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# 3D Printing: Enabling a New Era of Opportunities andChallenges for Manufacturing

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**Abstract:**3D printing has revolutionized manufacturing. Designs that were previously not possible are now being printedwith ease; whereas conventional manufacturing would not have been able to achieve the same results. In the 21st century, 3D printing enables and facilitates production of moderate to mass quantities of products that can be individually customized. Manufacturing lead times will be substantially reduced, new designs will have a shorter time to market, and customer demand will be met more quickly. This study discusses 3D printing evolving technologies and trends, identifies its implementation challenges, explores its transformative potential for different industries and surveys its impact on various industry segments.
**Keywords:** 3D printing, Rapid Prototyping , Additive Manufacturing, Component Manufacturing, Perceived Benefits, Global Supply Chain, Mass Customization, Selective Laser Sintering (SLS), Fused Deposition Modeling (FDM)

**3D Printing: Enabling a New Era of Opportunities and Challenges for Manufacturing**

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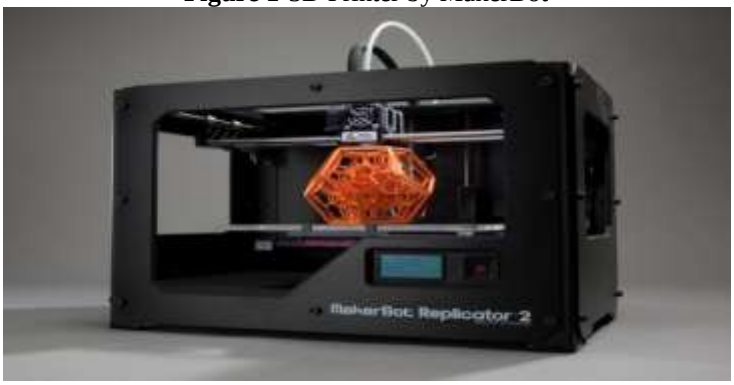
## I. INTRODUCTION

The first working 3D printer was created in 1984 by Charles W. Hull of 3D Systems Corp. He named the machine Sterolithgraphy Apparatus (Bogue, 2013). The technology was very expensive and not feasible for the general market in the early days. In the past few years, however, costs drastically decreased, allowing 3D printers to find their way into many industries.

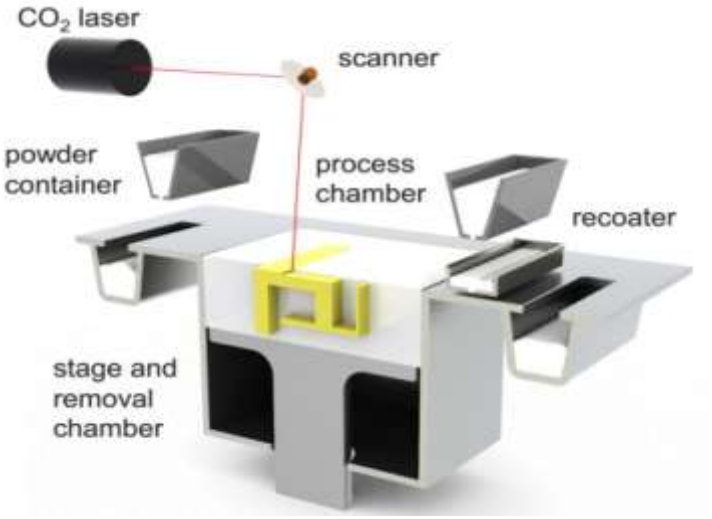
Instead of printing layers of ink on paper, a 3D printer uses materials to build a three-dimensional object (Berman, 2012). The terms 3D printing and additive manufacturing have become interchangeable. The terminology "additive manufacturing" refers to the technology, or additive process, of depositing successive thin layers of material upon each other, producing a final three-dimensional product. Each layer is approximately 0.001 to 0.1 inches in thickness (Wohlers, Report, 2013). Variety of materials can be utilized; namely, plastics,

**Figure 1**-3D Printer by MakerBot




**Source**: http://tbtf.org/3d-printing-the-good-the-bad-and-the-cool/

**Figure 2-** A diagram of the SLS build process




**Source:**https://www.sculpteo.com/blog/2014/05/13/right-plastic-production-method/

resins, rubbers, ceramics, glass, concretes, and metals (Bogue, 2013). Most commercial 3D printers use a computer aided (CAD) design to translate the design into a three-dimensional object. The design is then sliced into several two-dimensional plans, which instruct the 3D printer where to deposit the layers of material (Figuer 1).

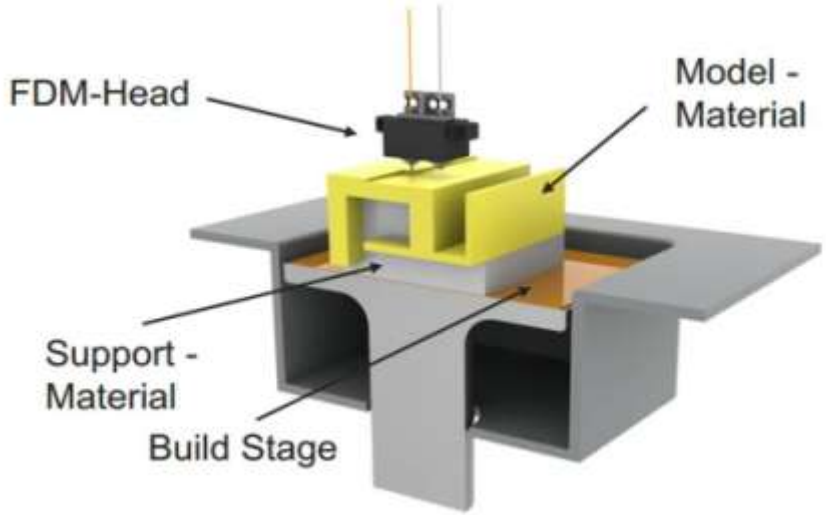
In the past few years, many companies have embraced 3D printing and are beginning to enjoy real business benefits from the technology. The technology is maturing and is slowly reemerging as a valuable way to improve internal efficiencies. It is now one of the hottest and most interesting advancements in the design and marketing world today.

According to a 2014 report the worldwide revenues from 3D printingwas $3.07 billion in 2013; the industry is expected to double to $5 billion by 2016, $12.08 billion by 2018,and exceed $21 billion by 2020These figures highlight a 3D market that is growing robustly. Drivers for the rapid growth are the reduction in cost to access the technology as well as an increase in applications (Wohlers Associates Inc., 2014).

## II. EVOLVING TECHNOLOGY TRENDS

The desire to cut supply chain costs made RFID technology one of the most discussed retail technologies in 2000 (Attaran, 2007, 2011). It seems the decade of 2010 belongs to 3D printing.

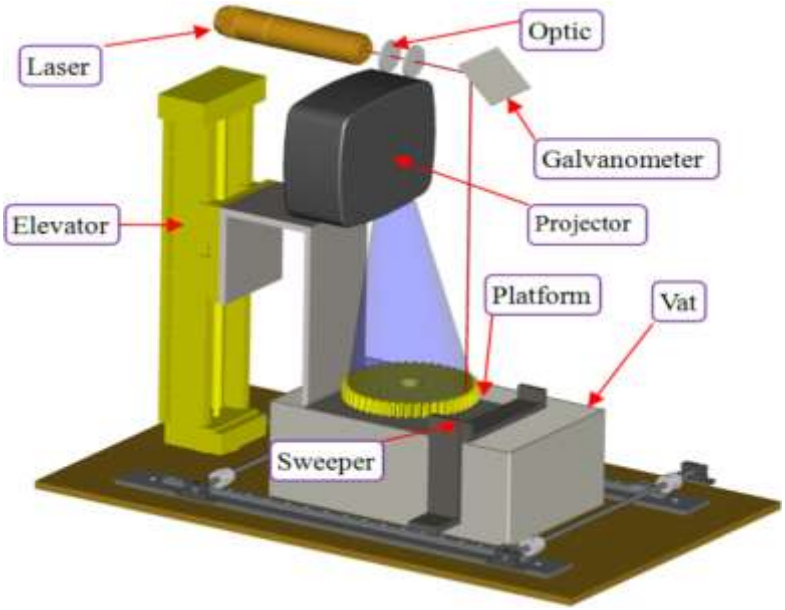
**Figure 3- A diagram of the FDM build process**




**Source:**https://www.sculpteo.com/blog/2014/05/13/right-plastic-production-method/

3D printers are using different technologies. They all use additive processes, differing mainly in the way layers are built to create the final object. Melting or softening material is used to produce the layers. The most common technologies using this way of 3D printing are Selective Laser Sintering (SLS) and Fused Deposition Modeling (FDM). SLS utilizes a high powered laser to fuse small particles of plastic, metal, ceramic or glass powders into a mass that has the desired 3 dimensional shape (Figure 2). FDM utilizes thermoplastic materials injected through indexing nozzles onto a platform (Figure 3).Another method used is curing a photo-reactive resin with a UV laser or another similar power source one layer at a time. The most common technology using this method is called Stereolithography (SLA)(Figure-4). This Very high-end technology utilizes laser technology to cure layer-upon-layer of photopolymer resin (3DPrinting.com, 2016). Finally, Direct Digital Manufacturing (DDM) is a process that produces parts directly from a CAD file.

**Figure 4-** A diagram of SLA build process




**Source:**http://computingengineering.asmedigitalcollection.asme.org/article.aspx?articleid=1918871

Several technology trends are fueling the evolution of 3D printing and are enhancing its abilities and offerings. These trends are summarized below:

- **Printer Cost and Speed –** Innovation in 3D printing must continue in order to improve overall performance. Becoming faster, autonomous, easier to use, reliable, and more economical are only a few key characteristic that could be improved to move 3D printing past its infancy. Speed of printing is an important performance factor in 3D printing and a key challenge in 3D printing that prevents it from being a practical means of manufacturing in some instances. While 3D printing is fast in comparison to standard manufacturing at times, for example, in the production of prosthetics, it still takes hours and even days to produce a product. Speed could be improved by using higher-quality components and by optimizing the designs and movement of the lasers" (Baya and Earls, 2014). Adding multiple print heads can also aid in increasing the speed of a 3D printer. With these technological innovations, print speed will no longer be a barrier to the further growth of the 3D printing industry (Baya and Earls, 2014).
- **Autonomous Abilities -** Many 3D printers still require upkeep and supervision to ensure the printing process is accurate. Having fully autonomous printers would reduce the need for the technology to be monitored by a human, thus greatly making 3D printing more practical and appealing to the masses.
- **Industry Change -** Technology trends are not the only thing that will help shape and predict the future of 3D printing, the growth of industries like the automotive and aerospace industries can and will affect the 3D printing industry. Small-volume Manufacturing and Healthcare are among the sectors with the greatest transformative potential. 3D printing is changing how whole industries operate. The technology is transforming the consumer experience, the way that businesses manufacture and distribute goods, and how industries function.

Table 1 summarizes 3D printing greatest potential and its capability to challenge manufacturing constraints and open up new opportunities in global supply chain.

**Table 1-** Impact on Manufacturing and Supply Chain

| Manufacturing Efficiency | Supply Chain Improvement |
|---|---|
| ▪ Mass customization<br>▪ On demand Manufacturing<br>▪ Decentralized manufacturing<br>▪ Reduce production lead times<br>▪ Multi-material capability<br>▪ Consumers become micro-manufacturer<br>▪ Ability to print complete systems or subsystems<br>▪ Quality improvement | ▪ Shorter time-to-market<br>▪ Avoid costly warehousing<br>▪ Eliminate the need for large bulk inventory<br>▪ Reduced lot size<br>▪ Reduced transportation cost<br>▪ Quick response to customer demand<br>▪ Eliminate penalty for redesign<br>▪ More Efficient Packaging<br>▪ Reduced production waste<br>▪ Improved sustainability |

## III – Challengesof 3D Printing

While 3D printing is a breakout technology poised to change manufacturing and a variety of other industries, implementation of the technology is only in its infancy. There are numerous challenges in applying 3D printing in a way that would allow for its significant and rapid growth. The major obstacles of implementing 3D printing are summarized below and range from the size of objects manufactured, to government and cost restrictions. Table-2 also summarizes current limitations of 3D printing.

1. **Status of Technology** – Additive manufacturing has existed for over thirty years, but only recently has this technology risen in popularity and captured the interest of both technology experts and the general public. The main reason that 3D printing technology was slow in its rise to fame was that last major patent for Fused Deposition Modeling or FDM, only expired in 2009. After 2009, FDM printers could be produced without infringing on intellectual property, creating a newfound interest and investment in 3D printing (Van Lancker, 2015). Since the industry only began to grow substantially after 2009, the industry is still very young, and technological advancements in 3D printing, as well as the discovery of new applications of the technology, are still in development. It may be a number of years before 3D printing truly revolutionizes manufacturing and other industries in a considerable way.
2. **Size Restrictions** –3D printing is only capable of producing an object that is smaller than the size of the printer casing. This places restrictions of the sizes of objects that can be manufactured. Although larger printers do exist, they need to be housed somewhere big enough to accommodate this technology. Some parts are manufactured in segments; however, this requires additional time to assemble the parts to the finished good, which starts to defer from the advantages.
3. **Production Time** – In comparison to mass production, 3D printing is relatively slow. Although the change time between production runs in 3D printing does not exist, the production outputs trail in comparison to conventional mass production run times (King, 2012). Unless the production times of the printers can be improved when large quantities are demanded, conventional manufacturing will be the preferred mechanism of production. 3D printing is more likely to be used in mass customization manufacturing, as it offers the ability to create highly customized products in limited inventory.
4. **Equipment and Material Cost** – One barrier to entry that currently exists is the cost of the printing equipment. However, this will not be a reality for much longer. With an increase in technical developments coupled with more manufactures entering the industry, the price of 3D printers will decrease. The printers are not the only expensive feature of 3D printing; the materials required for printing are expensive as well. The plastic filament used in 3D printing can range from $25 to $45 per kilogram (Covert, 2014). Some 3D printing companies want to force the cost of filament down by creating competition in the market. Other companies have turned to other means to find more reasonably priced filament. Protoprint, based in India, makes filament out of used plastic bottles. The company has partnered with garbage collectors in order to collect and recycle the plastic bottles (Covert, 2014). Just as the price of printers is expected to decrease

| **Table 2- Limitations of 3D Printing** |
|---|
| • Higher cost for large production runs |
| • Limited choices for materials, colors, and surface |
| • Lower precision relative to other technologies |
| • Limited strength, resistance to heat and moisture, and color stability |
| • Unchecked production of dangerous items |
| • Liability issues – who is liable for a faulty and harmful printed product? |
| • Intellectual property issues |

Over the coming years, it can also be expected that the cost of filament used to print will also decrease as companies find innovative ways to access and/or manufacture filament and sell it for a lower cost.

5. **Regulations –** The growth and adaption of 3D printing could have great social and commercial implications if not regulated effectively. With new technology, often the rules and regulations do not move at the pace of innovation. Regulation of 3D printing has already been brought into question. In 2013, the design for a plastic handgun was freely available on the internet (Bogue, 2013). Essentially, if a CAD design is available and there is a printer available large enough to print the item, then the product can be easily, and without restriction, brought into existence. The 3D printed gun was especially concerning as it could not be detected by metal detectors and, if printed by someone with malicious intent, could be a threat to public safety. As the limits of 3D printing continue to be tested and new issues become known, regulations and government intervention could restrict who can perform 3D printing and what can be printed.
6. **Intellectual Property –** An additional bone of contention arises around the subject of intellectual property. Any product that is 3D printed will have some form of design on a digital platform. This increases the chance that the design could be leaked from the company. A digital design has a vast reach over the internet; this was evident by the 100,000 download of the printable pistol (Bogue, 2013). Once the design is obtained it is very easy to print and resell the product (The Econmist, 2011). As access to the technology grows in the private sector, issues surrounding intellectual property will intensify as more people gain access to IP designs and the technology. When 3D printing gets to the stage where large amounts of products are being printed at home, additional considerations will need to be taken into account. One such consideration is who will be liable for malfunctions in the product? Does the liability fall onto the owner of the design, the manufacturer of the printer or the individual user printing the product?(Royte, 2013)

## IV –3D Printing Impacts on Manufacturing Sectors

The breadth and impact of 3D printing continues to expand as the technology gains acceptance and functionality, making it a feasible means of production in a variety of industries. While 3D printing is primarily used as a way to make low-cost prototypes and mockups, the technology is multi-faceted and has many existing and possible uses. There are two main categories of applications, as discussed below (Bogue, 2013):

**A- Rapid Prototyping -** Rapid Prototyping s a provocateur of innovation; it provides reductions in cost and time. The costs and time saving comes from the prototype manufacturing and product testing stages of innovation. When producing one kind of product, it is very costly to use traditional manufacturing, thus 3D printing is a far cheaper approach as the cost of the product. Additionally, when 3D printing is utilizedto produce a prototype, it is much faster compared to traditional manufacturing. Cost and time savings provides more focus on other areas of innovation, making companies more efficient and competitive at innovation.

**B- Component Manufacturing -** The production of component parts is the other main application of 3D printing. Industries that require low quantities of parts that must be printed to certain specifications with little tolerance for error most utilized 3D printing. Over 20% of the 3D printing market is made up of component part production for the aerospace and automotive industries (King, 2012). In 2013, the aerospace industry had in excess of 22,000 parts in use (Royte, 2013). The level of success and growth of 3D printing in these sectors is an indicator that the level of quality arising from 3D printing parts is satisfactory to tough industry standards.

Table 3 Summarizes applications and advantages of rapid prototyping and component manufacturing in three major industries. The application of either rapid prototyping or component part production across industries, by means of 3D printing, are summarized below:

1. **Aerospace** –3D printing has been pushed beyond the realm of prototyping and has become an effective means of advancing the way parts and tools are produced in the Aerospace industry. 3D printing makes it possible to have objects printed in remote locations, as delivery of goods is no longer a restriction. This benefit of 3D printing makes it possible for the use for 3D printing in Space. NASA has been testing 3D printing in zero gravity in hopes of establishing on-demand manufacturing for astronauts. This would allow component parts for maintenance and repair of the international space station to be manufactured in Space. This would decrease the need for shuttle to make trips to the international space station to deliver parts, thus greatly reducing the lead-time on replacement parts. A reduction in lead-time would imply a reduction in inventory and a reduction in costs. To quantify the cost reduction, transporting one pound of material into space amounts to approximately $10,000 (King, 2012). Not only could this be used to make repairs on the international space station, but could also allow deep-spaced crewed missions, as parts could simply be manufactured on the shuttle. Having the ability to print on-demand decreases the amount of cargo space needed and the need for spare parts, thus circumventing the weight restrictions on spacecraft ("Space Tools on Demand", 2014).

   Boing and Air Bus are both active in component parts additive manufacturing. Across 10 different models of military and commercial jets, there are 200 component parts being used (Crandall, 2013). There have been no reported failures on these parts (King, 2012.) Airbus has additive manufactured components parts on their A380, namely their cabin brackets (Brogue, 2013). Component parts produced by 3D printing allow for designs that are more efficient and lighter. A lighter aircraft has significant cost savings; a reduction in one kilogram equates to a savings of $1,300 in fuel per annum (King, 2012).

2. **Automotive** – One of the first applications of 3D printing was in the automotive industry. General Motors has been using 3D printing to make prototypes for over 20 years in order to speed up time-to-market and to reduce the cost involved in product development (Fish, 2011). Prototyping is not the only application of 3D printing in the automotive industry. In 2011, Kor Ecologic unveiled the Urbee. The Urbee is the first car to have its exterior and interior completely printed. This helped eliminate excess parts that cause drag and add weight. While the car is currently a prototype for developing efficient vehicles, the company hopes to release the Urbee 2 for consumer use. The use of 3D printing for automotive manufacturing could effectively change the way cars will look and function in the future (Bargman, 2013).The manufacturing of tools and parts is also another benefit applicable to the automotive industry. BMW is using the technology to print handheld tools that are used to attach bumpers and license plates (Bogue, 2013).
3. **Medical** – The Medical industry has found revolutionary ways to implement 3D printing. Fabricating custom implants, such as hearing aids, and prosthetics was one of the first ways that 3D printing transformed the medical industry (Berman, 2012). Practitioners are now able to scan a patients using CAD software, produce a custom implant or prosthetic, and fit the individual with a custom component that is specified to the patient's unique needs. The custom made implants reduce surgery time and cost as well as reduce the risk of post-operative complications (Bogue, 2013). Lead-time is also greatly reduced. Before 3D printing, patients would have to have molds made, which would then be fabricated; a process that could take months. 3D printing allows prosthetics to be fabricated in only a day, sometimes even in a few hours (Berman, 2012).

   Prosthetics were only the first step in the component production for the human body. Practitioners have been able to print organs that function properly. Most notably, a team led by Anthony Atala printed a human bladder using 3D printing of biocompatible materials. Layers of living cells are deposited onto a gel medium and slowly built up to form three-dimensional structures. 3D bio printing has been used for generating and transplanting several types of tissues, including skin, bone, vascular grafts, heart tissues, other vital tissues, and organs (Murphy and Atala).

   Another application in the medical sector is 3D printed dental copings. Dental copings are used in dental crowns and bridges These items can be quickly printed, are durable, and can be fitted to the exact specifications of the patient's mouth. This application of 3D printing has already been implemented as a way to enhance the patient experience by creating a range of dental and orthodontic appliances (Brogue, 2013). Other applications of 3D printing include reconstructing bones, body parts and heavily damaged evidence acquired from crime scene investigations in forensic pathology.

4. **Architectural** – Computer simulations and wood models have traditionally been used to review designs, but 3D printing brings realistic and undeniable detail and precision to the routine practice. Once an architect has designed a building, it is now possible to load those drawings into a printer and get an exact scale model of the building. This is an effective tool for architects as it allows improvements to be made on the design on a smaller scale, thus refining the architecture plan. The ability to review a model saves valuable time and money caused by rework.

   Models are not the only way that 3D printing benefits the Architectural industry. The construction industry can benefit from technology in terms of reduced construction time and manpower, increased customization, and finally construction cost.Various research groups across the globe are making progress towards printing houses. A group of Dutch scientists has built the "KramerMaker" which is a 6-meter printer. This printer is capable of printing plastic parts with dimensions of 2.2 x 2.2 x 3.5m. A research group in the UK is working at printing concrete component parts of a similar size. Researchers have managed to demonstrate the capability of printing components from cement mortar (Bogue, 2013). The ability to print housing components could be an effective means of providing low cost housing to poverty-stricken areas and could potentially revolutionize the way houses are built.

5. **Retail** – 3D printed shoes and clothing have already made their way into the market. 3D printed fashion and consumer goods are slowly making their way in the Retail industry. Retail is poised to gain some major advantages from innovations in 3D printing. According to John Hauer, co-founder and CEO of 3DLT, 3D printing's rapid prototyping abilities will create localized manufacturing, thus reducing supply chain costs and create overall better products. Huaure states ".Products are getting to market quicker, arguably as better-designed products with more end-user feedback because they are able to play with a working model of the product (Honigman, 2014)." The time and money that goes into forecasting what consumers may want to buy in the future, and how much of the product should be made, can cost companies billions. "3D printers could allow retailers to create and deliver products in small quantities in real time, providing actionable insight into which products will actually drive demand. For example, if a 3D model is well received, it can then be mass-produced through traditional manufacturing channels to meet higher demand (Honigman, 2014).

6. **Services** – 3D printing as a service to customers is another potential venture for Retailers. For instance, Staples not only sells 3D printers, but also offers 3D printing as a service. Just by going to the retailer's website, customers can upload their own design or customize one of Staples 100+ designs and have the finished product sent to their home or business. Staples offers 40 different print materials as well, fully harnessing the emerging market as 3D printing as a service ("Staples 3D Printing").
7. **Start Up Companies** – Startup companies could also benefits from Rapid Prototyping. When the company is launching it can begin with a low inventory of products and it is not necessary for the company to possess manufacturing capabilities. This provides cost benefits and reduces the risk associated with starting up the business (Bogue, 2013).

8. **Novelty Industry –** An additional application of Rapid prototyping is in the novelty sector. Typically, these products have a very short life span and will not remain in the market for a long period. To reduce the risk of excess or obsolete inventory, rapid prototyping can be used to produce the items. As rapid prototyping has sufficient turnaround times to respond to market demands, inventory levels are greatly reduced. In addition the manufacturing capability for the novelty items is not required by the company. 3D printing can be outsourced and does not require set up costs. Utilizing a personal printer, rapid prototyping can be used for household appliances' replacement parts (Crandall, 2013).

## V- SUMMARY

3D Printing technology has been in existence for over 30 years, but after the expiration of one of the technology's last patents in 2009, there has been tremendous industry growth, as well as huge steps in advancing the technology to make it more efficient and cost effective. 3D printing facilitates easy on-demand manufacturing of replacement parts. The technology makes it possible to have parts printed in remote locations by local distributors and service providers. Therefore, the delivery of goods is no longer a restriction. This results in shortening of the supply chain and saving as shipping and stockpiling inventory is not necessary. The need for large bulk inventories will be outdated.

3D printing technology is still in its infancy and will require further advancements in technology including reducing costs of printers and printer material, in addition to increasing printer capabilities to be faster, more accurate, and work autonomously. There are tremendous opportunities in a variety of industries,

ranging from industrial to retail, for 3D printing to make a substantial impact on the way products are made and the way companies do business. The world is ready to hop on to a decentralized industrial revolution.

Almost every sector of the industry is riding on the 3D opportunity bringing innovations to reality in industries like the automotive, aerospace, and medical. 3D printing technology undoubtedly has great potential. However, it is notgoing to revolutionize the manufacturing sector, rendering traditional factories obsolete. Instead, we should see it as a complement and exploit its unique capabilities. The technology is opening up new opportunities for manufacturing and global supply chain. It makes existing products better as well as enabling us to manufacture entirely new ones that we previously could not make.

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**Table 3-**Benefits of Prototyping and Components Parts Manufacturing in Three Major Industries

| **Industry/Process** | **Example**s | **3D Process** | **Benefits** Gained |
|---|---|---|---|
| **Automotive Industry** | • Printing prototypes and concept products<br>• General Motors has been printing prototypes for over 20 years<br>• BMW are printing handheld tools that are used to attach bumpers and name plates | • Rapid Prototyping<br>• Components Parts<br>• Manufacturing | • Reduced lead time on prototype parts<br>• Faster time-to-market on products<br>• More opportunity to test and compare multiple designs<br>• When models on cars change, tools can be replaced easily<br>• Help eliminate excess parts |
| **Aerospace Industry** | • Boeing has 3D printed component parts in 10 different models of military and commercial jets<br>• Airbus uses 3D printed cabin brackets in their A380 jets<br>• General Electric will be using 3D printing to make a fuel nozzle in their Leaf engine<br>• Lockheed Martin are using 3D component parts to reduce the cost and speed up production of UAV's | • Component Parts Manufacturing | • Enabled more efficient designs<br>• The parts are also being designed to be much lighter. A lighter aircraft has significant cost savings; a reduction in one kilogram equates to a savings of $1,300 in fuel per annum<br>• The parts GE are printing are reported to be 25 percent lighter and 5 times more durable<br>• Flight testing on a variety of models using different component parts is achieved in a shorter time span by using 3D printed parts |
| **Medical Industry** | • Custom implants such as hearing aids and prosthetics.<br>• Dental copings - used in dental crowns and bridges | • Component Parts Manufacturing | • With the use of CAD software the unique shape and size requirements for the part can be translated into the final product.<br>• Reduced surgery time and likelihood of post-operative complications<br>• Reduced lead time on the<br>• Enabled custom parts at low cost |