their designs. Interviewee 7 points out that this technology could be used in primary schools all the way up to the university level. For high-end 3D printers he believes they will find their place in niche manufacturing and industrial design.

Filament Producer 5 Represented by Interviewee 8

March 17, 2016

Interview: duration 40 minutes, audio recorded, interview notes were recorded in a field journal during the interview

Business Overview:

Filament Producer 5's mission statement is "To transform waste into ecofriendly, affordable materials while a creating positive environmental impact."

According to Interviewee 8, Filament Producer 5 plans to tackle two issues. Plastics pollution is the first issue. While she mentioned there is some controversy around the impact of this on the environment their company believes this is a problem. Secondly, they believe that if plastics *do* end up in the ocean then they should at least be designed to break down in water.

Interviewee 8 describes the company as a bootstrap startup. The employees built up the company through their own funds, business plan competition awards, and government grants. She said they have acquired the equipment and capital needed now, but that it has taken time to get there. They are focusing on developing a B2B relationship.

Competitive Advantage:

One advantage that Filament Producer 5 has over competitors comes from its raw material supply. The company creates bio-plastics from methane gas. The companies produces methane gas want to get rid off it, so for now, Filament Producer 5 receives their supply for free. This waste product comes in the form of a resin.

The organisms used traditionally to break down waste need to be in sterile environments. Filament Producer 5 uses an organism that works very well in unsanitary conditions, and thus it gives them an advantage over these other developers. In addition, there is potential for a closed-loop process. The materials from the waste facility are used for filament production, broken down, and then the cycle repeats.

Areas to Improve

Interviewee 8 states that they are producing 10lbs. of polymer per week. For the company this is an amazing achievement, however scalability will need to be looked at in the future. She noted that they need to produce larger volumes. They are learning as they go to figure out how to optimize their technology while scaling up.

Sustainability

Interviewee 8 mentioned the “green premium,” higher pricing for the added value of producing eco-friendly goods. This can allow small startups to produce a low volume of goods at a higher price point. She noted it was especially helpful for cosmetic products.

Having high profits in the beginning helps startups gain more capital to invest and grow the business. Over time it also gives them the option to lower prices without harming the company and allowing them to compete competitively. This helps shapes their long-term business sustainability plan according to Interviewee 8.

The business hopes to spread the environmental message through every part of its business processes. As a trade-off of their mission they may not be as financially successful to achieve their sustainability goals. Part of growing their business might mean they have to think outside the box. They will also need to educate businesses on what sustainability means and how their products fit into to this. This is a two-way street, as finding consumers who are receptive and willing to ask about sustainability will also be equally important. At the moment, though, appears to be mainly a company driven effort.

Industry Competition

The large chemical companies are a main concern for a small business like Filament Producer 5. She also mentioned other startups are beginning to focus on bio-polymers. She mentioned that these other start-ups are as much competitors as they are potential partners. In some sense they can help each other out while also giving them an understanding of who their competitors are.

Interviewee 8 mentioned that the industry is not really formed around bio-plastic production. She said it is hard to tell what everyone else is doing. In a sense, open source sharing has helped foster a sense of community and Interviewee 8 discussed how other

businesses are more willing to try and work together. This has potentially influenced the small startups that Filament Producer 5 competes with, in her opinion.

The Future

Company

In the short-term they may focus on product development and scalability. Perhaps in the future they may even explore making their own 3D printer. In the short-term they have lots of markets where their materials could be successful and provide revenue for the company. Microbeads are a growing concern, (the small plastic beads in cosmetics, like body scrub). A bio-plastic that can break down in the water will solve a problem and also give them the upper hand. Currently, several states have banned the production of plastic microbeads due to concerns for aquatic life and potential health concerns for humans. There are also opportunities for them to work with agricultural and marine fields.

They have an ambitious goal to reach production levels of one million lbs. per year. Their rough timeline for achieving this is 12-24 months. Due to the danger in transporting methane they hope to open facilities around the world following a decentralized strategy. This will decrease danger while also localizing production, further minimizing environmental impact.

Industry

Europe is more at the forefront of bio-polymer development according to Interviewee 8. Generally, there may be a larger shift towards localization in the future of polymer

development and production. Interviewee 8 sees potential for bio-polymers to grow in the future, however, she says they are not quite there yet. She also sees 3D printing becoming an important technology.

Filament Producer 6 Represented by Interviewee 9

March 30, 2016

Interview: duration 28 minutes, audio recorded, interview notes were recorded in a field journal during the interview

Business Overview:

Filament Producer 6 aims to produce bio-plastics in a sustainable and natural way. In this way they want "bring back love to plastics."

Filament Producer 6 was funded by a Kickstarter campaign. Many of the startups members have specialized in bio-technology and specifically in PHA. 3D printing is only the starting point for the business, according to Interviewee 9. They hope to move to packaging and agriculture in the future.

Currently, they are in the early stages of R&D. Interviewee 9 explained that they will likely wrap up prototyping in the next two months or so. After this they will enter a prototyping stage, hoping to start producing their filament for consumers.

Competitive Advantage:

Bio-plastics already exist and are produced a few companies. Filament Producer 6 is unique in that their substrate is different from substrates other companies are working with currently. Theirs is composed only of carbon dioxide and hydrogen.

Areas to Improve

The company needs to reduce purification costs. Interviewee 9 mentioned that this currently accounts for one third of their development costs.

They also plan to branch out and gain new connections. The more investors they have the more credibility they will gain. Interviewee 9 noted that he does not think it will be difficult to get backers, actually. He said investors do not see this as a risky endeavor. He said that they want to invest, but of course, are just waiting to see that the prototype works. He also mentioned that they would then need to get a patent. Their product is also compostable, so failed prototypes can be thrown away and composted

They hope to target anyone who has a sustainable mindset. They also mentioned there was interest from biotech companies in the U.S. and Europe. This could attract retailers. Starting in the 3D printing industry gives them the chance to develop whereas this would probably not be possible in the traditional manufacturing industry.

Sustainability

Filament Producer 6 is creating a bio-plastic that is compostable, clearly putting sustainability at the core of the business. The tradeoff is that it is more expensive to pursue sustainability. He said it is not an option to be more expensive so you have to accept a lower product margin. He explained that development and production would always be more expensive.

Industry Competition

In Interviewee 9's observation this is currently one of the fastest emerging markets. There are lots of new printers and materials coming and going. Platforms like Kickstarter have aided the rise of some of these startups. He mentioned that this has aided Filament Producer 6 in its development. While it did not meet its financial goal, he did note that it was good for advertising. A lot of people were interested and curious about their project.

The Future

Company

In the short term they will be building their business foundation. As of now Filament Producer 6 is in the early, R&D stages. They are finishing up prototyping in a few months and using crowd-funding. They will grow and develop within the 3D printing industry. Potential they will then expand into packaging and agriculture.

Industry

In Interviewee 9's opinion he sees open source sharing growing in a shift towards sustainability. He sees materials developing around filaments created from wood, paper, and starch. However, he mentioned that ABS and PLA will likely remain one of the big players in the realm of filaments.

End User 1 Represented by Interviewee 10

March 14, 2016

Interview: duration 46 minutes, audio recorded, interview notes were recorded in a field journal during the interview

Business Overview:

The business mission for End User 1 according to Interviewee 10 is "Our goal is to provide high quality components for our industry that help our customers be competitive…and be a leader in our industry in terms of the component and shade manufacturing and design. And to do so safely."

End User 1 has a business to business (B2B) model. They supply parts for window shades and provide services mainly for large and small businesses. These businesses are the shade fabricators. 3D printing adds value to their business by allowing them to better meet customer needs when designing and creating shade components. Interviewee 10 explained, "We have actually designed and 3D printed parts for single jobs and sent them out…So [our customers] can actually bid on those jobs and get them." This valuable capability helps End User 1 meet their customers needs and allow them to bid on unique projects. 3D printing also helps End User 1 create prototypes quickly for customers to look over. Interviewee 10 explained that 3D printers can create a prototype in a few hours, which can then be shipped out. Customers can examine the design and give

feedback for what they like or if they want something changed. It also enables them to be the largest component manufacturer in the world for the window coverings industry.

Competitive Advantage:

Their range of products makes End User 1 exceptional, according to Interviewee 10. They have an excellent brand reputation for producing high quality business, he says. This reputation is contained to their network of businesses, not the end users themselves.

He also mentioned that using 3D printing is pretty uncommon for this field. Usually there are not in-house capabilities or the same business plan for component manufacturers. “In terms of component manufacturers” Interviewee 10 explained, “I’d say that we’re one of the only ones that really have this kind of capability.” The vice president at End User 1 spent time researching and comparing printers to find the best fit for the company. The printer they use is in the $25,000 price range. In addition, this printer comes with its own maintenance package so the business does not have to invest time working on printer repairs. Interviewee 10 stated, “3D printing is part of [the company’s] value and we definitely wouldn’t be doing what we’re doing without it.” 3D printing has allowed them be innovative in their industry.

Areas to Improve

Interviewee 10 mentioned End User 1 just acquired a new company so they will be working on integration and consolidation. They also could move faster and have better

communication. He also mentioned created higher efficiency by moving all the equipment in one location.

Sustainability

During our discussion on sustainability Interviewee 10 commented that there would need to be a market force to cause the company shift towards more sustainable solutions. He mentioned several examples to highlight this point. If there were a demand for products that had lower toxicity then investing in materials with that property would become profitable. He cited an example where polyvinyl chloride (PVC) was a concern for consumers. PVC releases gas into the air, which created a push for fabrics to be made with low PVC or to offer PVC free options. Still, even with these new options the majority of shades are produced with PVC fabrics. Aside from being consumer driven organizations can also have an impact on sustainability. Interviewee 10 referenced the Leadership in Energy and Environmental Design (LEED) certification as an example of this. In addition, changing requirements may mean that a company may lose out on a job if they cannot produce products that meet LEED certification requirements. Of course there are also trade-offs to sustainability. Interviewee 10 referenced low-VOC paint, which reduces the level of chemicals (volatile organic compounds) that evaporate from paint at room temperature. While the paint decreases health hazards it can rub off easily and be hard to touch up.

Industry Competition

For End User 1, their customers are also their competitors. They mutually sell and buy from each other. Interviewee 10 also remarked that what they really have to keep an eye on is cheap knock-offs, which are produced using lower quality materials and could hurt the company's brand image.

In an industry that creates window shades there is always pressure to decrease costs. Interviewee 10 says End User 1 creates value from their products to avoid changing their business model to a cost leadership strategy. They focus on differentiation and their business reputation for high quality products to maintain an advantage in the industry.

Some businesses see the added value in 3D printing specialized products. Differentiation does not need to be directly tech related. According to Interviewee 10 this could be a design differentiation that distinguishes one company from the next, but using the same technical mechanisms to pull shades open and closed. However, he mentioned there is always a push to be more innovative and that having a limited product range increases the intensity of competition. The alternative would be to increase the products produced, however Interviewee 10 pointed out that the larger the range of products offered, the more difficult it would be to excel in overall product production.

The Future

Company

As the company moves forward they could potentially compete in multiple industries. Interviewee 10 commented that 3D printing has created value throughout the supply chain. Their parts production has only been in-house since 2014. In a short period of time it has become a core piece of the business. Before using 3D printing End User 1 used to contract out production of customized parts.

Industry

The 3D printing industry faces challenges with various aspects of 3D printing. Interviewee 10 noted the process for 3D printing parts versus injection molding is very different. Orientation is important when 3D printing as well as which materials are used and their properties. The point where each layer meets presents a weak spot as well.

Interviewee 10 sees 3D printing technology develop around manufacturing objects that are smaller and have minute details. He also predicts 3D printing technology will become more user friendly and affordable in the future.

End User 2 Represented by Interviewee 11

March 16, 2016

Interview: duration 52 minutes, audio recorded, interview notes were recorded in a field journal during the interview

Business Overview:

End User 2 is an architecture and industrial design firm. They provide design services to residential, commercial, and institutional projects. Their focus is on modern building design.

In regards to the benefits of 3D printing, Interviewee 11 is able to get closer to his final prototype than he could with previous technology. He also mentioned that this process is more cost effective for both the consumer and the company. “Before 3D printing came along it was probably three times the expense or even more than that, depending on what material you use.” Overall, it is more convenient and small changes in the prototyping stage can be made more easily and quickly.

End User 2 serves any customer that comes along within the realm of architecture and industrial design. He mentioned producing parts for buildings, toys, games, and even furniture.

Competitive Advantage:

While 3D printing aids in the prototyping process the benefits gained could be limited. For example, Interviewee 11 discussed material costs for the 3D printer. Pricing for metals is currently cost prohibitive whereas plastics are cost effective. Customized objects can also be produced. Formerly a custom design might have required a 10,000 unit minimum making small, custom projects impossible.

The business can provide service to multiple types of customers. Customers working on structural design or architecture come to Interviewee 11 for consulting. Due to the nature of this work open source sharing is not used. Products created are specialized or have patent protection, so they cannot be shared online.

Interviewee 11 discussed the advantage of investing in 3D printing before his competitors. He said that his company "could see the value of prototyping in plastic." There was a big push from Makerbot, he explained. However he approached cautiously, as it is easy to get caught up in the slick design and marketing. He searched online for customer reviews and said that an engineer who used Makerbot wrote a review that convinced him it was good fit for his work.

Areas to Improve

Interviewee 11 mentioned that he has used 3D printing to create end products. He has printed a few different toys. He is looking to expand his use of 3D printing in the future.

The 3D printing technology comes with a few issues itself. Interviewee 11 mentioned the challenge of maintaining room temperature and ensuring proper ventilation. An open window that serves to ventilate the room, for instance, actually may disrupt the printing process. The temperature needs to remain consistent for the plastic object to print properly.

Sustainability

When asked about issues around ventilation and customer education Interviewee 11 brought up an important point, emphasizing potential issues would likely be detrimental to a 3D printing company's sales. He stated that even the EPA has said it is not an issue.

Interviewee 11 discussed that architects are supposed to hold onto their documents, and so he does the same with his prototypes. He keeps his prototypes to track the iterations that led to the final product. He also talked about PLA and how he was not sure if it could be recycled. In addition there are concerns of waste produced by 3D prints that are part of the iterations or failed prints. Interviewee 11 discussed the importance of developing sustainable ways to protect and conserve our resources.

Industry Competition

End User 2 has competitors in mainly in Maine, but also the Boston area as well. However, he noted that while there are many architects not many are using 3D printing technology. Out of the two to three industrial designers Interviewee 11 said he was not sure if they use 3D printers. Manufacturing is his biggest competition in his estimation.

He also mentioned that there is a lack of demand for industrial design. His business focuses on product design more than architecture.

Interviewee 11 explained that to be competitive the companies that succeed will need to have the latest software and prototyping tools as well as young employees who are skilled at modeling and production. He also emphasized that an employee's skillset is more valuable than the tool itself.

The Future

Company

End User 2 will potentially expand 3D printing use in the future.

Industry

Interviewee 11 predicts that as 3D printers develop and become faster at production they will become more popular. He also mentioned hybrid materials and the potential to see more filaments made from a combination of plastic and metal or wood and plastic, for example. In the long term, Interviewee 11 claimed that 3D printing would likely become a part of the manufacturing process. He also talked about the development of mass customization. He also discussed that 3D printing companies may find an advantage in combining a filtration system into the casing of the 3D printer as long as consumers find value in it. The integrated system would result in a higher cost, but would help keep fumes out of the workplace.

AUTHOR'S BIOGRAPHY

Yvette Alexandrou has lived in Maine most of her life. Since childhood she has been intrigued by new and innovative technologies like 3D printing. She has also discovered a passion for learning languages and traveling. She attended schools in France, England, and Japan during her academic career. She is also a recent graduate of the University of Maine. In the future she hopes to pursue a career in marketing.