3D PRINTING TECHNOLOGY

The Radical Innovations and the Discontinuous Impacts therein

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1 Executive Summary

The recent innovation of 3D printing offers the competitive conditions for displacing existing businesses by growing a new industry and the new businesses therein. The world has seen a 400% increase in additive manufacturing revenue in the past 10 years. There is an estimated 320 million Global manufacturing workers throughout diverse and complex supply chains combining for an $11 trillion Global manufacturing GDP [5]. 3D-Systems, one of the largest manufacturers of 3D printers, has doubled their R&D investment in just the last two years [11]. Economically disruptive technologies have historically been responsible for several technology-based business failures. On the contrary, these technologies have also seeded new businesses and their exponential growth [29]. Successful technology managers must identify these discontinuous innovations and analyze their potential before they wield their discontinuous powers within the global economy. This report will attempt to identify how 3D printing is projected to create discontinuous impacts and what businesses are doing to incorporate this disruptive potential through the scope of the 3D printing technology businesses, traditional manufacturing industries, and service providers.

2 Methodology

Innovations in 3D printing are claimed to have the potential to create significant economic and lifestyle changes. The aim of this project report is to evaluate how 3D printing is impacting the world. A review of available literature was conducted looking at answering three primary questions:

-What is 3D printing and what is the current state of 3D printing technology?

-What are the current and potential markets for 3D Printing?

-What strategies are industry leading companies using to serve existing markets and create new ones?

3 BACKGROUND

3.1 HISTORY OF 3D PRINTING

3D printing is a form of additive manufacturing in which a printer assembles layers of material to create a three dimensional object from instructions contained in an electronic design file. Additive manufacturing differs from common, traditional subtractive manufacturing techniques in that material is added to the work piece, rather than being cut or machined away to create the finished product. A 3D printer is in some ways similar to a typical inkjet and paper printer, but instead of depositing a single layer of ink on a sheet of paper, the 3D printer applies multiple layers of material to create a three dimensional object. Stereolithography, the first form of 3D printing was invented in the mid-1980s by Charles Hull, founder of 3D Systems [3]. The successful commercialization of 3D printing technology required developments not only in chemistry and imaging technology, but also the creation of file formats and software for communication between computer aided design software and the new printer systems. Plastic was the first material used in 3D printing and remains the most common working material for 3D printers, though current 3D printing technology allows creation of printed objects made of plastics, metals, ceramics, food products, or living cells. The most common printers in use today deposit a single type of material at a time, but printers are available for printing of a parts made from multiple materials [1].

3.2 CURRENT TECHNOLOGY

There a several printing techniques for assembling these layers. A convenient means of categorizing the current techniques is to break them into two groups, selective deposition printers and selective binding printers [1].

3.2.1 SELECTIVE DEPOSITION

The defining characteristic of selective deposition printers is that they force the raw material through a nozzle and deposit it onto the print bed. The material then sets or dries to create the finished object. Most 3D printers available for home use fall into this category. In a typical selective deposition printer, a working material such as soft plastic is sprayed through the print nozzle. The printer begins creating an object by depositing a base layer of material shaped in the footprint of the object. This layer is allowed to set and a second layer is then deposited on top of the first [1]. The layering is repeated until the complete object has been printed.

3.2.2 Selective Binding

The defining characteristic of selective binding printers is that they do not deposit raw material through a nozzle, but instead use targeted light or heat to fuse the working material together in the desired shape. Selective binding printer processes include stereolithography and selective laser sintering [1]. In stereolithography printing, a laser is used to trace out the shape of the part in a film of liquid polymer. The laser fuses a layer of the liquid polymer together. The process is then repeated to create additional layers until the part is complete. In selective laser sintering, the laser traces the part shape in a layer of powdered working material. The laser fuses the powdered material together, successive layers are added to create a finished part.

3.2.3 Advantages and Disadvantages

3D printing offers a number of advantages when compared to traditional manufacturing techniques. 3D printing allows creation of complex shapes and internal parts structures that are not possible with other manufacturing techniques. 3D printing also allows for more rapid transition from idea to finished product. With a 3D printer, a designer can print out a prototype from an electronic CAD file. Steps in the prototyping process such as contracting with a machine shop to fabricate parts or creating molds and castings can be removed, saving both time and money. Additive manufacturing techniques offer reduced material usage when compared to traditional subtractive manufacturing. This reduction in material used makes 3D printed parts potentially less expensive and more environmentally friendly from a material use perspective [5].

Challenges associated with the use of 3D printing include limitations on materials suitable for use with current printers and slow build speeds [5]. Regarding build speeds, 3D printing provides comparatively quick production time for prototypes and unique parts, but is much slower than traditional manufacturing techniques for mass produced parts. It is expected that short term research and development will lead to reduction in print times, increased limits on printed object size, and availability of a broader range of print materials [5].

4 3D Printer Manufacturers

There are a number of companies working to satisfy the current market for 3D printers and to create new markets and applications. The approach of the two leading 3D printer manufacturers, 3D Systems and Stratasys, is evaluated here. A growing open source printer building community is presented as an alternative and possible competitor to these companies.

4.1 3D Systems

Currently the biggest player in the 3D printing market, 3D Systems has focused on selling consumer models. 3D Systems products include 3D printers, print materials and on-demand custom parts service. Their primary 3D printing technologies consist of stereolithography, laser sintering, multi-jet modeling, film transfer imaging, selective laser melting, and plastic jet printers [11]. In 1986 Chuck Hull founded 3D Systems after inventing stereolithography. In 2003 he was succeeded by Abe Reichental as CEO of the company. Chuck remains with the company as the chief technology officer. For the bulk of 3D Systems history they focused on 3D printer technology developed by Chuck Hull. Over the last few years however, the company has looked to expand with acquisition. 31 companies were acquired in 2010, 2011 and 2012. Spending 19.2 million in 2010, 92.7 million in 2011 and 183.7 million in 2012 [11]. These acquisitions have been done in an effort to "…develop new products and services and expanded our technology platform…" [11]. Some of the acquisitions include 3D modeling software companies (Alibre and Rapidform), 3D printer manufacturer (Huntsman), 3D scanning companies (Z Corporation and Vidar Systems), 3D modeling software for non-experts (Robot Nation and Viztu Technologies), manufacturers of 3D printers for aerospace and medical industries (Paramount Industries and Bespoke), as well as parts on demand 3D printing (Kemo Model Maker and The Innovative Modelmaker) [12]. With these acquisitions, 3D Systems is developing a comprehensive approach to 3D printing technology; not just investing in the printers but building the whole infrastructure to help bring the technology to utility.

In addition to accelerating its acquisitions, 3D Systems has accelerated its R&D; spending 10.7 Million in 2010 to 14.3 million in 2011 and 23.2 million in 2012. As of December 31 2012, 3D Systems had 852 patents worldwide. "We believe that, while our patents and licenses provide us with a competitive advantage, our success depends primarily on our marketing, business development and applications know-how and on our ongoing research and development efforts" [11].

3D Systems has put substantial effort in reaching everyday consumers with its products. In an interview with 3D Systems CEO Abe Reichental stated, "By democratizing creativity we want to remove all of the friction that exists between millions of people and this amazing technology" [13]. 3D Systems believes much of this friction is due to the steep learning curve that customers have when using 3D printing. In the same interview Abe Reichental stated, "The printer is only an output device, and to get to an output you need lots of inputs. Today those inputs are, to the average potential user, largely bewilderingly complex……We are passionate and committed to removing the expert user friction in the space between content to print and, as we do that, we will have a printer in every home" [13].

In their 2013 annual report 3D Systems stated that its growth strategy consists of building their global custom parts and services, accelerating 3D printer penetration, growing healthcare solution revenue, building 3D consumer content products and services and integrating 3D printing solutions [11].

4.2 Stratasys

Stratasys was founded by Scott and Lisa Crump after Scott patented Fused Deposition Modeling (FDM) technology. Today Scott Crump is still with the company as the CIO for Stratasys. A few years after the invention of FDM IBM started developing a 3D printer that relied on an extrusion system similar to Crump's patented FDM technology. Instead of fighting each other in court, in January 1995 Stratasys issued 500,000 shares of its stock to IBM for its 3D printing technology [14]. The IBM partnership helped increase Stratasys business opportunities.

Stratasys invested heavily into its R&D which paid off for the company. These efforts allowed them to create technologies such as WaterWorks which immersed models into a water based solution so that supports were not needed. This eliminated the need for post processing work on the models. Not all Stratasys technologies were successful. The Genisys 3D printer was in high demand for its price point but ended up having problems with the nozzles being jammed and printed models curling up along their edges [14]. Although some products were not successful, many of them were. "Stratasys, with its focus on low-end systems, became the market leader in the RP industry in 2003, shipping nearly half of all RP systems. In addition, for the first time Stratasys accounted for the largest installed base of RP systems worldwide" [14]. To this day one of Stratasys strength is its customer base in Fortune 100 companies and universities. Some of their customers include Nike, Boeing, Black & Decker, Dell, Ford, Hasbro, Intel, NASA, and Philips. Their R&D effort has helped them obtain more than 500 granted or pending additive manufacturing patents. In 2012, Stratasys spent $19.7 Million on R&D with engineering and R&D teams consisting of 211 employees out of 1,125 employees for the company. "We believe that we have a culture of innovation, and we expect to continue to enhance our solutions both to further drive market adoption of 3D printing and to broaden our market reach" [15].

Similar to 3D Systems, Stratasys states its technology is important but not the primary key to their success. "We believe that, while our patents provide us with a competitive advantage, our success depends primarily on our marketing, business development, applications know-how and ongoing research and development efforts" [15].

For most of Stratasys' history they have focused on selling to industrial customers, which use Stratasys FDM technology to rapid prototype their products and cut down lead times for manufacturing. Earlier this year Stratasys took a shift from this strategy with the acquisition of MakerBot, a very popular consumer based 3D printing company [16]. In August Stratasys announced a partnership with UPS to be "the first national retailer in the U.S. to offer 3D printing service to entrepreneurs, architects, start-ups and other retail customers" [17]. Stratasys is actively looking at beneficial acquisitions but in an interview with Crump he stated, "…you won't see us making 38 acquisitions anytime soon" [16], alluding to 3D Systems rapid acquisition approach.

4.3 Open Source 3D Printers

For the in-home use 3D printing market, the RepRap community provides an example of an intriguing alternative to corporate, mass-produced print systems. The RepRap community is in some ways the 3D printing equivalent of the open source software movement. Open source designs are available for building home-use printers, with the majority of the 3D printer parts made from plastic. This means that the typical RepRap printer design is nearly capable of re-producing itself. It is estimated that over 29,000 3D printers based on RepRap open source designs have been built [30]. The RepRap movement provides a lower cost alternative to purchasing a commercially available home use 3D printer. The downside of this approach is that personal manufacture and assembly of a printer requires time, research, and contact with another RepRap user willing to print a new system.

The open source 3D printer community has developed some innovative uses for in home 3D printing and spawned some of the companies now offering commercial built home use printers. The open source approach to 3D printer design and manufacture provides an interesting challenge and opportunity for companies working in the 3D printing arena.

5 3D Printing in Traditional Manufacturing Operations

Additive manufacturing is slowly gaining momentum in traditional manufacturing operations, and becoming a popular alternative to traditional manufacturing methods as the technology becomes less cost prohibitive and now offers a more diverse range of potential applications for adopters of this new production method. “In industry, layered manufacturing is usually referred to as rapid prototyping (RP) reflecting the most common use. It is used for the rapid fabrication of physical prototypes of functional parts (important in the design stage), patterns for molds, medical prototypes (implants, bones), consumer products, and so on. Rapid tooling is one of the largest application areas of RP today” [2].

5.1 Production Advantages

3D printing is on track to displace several different traditional manufacturing methods, simply due to the economies of scale that apply to the technology that allow manufacturers to produce small batches of highly customized product while eliminating the costly setup time and procedures necessary to accommodate different designs or requirements. Contrasted to subtractive technologies which produce large amounts of waste that cannot be used in the production process, 3D printing waste materials can be recycled and used in the future for the production of additional parts or components. When compared to traditional manufacturing methods such as injection molding or subtractive processes, this new process is able to provide manufacturers with a more rapid turnaround time with less cost and less waste.

According to the periodical, *Assembly Automation*, "The production economics, which permit virtually unlimited design flexibility without tooling costs, encompass several cost advantages.

- Waste. Unlike subtractive machining processes that generate waste in the form of chips and unused stock, additive processes use little more material than the object requires. In addition disposal or recycling costs are avoided.
- Inventory. Generation of objects of various sizes from a common pool of powdered materials as opposed to a diverse inventory of pre-sized stock cuts cost.
- Labor. Near net shape eliminates the skills and time needed for multi-part design, machining, and subsequent assembly.
- Quality control. As production is driven by digital information, there is less opportunity for human error.
- Set-up. If a single material is used, set-up costs are principally focused on CAD file preparation and verification. These, however, are done off-line, and do not impact machine production utilization" [4].

This new technology has potential applications in many different industries, and extends its potential to the home-user with the possibility of either replacing or augmenting traditional manufacturing with in-home replication and production of commercial parts. It is poised to be a game-changer in the way that consumers receive components or products and where those products are produced. "This 'game-changing' is not in the same paradigm as the 1959 imagination of the impacts of automation – anthropomorphic machines directly replacing physical labour, 'pushing' them out of factories. Instead, additive manufacturing will involve transitional features already witnessed in other digital innovations, potentially returning manufacturing to post-industrial regions" [7].

5.2 Production Implementation

Within the realm of large-scale traditional manufacturing environments, additive manufacturing has begun to establish roots within certain industries as a practical supplement to existing production methods. Through the combination of next-generation components, such as carbon fiber and ceramics, and 3D printing, General Electric has begun the manufacturing of new jet engines, which will be used to power future passenger aircraft. "The engine, called LEAP-1A, contains 3D printed fuel nozzles, fourth-generation carbon-fiber composite blades, and parts made from ceramic matrix composites" [10]. General Electric's commitment and vision to pursuing 3D printing extends beyond simply prototyping and testing with components, as is evident through the company's recent purchase of Morris Technologies, a small engineering firm based out of Cincinnati, Ohio. By leveraging the tools in place at Morris Technologies, General Electric is working to expand its usage of 3D printed parts beyond what is currently utilized. "GE sees the purchase as an investment in an important new manufacturing technology. 'Our ability to develop state of the art manufacturing processes for emerging materials and complex design geometry is critical to our future,' said Colleen Athans, general manager of GE Aviation's supply-chain operations"[19].

While the adoption rate of additive manufacturing within large organizations for applications beyond prototyping has been slow, manufacturers are beginning to recognize that the 3D printing revolution poses both a serious threat and a unique opportunity to create a competitive advantage. Organizations willing to explore the application of this technology to offset costly traditional manufacturing techniques can take advantage of the diverse capabilities that this new manufacturing method offers, from reduced materials cost, to more complex product design, to the production of organic tissue materials and compounds, 3D printing is positioned to disrupt the manufacturing techniques of those organizations unwilling to accept this next phase in manufacturing technology. "Perhaps even more important than what 3D printing can build is what it can destroy….In fact, by 2018, an estimated $100 billion per year will be lost in intellectual property as a result of counterfeit goods made with 3D printers" [20].

6 3D Printing as a Service

Since 3D printing is currently an emerging technology, it is still very expensive to own a high-end 3D printer. While large companies such as car manufacturers are able to afford industrial 3D printing devices, it is not yet economically feasible for smaller businesses, startups and individuals to purchase these types of 3D printers. Still, small businesses, startups and individuals can greatly benefit from 3D technology and therefore a market has evolved to fulfill this need and provide 3D printing as a service. It is difficult to predict where 3D printing will take us, but it is clear that 3D printing services will significantly evolve as the technology becomes less expensive and more widely available. We can expect that, just like 2D printing, there will always be a market for 3D printing when more complex or high volume jobs are needed. Yet it is difficult predict how big of a market this will be and what type of innovations it will bring.

6.1 Applications

6.1.1 The UPS Store

The UPS store is one example of a major corporation that decided to make a strategic use of 3D printing technology and offer it as a service. UPS has offered its franchises the option of offering 3D printing and several UPS stores around the country have decided to give it a try. They use the printer Stratasys uPrint SE Plus that creates objects layer by layer using the Fused Deposition Modeling (FDM) Technology. The 3D printing process starts with a digital file that represents the 3D object. Printing a 3D object is a lengthy operation, it can take from 2-3 hours for a simple object to more than 24 hours for a complex prototype. According to the UPS website, “A recent poll of small business owners conducted by The UPS Store showed high interest in trying the services, particularly for those needing to create prototypes, artistic renderings or promotional materials.” [25]

6.1.2 Shapeways

At the present time, 3D printing is changing from uncommon and expensive to cheap and simple; becoming as easy as uploading a file. Companies like Shapeways are taking advantage of this new technology and offering commercial-grade printing services that allow the consumer to design the final product. With Shapeways every consumer has the opportunity to be an artist and create something unique. The process is simple -- the customer will upload a design, chose the material, and Shapeways will fabricate the 3D object and ship it to the desired location. This service can be very appealing to consumers who want to be creative. It is easy to imagine a variety of personal gifts, mementoes and art that can be created with this service [26]. Shapeways also offers designers and artists the opportunity to sell their designs without the need to produce them. An artist or designer can upload a product design such as clothing accessories, jewelry, toys, and more. These products are created on demand and shipped to the individual consumer. The designer receives a percentage of the profit from each item produced from his or her design. Similar to Etsy.com, Shapeways enables anyone to become an artist or designer.

Despite Shapeways success and their effort in improving their service Michael Wolf, founder and chief analyst of the high-tech research firm NextMarket Insights, says he expects “serious competitors to emerge in the next year or two, naming Amazon.com as one potential rival” [27].

6.1.3 3D ProParts

3D printing is not just about art and design, it can be a lifesaver in certain industries. In situations where parts are not mass- manufactured and they are not widely available it can take many weeks to order and produce the needed parts. A company call 3D ProParts has stepped up to fill this need by offering a service that produces necessary part by utilizing 3D printing. They offer quick injection molding aluminum parts that are available in short order. While their service may be expensive it can be crucial to companies who need to meet certain manufacturing details.

One of the most significant uses of 3D printing is prototyping. 3D ProParts and another company called Graphics/Systems both offer this service. These companies offer comprehensive services to assist businesses in the implementation of new engineering ideas, resulting in rapid production of the optimal prototypes. Creating a prototype using 3D printing streamlines the prototyping process. It significantly cuts costs as well as the time needed to produce a functional prototype. 3D printing eliminates the need to specifically design a machine that will create the initial prototype or to pay a craft-person to create a prototype by hand. With 3D printing, a prototype can be produced from a 2D design within a few days. The rapid creation of prototypes also propels an easy testing and modification process resulting in the perfect prototype with a fraction of the time normally needed.

7 Trends

7.1 3D Printing Technology Acquisitions

Acquisition of firms can potentially rapidly expand the acquirer’s knowledge base and increase its innovation output. Acquisitions, however, can disrupt business process of both the acquired and acquiring firms thus reducing productivity. “Research suggests that acquisitions integration entails far-reaching disruption, and involves significant managerial attention and transaction costs" [18]. Focusing on acquisitions takes time and focus away from management to deal with the day to day decisions of the company.

3D Systems rapid acquisition approach has made it the largest manufacturers of 3D printers. Their annual report, under the '*cautionary statement and risk factors*' section, declares "We may not realize the anticipated benefits of past or future acquisitions and integration of these acquisitions may disrupt our business and divert management" [11]. The acquisitions have helped 3D Systems growth but has also exposed them to more risk.

Stratasys, on the other hand, has taken a slower more calculated approach leaving them with a more manageable company. This approach has resulted in Stratasys being behind 3D Systems in certain areas like consumer 3D printing. "The market in which we participate is competitive. Our failure to compete successfully could cause our revenues and the demand for our products to decline" [15].

3D printing companies have a lot of potential and risk from larger companies entering the 3D space. It was recently announced that HP will have a 3D printer offering by mid-2014 and will be concentrating on affordability and speed. HP's resources, larger distribution network, pricing power, and capital give them the potential to propel themselves past 3D Systems and Stratasys. Meg Whitman, HP CEO has "Suggested plans to enter the space via acquisitions" [18]. 3D Systems or Stratasys could be potential targets of HP. Being acquired by a larger company like HP could be highly beneficial for these 3D printing companies and might be a key step to help propel 3D printing to the mainstream.

7.2 Policy

As with most radical innovations, the legal system has to catch-up with technology. With 3D printing services becoming more and more prevalent they will inevitable become cheaper. When the cost of 3D printing drops it will become more likely that consumers will attempt to print products rather than purchase them. For example, a consumer could print a trademarked brand name toy rather than buying the original. This brings up some serious questions about whether this is a violation of intellectual property law. Similarly, recently in the news there was a story about a person who printed a gun using 3D printing. Since there are no laws about 3D printing there is no way to determine legislative hurdles this technology will face.

7.3 Future Developments

While there are currently many applications for which 3D printing is currently used, there are others potentially innovative applications where its use is still in the research stage.

7.3.1 Medical Devices

Additive manufacturing is responsible for many advancements in the medical device sector, which continues to be one of the biggest areas for the investment in mass customization due to the diversity of need between individuals for personally customized products. "Additive manufacturing has had a huge impact in the manufacturing of hearing aids as well as dental, spinal, and hip implants. In fact, around 99% of hearing aids that fit in the ear are made using 3D printing techniques" [22]. This process is advantageous to the manufacturer and to the customer, as it brings a higher level of product diversity to the consumer, while not adding additional cost or complication.

Bio-printing is one such application. 3D printers that use living tissue as the print medium may someday allow for printing of create artificial organs, blood vessels, or bone replacements. Living cells are cultivated and packaged for printing and then printed with a gel support structure, and then transferred to a bioreactor to allow cells to mature before implantation [6]. Though 3D printed organs and tissue for human medical transplant are not yet widely available, one company, Organovo is planning a 2014 release of a 3D bio-printed liver model for use in toxicology testing. The bio-printed model would be used to test the toxicology of new medicines [7]. Though this liver model is not suitable for transplant to humans it is a potential stepping stone to bio-printed organs for surgical use.

7.3.2 Synthetic Food

3D printing of synthetic food is another area of anticipated future development. Current food printing technology allows printing of custom shaped desserts and other novelty items. A synthetic food 3D printer would print entire meals from a selection of replaceable cartridges, each cartridge containing a chemical paste of basic nutrient building blocks. Though synthetic food may sound unappetizing, the ability to precisely control nutrient intake could offer great benefit to people needing careful control of diet to manage diseases such as diabetes [1]. There is also potential demand for printing of synthetic food in instances where both long term storage of food and a varied diet are required. As an initial step in this area, NASA recently funded a grant for development of a 3D food printer for potential use on manned deep space missions [1].

7.3.3 Active Systems

Printing of active systems may radically expand the possible uses for 3D printers. Active systems are defined as printed objects or materials that can "act, react, sense, compute, or respond to their environment" [1]. A possible printed active system could range from a simple actuator to a fully assembled and functioning printed robot. In laboratory and research settings, systems such as batteries and simple electronics have been created using 3D printing, but the technology is not yet commercially viable. To create an active system, a single printer would need to be able to print in multiple different material types. The primary challenge in printing in this manner is compatibility of materials. Many of the materials necessary to create active systems have very different melting points, making printing with current technology difficult [1].

8 Conclusion

3D printing technology has the potential to be economically disruptive due to its broad reach, affecting industries and creating a wide range of applications, products, or services. Discontinuous innovation disrupts existing strategy and skillsets within organizations and, consequently, may render them irrelevant. 3D printing technology creates competition from entrepreneurs and will shift value directly to the consumer. 3D printing technology companies must overcome material, cost, and speed restraints through further technology development in order to truly reap the benefits of being first-movers of a discontinuous radical innovation. These organizations also have risk from larger companies potentially entering the emerging market. Traditional manufacturers and the supply chains therein need to be innovative with customized products that surpass the advantages of consumer 3D printing. Service providers must understand that the transportation of goods will be done on the informational highway. Concurrently, online exchanges for 3D printable files need to be carefully managed to protect intellectual property rights without being invasive to the free distribution market. Successful organizations within all markets will not be in the crosshairs of this discontinuous technology, they will be the ones who are aiming.

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