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**The rise of 3D printing (Additive Manufacturing) in America**

3D Printing was originally coined as stereolithography in 1984 when the concept was first introduced. It was created by Chuck Hull who is known as the father of 3D Printing. While working for a company that used UV light to harden tabletop coatings, Hull had the idea that if he could place thousands of thin layers of plastic on top of each other and etch their shape using light, he would be able to form three dimensional objects. He eventually developed a system where light was shone into a vat of photopolymer (which changes from liquid to solid when light shines on it) and traced the shape of one level of the subject. Layers were printed until it was complete. In 1986, Hull founded 3D systems in Valencia, California (*Hickey 2014)*. With the company, Hull was able to build up a patent portfolio that contained many fundamental aspects of today’s additive manufacturing. Stereolithography was the first process established for rapid prototyping (*3D Printing)*.

Objects that are produced using stereolithography generally have smooth surfaces, but the quality of an object depends on the quality of the machine used to print it. With stereolithography, the amount of time it takes to create an object depends on the size of the machine used to print it. Small objects are produced using smaller machines and take between six to twelve hours to create. Larger objects can take days to create because they can be several meters in three dimensions.

In the process of 3D printing, the computer-aid design files are translated into a file type that 3D printing machines could understand. Standard Tessellation Language (SLA) is the most commonly used for stereolithography. SLA machines start with an excess of liquid plastic to form a solid object. The machines have four essential parts, a tank that can be filled with photopolymer (liquid plastic), a perforated platform that is lowered into the tank, an ultraviolet laser, and a computer controlling platform and laser. In the first step of the SLA process, a thin layer of photopolymer is uncovered above the perorated platform. The UV laser hits the perforated platform, “painting” the pattern of the object being printed. The UV-curable liquid hardens immediately when the UV laser touches it, forming the first layer of the 3D-printed object. Once the first layer has hardened, the platform is lowered, showing a new surface layer of liquid polymer. The laser traces a cross section of the object being printed which bonds to the hardened section under it. This process reoccurs over and over again until the entire object has been formed and is fully submerged into the tank. After, the platform is raised to reveal a three-dimensional object. Subsequently, the 3D object is rinsed with a liquid solvent to free it of excess resin. The object is then baked in an ultraviolet oven to further cure the plastic (*Palermo 2013)*.

One the first printers to be produced by Hull’s company 3D Systems Corporation was the Actua 2100. It was released around February of 1996. The printer was developed to meet the needs of the mechanical computer-aided design (MCAD) design office. The printer, about the size of an office copier was fully compatible with design office environment. It was priced at $60,000 per unit. It allowed design engineers to print solid three dimensional models of their design concepts easily, it enabled them to go from computer-aid design to a physical model in a couple of hours. According to Arthur B. Sims, Chief Executive Officer of 3D Systems during that time, “Actua 2100 offered a fast and easy way to produce inexpensive concept models directly in the design office prior to accurate prototyping with stereolithography.” The Actua 2100 had pull-down menus that provided point and click options for model selection, scale, and number of model copies. It enabled designers to be able to submit designs to be modeled without leaving their workstation. The printer would automatically position the object to be created, designed any necessary supports, prepared the computer input data, and began the printing process. When the concept model was complete, a notification would appear on the screen. The printer operated by building models in sequential layers using a Thermojet (a special thermopolymer material). The device contains a print head of 96 jets which speed back and forth, building layer upon layer of material which solidified in a matter of seconds to form a physical model (*mfgnewsweb.com)*.

During this time period, 3D Systems was not the only company in the United States to produce 3D printers. During the 1990s, there were several companies such as Stratasys, Z Corp and BPM (Ballistic Particle Manufacturing) Technology whom also created these machines. In 1996, Z Corp released it *Z402 3D Printer*. This printer was used mainly for concept modeling. BPM Technology produced the *Personal Modeler 2100.* Although all three companies had promising beginnings, only one of them continues to exist. The BPM Technology Company ceased its ventures in October of 1997, Z Corp was acquired by the 3D Systems Company in 2012 and Stratasys still operates as one of the top companies in 3D printing. After 3D Systems introduced the ThermoJet which was a faster and inexpensive version of the Actua 2100, more companies arose whom took part in the 3D printing innovations. In the early 2000s, more 3D printers and subsequent accessories were produced by companies that started up (*Wohlers & Gornet 2011)*.

In July 2004, 3D Systems began to ship the InVision HR. This was a 3D printer that was targeted at the jewelry market. The printer allowed customers the ability to custom design and manufacture jewelry. The printer helped to reduce inventory costs and the need to hold expensive inventory. Later in year the company produced its dual-vat Viper HA stereolithography system for the hearing aid industry. The Viper HA system produced hearing aid shells. It optimized the production of hearing aid shells and lowered the cost per part. The Viper HA marked the beginning of three dimensional systems pursuing and targeting manufacturing solutions. In January 2006, 3D Systems announced its InVision Dental Professional (DP). This system included an InVision 3D printer and 3D scanner. It was targeted at the Dental market. It was designed for dental lab and printed wax-ups with an exclusive light cured resin. The printer increased laboratory productivity, delivered the product faster and reduced the time and cost of wax-ups. 3D Systems continued to expand in the 2000s, opening up headquarters in locations such as Rock Hill, South Carolina. This led to the expansion of 3D printing in other states (*Wohlers & Gornet 2011*).

3D Printing continued to have an impact on a variety of markets in the United States. One of the biggest headlines that occurred was the announcement that General Electric also known as GE was on the verge of using 3D printing to make jet parts. The company planned to produce a fuel nozzle for a new aircraft engine by printing the part with lasers. GE chose to utilize the 3D process for manufacturing the nozzles because it used less material than conventional techniques. This reduced the company’s production costs because it made the parts lighter which resulted in fuel savings for airlines. Using 3D technology was very beneficial because the process was a faster way of making complex shapes. The printing process preserved material because the printer could handle complex shapes that eliminated pointless bulk and created them without the typical waste. The process would allow GE engineers to be able to formulate new shapes without regard for existing manufacturing limitations. GE Power & Water, whom make large gas and wind turbines, identified parts of its turbines that it could make with 3D printing (*LaMonica 2013)*.

Another market that 3D printing has had a significant impact on is the Medical field. One specific example involved a young ten year old by the name of Anastasia Rivas. She was born with amniotic band syndrome which led to congenital abnormalities that resulted with Anastasia not having a left hand. Due to 3D printing, Anastasia was able to receive a robohand. The printer created the hand by laying down an ultrathin layer of material. The machine that built the robohand was the *MakerBot Replicator 2*. 3D Printing is also being used to produce human body parts such as ear cartilage and muscle tissue.

Doctors across the United States are fascinated as to how 3D printing can be taken to the next level. Faiz Bhora a Medical Doctor, chief of thoracic surgery at Mount Sinai Roosevelt and St. Luke’s Hospitals stated that

“within five years, we are going to see parts of 3-D-printed organs being implanted, as well as things like jawbones, tibia bones—things that are not very complicated and where failure is not usually catastrophic. The next step up perhaps is tubes and ­cylinders—the airway, perhaps, the ureters, arteries, veins. The third tier will be whole organs, heart valves, maybe parts of the kidneys, nerve cells.” She states “We’re going to get to a point, where if you have a defect in an organ, you’ll just get a new one. Imagine: You’re 40 years old, and you can print the same organ you had when you were 21. It’s like a car: You fix it a couple times, and then you realize it’s cost-effective to replace the part” (*Winter 2014*).

Some of the issues that have come with 3D Printing vary from limited use of materials to questions about whether the technology is practical for short-run and long-run manufacturing. The materials that could be used for 3D printing are limited. For instance, plastic which is the 3D printing material of choice is used in melting layers to form the final part. The kinds of plastic vary among high strength and high temperature materials. Some companies are offering metals as a material but the final parts are not fully dense. Other companies are printing in materials such as glass and gold, but those technologies have not been commercialized yet. There is also a problem with accuracy, 3D printers with plastic materials often come with an accuracy disclaimer. This means that many materials print to either +/-0.1 mm in accuracy entailing that there is room for error (*Cornell)*.

Furthermore, parts that are created through 3D printing are limited in size. The most affordable and common 3D printing machines are small enough to fit on a desktop. However there are 3D printers that are able to create large parts but they are more expensive. Therefore these printer types are an unlikely option for many companies because larger parts usually take a longer time to create (*Cornell)*. One of the bigger problems that 3D printing creates is the potential to lead to fewer manufacturing jobs. With the ability of 3D printers to produce several products, there would be less of a demand for workers because manufacturing industries would be purchasing the printers. This would have a significant impact on any economy. An additional issue, is the fact that 3D printing could lead to a dangerous society. With no limit on the amount of products 3D printers could produce, there is a possibility that some companies or individuals would create items such as guns and knives. There are already many issues with weapon control in our current society and with the possibility that a 3D printer falls into the wrong hands, there would be an even greater threat in society.

3D Printing will continue to expand in the American society. It is slowly revolutionizing several industries by enhancing and advancing traditional manufacturing. It has already made an impact in the automotive, retail, and medical market. It will continue to infiltrate new markets and improve current ones. Specifically in the medical field, 3D printing could help surgeons to build organs for transplants and harvest new nerve cells. Some envision a future in which 3D printers are in every kitchen printing dinners or cabinet hinges. With this new technology, there is endless possibilities as to what can be created. Although 3D printing provides a path to a brighter future, it brings about a looming society. With the endless possibilities of what 3D printers could produce, there is a likelihood that companies or individuals would produce weapons or other products that could cause harm to society. This would be a huge downfall in using this technology. The early creators (such as Chuck Hull) generated this product only as a means of making processes easier for industries. In order to envision a future with 3D printing, there must be a focus on how it can be used for the progress of society and not a means to an end.

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