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Additive Manufacturing in A Supply Chain Solution Provider Environment

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Abstract
Additive Manufacturing has recently been brought into the spotlight as an alternative manufacturing method. While there are many different additive manufacturing technologies, the two that will focused on from the paper's perspective will be Fused Deposition Modeling (FDM) or Fused Filament Fabrication (FFF), and Direct Metal Laser Sintering (DMLS).

Fused Filament Fabrication is the extrusion of a material through a heated nozzle onto a build platform. The material is layered until a 3 dimensional part is created. This technology allows for fast cooling times and a variety of materials and colors to be printed as well as flexibility for the creation of 3D objects. DMLS technology is used to print metal parts, where a bed of powered metal is sintered with a laser, then a roller levels another layer of powder over the sintered layer and the laser sinters it again, bonding the melted metal to the layer below it. This is continued until the part is finished.

The company is utilizing both of these technologies to help with the manufacturing and product development process for its customers as well as internal use. The company facility utilizes the FFF printers for quick turnaround of prototypes for customer products or processes as well as for internal jig and fixture use on the assembly lines. The DMLS technology is used for customers who desire to see their product prototype in metal for visual or functional purposes as well as internal use for tooling for equipment or projects. As the technologies are used the company is using the current uses as use cases for more areas that additive manufacturing can be implemented along the assembly process, as it is currently used in the earlier stages of development.

This paper will review some of the various types of additive manufacturing used and will show how some of the additive manufacturing is being used in a supply chain solution provider environment.

Introduction
Though the areas of 3D Printing and Additive Manufacturing have recently been receiving much media attention, research of the concept started many decades ago. The first process emerged in 1987 with a company which created a process known as Stereolithography (SLA). That same year, it released a SLA printer into the market making it the first commercially available printer in the world.

In the next 3 years, more than 7 companies had released their own versions of stereolithography printers into the market. Following this is when non-SLA technologies and processes began to emerge in the market. The year 1991 saw the introduction of Fused Deposition Modeling (FDM) which will be covered more in this paper along with Laminated Object Manufacturing (LOM).

In 1992, Selective Laser Sintering was also released as a technology. Four years later in 1996, there was the introduction of low cost 3D Printers into the market from various companies. Until the year 2000 there were several companies that introduced new technologies and low cost printers, while this was also the period for many companies opening and shutting down.

As with any new technology, many players were entering the market, with a few coming out as successful. For the next 9 years, the market saw a large number of companies and machines entering the industry with new and variably priced systems which were used globally.

In 2009 the 3D Printing and Additive Manufacturing industry took a large step in being formalized as a technology. A group of an estimated 70 individuals from all around the world met at a ASTM conference to establish the ASTM Committee F42 on Additive Manufacturing Technologies. The committee created standards on testing, processes, materials, design (including file formats) and terminology.

From 2010 onwards, many companies began as start-ups with new and inexpensive printers using established technologies, and when a key patent for Fused Deposition Modeling expired in 2011 a surge of desktop 3D desktop printers entered the market, causing an increase of the participants in the RepRap movement, a Do-It-Yourself kit for 3D Printers that became a community of individuals who were making their own 3D Printers. Individuals who affiliated themselves with the 3D Printing community began to refer to themselves as "Makers".

For the next 5 years many companies and individuals arrived into the industry participating in new ventures or being a part of the many acquisitions or shutdowns that occurred. Currently, the market is still seeing growth with new additions of machines, materials and processes. In the year 2020, the market is expected to cross $21 billion.

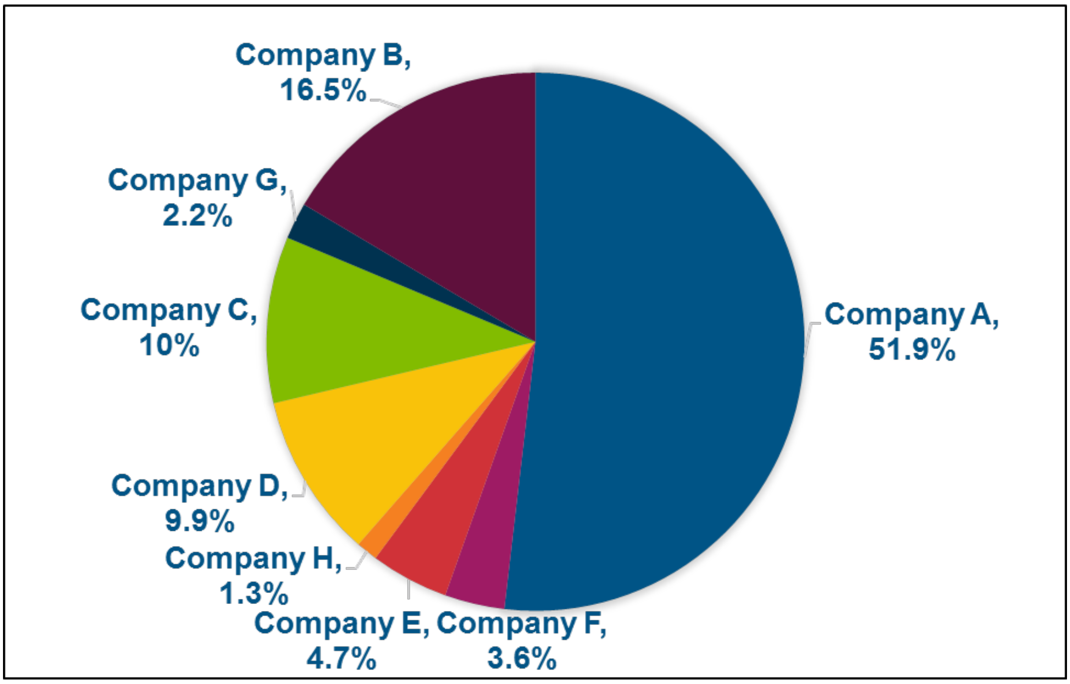

Figure 1 - Market Share by Manufacturer (as of 2014)

Due to the creation of ASTM F42 many aspects of 3D Printing and Additive Manufacturing were standardized, such as the terminology. Contrary to popular belief 3D Printing and Additive Manufacturing are not the same thing, but can be used interchangeably for the sake of ease. 3D Printing, according to ASTM F2792- 12a "Standard Terminologies for Additive Manufacturing Technologies" is defined as "the fabrication of objects through the deposition of a material using a print head, nozzle, or other printer technology".

The process starts with a 3D model drawing that is done on any standard CAD software. This 3D model file is then converted into a stereolithography file format by either the native program or a 3rd party file converter. Some printers have this file conversion capability as part of their software suite for their printers. The file is then converted into G-Code or a language that the printer can understand, essentially creating the file into cross sectional slices of the part. This step is commonly known as "slicing".

Once the slicing of the drawing has been done the printer is ready to start the print. For nearly all 3D printers, the above process is the same, with the printing process itself being the main differentiator. In a Fused Filament Fabrication printer, once the 3D drawing is sliced, the printer can begin printing. The main components of the printer are, the print bed, the extruder, the hot-end, and the material. Material for this technology usually comes in a wire form on a spool. This wire filament is fed into the extruder, the extruder uses torque and pinch to control the speed of the filament being fed into the hot-end. Once the filament is in the hot-end, it is melted using heat.

The melted material is forced out of the hot-end by the extruder that is pushing in more material from the top. The hot-end, usually made of aluminum, deposits the melted material onto the build plate in a designated pattern as dictated by the software. As the material is being deposited by the hot-end, the build plate is moving in a X, Y or Z-axis depending on the part requirements of what is being printed. In some printers the build plate will stay stationary and the hot-end will move in a Cartesian plane to create the print. This process describes Fused Filament Fabrication (FFF), which is one of the technologies that the company currently employs.

Fused Filament Fabrication currently is used mainly for plastic materials. If metal printing is required, Direct Metal Laser Sintering is utilized to print metal parts. The process of creating a 3D model to be understood by Direct Metal Laser Sintering printers is as described above, however, the process of printing is vastly different. Metal printers are usually larger in footprint due to the high quality components and the auxiliary processes required to ensure effective operation of the machine as well as quality of the print. The main components of a metal are the build plate, recoater, laser and powder.

Before a metal part is printed, the build chamber will fill up with an inert gas, usually Argon. This is to ensure that no oxidation occurs during the process. The build plate where the powder is residing and the recoater blade will be leveled. This can be done manually, but most printers can be automatically calibrated to level before a print starts. After the components are leveled, the print can start. A laser will sinter the powder in the cross-sectional geometry of the part.

Once the sintering for that level has finished, a recoater blade that was located off to the side of the build area will move over the sintered layer and coat a new layer of powder on top.

The layer of powder that is recoated onto the sintered layer is very important to the integrity and quality of the print. If too much powder is recoated, the layer below and the layer above may not be sintered together well by the laser. If there is too little powder, the laser might sinter already sintered powder, causing varying layer heights in the print. The even distribution of powder and the correct amount of powder is a key area that currently affects how the powder is recoated on top of itself. Layer by layer powder will be recoated and sintered by the laser until the part is complete.

Product Life Cycle and Supply Chain

Doing research in the field of 3D Printing has led us to learn that currently 3D Printing is being used in a variety of different applications and areas throughout companies and their value chain. 3D Printing can be seen in areas such as consumer printing to industrial applications to aerospace and medical. We have researched studies of the market as well as the industry to see where 3D Printing is being used most and for generally what purpose. Our findings are indicated below in Figures 2 and 3.

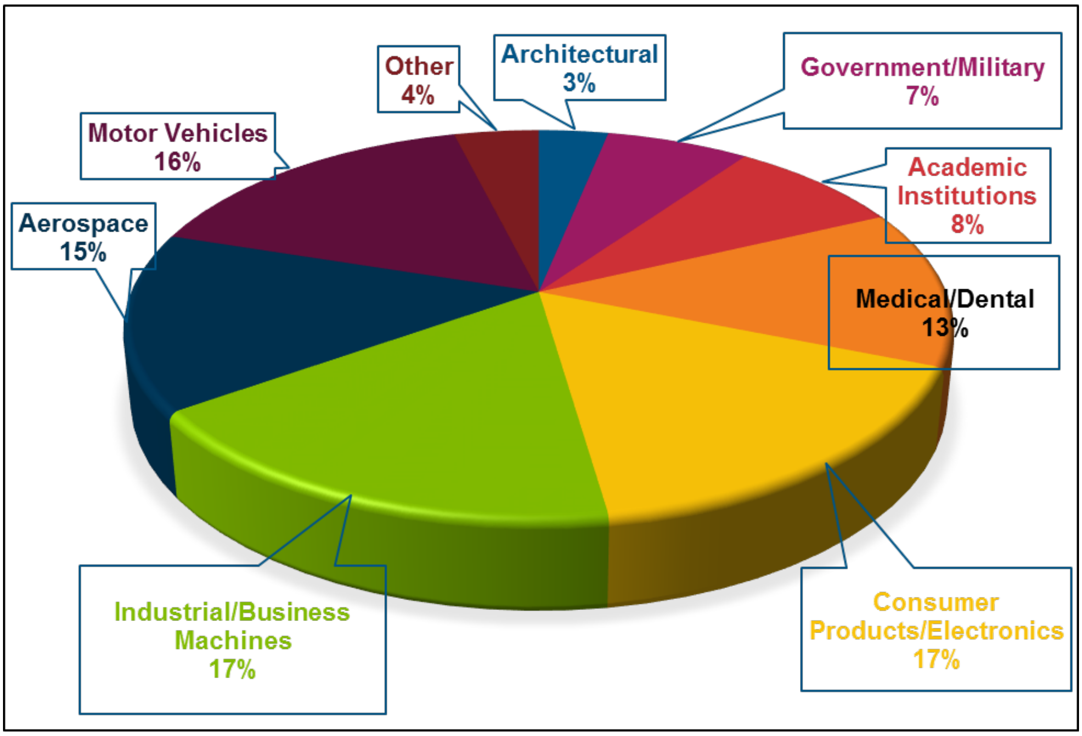

Figure 2 - Industries Using 3D Printing

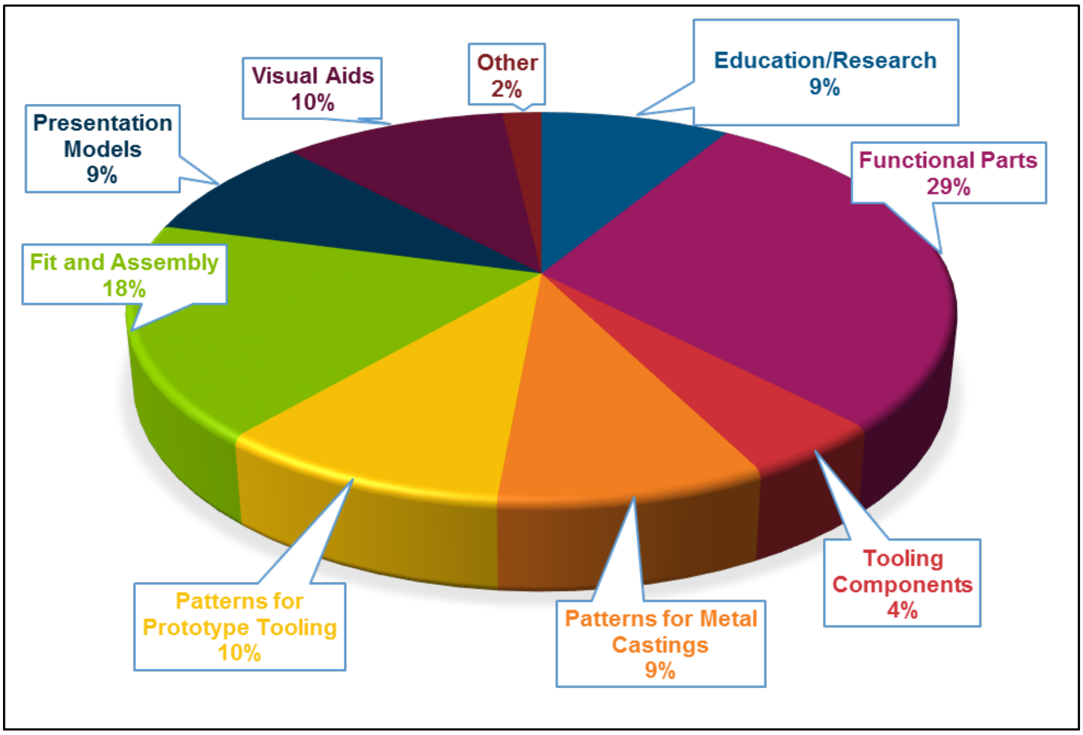

Figure 3 - Purpose of 3D Printed Part

By studying the above graphs, we were able to reach the conclusion that 3D Printing can be used in almost every step in the life cycle of a product. However, before inserting it into every aspect of the supply chain we looked at how to exactly enter the market as a user and adopter of the technology. It was found that there are general market approaches that companies have taken to implement 3D Printing into their value chain.

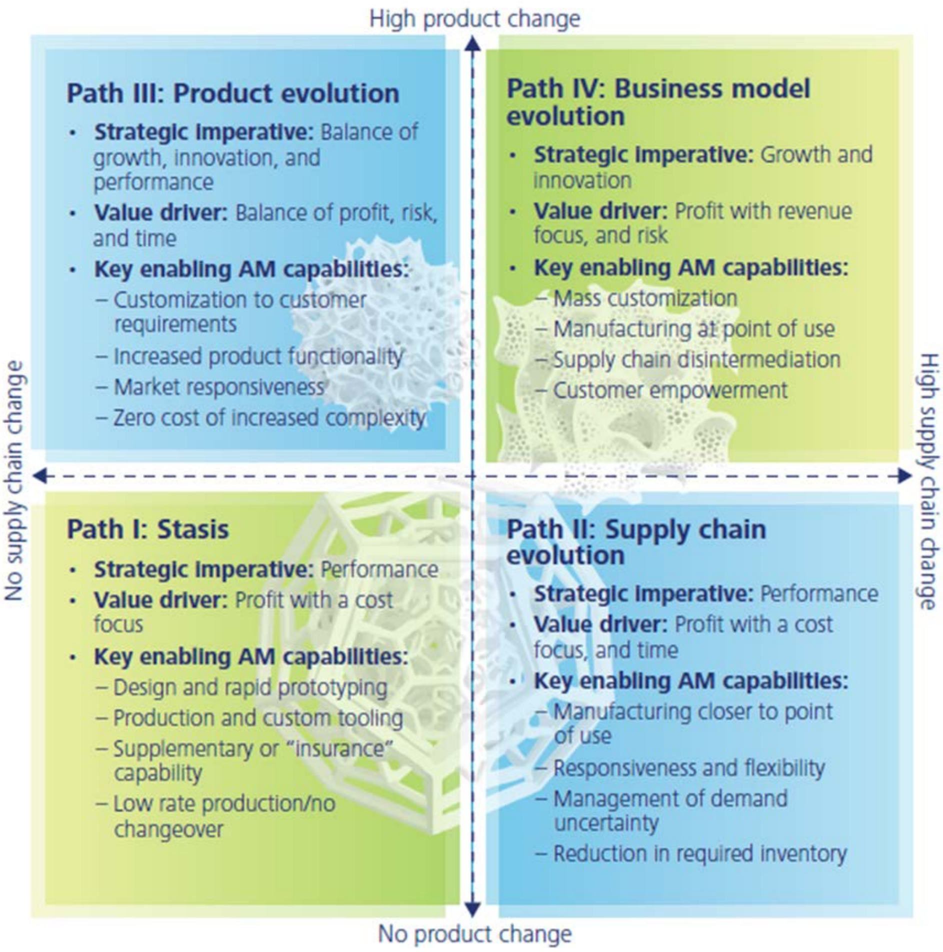

Figure 4 - Market Approach and Adoption to 3D Printing (Source: Deloitte University Press)

By using Figure 4 as a reference, we were able to discover that most companies take the above path, Path I: Stasis; where they enter the market by using 3D Printing solely for prototyping, tooling, or small volume parts. This can be seen as being used mostly by companies that have little to no product or supply chain change.

Path II is used by companies that have supply chain change but little to no product change. They tend to look at 3D Printing as a solution to be used in a flexible environment with a reduction in inventory. Path III is used in companies where there is a little to no change in supply chain but high change in product, as they tend to utilize 3D Printing to satisfy their requirements of customization for customers as well as a possible solution for product complexity.

Path IV is usually for companies who have high product change and high supply chain change, with these companies usually using 3D Printing to overhaul their operations and use 3D Printing for mass customization as well as using it to closely collaborate with their customer on product design. We used the above as a reference and then studied our product life cycles to see how we could fit in 3D Printing into various aspects of it. At a very basic and generic model our life cycle is as below:

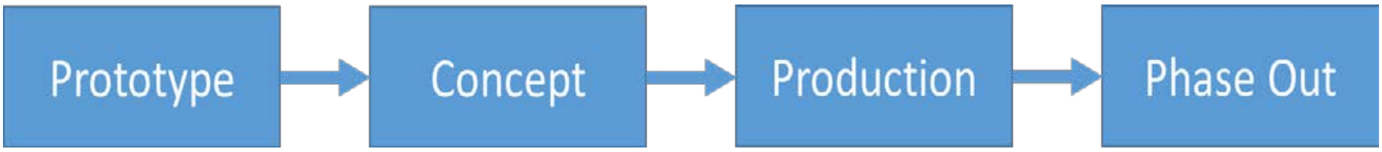

Figure 5 – Company Product Life Cycle

It was found that in every step of the life cycle we were able to take advantage of 3D printing in one form or application or another. In the feasibility stage of the life cycle we were able to use 3D Printing in a variety of ways. During the feasibility phase of the life cycle a product is discussed by either being presented or discussed based on a drawing, document or description.

This product needs to be conceptualized and needs to be described by the customer in detail. By taking advantage of 3D printing, we are able to 3D print the design that the customer is thinking of, and in addition, it will be able to help the customer visualize their own product, which presents the ability to review and improve product design.

After the initial printing and discussion of the product the customer will usually review and then revert back to the company team with an engineering prototype. This engineering prototype is sometimes injection molded or discussed in a paper format. With 3D Printing we can offer the service of printing the prototype for the customer and then present it to them for a discussion. After the prototype is printed and discussed we will sometimes be asked for a “form, fit and function prototype” or a prototype that is exactly to scale or similar so that they are able to see if the product satisfies their requirements and is able to illustrate the basic form and fit of the product.

After this product is printed, and it moves through several other steps which are imperative to the process of a product life cycle. When the product arrives into the “Concept” area of the life cycle, it can be made into a concept in a number of different ways. Since there are many types and forms of a concept, the concept is sometimes fully made with production ready materials and parts or is sometimes still made with prototype materials or parts depending on how the customer would like the part to be done.

In this stage of the product life cycle, 3D Printing is very viable due to the fact that the whole concept can be printed or parts of the concept can be printed depending on the requirements, desires, availability of the parts, ease of sourcing the parts, lead time, or development work required to create or obtain the part or parts. When production of the product starts, 3D Printing can be taken advantage of in a variety of different areas.

Many companies are currently trying to print serial parts for mass production but have not done so to the level that the manufacturing industry desires or requires. At this point the serial mass production of 3D printed parts is not fully capable and seems to be immature. However, other areas that 3D Printing is able to assist or augment production is through the printing of jigs and fixtures, printing of production related consumables as well as production components.

3D Printing can be used for the printing of jigs and fixtures such as guiding fixtures, holding jigs, alignment jigs and others. Printing of production related consumables is being done and studied more. Currently, things such as holders for barcode scanners, replacement buttons for different machinery and equipment, holders for small tools are being either replaced or recreated using 3D Printing.

The areas in the production of the product are studied heavily by the company to see where 3D Printing can be used to help reduce lead times, cost, and even quality, depending on the parts that are being printed. After a product has been cycled out of manufacturing, the End-Of-Life process starts. The manufacturing for the product stopping means that the components that were used to manufacture and assemble the product will be retrofitted or recycled to be used for the next product.

For the End-of-Life servicing of the product, companies are required to keep spare parts of the product on hand as well as any special tools or other auxiliary equipment that is required to repair and/or service the product. This creates inventory as well as keeping possibly obsolete parts and tools on hand. This is an area that 3D Printing can be applied to well due to the fact that printing parts or tools required can reduce inventory greatly and allow for better space utilization as well as cost reduction.

In addition to looking at the areas that 3D Printing can be used, we are looking at reviewing of the relationship and correlation on how the type of process and technology affects the areas which can take advantage of 3D Printing. For example, using Fused Filament Fabrication might be better for printing some types of jigs and fixtures but not be good for others. The same model applies to SLA, DMLS and other processes. This combined with the types of materials and equipment capabilities, creates an area of study that needs to be focused on as well.

The Future of 3D Printing
Since we are looking at the current state of 3D Printing, it is worth looking at where the market is going so that we can be prepared and take advantage of the advances that are being done in the field as well as create any new advancements to it.

For example, looking at the market of 3D Printing, it can be concluded that 3D Printing is becoming more and more popular not only in the consumer market but in the industrial market as well. The market is seeing a huge rise in research and development in all the areas of 3D Printing and Additive Manufacturing such as materials, equipment, and processes. Materials science is getting much more attention from 3D Printing enthusiasts due to the fact that material limitations are part of the key reason that 3D Printing is not being able to be considered an option for consumer ready parts and products.

Equipment is seeing many advances such as the quality of the components being used as well as the technical capabilities of the components. Both industrial and consumer markets are seeing 3D Printing processes being optimized for higher quality parts, improved cost as well as speed of making the parts. Due the expiration of patents, the advances of materials, processes and equipment, the popularity and use of machines is now greatly diversified across many market segments and industries, ranging from aerospace and defense applications to domestic and hobbyist use.

This is apparent from the market studies being conducted that are showing a rise in the number of systems sold over the last several decades. By researching different market and industry information, Figure 6 was obtained that indicates the total number of systems sold from 1988 to 2014. This graph does not take into the account the number of 3D printers that were made by people or the number of printers that are sold or made and sold by startup companies. The fact that 3D printers are being made by people personally in their own homes or being made for recreational uses adds to the idea that this technology seems to have a future ahead of it due to the ease of use and accessibility.

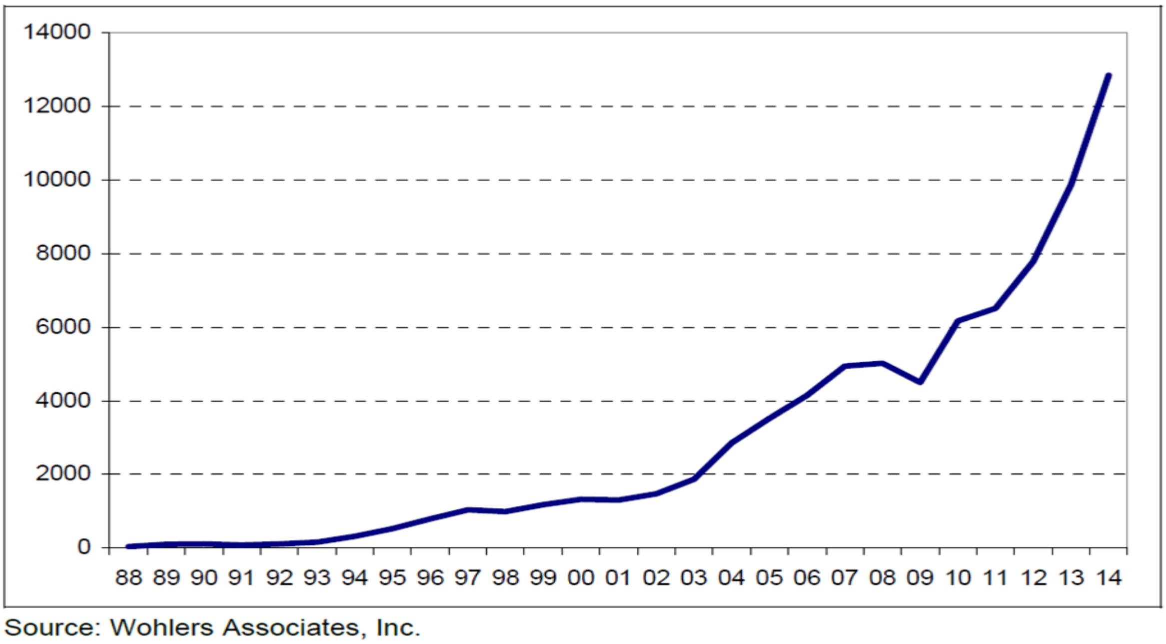

Figure 6 - Number of Systems Sold

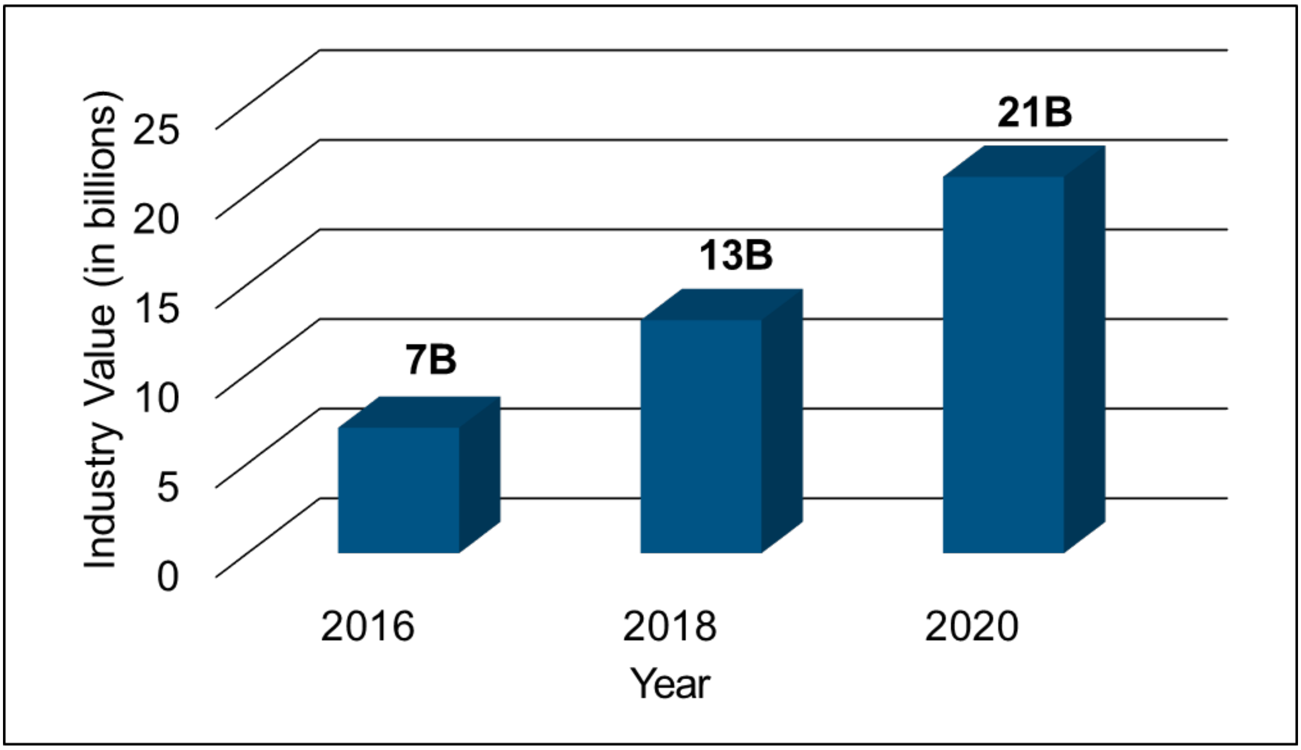

Figure 7 - Forecast of the Additive Manufacturing Market

Figure 7 shows the expected growth and forecast of the 3D Printing and Additive Manufacturing market over the next 4 years. As the technology as well as materials and equipment become more and more available and easy to use, the world will be seeing many more 3D Printers and 3D printed parts around us. Since we see a growth in the market of Additive Manufacturing and 3D Printing, it is exciting to be working in this area and see what the future holds for this industry as well as for the world.

General References

1) Wohlers Industry Report 2015
2) Deloitte University Press