Politecnico di Torino

Master’s degree in Engineering and Management

Economic aspects of additive manufacturing

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Abstract

Additive manufacturing is becoming the main part of industries due to the fact that it has many advantages. Therefore, there are many industries that have already adopted additive manufacturing technologies, besides that, other companies are also considering integrating additive manufacturing technologies into their industries. It is believed that additive manufacturing is bringing our traditional industries to a new phase, and it is playing a major role in Industry 4.0. Additionally, additive manufacturing technologies are being improved to create more value and achieve higher adaptability for industries for some reasons, such as avoiding supply chain issues.

The purpose of this thesis is to analyze additive manufacturing technologies and their role in different industries. In the first chapter of the thesis, additive manufacturing technologies have been introduced, including vat photopolymerization to directed energy deposition, and also step-by-step processes while working. Furthermore, which kind of materials are used in the processes has been introduced.

Chapter two is mostly based on the economic perspective of 3D printers. From that chapter, it is possible to easily understand what kind of advantages additive manufacturing technologies have, besides the limitations that have been also analyzed. Additionally, in this chapter, different sectors have been studied also according to an economic perspective.

The 3D printer market has been also studied in chapter three in more detail. In this chapter, some of the leading companies in additive manufacturing have been introduced also, and their expenses and revenues have been analyzed, such as Stratasys, 3D systems, and ExOne. Additionally, the chapter includes information about segments such as medical, aerospace, and transportation, also from e-commerce to 3D printer prices.

Chapter four is mainly based on the role of additive manufacturing technologies in the automotive sector. This chapter provides information about the advantages of AM technologies in the automotive sector, and also the construction of automotive components depending on the material type and production processes. Furthermore, chapter four gives some information about the future and forecasts of AM in the automotive sector, besides that, the role of Artificial Intelligence(AI) has been studied.

The last part of the thesis, which is Chapter five, is a case study, studying one of the leading 3D printer manufacturing companies, Stratasys, Ltd. In this chapter, the background of the company, including its history and products, has been studied, and also external and internal analyses have been examined. For external analysis, Porter’s five forces and for internal analysis, SWOT have been studied.

Contents

Chapter 1 Additive manufacturing technologies

1.1 Introduction

Human beings built today’s advancing technological world by introducing traditional manufacturing which enabled the revolution in the industry later on, however, there are many constraints that require new paradigms to design new products and to reorganize the manufacturing processes to get competitiveness in the industry. The introduction of Additive manufacturing (AM) processes offers a new paradigm and brought great value to the industry because of its fast and reliability. First, it is important to understand the meaning of Additive manufacturing. In order to create components from 3D-model data, the relatively new manufacturing technology known as additive manufacturing (AM) combines a number of techniques for joining materials together, namely layer by layer. A number of processes come together to create additive manufacturing, including computer-aided design (CAD), computer-aided manufacturing (CAM), laser and electron energy beam technology, computer numerical control (CNC) machining, and laser scanning. Many of the technologies required for additive manufacturing were developed as early as the 1950s, but it wasn't until the 1980s that the technologies were mature enough to be used together[1]. Besides that, it is necessary to define the difference between Additive manufacturing and 3D printing which are used interchangeably. Additive manufacturing is a more common term, consisting of many technologies and 3D printing is one of these technologies.

Companies over the world are producing AM technologies and it is possible to see the distribution of AM companies by region in the world in the pie chart, Figure 1.1

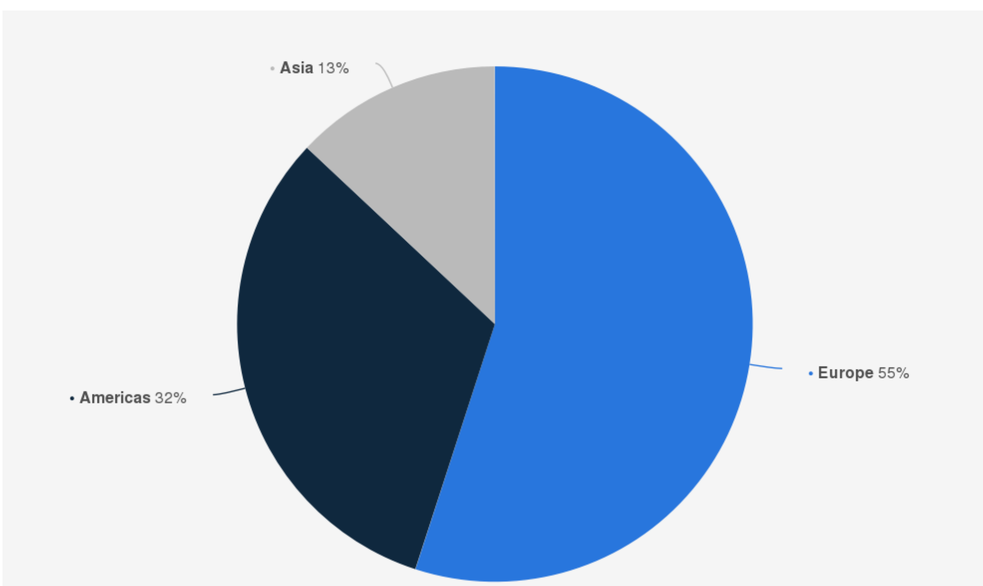

Figure 1.1 Distribution of companies by region-2019, source[2]

As we can see in the annual report-2019 by Martin Placek,(Figure 1), the leading companies in producing AM technologies are located mostly in Europe with a share of 55% and Americas acquiring 32% of the market share and the rest is Asia companies, 13%.

1.2 Basic aspects of additive manufacturing

Additive manufacturing describes processes that use material addition to create three-dimensional objects. When compared to subtractive methods used in which parts of a block of raw material are milled away until the desired shape is achieved. The academic community prefers the term "additive manufacturing," which is synonymous with "rapid prototyping" or "3D printing," because it does away with the misconception that the manufacturing parts obtained using these techniques are only suitable for creating prototypes[3].

The first step is to create a 3D model of the finished product on a computer which is converted into a mesh file (.STL) and can then be imported into dedicated software that will slice the object transversely while preserving its original geometry. The software also creates the necessary commands and routines for the 3D printer to produce the finished product, Figure 1.2 shows the process of AM workflow

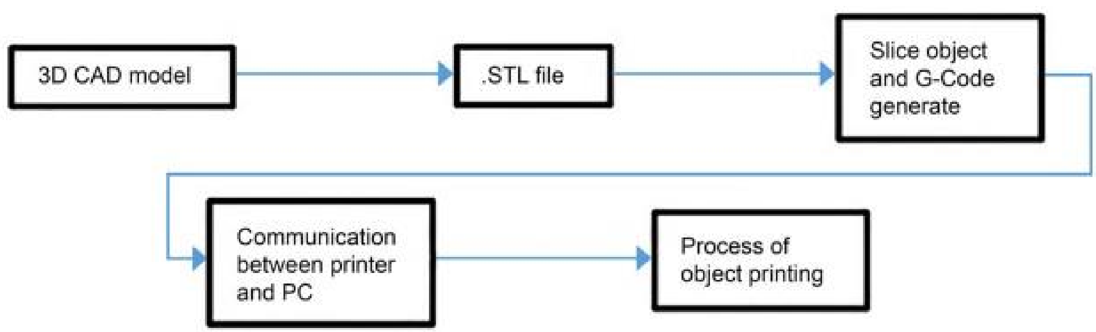

Figure1.2 Workflow of 3D printing

1.3 Technology

AM manufacturing consists of 7 categories which are Vat photopolymerization, material jetting, binder jetting, material extrusion, powder bed fusion, sheet lamination, and directed energy deposition.

1.3.1 Vat photopolymerization-

Stereolithographic (SLA)

In stereolithography, liquid resins are solidified in a controlled manner via photopolymerization using either a laser's beam of light or a projected image of the laser's beam obtained through an optical setup. These computer-driven methods are identical in their operation. Figure 1.3 illustrates those two configurations

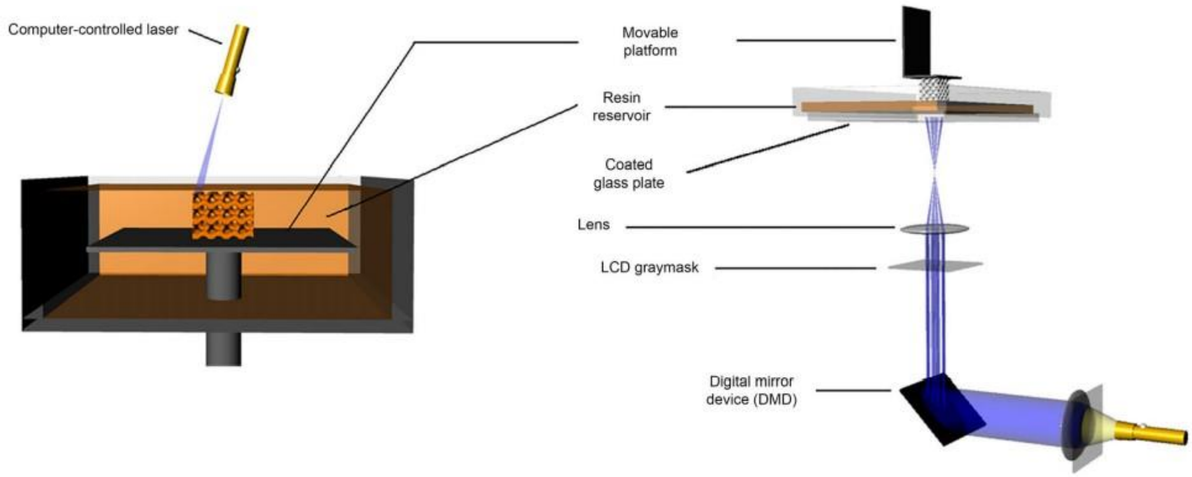

Figure 1.3 Two configurations of laser projection in stereolithography (a direct laser projection, b laser projection by an optical)

To create the first layer, the laser's light is aimed at the resin's surface in a very specific geometric pattern. Consequently, the resin will adhere to the base at a predetermined depth where the solidification process initiates. When the first layer solidifies, the platform is moved to make room for the next layer of liquid resin. Again, light beams in a predetermined geometric pattern are used to solidify the new layer so that it sticks to the old one. The procedure is repeated until the required 3D shape is created. Layer heights are predetermined in the slicer software according to[3].

1.3.2 Material jetting

The process of material jetting is analogous to that of a conventional inkjet printer, but it produces three-dimensional objects instead of two. A continuous or Drop on Demand (DOD) method is used to jet material onto a build platform. The model is constructed by jetting material onto a platform or build surface, where it solidifies and is subsequently added to. A horizontally-moving nozzle deposits the material onto the build surface. Different machines have different levels of complexity and use different techniques for regulating the deposition of materials. Afterward, ultraviolet (UV) light is used to cure or harden the layered materials according to [4]. Figure 1.4 shows the scheme of Material jetting processes

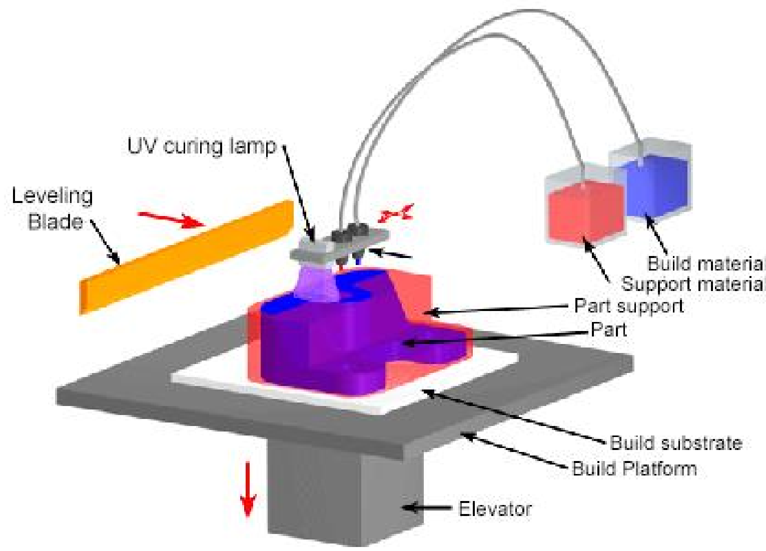

Figure 1.4 Material jetting process

1.3.3 Binder Jetting

According to Loughborough University research, in the process two types of materials are used, powder-based material and a binder. A binder, in the form of liquid, is used to adhere to the powder layers, but the build material is usually found in powder form according to[5]. Figure 1.5 shows the scheme of the Binder jetting process. The following steps are done in the process :

1. The roller spreads the powder over the build platform
2. The binder is poured by the print head on the powder to make it adhesive
3. It is necessary to decrease the build platform by the thickness required by the model
4. Roller spreads the powder over the layer built in the previous step, and the desired part is created by adhering the powder with a binder
5. This is done over and over again until the entire object is complete.

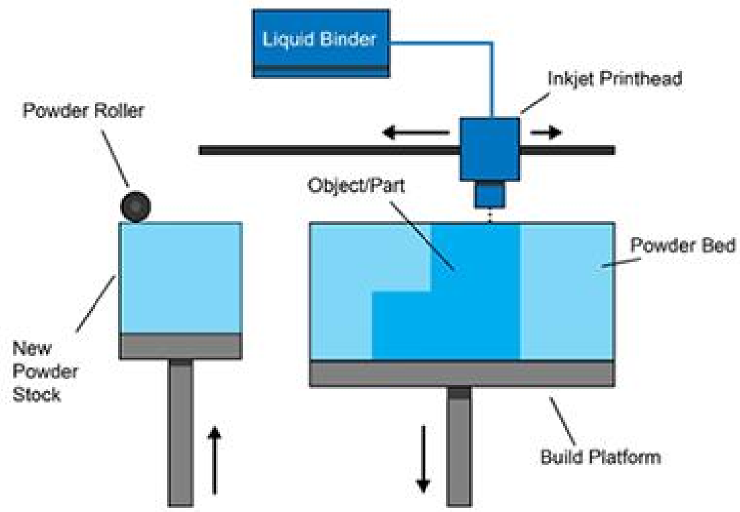

Figure 1.5 Binder jetting process

1.3.4 Material extrusion

Stratasys owns the trademark for the material extrusion process known as fuse deposition modeling (FDM), which is widely used in the manufacturing industry. A nozzle is used to feed material, which is then heated before being deposited in successive layers. Following the deposition of each successive layer, the nozzle is free to move horizontally, and a platform rises and falls to accommodate the process. It is a standard method employed by many low-priced, home-based, and hobby-oriented 3D printers. Although the process is similar to other 3D machine processes, the difference is that the material is drawn from a nozzle under pressure and a continuous stream. In order to achieve the desired result, the pressure must be maintained at a constant rate. Controlling the temperature between layers or using chemicals are both viable options for forming bonds between materials according to[6]. As can be seen in the diagram below, Figure 1.6, the material is typically fed into the machine on a spool. Step by step explanation is given below

1. The nozzle makes the first layer by drawing the material under pressure
2. And the next layer is added on top of the previous layer
3. The layers are bonded by melting them

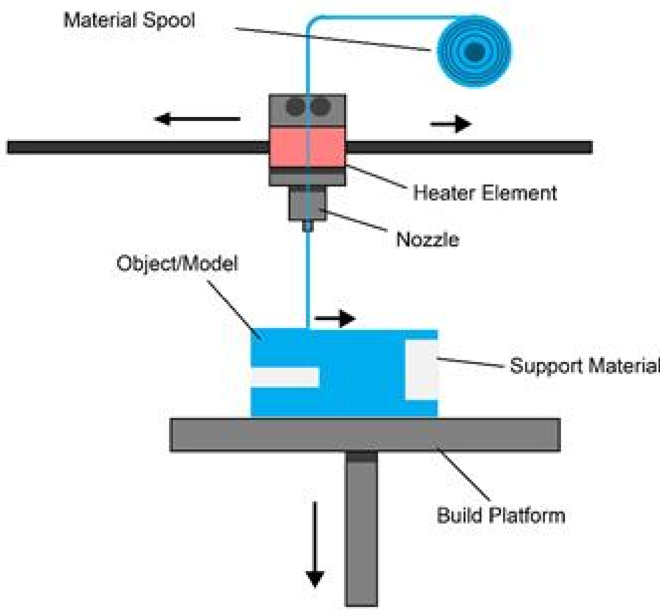

Figure 1.6 Material extrusion process

1.3.5 Powder bed fusion

In powder bed fusion, there are two ways to join the materials by melting, the first is a laser beam and the other is an electron beam. Although electron beam melting (EBM) techniques can only be used in a vacuum, they can be used to make functional parts out of metals and alloys. The powder is spread over the previous layers in every Powder bed fusion (PBF) process by using a roller or blade, and there are hoppers or reservoirs which can supply the material. The powder is sintered layer by layer by Direct metal laser (DMLS) using metal. In contrast to other methods, Selective Heat Sintering employs a heated thermal print head to fuse powder components together. The process of adding layers with a roller in between fusions is the same as before. The model is adjusted to a lower height by means of a platform according to [7]. It is possible to easily understand the process by looking at the step-by-step explanation in Figure 1.7

1. Spread out a thin layer of material (about 0.1 mm) on the build platform.
2. The initial layer or slice of the model is fused with a laser.
3. Using a roller, more powder is applied on top of the existing layer.
4. New layers are fused and added on the top of previous layers
5. This continues until the entire model has been built. The un-melted powder is left in place but is swept away in the post-production stage.

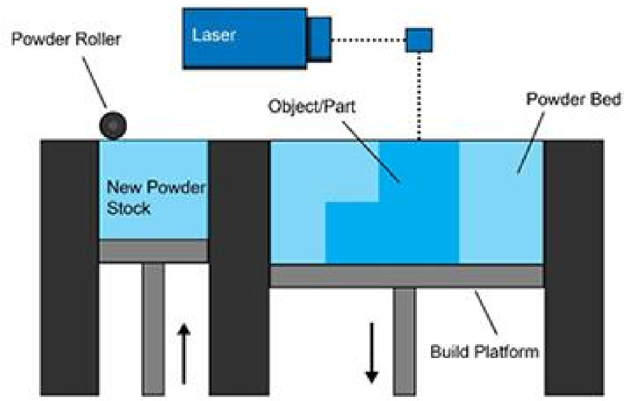

Figure 1.7 Powder bed fusion process

1.3.6 Sheet lamination

In Sheet lamination, ultrasonic additive manufacturing (UAM) and laminated object manufacturing (LOM) is applied in the process. Sheets or ribbons are used in the UAM, with ultrasonic welding, and where the additional CNC machine is needed, while the traditional method, layer by layer, is used in LOM, but with paper and adhesive, not welding in contrast to other methods. However, metals such as aluminum, copper, and titanium are the main materials of UAM according to[8]. Step by step is provided below and it can be easily understood in Figure 1.8

1. On the cutting bed, the materials are set
2. Using the adhesive, the material is affixed in place atop the prior layer
3. After that, a laser or knife is used to cut the desired shape out of the layer
4. The subsequent step is to add the second layer

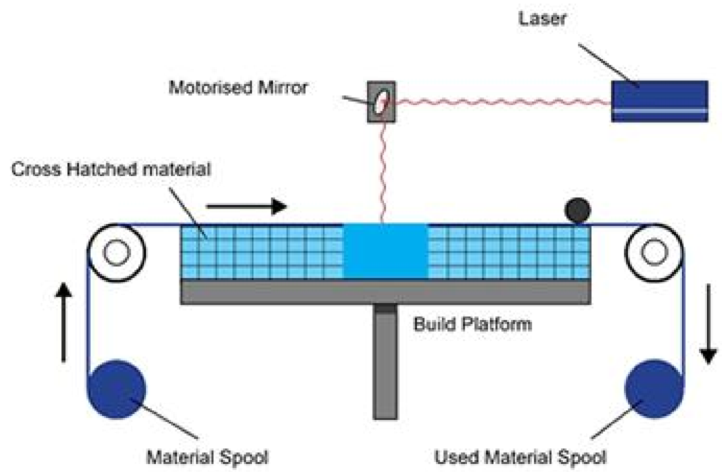

Figure 1.8 Sheet lamination process

1.3.7 Directed energy deposition

Direct energy deposition (DED) is a machine that uses a nozzle attached to a multi-axis arm to deposit molten material onto a target surface, where it then cools and solidifies. It's conceptually similar to material extrusion. The difference from a material extrusion machine is that DED uses a nozzle that can move freely, namely it is not fixed. With 4 and 5-axis machines, the material can be deposited from any direction, and then melt with a laser or electron beam during the deposition process. This method works well with metals in powder or wire form, but it can also be applied to ceramics. In addition, this process can be applied to repair or add materials to broken components, Figure 1.9 according to [9]. Step-by-step process:

1. The nozzle deposits the material onto the object's surface
2. The material is drawn in the form of wire or powder
3. Laser or electron beam melts the material in the deposition process
4. As a regular machine, When new layers of material are added to an object and allowed to solidify, new material features can be made or repaired.

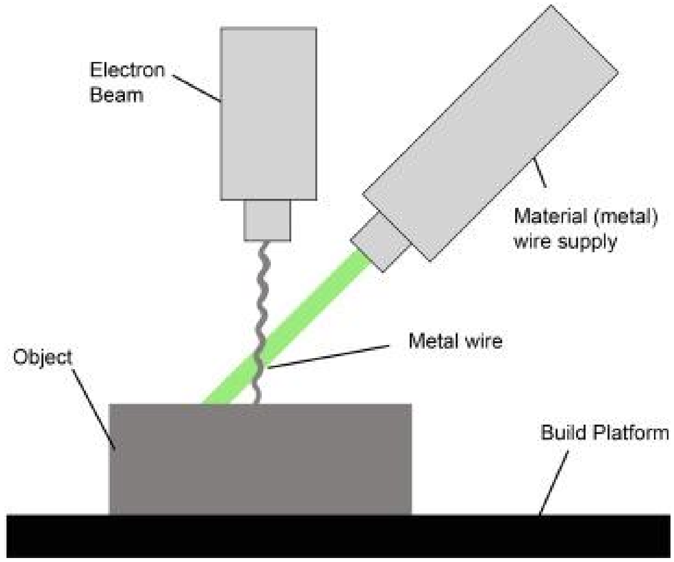

Figure 1.9 Direct energy deposition

1.4 Post-processing

In the following paragraphs, we'll talk about how post-processing techniques are used in the AM procedure. There are many post-processing techniques, such as Laser shock peeling (LSP), Laser polishing(LP), and Heating processes (HP). A lateral expansion technique, LSP makes use of plastic compression that runs perpendicular to the surface of the material being expanded. In addition to its traditional uses, LSP is being used in the aero industry as well. LSP has recently been implemented to increase the fatigue life of aircraft components. Similarly, LSP has been used to improve maraging steel's performance. Additionally, it has been used to bend and stretch aircraft fenders to improve the realism of aerodynamic models. Regarding the LP, it is used to improve the surface roughness of the component, it changes the morphology of the surface without influencing the component characteristics. However, HP has a relative effect on the microstructure of the component, for example, it reduces the residual stresses and decreases the cracks, and homogenizes it according to[10].

1.5 Materials

The main raw material sources are ceramics(Glass, Silica, Porcelain), polymers (Acrylonitrile butadiene styrene (ABS), polylactide (PLA), polycarbonate(PC), polyamide(Nylon)), composites and metals (Steel, Titanium, Aluminum, Cobalt chrome alloy). In addition to them, adhesive paper or chocolates are used in manufacturing. Despite the rapid pace at which materials are progressing, the selection of materials available for AM is still quite limited. If a material's potential or an existing application is identified and evaluated favorably enough, then it may be possible to fund the research and development of the new material. Absolute material costs are low in AM, especially metal AM, because of low production volumes, so material cost savings are not a major factor according to[11].

1.6 Conclusion

Additive manufacturing processes have a relatively positive impact on production because of their reliability, quality, time effectiveness, and lower cost since the priority of the production processes is speed, quality, and cost. As a consequence, in the competitive industry, the demand is so high for

Additive manufacturing technologies due to its high capability. Furthermore, Engineers and researchers are developing new additive manufacturing techniques and materials being used in the processes.

Chapter 2 3D printers from economic perspective

Additive manufacturing is one of the key drivers of the country's economy, mainly in its industry. As AM, 3D machines play the main role in the industry, not only developed countries but also developing countries are making investments in the AM to increase their GDP by adding great value to the economy. Below, Figure 2.1, the additive manufacturing market growth from 2020 to 2026 is illustrated according to data by Statista, between 2020 and 2023 there is an expectation of an increase of 17%, and a slightly increase again next 2 years.

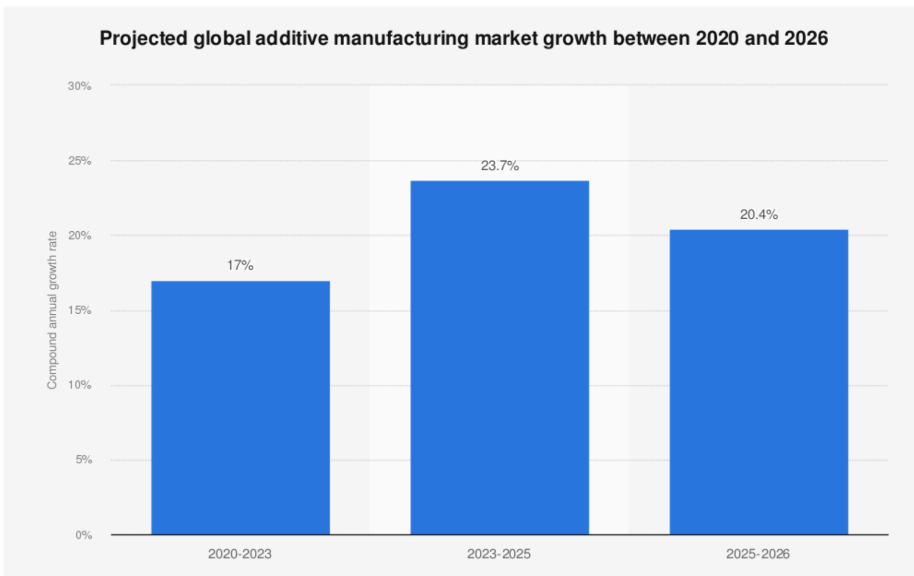

Figure 2.1 Global AM market growth, source[12]

2.1 Benefits of Additive Manufacturing

In this competitive world, companies are switching to additive manufacturing, 3D printing from traditional ones due to its high capability and efficiency. When compared to conventional production methods, additive manufacturing has more advantages. In this chapter, some of them will be introduced, such as time and cost savings, build time, controllability flexibility, labor, and customization.

2.1.1 Controllability and Flexibility

A company's controllability measures how well it can regulate internal operations. The major aim is to maximize accuracy and production while reducing costs. However, The capacity of a company to adapt to changing circumstances, both internal and external, is a measure of its flexibility according to [13]. To do this, one must be able to adapt to new conditions while experiencing minimal losses in terms of time, money, or efficiency. In short term, there is a choice to choose controllability and flexibility or a combination of them as shown in figure 2.2.

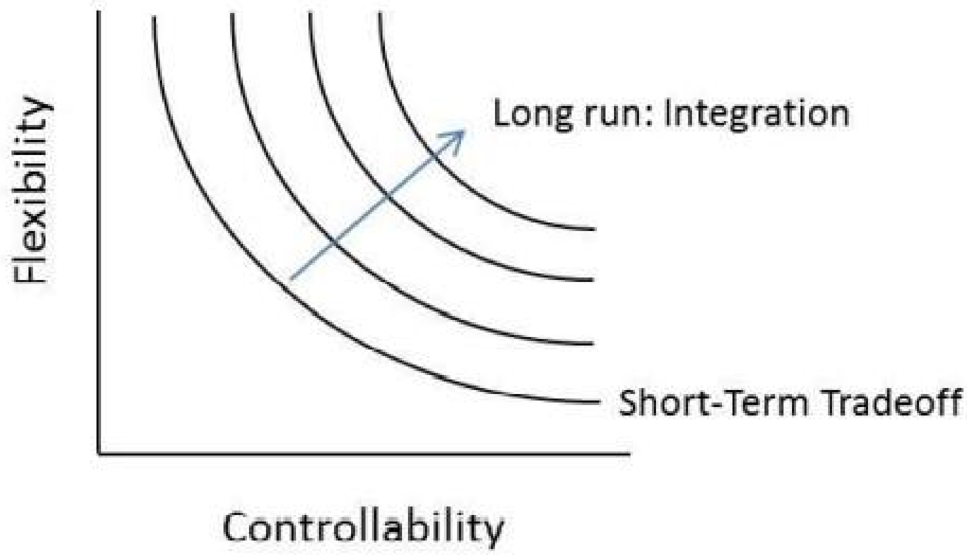

Figure 2.2 Flexibility and Controllability of production by company

2.1.2 Production time

When the production time of additive manufacturing is compared to traditional production time, AM takes longer time than traditional one. Even though there is no change time (change time is a measurement of how long it takes to change from one product to another one) in additive manufacturing, AM requires more time than conventional production. However, since AM allows for the production of highly customized products with a small initial run, it finds a more common application in mass customization manufacturing, and when the production line is in parallel method, production time takes less time than traditional production

2.1.3 Quality

Using AM technology does result in improved products and a slightly different quality overall. Additive manufacturing allows for greater geometric freedom and greater flexibility, but it does have its limitations, as some designs need to be supported by structures or have some way of dissipating heat during the manufacturing process. While complexity typically leads to higher production costs when using conventional methods, this is not the case here. It is possible to personalize each item manufactured at minimal to no additional cost, apart from the initial design investment. Replacement joint implants, dental work, and hearing aids are just a few examples of where tailor-made goods are desperately needed in the medical field. Customers can also have a hand in product development by designing unique versions of existing products. On the other hand, quality control is an issue in additive production. In order to achieve the desired part quality, standardized methods are required for assessing and guaranteeing precision, surface finish, and feature detail and there are many tools and techniques to control and assess the quality of the manufactured parts by AM such as traditional manual tools like calipers or gauge, Coordinate measuring machine, optical 3D scanners, computed tomography, In-situ inspection.

2.1.4 Mass Customization

Customized goods are difficult to produce using conventional manufacturing techniques. If a manufacturer wants to make a custom product by, say, injection molding, they'll need to make a new mold for each product. Delays and the increased cost of tooling and fixtures, cause production times to lengthen. One possible answer is to utilize a digital manufacturing technique, such as 3D printing. Given that AM doesn't necessitate time-consuming and costly tooling changes based on individual specifications, it opens up new avenues for customization. In 3D printing, the manufacturer uses only the machine itself, as the design data is sent directly to the printer. Because of this, the complexity that naturally arises from customization is not reflected in the price. Because 3D printing requires no special equipment, printing multiple designs from different sources does not increase production costs. Consequently, numerous sectors have begun exploring the potential of 3D printing for mass customization because of its toolless production and extreme adaptability[14].

2.1.5 Build envelope and envelop utilization

The cost of an additively manufactured item can be affected by the build envelope's size and how much of it is used. There are two effects that are related to the build envelope size. It may be impossible to manufacture some products with additive manufacturing technologies unless the building envelope is increased in size, which brings up the first issue. The second factor that is affected by the building envelope is the extent to which the available building space is utilized. Utilization of all available space in construction is a key efficiency factor[13].

2.1.6 Efficiency

A further area of the market that could be disrupted by 3-D printing technology is the fabrication of consumer-ready components. Using 3-D printing, customers might produce replacement or spare components for their own products if they ever break. It is expected that simple replacement components will be downloaded as 3-D printing files and marketed all over the world. Individual buyers can take on the role of manufacturer.

2.2 Limitations

Although AM has the potential to revolutionize manufacturing and many other sectors, the technology is still in its initial phases of adoption, and there are many obstacles standing in the way of its widespread and rapid adoption. The following sections provide a concise overview of the most significant challenges inherent in adopting AM technologies. Figure 2.3 shows some barriers to using 3D machines

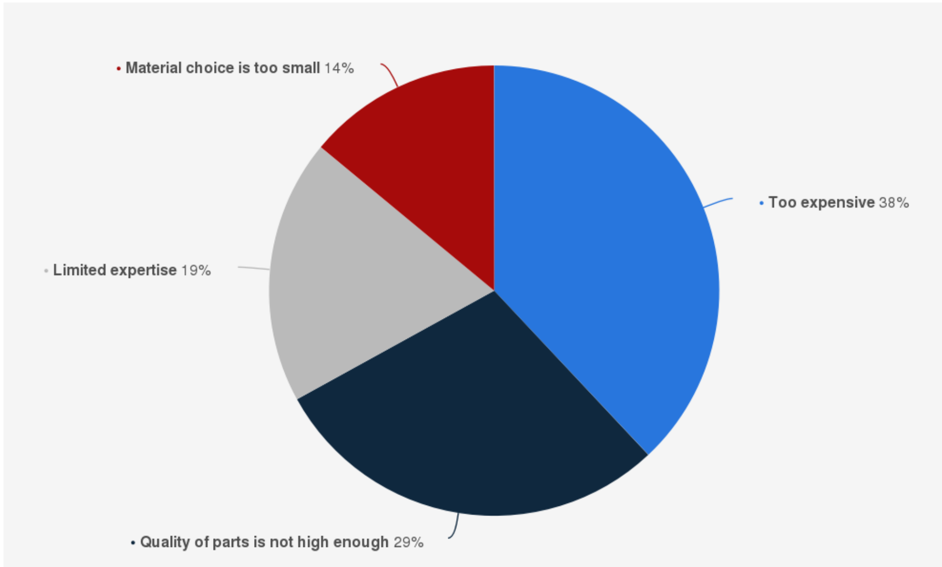

Figure 2.3 Factors preventing you from using 3D printing, source[15]

2.2.1 Regulations

Increased use of 3D printing technology could have far-reaching economic and social consequences if it is not properly governed. The rules and regulations often lag behind technological advancements. The question of how to regulate 3D printing has already been raised. In 2013, instructions for making a plastic handgun were posted online for anyone to use. In essence, if a CAD design exists and a printer exists that is large enough to print the item, the product can be made easily and without limitation. Metal detectors wouldn't pick up on the 3D printed gun, making it a potential threat if it fell into the wrong hands. Regulations and government intervention may limit who can perform 3D printing and what can be printed as the limits of 3D printing are continued to be tested and new issues become known.

2.2.2 Size limitation

A 3-D printer's maximum output size is limited by the size of the printer enclosure. This limits the maximum dimensions of manufactured items. Larger printers are available, but they require storage space that is large enough to accommodate them. When a printer isn't big enough to make the whole product at once, it has to make the parts separately, which adds time to the process but reduces the benefits.

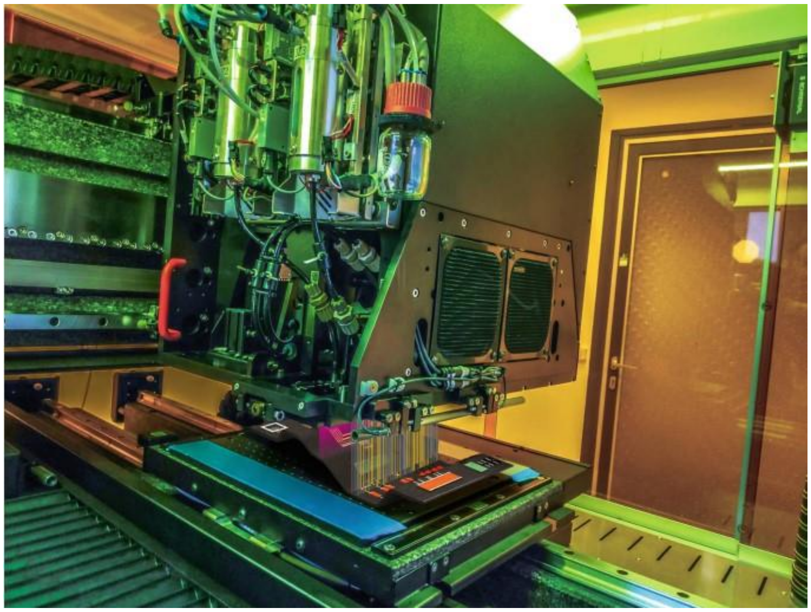

Figure 2.4 Printing inkjet technology that can handle multiple materials, producing fully functional 3D objects

2.2.3 Material costs

Additive manufacturing's geometric flexibility makes it possible to produce products with less raw material while still achieving the required level of performance. As a result, products can be made to meet or exceed their required performance levels rather than significantly underperform, as is the case with conventional manufacturing. Materials for additive manufacturing can be more expensive than traditional manufacturing methods at the moment. We can divide the material costs into two parts, metal material costs and plastic material costs. In the case of metal material costs, the costs of metal materials for AM are much higher than the traditional production, to be more precisely 2.59 € per part for conventional production and 25.81 € for AM, laser sintering method according to the research of Atzeni and Salmi. Regarding the plastic material costs, plastic filaments may change between 25$ and to 45$. However, companies that specialize in 3D printing hope to bring down the price of the filament by increasing competition in the market. Some businesses have looked elsewhere for cheaper filament. In the same way, that printer prices are predicted to fall in the future, so, too, is the price of the filament used in them likely to drop as businesses develop more efficient means of obtaining and, or producing and selling it at a lower price.

2.2.4 Labor

Labor is also a part of the manufacturing processes. Even if the cost of labor in additive manufacturing is not high as the labor cost of traditional production, there is a potential effect of labor on the cost of the final product. Regarding duty, employees can be in charge of taking away the finished product or refilling the filaments.

2.2.5 Energy consumption

Energy consumption could be divided into two parts, machine level and process level as shown in figure 2.3. For a metal AM machine, the energy beam is the most power-hungry component. Distributing the energy used in the AM process in an optimal manner is crucial at the process level[16]. Thermal history, microstructure, defect types, and mechanical properties are all profoundly affected by the energy density presented by process parameters. Indirect embodied energy consumption from material usage is highlighted in the life cycle assessment of energy use. Increasing capacity utilization is one way to lower AM's energy consumption. Optimal component design and AM pre-process planning can both contribute to low energy requirements during production.

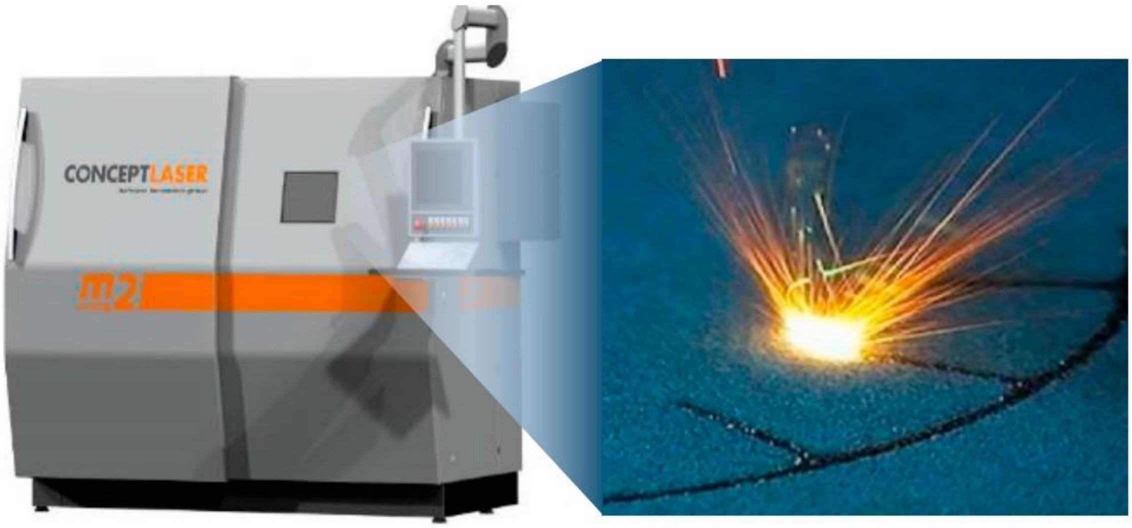

Figure 2.5 a) machine level b) process level

2.3 Additive manufacturing in different sectors

Additive manufacturing has many advantages in many industries due to its high capability to change not only the efficiency of the company but also its competitiveness in the market. Nowadays many industries are adopting AM and increasing their profitability. In this part, some of the sectors will be discussed.

2.3.1 Aerospace

When it comes to the rapid development of 3D printing technology for producing finished products and prototypes, the aviation and aerospace industry has been one of the most influential driving forces. However, due to the stringent standards placed on the aerospace and aviation industries, the materials used must be verified as safe and of the highest quality. In 3D printing, certified high-performance polymers are used. High-performance characteristics ensure the highest quality and longest lifespan in even most aviation settings[17].

The most valuable objectives of the AM in the industry are

- Leadtime
- Cost
- Lightweight
- Complexity

The reason why the complexity is valuable is that in order to achieve the desired functional performance in the intended environment, these designs inevitably involve a high level of complexity, as they typically consist of hundreds, if not thousands, of individual parts. These elements are part of the larger flight system, which may consist of millions of individual parts. In order to achieve structural, flow, thermal, reliability, durability, compatibility, etc., and functional performance, these components must be extremely complex.

The technical and financial efficiency of aerospace structures is both affected by lightweighting. Aerospace structures have physical limits on their technical performance and allowable mission-defined payload, so decreasing the overall mass of the system improves both economic and technical metrics like fuel efficiency, emissions, payload capacity, and range.

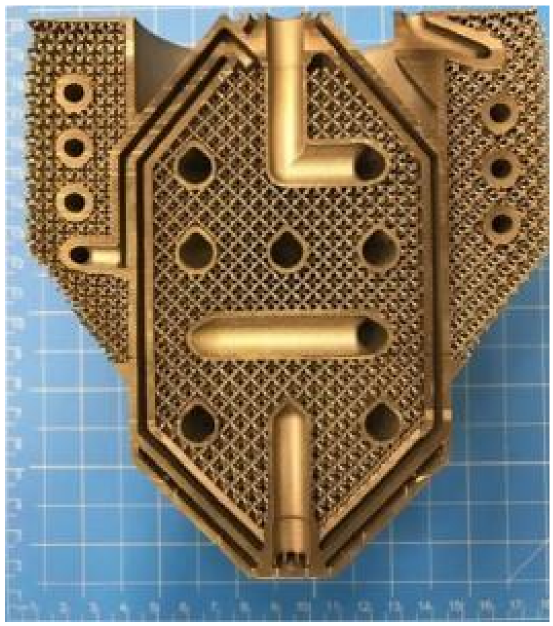

Figure 2.6 Cryo heat exchanger, injector, Condenser, source [18]

2.3.2 Dental Industry

The AM process begins with a digital model, usually produced by a 3D scanner or CAD software, from which the final product is manufactured using one of several AM techniques. When it comes to solving difficult problems, both dentistry and medicine have found solutions in AM technologies. As a result, these tools can now be used to enhance health outcomes for patients. Stereolithography (SLA), commonly used for fabricating aligners, and direct metal laser sintering (DMLS), capable of producing high-quality metal dental crowns and appliance frames, are two of the most prominent technologies in the field of dentistry[19]. In dentistry, patients may need a variety of services, including crowns, implants, and bridges. Dental care can benefit from a number of AM technologies. Dental prostheses are made with the aid of binding jet technology. The amount of drying powder, the amount of binder, the drying time, and the spreading rate of the powder are all measured. The findings demonstrate that it delivers a high-precision implant at a reasonable price and with increased durability. Patient-specific additively manufactured eruption guidance appliances improve patient satisfaction and lower total system cost. The main benefits of the AM in dentistry are reduction in cost, precise implant sizing, capability to check the depth and width of the teeth, and less fabrication time.

Figure 2.7 Clear aligners, one of the most popular orthodontic treatments, source[20]

2.3.3 Automotive industry

The auto industry has long been a leader in leveraging cutting-edge innovations for the good of enterprises at large. The automotive industry has spent decades pondering how to improve its products in light of growing concerns about things like the need for more eco-friendly motors, lowering their carbon footprint, rising production costs, and the need for new innovations. In recent years, additive manufacturing methods have gained widespread popularity in the automotive industry due to their ability to boost the quality and performance of conventional components. Technologies like selective laser sintering, fused deposition modeling, and polyjet 3D printing are allowing for better and faster prototyping in the design phase of new product development and in the precision pre-production of form fit pieces.

Figure 2.8 Additive manufacturing, source[21]

AM has been around for nearly three decades, making it a significant technological innovation. Its significance originates from the fact that it can invert two primary performance compromises that are currently in place. The initial investment needed to reach economies of scale is decreased by AM. Additionally, it allows for more maneuverability and less investment to accomplish the same scope.

2.4 Conclusion

The purpose of this part was to understand the benefits and limitations of additive manufacturing and its role in different sectors of the industry. Regarding the benefits of additive manufacturing, even though the production time depends on the category of the AM, controllability, flexibility, quality, and efficiency are obviously the most advantage of the AM over traditional production, additionally, they create high value to production. With respect to the limitation, the cost and energy consumption are considered the major disadvantages of the production. However, scientists and engineers are working on the limitations of the AM in order to eliminate or improve manufacturing, besides that innovators are finding new solutions to overcome the above-mentioned issues and supply customers with high-quality and lower-priced products.

Chapter 3 3D printers market

In our competitive world, the demand for the 3D market is increasing among companies and in several industries. As a consequence, the market of 3D printers is enlarging and becoming more profitable, and companies are adopting this perspective technology and making innovations to improve it and stay competitive. In this chapter, the printer market including the producers, customers, and revenues will be discussed deeper

3.1 Market

For manufacturing purposes, industries like the auto industry, the healthcare industry, the aerospace industry, and the military are driving innovation in 3D printing. Using additive manufacturing in product development processes is a game-changer for businesses, and the top companies are taking notice. Figure 3.1 given below shows the 3D printing market size including 25 companies, growth rate, and regions.

Report Metric	Details
Estimated Market Size	**USD 12.6 billion**
Projected Market Size	**USD 34.8 billion**
Growth Rate	**CAGR of 22.5%**
Market Size Available for Years	2017-2026
Base Year Considered	2020
Forecast Period	2021-2026
Segments Covered	By Offering, By Technology, By Process, By Application, By Vertical
Geographies Covered	North America, Europe, APAC, Rest of the World
Companies Covered	Stratasys (US), 3D Systems (US), Materialise (Belgium), EOS (Germany), GE Additive (US), ExOne (US), voxeljet (Germany), HP (US), SLM Solutions (Germany), Renishaw (UK), Protolabs (US), CleenGreen3D (Ireland), Optomec (US), Groupe Gorgé (France), Ultimaker (The Netherlands), Beijing Tiertime (China), XYZprinting (Taiwan), Höganäs (Sweden), Covestro (Royal DSM) (Germany), Desktop Metal (US), Nano Dimension (Israel), Formlabs (US), Carbon (US), TRUMPF (Germany), and Markforged (US) are the key players in the 3D printing market. (Total 25 companies)

Figure 3.1 3D printing market based on 25 companies, source:[22]

The table shows an estimation of the market size from 2017 to 2026 and it includes also the growth and segments and companies. According to the research market size will reach 12.6 billion USD while projected one almost 35 billion USD and a growth rate CAGR of 22.5 %. When it comes to regions, North America, Europe, and APAC dominate. Besides that, there are numerous companies in the industry, for instance, Stratasys, 3D Systems both in the US, Materialise in Belgium, and EOS in Germany and others. Additionally, the segment is also divided into by offerings, by technology, by process, by application, and by vertical.

Suppliers of 3D printing services are teaming up with local players and software developers to improve and expand their product lines in order to keep up with the rising worldwide demand for high-end 3D printing and to offer unique solutions to their customers. For instance, Siemens, a global leader in industrial automation and digitalization, and the company recently announced a partnership in June 2019. The purpose of this partnership is to leverage the benefits of Industry 4.0 by integrating ExOne's S-Max Pro with Siemens' Digital technologies[23].

3.2 Producers

Producers of 3D printers are divided into segments such as medical, automotive, aerospace, robotics and etc. In the automotive industry, there are numerous companies which are some of them competing with each other, and others making cooperation in order to stay competitive in the industry. The automotive industry includes following big companies:

- Stratasys
- 3D systems
- Organovo
- Arcam
- SLM solutions
- ExOne

Most of the major players in this market are working hard to meet the growing needs of various sectors by introducing innovative and superior products and services. These well-known businesses are funding R&D to develop innovative products, processes, and materials. They are banding together strategically and working together to create cutting-edge answers. These companies aid expanding businesses by offering services focused on customers. The top firms are similarly eager to supply a wide range of 3D materials for purpose of broadening their reach in all commercial sectors.

In the medical device additive manufacturing market, there are also some leading companies. They are also constantly improving by making investments in R&D and acquiring competencies and knowledge on it. The companies in the industry are below

- Allevi
- EOS
- Materialize
- Stratasys
- GE additive …

3.2 Intellectual property right

One exciting aspect of additive manufacturing is the way in which it exemplifies the overlap of various IP rights. A printer follows the instructions in a digital file that has copyright protection. Objects made possible by AM's 3D printing technology can be certified for design protection, and some of them, like a figurine or vase, are indeed protected by copyright because of their visual appeal. Tools and functional components may also be protected by patents for their novel and innovative technological specifications. However, patents primarily safeguard additive manufacturing printers themselves, as well as the methodologies that they use. The research shows that over the past two decades, patent claims for technologies that make AM possible have increased dramatically, with numerous innovations in machines, materials, and processes. As the demand for 3D printers is increasing year by year, the market is enlarging, which means the competitiveness is rising. As a result, companies have to protect their products from rivals and need to have patents for their products. Figure 3.2 shows the largest number of patent owners in additive manufacturing.

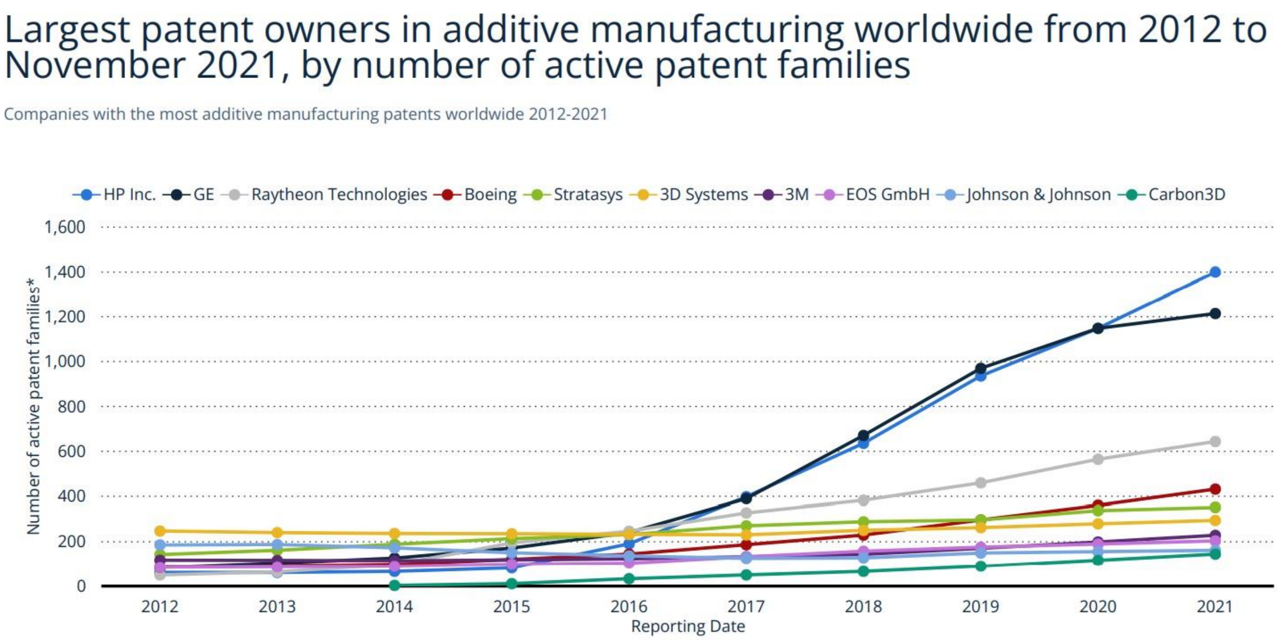

Figure 3.2 Patent ownership from 2012 to 2021 source: Statista [24]

As it is clearly seen that there are 10 world-leading companies in 3D printer manufacturing in the graph, the most patent-owning companies are HP Inc. and GE with 1200 and 1400 active patents respectively. In the 3rd place, Raytheon owns the number of active patents more than 600.

3.3 Key companies in the industry

As we have seen numerous companies above, we will introduce some key players in the market. Additionally, their expenses for Research and Development, revenues will be analyzed in detail.

3.3.1 Stratasys

With cutting-edge 3D printing solutions for sectors like aerospace, automotive, consumer products, and healthcare, Stratasys is at the forefront of the worldwide transition to additive manufacturing. When it comes to 3D printing, Stratasys is pushing the envelope in terms of realism, accuracy, and speed. Stratasys' solutions provide a competitive edge across the entire product value chain through the use of smart and connected 3D printers, polymer materials, a software ecosystem, and parts on demand. Stratasys is trusted by the world's most innovative companies to revolutionize product design, increase the flexibility of manufacturing and supply chains, and enhance healthcare. The company is an American-Israeli company and its headquarters are in Eden Prairie, Minnesota, and Israel, and its current CEO Yoav Zeif, and its chairman Dov Ofer[25]. According to report of Wohler association 2013, the company sold 3026 FDM systems in 2012, and 1855 of them were Dimension, uPrint, and Mojo models[26]. Furthermore, the company makes investments in R&D and Figure 3.3 shows how much it spent from 2008 to 2021.

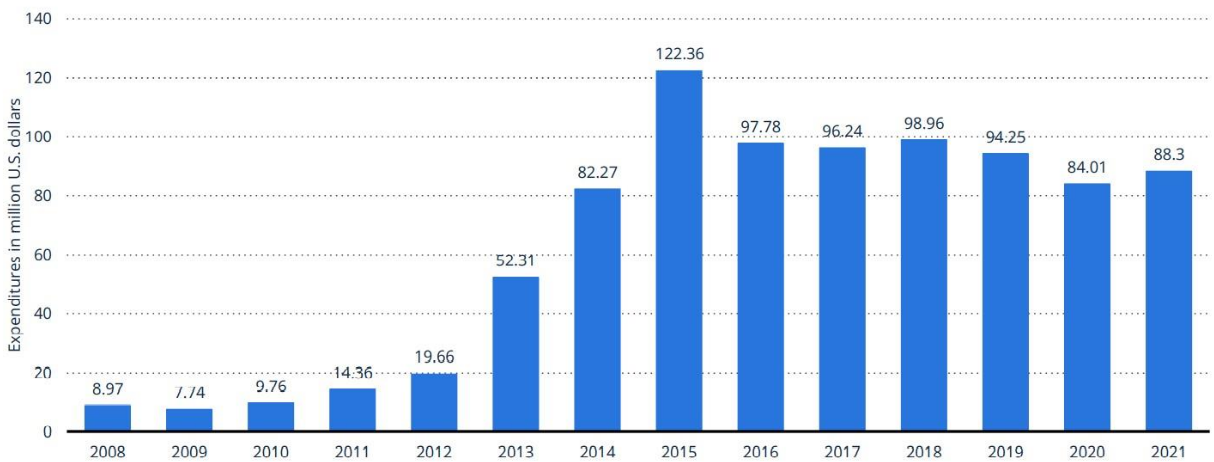

Figure 3.3 Stratasys Ltd.'s expenses in R&D, source: Statista [27]

The graph shows how much the company spent on R&D from 2008 to 2021. It is possible to see that expenditures grew rapidly from 2008 to 2015, reaching 122.36 million U.S. dollars and between 2017 and 2021 they spent almost stable from 97.78 million U.S. dollars to 88.3 million U.S. dollars

Regarding its revenues, Figure 3.4 shows how much the company made revenue between 2008 and 2021

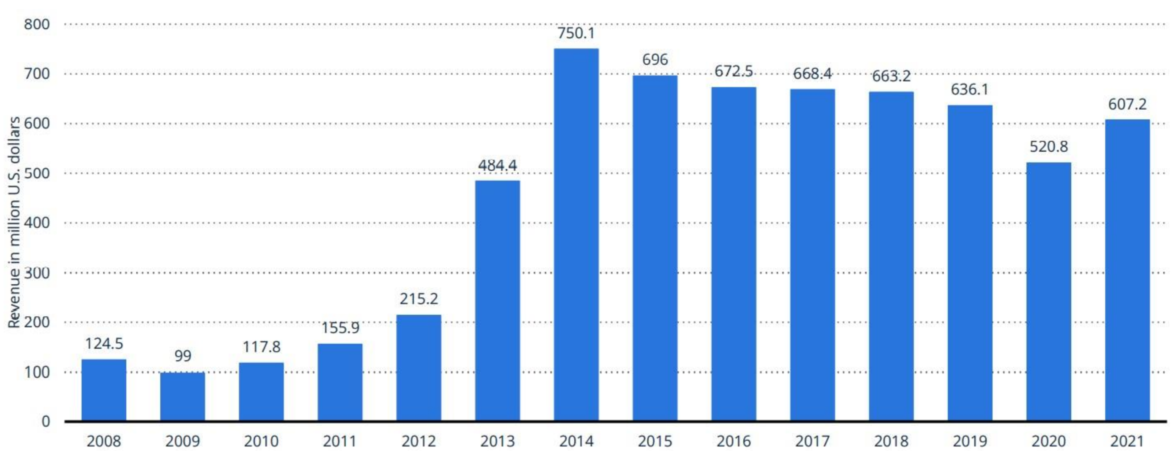

Figure 3.4 Stratasys Ltd's revenue from 2008 to 2021, source: Statista [28]

The company revenue reached 750.1 million U.S. dollars in 2014, after that there was little decrease in revenue from 750 to 607 million U.S. dollars.

3.3.2 3D Systems

The company was established in the industry in 1986 as a 3D printer manufacturer. The company is one of the leading companies in the industry around the world. Its headquarter is located in Rock Hill, South Carolina. The company deals with selling 3D printers, the materials used in the industry, and even 3D printing services. Furthermore, they have a patent for the stereolithography technique, which uses ultraviolet lasers in order to make complex shapes and parts, and it enlarged its capacity in the industry by innovating multi-jet printing, color-jet printing and etc[23]. The market capitalization of the company is $1.19 billion. Figure 3.5 illustrates the expenses of the company according to data on Statista

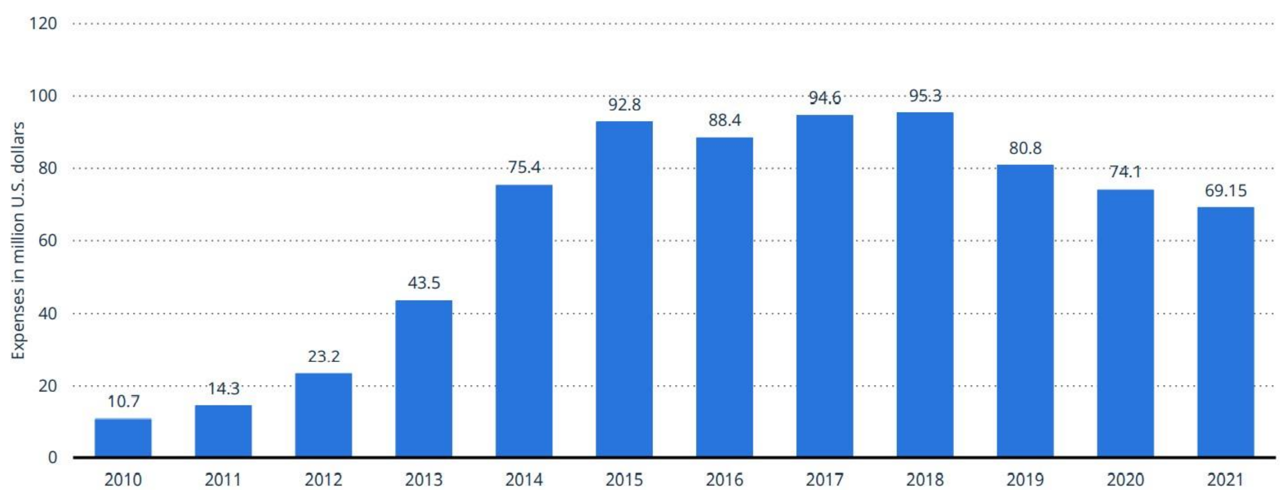

Figure 3.5 3D systems' expenses for R&D from 2010 to 2021, source: Statista [29]

It is clearly seen that the expenditure dramatically increased from $10.7 million to $92.8 million between 2010 and 2015. However, there was not a big change in the expenses from 2015 to 2018, and there was a slight decrease from $95.3 million to $69.15 million in the last 3 years.

Regarding revenues, the company made relatively high revenue due to its selling, services, and materials. Figure 3.6 demonstrates the total revenue of the company from 2010 to 2021

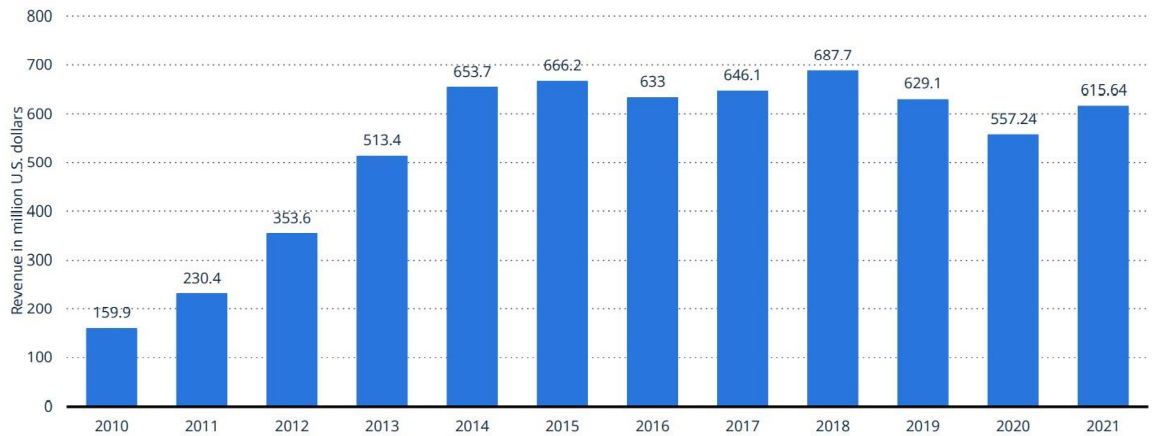

Figure 3.610 3D systems' total revenue from 2010 to 2021, source: Statista[30]

As we can clearly see in the graph, the revenue dramatically increased from $159.9 million to $653.7 million between 2010 and 2014 while it remained almost stable at around $650 million till 2021.

3.3.3 ExOne

ExOne is also a leading manufacturer in the 3D printing industry, serving clients in a wide range of markets. It also produces 3D-printed products on demand for business customers. The ExOne 3D printers use binder jetting technology to fuse powder particles of materials like metal or ceramics and other products. The ExOne headquarters are located in North Huntingdon, Pennsylvania. Figure 3.7 shows the expenditure of the company in the last 10 years

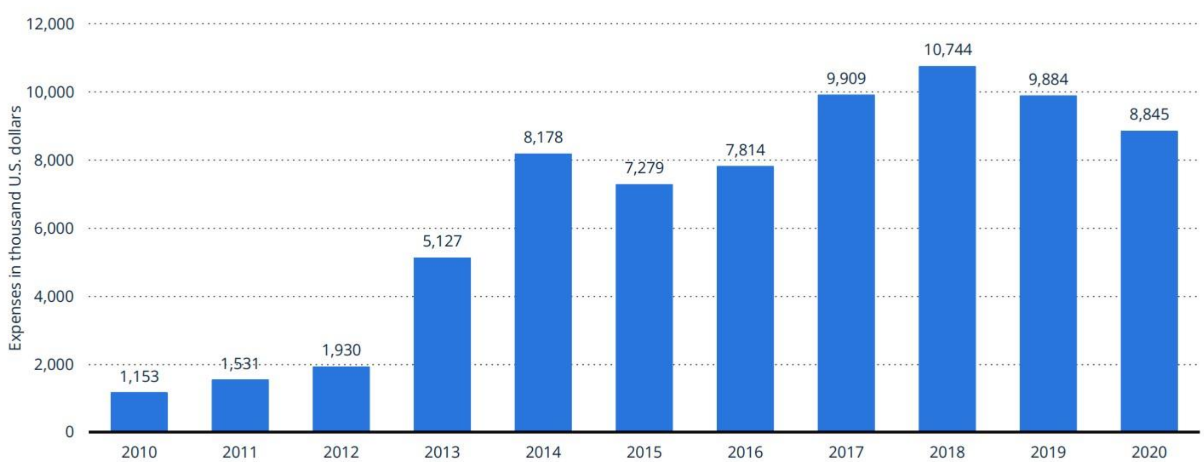

Figure 3.7 ExOne's expenses for R&D from 2010 to 2020, source: Statista [31]

The company was not rich as other above-introduced companies and it is clearly seen that ExOne spent from $1,153 thousand to $8,178 thousand between 2010 and 2014. Besides that, it kept spending a lot from 2014 to 2020. We can understand from the expense graph that all the companies spent a huge amount of money from 2015 to 2020 to compete and stay competitive in the industry.

Regarding revenue, the company relatively made high revenue in 10 years. Figure 3.8 below gives detailed information about it.

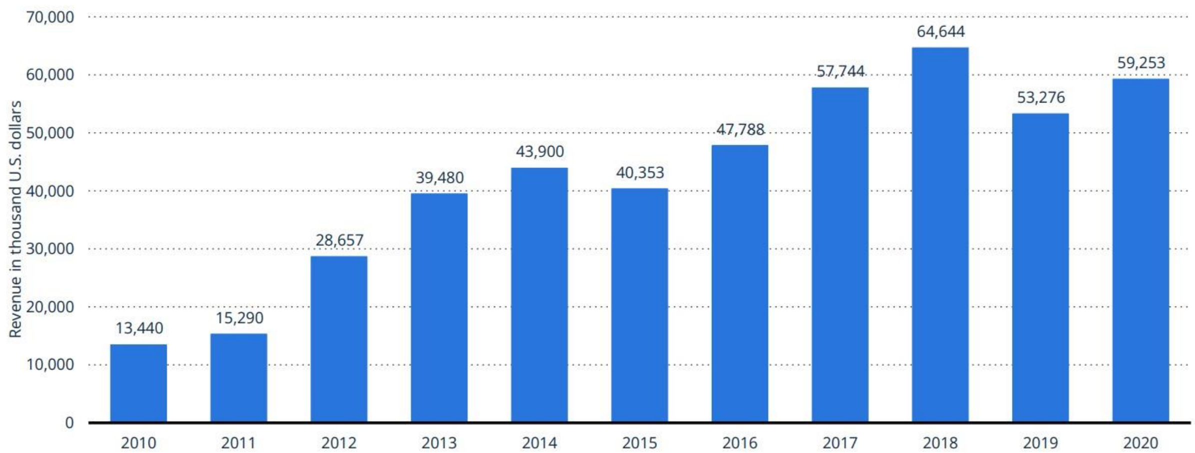

Figure 3.8 ExOne's total revenue from 2010 to 2020, source: Statista [32]

We can clearly see that the revenue gradually increased from $13,400 to $64,644 between 2010 and 2018. However, there was a slight decrease to $59,253 in the last two years. It is possible to understand from all of the graphs we studied above that the companies achieved a high amount of revenue whenever they spent a lot on Research and Development, which brought them to get competitiveness in the industry.

3.3 Sales revenues worldwide by Industry

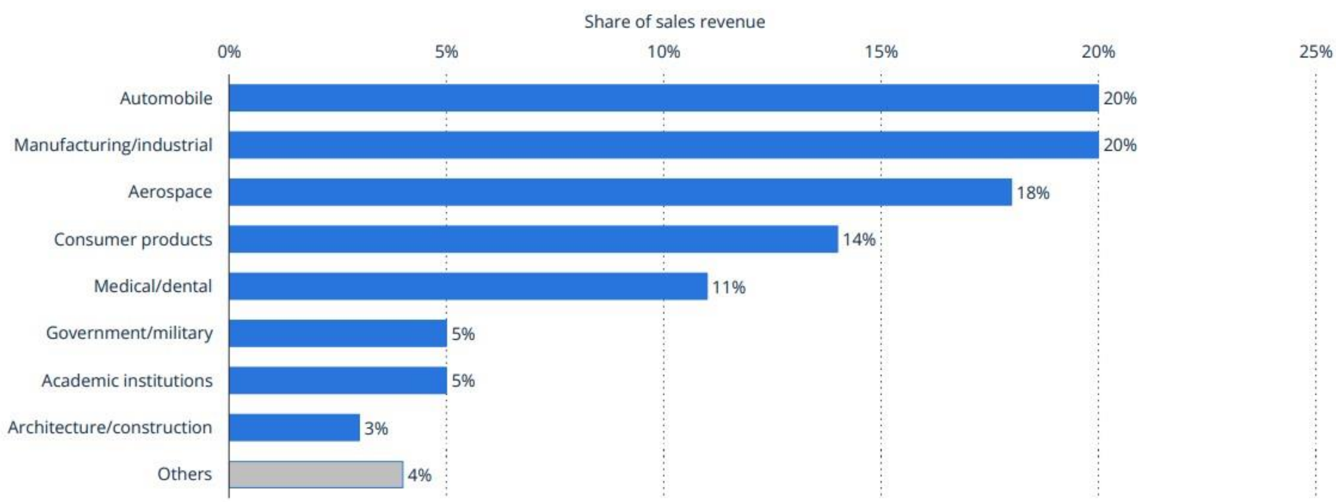

Figure 3.9 Distribution of sales revenue in 2019, source: Statista [33]

In the additive manufacturing market, the automobile industry got 20% of the total sales revenues worldwide, similarly the Manufacturing/industrial achieved also the same amount as the automobile.

Additionally, 18% of the total revenues worldwide was generated by Aerospace. In third place, Consumer products accounted for owning 14% of the total revenues in 2019.

3.4 Consumers

The additive manufacturing industry is a huge field and comprises different sectors worldwide. The market for 3D-printed consumer goods is rapidly expanding within the realm of additive manufacturing. Hundreds of thousands of products are now using 3D-printed parts that were either mass-produced or mass-customized. The market for 3D-printed consumer goods is rapidly expanding within the realm of additive manufacturing. Hundreds of thousands of products are now using 3D-printed parts that were either massively produced or customized. First of all, it is better to understand the meaning of the term “Consumer”. A consumer can be a person or a group of people who buy or use a product or service for their own needs rather than for resale or further production. When it comes to the sales distribution chain, they are the consumers at the end.

According to research by Thomas D [34], distributed manufacture, which can be achieved with additive manufacturing, can bring manufacturing closer to the purchaser for some goods. Additive manufacturing, in contrast to traditional methods, can produce a finished product in a single construction process, exposes workers to fewer potentially dangerous conditions, and generates less dangerous waste, allowing for production to take place outside of traditional industrial spaces. Besides that, to be attractive to consumers in the additive manufacturing industry it is mandatory to compete with rivals, in order to achieve high attractiveness in the market, the company should compete with others on cost and quality. Figure 3.10 shows how much consumers spent on 3D printers in 2015 and 2018

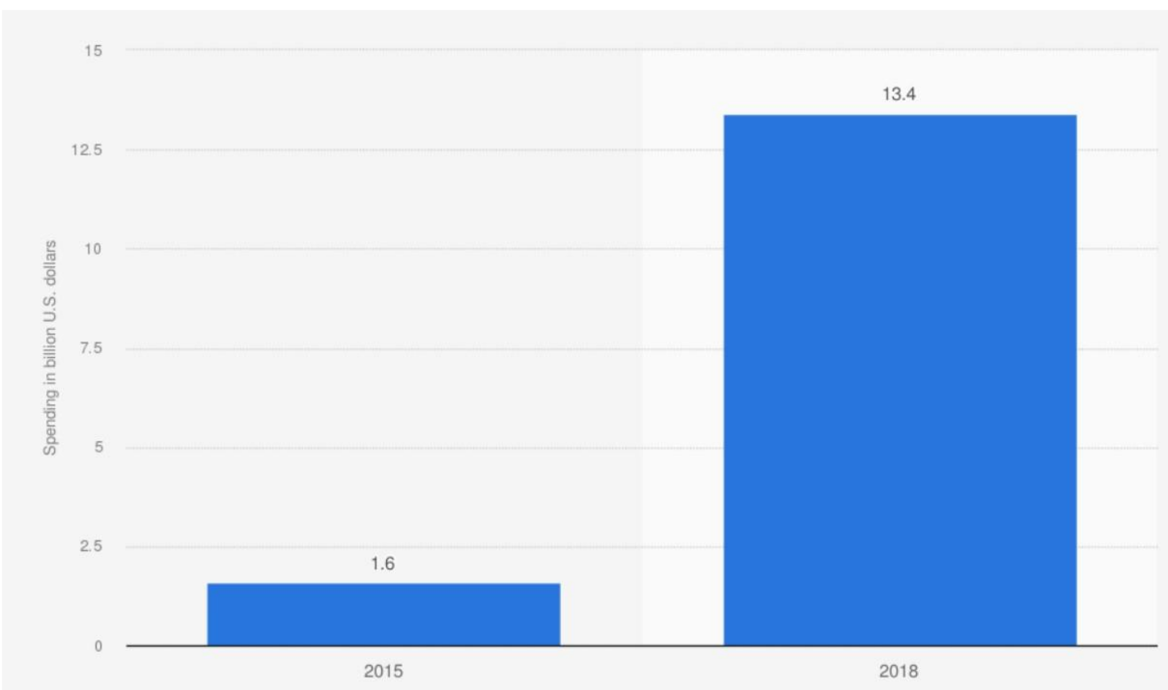

Figure 3.10 Consumer expenditure on 3D printers, source: Statista [35]

This graph illustrates the expenditure of consumers worldwide on 3D printers in 2015 and 2018. End-users spent $1.6 billion in 2015 while in 2018 they spent eight times more than in 2015, with reaching $13.4 billion. It is a remarkable rise in expenditure obviously because there are numerous reasons lying behind it. One of the main reasons for this is an increase in the market where those consumers are.

Additionally, there are a number of manufacturers of 3D printers, competing in the market. For instance, many of the world's most successful businesses rely on Stratasys to help them maintain a competitive edge. Aerospace and automotive industry giants, cutting-edge medical startups, and tech industry titans all benefit from the use of these tried-and-true technologies because it enables them to streamline their processes, think outside the box, and save money.

3.4 Global investments by application

Some would argue that manufacturing is one of the most vital sectors of our global economy. A certain amount of progress is stymied by the burden of that label, unfortunately. Many companies prefer to stick with proven methods for as long as they can before investing in cutting-edge technology. It's understandable to err on the side of caution when implementing new advanced technologies or methods because opportunity costs can skyrocket. However, this has unintended consequences, especially with regard to capital expenditures, for a relatively new and exciting innovation such as additive manufacturing (AM). If businesses don't put money into developing new technologies, they won't get better, and if it doesn't get better, fewer companies will want to integrate them into their daily operations. Here is where outside investment from both private companies and government intervention can make a significant impact in facilitating the widespread adoption of new technology such as AM. Furthermore, according to Statista, Figure 3.11 illustrates the investment in the industry by application in 2019

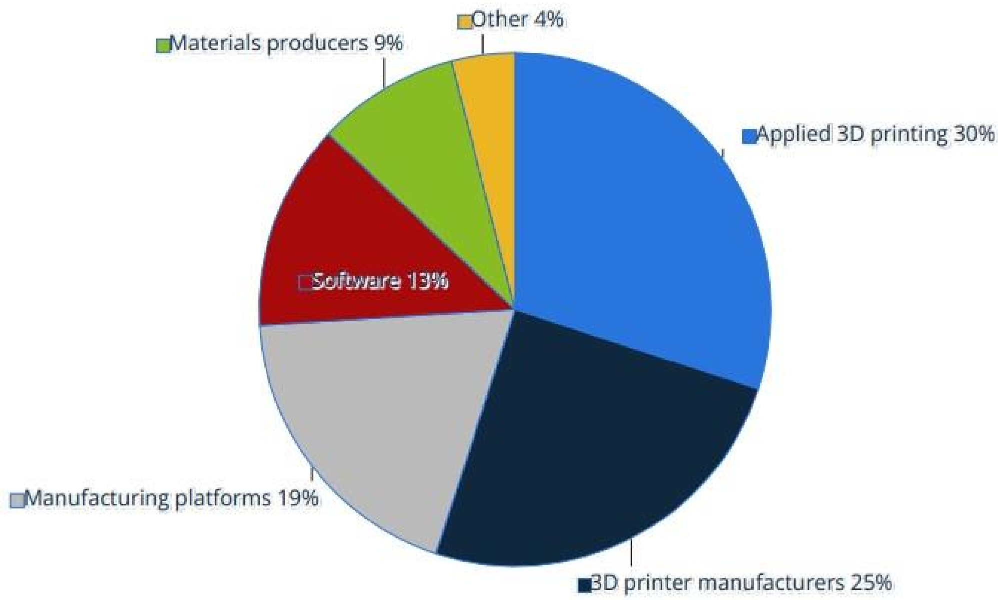

Figure 3.11 Investments in 3D printing, source: Statista [36]

It is clearly seen that Applied 3D printing accounts for the most invested applied field in the pie chart, with 30%, while 3D printer manufacturers invested 25% of the total investments. Besides that, since the software is the core of the additive manufacturing industry, it also invested in development at 13% and, material producers and manufacturing platforms invested at 9% and 19% respectively.

3.5 Segments

As additive manufacturing has developed, 3D-printed components have graduated from the prototyping phase and entered the mainstream manufacturing sector. These essential procedures allow for the creation of ideas that were previously impossible in the industrial sector. Additive manufacturing's revolutionary capabilities have already had a profound impact on five specific industries. In this section, some of these 5 industries will be discussed, and they are

1. Medical device
2. Aerospace
3. Transportation
4. Energy
5. Consumer products

3.5.1 Medical device

Additive manufacturing technologies are being used by the fast-evolving medical industry to bring advances to clinicians, patients, and academic institutions. Greater and biodegradable 3D printing materials, ranging from hard to elastic and invisible to transparent, are being put to use by the medical manufacturing industry to create highly individualized products. Moreover, Further research into biomaterial and the procedures used to manufacture parts could pave the way for more individualized implants, life-saving technologies, and pre-surgical instruments, all of which aim to improve patient outcomes. In Figure 3.12 we can see

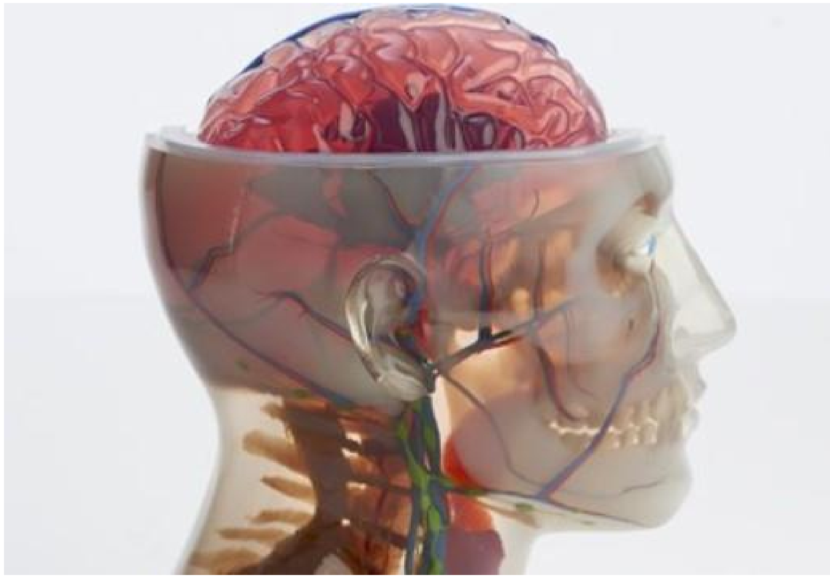

Figure 3.1211 Realistic concept model by Polyjet multi-color, source [37]

If we look at Latin America's medical device 3D printing market, it is one of the biggest markets in the world, and Figure 3.13 shows the market value forecast between 2022 and 2027

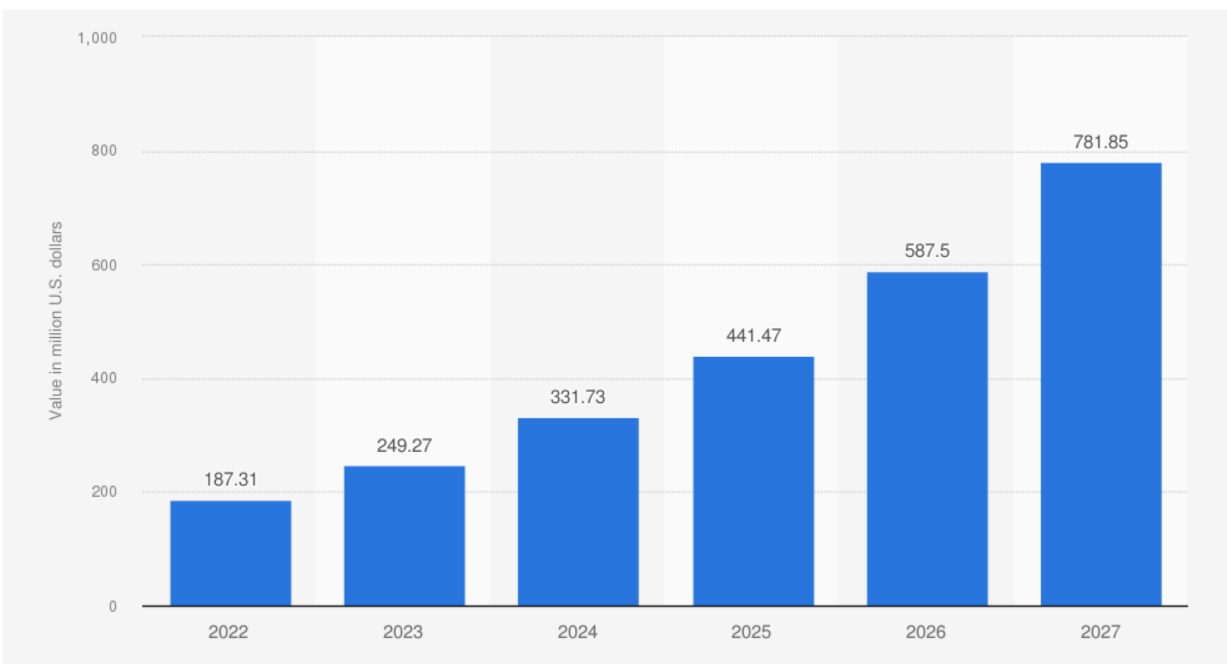

Figure 3.13 12 Market value forecast, source: Statista [38]

It is clearly seen that the market value of 3D printers in Latin America accounted for 187.31 million U.S. dollars in 2022 while the market value will be expected to reach 781.85 million U.S. dollars in 2027 with an increase of 317 percent in five years.

3.5.2 Aerospace

The aerospace sector, as a producer of high-priced goods, has historically been a key figure in the spread of cutting-edge production techniques. Companies in the aerospace industry were early adopters of additive manufacturing. This field is home to some of the most stringent performance criteria in the business world, therefore components must be able to withstand extreme conditions. Engineers working on both civilian and military aerospace systems require flight-worthy components produced from high-quality materials. The complexity and consolidation of 3D-printed parts result in high strength. The overall weight can be reduced by using less material and consolidating designs, which is a crucial factor in the aircraft industry. AM's advantages for large corporations keep driving the development of novel airplane designs and uses.

Figure 3.14 shows the additive manufacturing market size by different sectors from 2013 to 2019. As it is clearly seen that the biggest market size in additive manufacturing is the aerospace sector, and it accounted for almost 2 billion U.S. dollars in 2019. Moreover, the whole market size reached almost 12 billion U.S. dollars in 2019, with a great increase in annual growth rate.

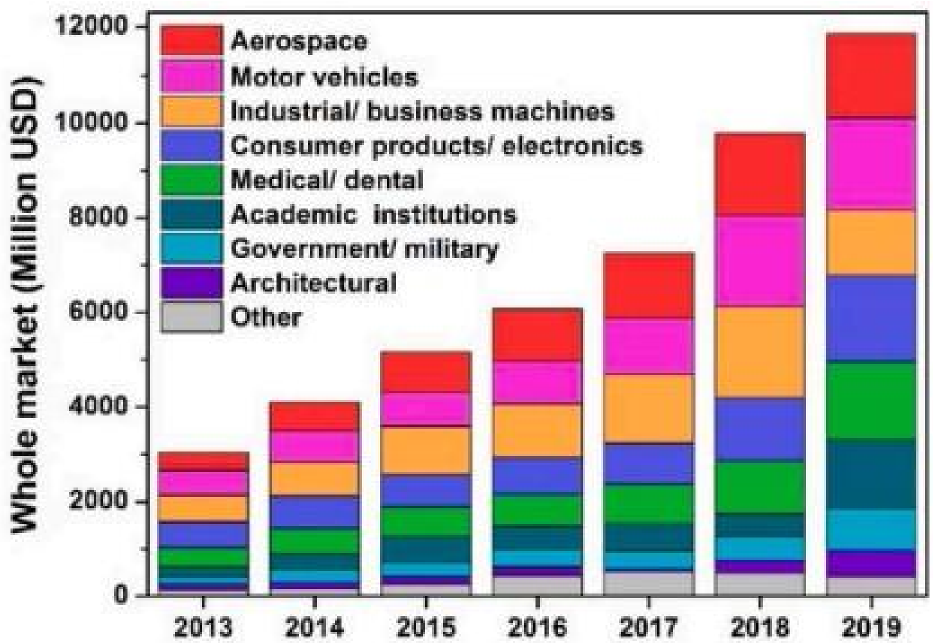

Figure 3.14 Different sectors by market size in Additive manufacturing, source [39]

3.5.3 Transportation

The fast lane requires tolerance to harsh conditions, such as high speeds and high temperatures. The transportation sector requires components that can withstand rigorous testing while remaining lightweight enough to cut down on unwanted drag. Transportation companies are just scratching the surface of what can be additively manufactured for their vehicles with the wide range of durable, high-temperature components and additive manufacturing technologies. Furthermore, Companies in the logistics and transportation sectors have the highest hopes that AM will help them better meet customer needs in the future. They understand that AM will open up new opportunities and increase customer demand for things like lower prices and shorter wait times. Many anticipate a time when they will not only deliver a component and moreover produce it with AM, using a design retained in their electronic warehouse, due to the anticipated downstream shift in manufacturing.

3.6 Experiences of countries with AM

In 2019 some developed countries around the world were surveyed with experience in additive manufacturing, with 3 categories which are if they “Already applied”, “Consider to apply” or “Do not consider applying”. Figure 3.15 below illustrates the result of the survey.

As we can clearly see from the Figure 3.15, South Korea accounted for 81 % of Already applied additive manufacturing in their manufacturing processes, while 14 % of them had yet to consider applying AM. Additionally, the second largest country that Already applied AM technologies in their production was China with 78%, and 18% considering applying but 5% Not considering yet applying. One of the largest countries from Europe that Already applied AM technologies was Belgium/France with 74%, and 21% Considering applying, but lower Do not consider applying as South Korea and China with 5%. Moreover, Spain and Italy already applied additive manufacturing technologies with 42% which was lower than other selected countries due to some limitations in the supply chain or from the government.

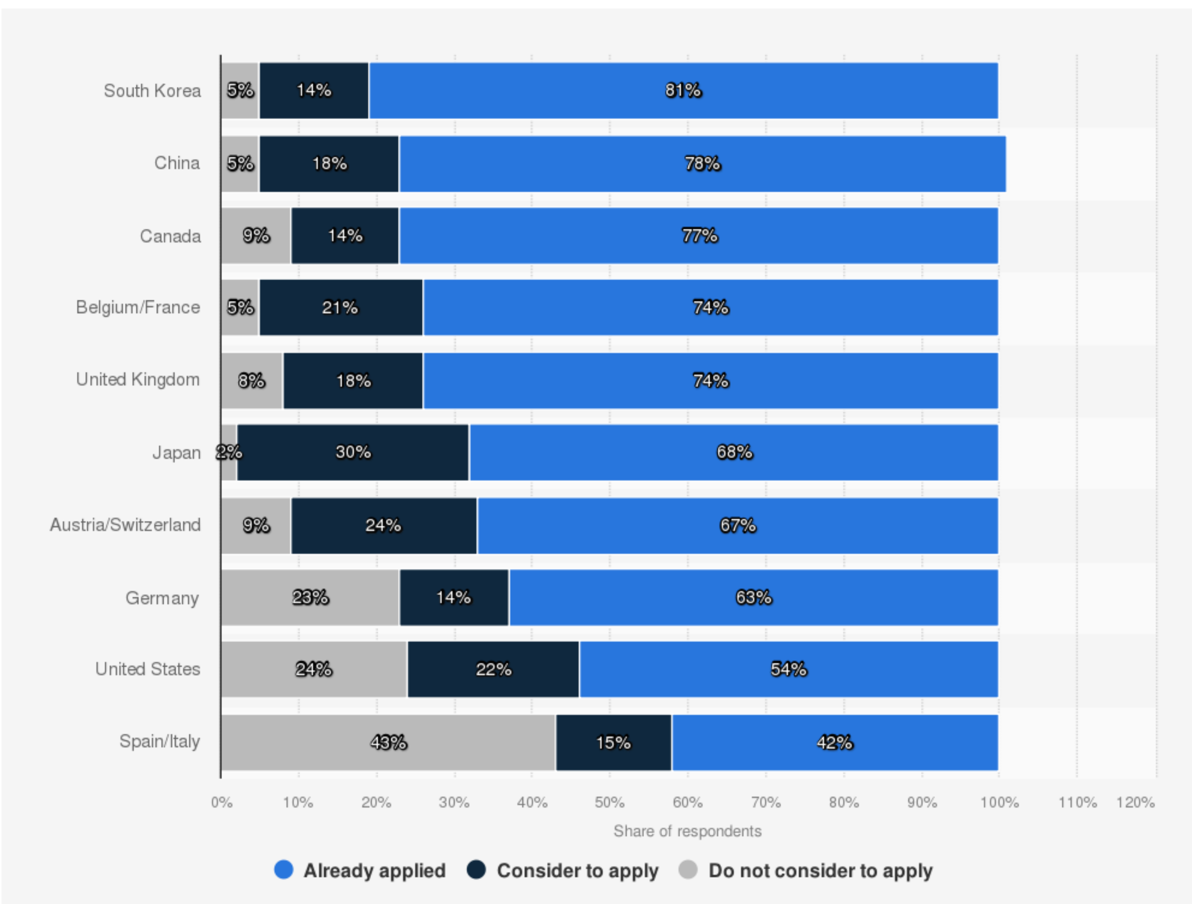

Figure 3.15 Experience of countries around the world, source: Statista [40]

3.7 Metal 3D printing market

When it comes to the Metal 3D printing market, it is also one of the biggest industries in the world. It is also the most competitive market and requires a lot of investment into it. North America and Europe are the biggest players and game-changers in the industry since they have good supply chains, economies of scale, economies of learning, and knowledge about it. However, there are other countries also competing in the industry world. Figure 3.16 shows the value of the metal 3D printing market by region in 2019, and we can see which countries are in the market.

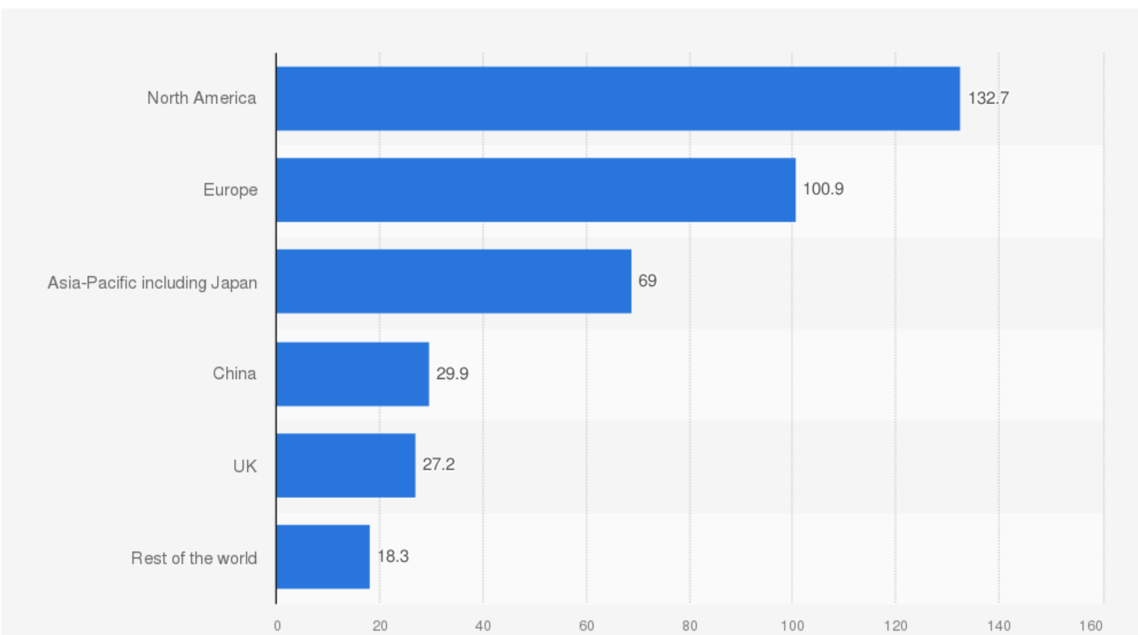

Figure 3.16 Value of the metal 3D printing market, source: Statista[41]

According to Figure 4.7, we can easily understand that the biggest market value of the metal sector was owned by North America with 132.7 million U.S. dollars in 2019, while Europe was the second largest one, with a market value estimated at almost 101 million U.S. dollars, and the third one was Asia-Pacific with Japan accounted for 69 million U.S. dollars of market value. In addition to them, China and UK had 29.9 and 27.2 million U.S. dollars of market value respectively. However, the rest of the world had 18.3 million U.S. dollars in market value.

3.7 E-commerce

First of all, it is mandatory to understand what is the meaning of e-commerce and its role in the market. According to Investopedia, E-commerce, or online commerce, is the exchange of goods and services over the internet. These days, you can buy just about anything online, which means that online marketplaces are often crowded with numerous competing products. It's an alternative to traditional stores, though some companies choose to do both. There are many different types of e-commerce markets, such as B2B, C2C, and C2B. Consumer behavior in regard to purchasing and using goods and services has been revolutionized by the rise of the internet. More and more consumers are placing orders for products online and having them shipped directly to their homes thanks to the widespread adoption of computers and mobile devices. Because of this, the traditional shopping experience has been altered. The meteoric rise of online marketplaces like Amazon and Alibaba has compelled more established stores to adapt. Additionally, One growing trend in the e-commerce industry is the participation of private individuals selling their wares through their own internet sites. Also, websites like eBay and Etsy facilitate commerce between numerous consumers and sellers. Figure 3.17 shows the share of worldwide retailers of e-commerce in 2021

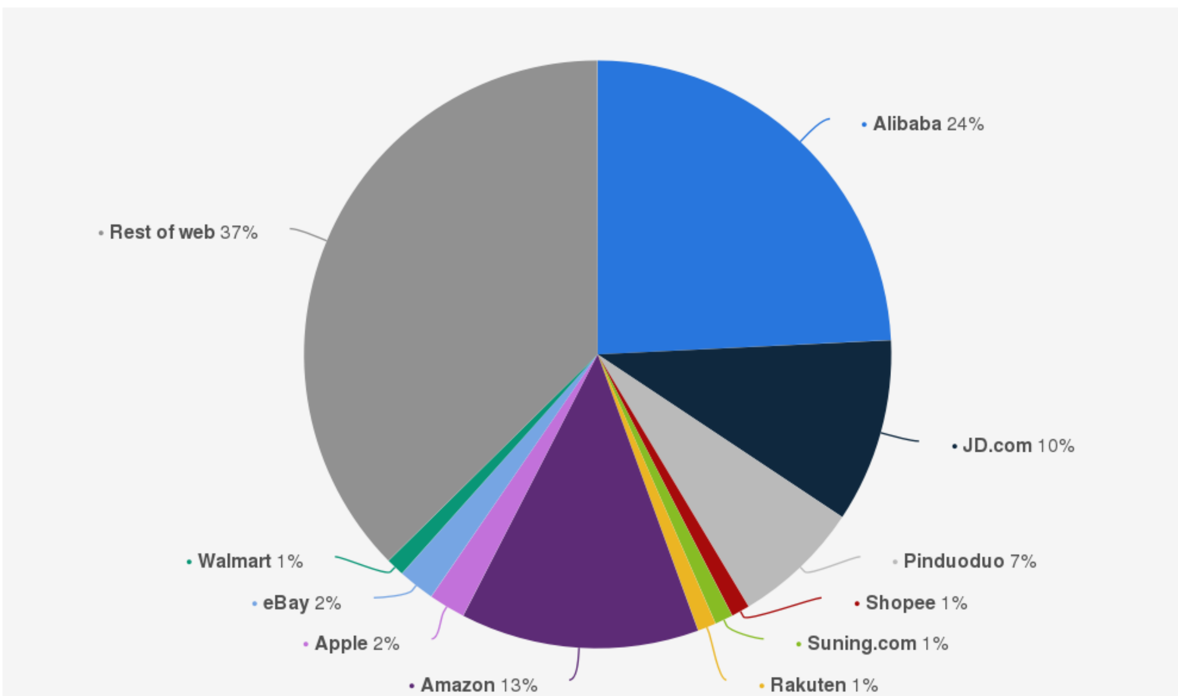

Figure 3.17 Market share of worldwide e-retailers in 2021, source: Statista [42]

As we can see in the figure, there are many e-retailers in the world, such as Alibaba, eBay, Amazon and etc. it is clearly seen that Alibaba is the most shareholder in the market, with 24%, and gives advantages of doing business, like Business to business, consumer to consumer, and business to consumer as mentioned above. Amazon is the second largest one in the world, owning 13% market share of the world.

Regarding the 3D printers in e-commerce, e-commerce is one of the best ways to keep and stay competitive in the market and provide the best services to customers, even if they are far distance. Therefore, One reason for this is that, unlike traditional manufacturing methods, 3D printing can be located relatively close to the point of consumption or use. Similar to how Amazon runs its company, 3D printing's customizability and the ability to produce small production batches on demand is a quite certain way to attract consumers, and minimize stocks.

3.8 3D printer price

In this part, the prices of different types of 3D printers will be discussed, and their prices change according to their type, for which reason you use it, for example, hobby, enthusiasm, or industry, and also brands, accordingly the quality. Furthermore, prices of Fused Deposition Modeling (FDM), Stereolithography(SLA), and Selective Laser Sintering (SLS) will be introduced according to Formlab[43]

FDM 3D printing type also introduced above and known as Material extrusion is one of the common methods of additive manufacturing. The price changes depending on the usage, as a hobby or industry. The starting price is $200 for hobbyists, and it is like toys and you should assemble them after purchasing, besides, it takes much time respectively to assemble and calibrate. However, professional printers cost much more than hobbyist ones, and the price ranges from $2500 to $10000 to more. However, the quality is accordingly worthy of buying and does not take to assemble and calibrate since the printer companies send it ready to use, and it has the advantage of that you can have the possibility to use it with a variety of materials.

Regarding Stereolithography, as it is mostly used for complex shapes and in large industries, its price is more expensive than FDM printers, starting from $3750 for industrial quality and $11000 for Large manufacturing. Besides, Figure 3.18 below illustrates different types of products made from a variety of materials

Figure 3.18 Variety of products made by SLA

SLS (Selective Laser Sintering) is also used for printing complex shapes and therefore that type of 3D printer costs more expensive than FDM, like SLA. 3D printers, which are industrial usage, costs starting from $18500 and around $30000 with additional costs such as setup.

3.9 Conclusion

This chapter focused on assessing the 3D printers market from different views. First, I started introducing the market and showing different industries such as aerospace, healthcare, and automotive, and their role in the industry. Besides that, some leading companies such as Stratasys, and 3D Systems, have been introduced in general, and their revenues and expenses have been also analyzed according to data in Statista. Furthermore, Intellectual property plays a major role in additive manufacturing and provided some information about it in the chapter. According to research, Hp Inc. is one of the most patent owners among its competitors in 2021.

3D printers became key players in big industries and manufacturing to get high quality and competitiveness, and some reasons why they became a key player in the industry were mentioned in this chapter. Although 3D printers have some disadvantages over traditional manufacturing, such as the expensive cost of the printers, and excessive printing time, the industry has integrated into many manufacturing industries due to the fact that it has also many advantages, like printing complex shapes, efficiency, and flexibility. Besides, one of the limitations which additive manufacturing companies are facing is the cost of services by 3D printer companies due to material costs, for that reason, currently, scientists and technologies are making innovations for materials and tools, and improving 3D printers to cut manufacturing costs.

Regarding the competition among the 3D printer companies, in the chapter above there were given many companies such as Stratasys and 3D Systems. As we analyzed the competition is so high, and the market is divided into segments, such as hobbyists, enthusiasts, professionals, and industrial purposes. They are offering 3D printers to different segments, with different services and prices accordingly. In order to get more profit and stay competitive in the market, companies are making facilities for end-users, for example, hobbyists receive their 3D printers nicely packaged, but not calibrated, and not automatic and semi-assembled for relatively lower prices than others, and end-users have to take time to assemble and calibrate it. However, the professional segment gets their 3D printers ready to use and already calibrate, besides that, they have the possibility to have 24/7 customer service.

Chapter 4 Additive manufacturing in the automotive sector

Chapter 4 is focused on additive manufacturing in the automotive sector, and it will be discussed more deeply. As additive manufacturing became one of the key game changers in that sector, the automotive sector has been chosen, and in that chapter the role of the AM, which companies that have integrated AM technologies in manufacturing processes, which parts of the cars and others will be introduced.

4.1 Introduction to the automotive sector

Automotive is a common term for companies and activities associated with manufacturing motor vehicles. The automotive sector is one of the biggest and most profitable and developing industries in the world. It includes many industries, such as passenger automobiles, vans, and even light trucks. Since the demand for automobiles is increasing, the competition among companies is getting high also. Besides that, historically, the main part of the automobile is its internal combustion engine which requires too much time and knowledge to build, and there are many companies producing internal combustion engine ICE, such as Honda, Toyota, Volkswagen, and Hyundai. However, a new paradigm is emerging, which is a disruptive innovation in the automobile industry, and this new paradigm is electric engines, and electric vehicles EVs. Furthermore, there are many advantages of EVs, one of them being a reduction in carbon emissions and environmentally friendly cars by electrifying automobiles and increasing efficiency in many ways, like reducing the total weight with the introduction of new lightweight materials, therefore, the world is adapting the electric cars.

Figure 4.1 American Motors Corporation: Rambler, source: Encyclopedia Britannica [44]

Figure 4.2 Electric car: Model Y, source: Encyclopedia Britannica [45]

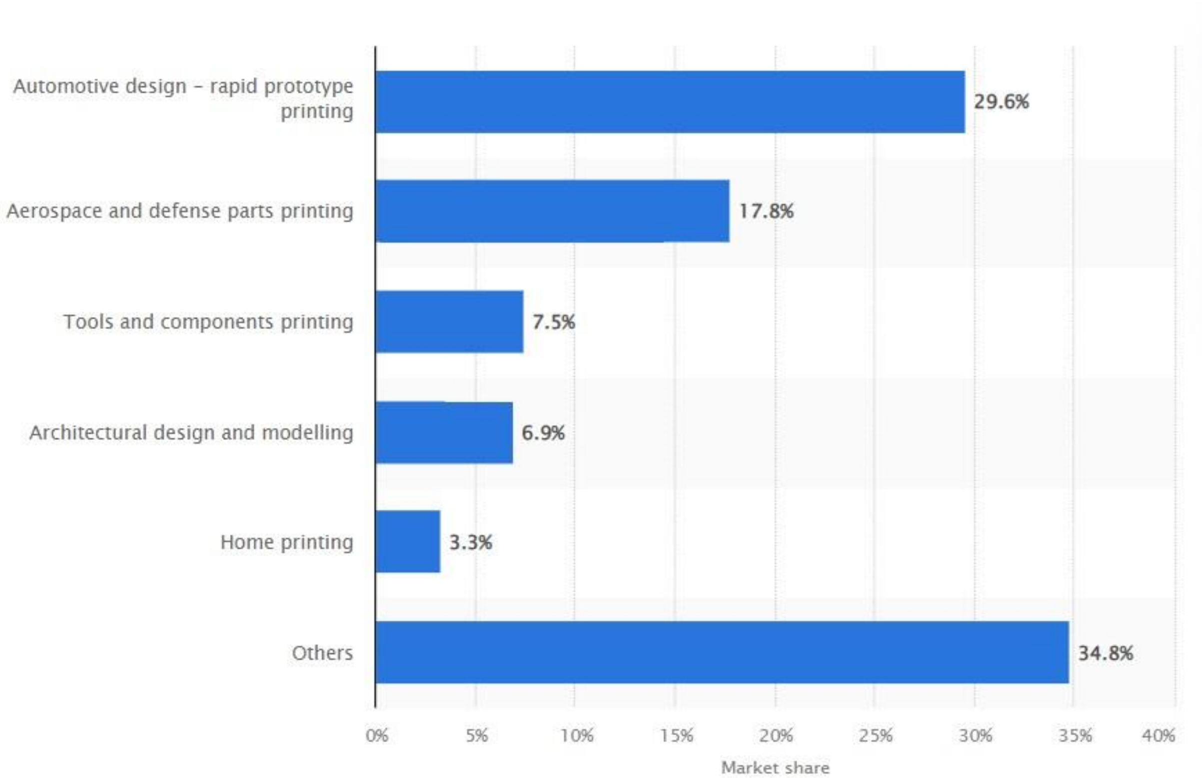

Figure 4.3 3D printing market distribution worldwide in 2016, source: Statista [46]

Additive manufacturing is becoming more and more popular, and industries are integrating it into manufacturing processes due to its many advantages even if they are costly. Figure 4.3 shows the market distribution of 3D printers worldwide in 2016. As we can see from the graph clearly, automotive design and rapid prototype printing own the most percentage of the market share worldwide at 29.6% while aerospace and defense part printing accounts for 17.8%.

4.2 Current status of additive manufacturing in the automotive industry

Additive manufacturing plays a major role in the automotive industry. In automotive manufacturing, almost all types of additive manufacturing processes are currently being used to produce automobile components and parts. It is very useful when it comes to manufacturing complex shapes and even engine parts. Additionally, the auto industry stands to benefit greatly from AM, and manufacturers are looking into using it in two different ways right now, first one is a product innovation driver and the other is a supply chain transformation driver[47].

For the product innovation driver, Using 3-D printing, automakers can quickly test out new prototypes and create a wide range of prototypes, some of which wouldn't be feasible using conventional manufacturing methods. The design freedom of additively manufactured components is greater than that of products made using more conventional methods, according to a study by Deloitte. Because of this adaptability, it is possible to incorporate more features into a product's production run, including electrical wiring that is already embedded in the product, intricate geometries, and lighter weights. It is impossible to produce these goods using conventional methods.

Regarding the supply chain transformation driver, Additive manufacturing offers the possibility for automakers to produce some of the final assembly components they use in their automobiles. The company will be able to reduce the usually lengthy period between developing a product and releasing it to the public. Additionally, the reduced stocking and handling costs that result from AM-manufactured lightweight elements can be offset by the lower costs associated with on-demand and local production. For instance, using additive manufacturing, Ford was able to cut the time and money needed to develop a prototype of an engine manifold from four months and half a million dollars to just a few days and three thousand dollars. Additive manufacturing has made mass customization feasible, which will become a competitive differentiator for the industry's top players in the automotive sector.

4.3 Advantages of 3D printers in the automotive industry

In the automotive industry, 3D printers are used widely in manufacturing processes, and in this section, there will be introduced some benefits of 3D printers which help manufacturers to increase the quality of their products and decrease their prices of them[48].

4.3.1 Time reduction in the product development phase

Product development organizations typically go through a number of revisions in the design phase before settling on a single version. AM's ability to mass-produce variants of a product at low extra cost is a huge boon to the automotive industry, which can use physical models to refine its product designs. A well-known tire manufacturer, for instance, uses AM to quickly create prototypes during the design phase so that they can compare the feel of different options before settling on the best one. The prototypes help the business in two ways: they allow for individualized solutions in response to OEM requirements and they facilitate brand separation. The company's OEM customers benefit from the physical models because they can see the product in action, unlike their competitors who may only be able to share design specifications and plans.

4.3.2 Achieving higher quality via rapid prototyping

Additive manufacturing helps manufacturers to make prototypes of the products well in advance of the actual final product and check for flaws before starting mass production schedules. The adaptability of additive manufacturing's design allows manufacturers to create and test a wide variety of prototypes. Besides that, in the production processes of car manufacturers like General motors one of the common additive manufacturing technologies, SLS (selective laser sintering) and SLA (stereolithography) are used in the design phase throughout all of its practical fields of product development such as design, production, engineering with the ability of quick iterations.

Figure 4.4 GM manufacturing engineer Benjamin LeBlanc inspects a 3D printer, source [49]

4.3.3 Customization of tooling

One of the most crucial manufacturing processes in production is tooling and the flexibility of the tooling plays a major role in production since it gives the opportunity to make high-quality products and save production time as well. With the help of additive manufacturing, it is possible to customize the tools also and this is one of the best advantages of AM. Therefore, many big automobile manufacturing companies are using additive manufacturing. For instance, BMW uses additive manufacturing in direct manufacturing to build hand tools in the process of testing and assembling. Additionally, the company announced that customized tools helped to decrease overall production costs by half and also projected duration also by 92%, which is a great achievement in the automotive industry.

4.3.4 Measurements on demand

Devices that can take measurements can be printed out on a 3D printer. To take one example, a single 3D-printed tool can be used to measure multiple points along a headlight or taillight before it is assembled. This kind of technology has been introduced by Stratasys and Stratasys combined three separate tools into one 3D-printed tool to make this, and also it can be printed by FDM technology. Contributing to better functionality and shorter measurement times. The accuracy of the measurements was improved with the aid of this instrument. The 3D printed tool was both functional and economical, as the other three were made of expensive metals like steel or aluminum while the 3D printed tool was made of cheaper plastic. Lightweight and portable, this tool can be taken to any stage of the manufacturing or assembly process. To cut costs, innovations like this one that has multiple applications and require fewer resources are essential.

Figure 4.5 Fortus 450mc Industrial FDM 3D printer, source: Stratasys.com [50]

4.3.5 Reduction in supply chain

One of the advantages of additive manufacturing in production can be the reduction in the supply chain since the supply chain is one of the main production drivers, it has been always in the development department of the companies. Additive manufacturing may give an opportunity to simplify and reduce the supply chains. Manufacturing companies have huge numbers of suppliers who make automobile components for them, and they always have problems with logistics, and delays in the projects due to Force majors or some unexpected issues which result in consuming time and spending a lot of money on it. Therefore, automobile manufacturing companies always look for ways to cut supply chains to achieve greater value in production. For instance, Ford announced that he could reduce the suppliers by 500 in 2013 with help of 3D printers, however, he had 1250 suppliers one year before.

4.3.6 Maintenance and repair

It could be costly to replace certain auto parts, such as the drivetrain or the engine if they were to break. Repairs using AM at designated service centers would be possible in such a scenario. Laser metal deposition (LMD) is a technique that can be used to repair on-site parts with a low to medium degree of complexity, and it has a significant net precision, for instance, the component in Figure 4.6 can be easily repaired by LMD. LMD was originally designed for use in the aerospace industry, where it has proven effective at extending product life and thereby reducing maintenance costs. This method shines when more expensive high-performance composites are called for. Although Aerospace and Defense technology has advanced significantly, it is still too expensive for widespread use in the automotive sector. It can be anticipated that as the number of applications increases, the total costs will go down and the technology will eventually get to be financially feasible.

Figure 4.6 Audi motocross footrest, source EOS [51]

4.3.7 Reduction in service, component, and aftermarket part storage

When it comes to competing in the auto aftermarket, speed of delivery and accessibility of parts are crucial factors. Due to the high costs associated with holding stock, most retailers and dealers of automotive parts only keep in-house the most commonly sold components, with the stock of low-demand or pricey parts being kept in more distant, centralized locations. With AM's on-demand production, the supply chain can better meet the demand for these "long-tail" parts, which are in high demand but produced in limited amounts. The market for performance components is related to this in many ways. About 20% of the retail auto parts market is comprised of products in this category, and since their purchase is entirely up to the discretion of the buyer, demand is highly variable. Last but not least, AM may be particularly useful when combined with 3D scanners for making parts for discontinued models for which the corresponding computer-aided designs (CAD) are unavailable. Scanning the object in question three-dimensionally makes a CAD file from which the component's basic design can be derived; additive manufacturing can then be used to build the part.

4.4 Construction of automotive components

With the help of 3D printers, the prototypes of car components can be printed, and almost all automobile parts can be printed as well with high precision. Spare parts of the car are the most wanted components to repair. Additionally, according to the research on automobile parts, a common structure to understand car components, and the body has been released[52]. The automobile body division can be divided into four parts, which are clearly seen in Figure 4.7

1. Interior, which includes the dashboard, mirror, handlers, seats, and others.
2. Powertrain, which includes the engine, clutch, gearbox, pumps, and others.
3. Structural parts, which include wheels, steering, suspensions, and others.
4. Bodywork, which includes mirrors, body panels, indicators, handles, and others

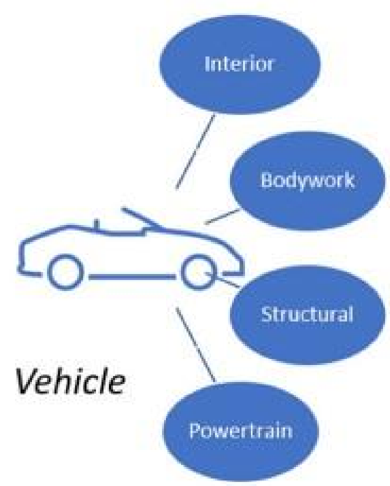

Figure 4.7 Vehicle body division

Regarding the materials, in additive manufacturing, there are many types of materials being used in the automotive industry. In this chapter, the materials are divided into 3 groups as shown in Figure 4.8 and below

1. Polymers, ABS, ASA (acrylonitrile styrene acrylate), and others.
2. Metal parts.
3. Composites

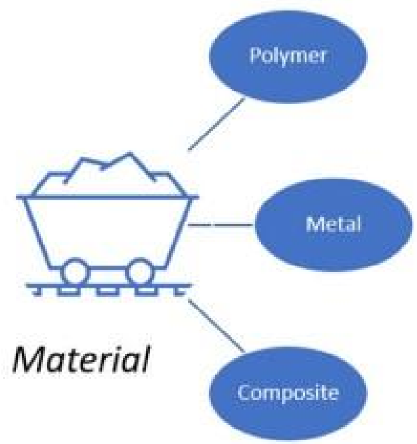

Figure 4.8 Material division

With respect to processes, there are two criteria that are very convenient to understand, they are Direct and Indirect additive manufacturing processes. They are completely different from each other, and they will be introduced below in more detail.

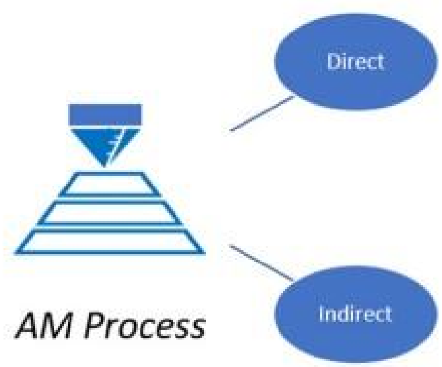

Figure 4.9 Additive manufacturing process division

4.4.1 Polymer components manufactured by Direct AM processes

There are many car spare parts that are made from polymers, for example, door handles, air vents, etc. These components are made from different types of additive manufacturing processes, such as Fused Deposition Modeling (FDM), and stereolithography (SLA). The most common materials used are acrylonitrile butadiene styrene (ABS) and acrylonitrile styrene acrylate (ASA), but other industrial polymers and post-processing steps are also considered to vary based on the implementations. Additionally, there is high competition among car manufacturers, and many companies focus on the reproduction of classic car components. For instance, Porsche Classic utilized 3D printing to produce replacement components for its vintage automobiles. So many parts, such as the 946's crank arm and the 959's filler-cap seal, were reproduced by the company using SLS PBF, a plastics manufacturing service. All of these components passed quality checks to guarantee they would function as well as the originals do. This involved selecting the appropriate polymeric materials to be sure they would be avoidable to vulnerability to oils among other factors. In figure 4.10, the pictures of the Porsche 946 crank arm and 959's filler-cap seal are given below

Figure 4.10 Porsche 964 crank arm and 959 filler-cap seal, source [53]

4.4.2 Polymer components manufactured by Indirect AM processes

The creation of conformal-cooling metal transistors and inserts for mass production is a common application of AM in IM polymer technologies. In recent years, additive manufacturing (AM) has been used to make polymeric infusion molds or polymeric masters for creating silicone molds for low-pressure molding, both of which are used in production runs that are either short or not at all. Additive manufacturing technologies based on polymers are used in IM to make low-volume production tools and molds; these include SLA, PolyJet, and SLS. Metal dies typically house polymeric AM inserts of insert dies for injection molding (IM) that are used to manufacture finished goods. However, there are also many problems. The main problem is that polymeric RT materials have a lower thermal conductivity, which can have unfavorable effects on the warpage and mechanical properties of molded finished components, and also cause slower cooling rates, which in turn causes longer packing and additionally, it takes more time than others. When it comes to grain structures, in the automotive industry, they are built from polypropylene and LyondellBasell manufactured the aforementioned mold of grained parts with Moplen EP240P.

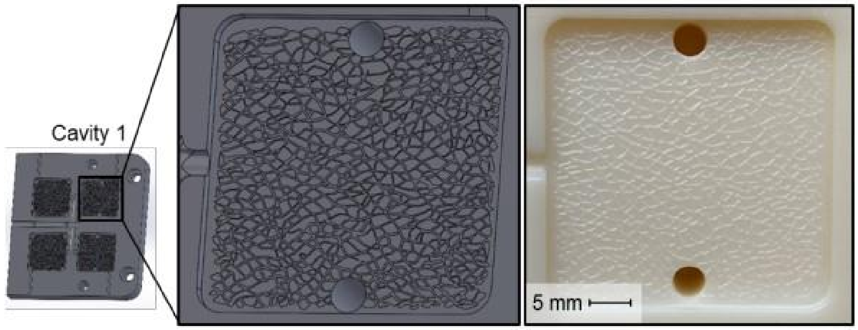

Figure 4.11 IM polymer mold, source: [54]

4.5.1 Metal components manufactured by Direct AM processes

Although many interior components of automobiles are made from polymer materials, there are components also which are made from metal materials such as titanium, stainless steel, or cobalt since they have high resistance to corrosion, are lightweight, and highly ductile. These components usually belong to technical parts of the automobile, for instance, the clutch, gears, or components of the engine. There are so many additive manufacturing processes to produce, and one of the most used ones in the industry is Powder bed fusion (PBF). Powder bed fusion is commonly divided into two methods, the first is the Laser beam and the other is Electron beam. In the automobile industry, the Laser beam is preferred using in manufacturing processes. Additionally, another additive manufacturing technology is Directed energy deposition (DED) which is known for its high efficiency and high manufacturing precision. Since many automobile industries are using additive manufacturing technologies, there is high competition among companies. One of the biggest automobile companies is Porsche, which is using widely additive manufacturing technologies in its industry. For instance, Porsche manufactured many spare parts for classic automobiles due to the lack of them which results in problems for classic and rare car enthusiasts, for example, the bracket for 356 B/C as shown in Figure 4.12

Figure 4.12 the bracket for Porsche 356B, source:[55]

Besides that, another car manufacturer has a high potential to produce additively manufactured spare parts, which is the Mercedes Classic manufacturing company. It manufactured the base for the mirror of Coupè 300 SL shown in Figure 4.13

Figure 4.13 13 Mercedes Coupè 300 SL mirror base by AM, source: [56]

4.5.2 Metal components manufactured by Indirect AM processes

In the Indirect AM processes, first of all, patterns are built using 3D printer technologies, there are many 3D printing technologies to make patterns, for instance, Fused deposition modeling, Stereolithography, and others. There are many ways to use indirect additive manufacturing processes, for example, patterns, cores, or gating since they do not take much time and are not costly. According to research by Enrico Dalpadulo [52], we can understand that investment casting is one of the best ways of indirect AM technologies. Investment casting is known as also lost-waxing. In this process, wax is used as the pattern, which is made by investing refractory ceramic coatings on them, to make metal components, then the ceramic mold is made using those patterns. There are many advantages of indirect additive manufacturing, such as

1. Adaptability to the industry due to its low rate of restrictions on materials, namely, it can be used with a variety of metal materials.
2. Reusability of the lost waxes which were removed by heating the used pattern
3. Flexibility of the end products

4.6.1 Composite components manufactured by Direct AM processes

The science of physical metallurgy is used to create composites, which are materials made up of a mix of other materials. There are at the very least two parts to them. The matrix, the first continuous part, acts as a glue, and the discontinuous second part provides reinforcement. Although polymers and metals have been the most used materials and preferred ones in the automotive industry, the development of materials and improvements in the industries pave the way to creating composite materials that are being used instead of other materials. Composite materials are currently playing a major role in many industries, such as automotive, aerospace, and biomedical industries since they have high capabilities to compete with other materials, for instance:

1. Durability
2. Easier to produce
3. Lower production costs depending on the material
4. Fire resistance
5. Reusability
6. Reduction in total weight

Additionally, producers of automobiles are making efforts to cut emissions of greenhouse gases by adopting new, superlight resources. The only barrier to using such materials is their expensive costs, so advanced inventions and manufacturing processes are being heavily prioritized[57]. Regarding the Direct additive manufacturing processes, many spare parts in automobiles are made from composite materials, such as bumpers, engines, transmission, pillars, spoilers, and etc. Figure 4.14 shows the 3D-printed car model with composite materials.

Figure 4.14 Composite part construction of Shelby Cobra, source: [58]

4.6.2 Composite components manufactured by Indirect AM processes

Mold and core fabrication are the most common examples of indirect AM processes for fiber-reinforced parts. Rapid prototyping and low-volume production often necessitate the use of specialized tooling, which is why additive manufacturing (AM) of large molds and dies is so common. In order to reduce tooling costs and increase productivity, AM technology has evolved over time to accommodate the two primary types of composite molding. The first one is Prepreg which is used for mostly fiber, the other is wet molding, also known as liquid molding. In this regard, Big Area Additive Manufacturing (BAAM) has been put into practice with promising outcomes, and there have been great advancements in metal additives for the compression molding of composite materials.

Figure 4.15 The composite turbo inlet duct by Indirect AM, source: Stratasys [59]

4.5 The future of additive manufacturing in the automotive industry

The technology required to create objects using 3D printing is rapidly developing into a sophisticated manufacturing method, to be precise, getting mature phase. It serves a purpose for prototypes and provides considerable advantages for low to medium-volume volume manufacturing. Additive manufacturing has been making huge changes and developments in the industry due to the demand by customers and other factors such as regulations, requirements, competition, and others. Additionally, additive manufacturing technologies are still being developed by researchers, innovators, and technologies, and they are working on not only 3D printers but also drivers of them too, such as Artificial intelligence (AI), machine learning (ML), supply chain, and materials. Artificial intelligence and machine learning play a major role in the additive manufacturing industry, and they will be discussed in this chapter below, besides, some future forecasts will be introduced as well. Regarding the future trends of additive manufacturing, we can bring some forecasts for AM, for instance, how they will be and how they can create value for the world, below there are given some of them.

4.5.1 Forecasts in additive manufacturing

Bigger size of printer. As we mentioned before, the development of additive manufacturing is so high due to demand from the market. Nowadays the quality and lifetime of the end product are the key drivers of the industry and business, and this requires materials with high properties which results in pushing forward the growth in the range, size, and creation of other types of 3D printers in order to work with these materials. The development of 3D printers can give some advantages to businesses and technologies, for instance, flexibility, and the ability to print in one piece.

Cost reduction. As we know the price of 3D printers is still high. However, as additive manufacturing is penetrating other sectors, and broadening also the usage of AM technologies, the demand for additive manufacturing is getting high and this results in the reduction of prices.

Speed. One of the main characteristics of additive manufacturing is the speed of printing along with quality. Nowadays 3D printers take much time to print something, of course, it depends on the size of the component being printed and the size of the 3D printer, and its capability. Therefore, improvements in 3D printers are being achieved by investing in the industry since it requires high capital. If they have higher printing speeds, there will be a crucial effect on the supply chains of manufacturing industries that use 3D printers in their processes, for instance, the time spent on supply can be cut, and also the costs associated with 3D printing processes can be reduced due to the fact that energy consumption will be reduced with high speed. It is expected to have faster 3D printers in near future.

4.5.2 Artificial Intelligence(AI)

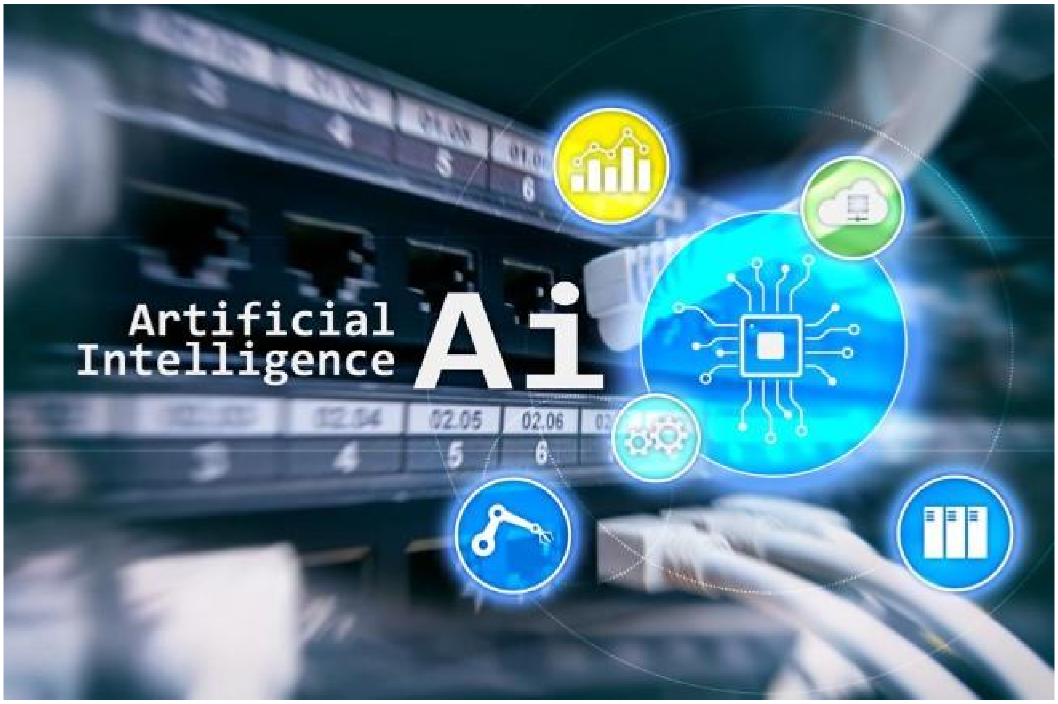

Figure 4.16 Artificiel Intelligence, source: Forbes[60]

One of the most commonly known disruptive technologies is Artificial Intelligence. Nowadays, it plays a major role in many industries such as robotics, automotive, mobile phone, aerospace, healthcare, financial services, etc. Artificial Intelligence can be seen as a technology that can perform some activities given by human beings, it can recognize speech and answer questions, and it may have the ability to learn, plan, or solve quizzes. Artificial Intelligence is becoming more and more widespread due to the fact that they have huge potential to change business and industry, and it may have an effect on the government economy also. Additionally, Artificial intelligence is being adopted by many other industries, and industries are making investments globally in order to make more improvements. Figure 4.17 shows the investments globally from 2015 to 2021.

The graph shows the total global investments in Artificial Intelligence(AI) between 2015 and 2021. It is clearly seen that there were 12.75 billion U.S. dollars in total investment in Artificial Investment in 2015. However, there was a dramatic increase in investment by more than 30 billion U.S. dollars in two years, while in 2018 there was a slight decrease, reaching 43.81 billion U.S. dollars. However, in the last three years, the investment dramatically increased by almost double, 93.5 billion U.S. dollars.

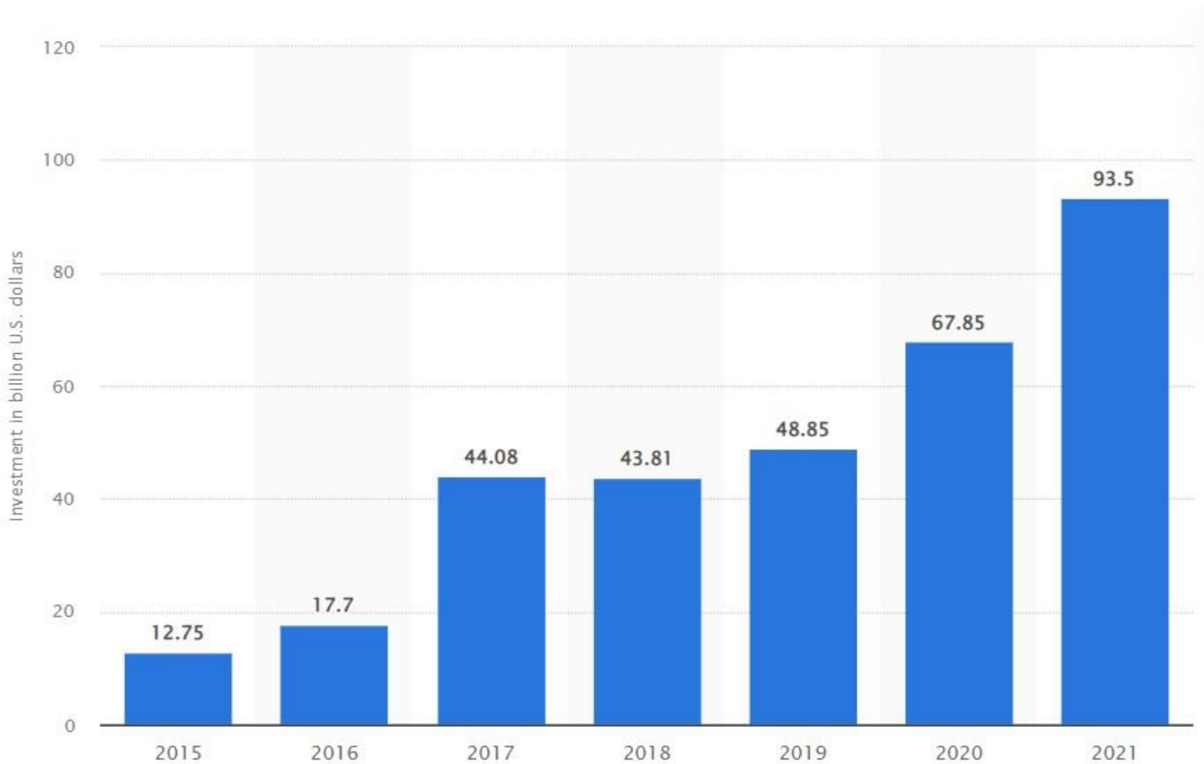

Figure 4.17 Artificial Intelligence Investments between 2015 and 2021, source: Statista[61]

4.5.3 The role of Artificial Intelligence in additive manufacturing

Additive manufacturing is one of the leading manufacturing technologies in our world and Artificial intelligence is becoming a key part of additive manufacturing. There are many advantages of AI in additive manufacturing. The integration of Artificial intelligence with AM has positive impacts on the manufacturing processes, for, example, the more precise printing processes, lower costs, lower waste of materials, less production time, etc. Additionally, more advantages of AI will be introduced below in more detail :

1. Printability of component
2. Higher efficiency
3. Defect detection
4. Maintenance
5. Lower energy consumption
6. Data security

Printability of component. According to research done by M.B. Kiran [62], the meaning of printability of components is that if it is possible to print the given component by the 3D printer or not. This concept has been introduced into science since there are many restrictions and limitations of 3D printers, for example, material limitations.

Higher efficiency. Artificial Intelligence improves the efficiency of printing processes since nowadays the shapes of the components are becoming more complex, and time-consuming to print respectively. Artificial intelligence allows 3D printers to be able to analyze every corner and point of spare parts and components in the process[62].

Defect detection. With the help of artificial intelligence technology, it is possible to check and find defects in the process of printing since there are already installed AI technologies in the 3D printers, such as sensors, and cameras. The component which is under the printing process is always under the control of sensors, and if AI technology finds any defect in the process, the engineer will be signaled and informed about the defect[62].

Preventative maintenance. Artificial Intelligence has a wide range of usage across industries, and there are also many aspects not discovered yet. With the help of sensors installed in 3D printers, Artificial intelligence can check any part of the machine before it breaks and fixes it, or at least it can inform the operator or engineer about the problem which may occur. It is possible to easily understand how preventive sensors work from scheme 4.18

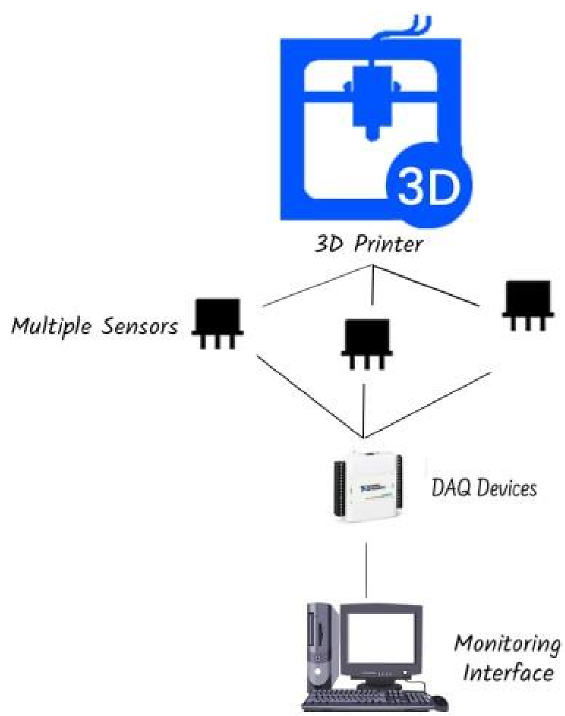

Figure 4.18 Preventive sensors scheme, source[63]

It is seen clearly from the scheme that some sensors are installed on 3D printers, and these sensors collect data in the process, if there something starts to happen, they immediately signal to the DAQ device (data acquisition device) to read the sensors' language and bring these data to the server.

4.6 Conclusion

In this chapter, we have introduced the role of additive manufacturing in the automotive industry. As we can see in the chapter, 3D printers play a major role in the industry, especially, in spare parts for automobiles due to their many advantages, such as customization, time reduction, reduction in services, and maintenance. Those advantages made 3D printers become the most wanted part of the automobile industry. Additionally, we have analyzed how 3D printing is implemented in automobile production, which depends on the car body part, material type, and additive manufacturing processes such as direct and indirect manufacturing processes, this manufacturing process is so efficient that it gives many opportunities to the industry. Besides, artificial intelligence also plays a role in the automotive industry, and it is an emerging technology. Due to its many advantages, artificial intelligence is being improved to create more value for manufacturing processes.

Chapter 5 Case study: Stratasys

In this developing world, since the demand for competitive products is increasing, the role of complex-shaped components and spare parts is becoming important in all industries due to their many advantages and technical properties. Therefore, to manufacture complex-shaped components and end-products there is an increase in the need for technologies that can produce these types of components such as 3D printers. There are many additive manufacturing companies in the world, for instance, 3D systems, Materialise, Protolabs, Stratasys, and Desktop Metal, and they are competing on all market sides of the industry, such as cost or quality. In this chapter, one of the top additive manufacturing companies, Stratasys Ltd will be introduced. Due to the fact that there are many competitors in the additive manufacturing industry, it is reasonably difficult to enter and develop in that industry. Additionally, in this chapter, internal and external analysis of Stratasys will be discussed

5.1 Stratasys background

Figure 5.1 Stratasys logo, source: Stratasys [64]

5.1.2 History

The global leader in additive manufacturing, Stratasys, Ltd. was founded by Scott Crump and Lisa Crump in 1989. The company was initially based in Eden Prairie, Minnesota. Mr. Scott Crump brought this innovative technology to life with the idea of making a toy for his daughter, he invented FDM(Fused Deposition Modeling) technology only for prototyping purposes and patented it in 1988[65], and sold first this FDM systems in 1991, and sold more than 21,000 systems according to Wohler's report 2013. Additionally, the company made so many efforts in order to grow and create value for the company, such as merging, acquisition, or IPO. After four years after establishing the company, the company started its IPO on NASDAQ (National Association of Securities Dealers Automated Quotations), selling 1.38 million shares, and achieving 5.7 million U.S. dollars. Due to the increasing number of competitors and competition Stratasys also made many acquisitions, for instance, the company made an acquisition of Origin, worth 100 million U.S. dollars, besides them, Stratasys acquired many other companies such as Xaar 3D, RPS, and Riven. With acquisitions, the company can increase its market share in the market, and also attractiveness. Besides that, there was a merger between Stratasys and Object Ltd which specialized in 3D printers and is located in Israel in 2012. Regarding investments, there were many investments by Stratasys, for example, Stratasys invested in Massivit 3D in 2016, the company is specialized in 3D printers and materials for their usage in their manufacturing productions. Furthermore, Stratasys invested 15 million U.S. dollars in Axial3D, the purpose of this investment is to produce 3D printers for the healthcare sector in order to provide solutions for complicated patient issues[66].

5.1.3 Products

Stratasys produces a wide range of 3D printers for different industries such as aerospace, automotive, dental, medical, and education. Besides that, the company produces 3D printers for many various applications, for instance, rapid prototyping, production parts, design, and dentures. As we mentioned before, the first Stratasys 3D printing was invented in 1988, and below some 3D printers will be introduced depending on the industry.

Figure 5.2 Objet 350 Connex 1-2-3, source: Stratasys[67]

Objet350 Connex 1-2-3 is the most advanced 3D printer with high efficiency. This printer is used in the automotive industry with different applications. This 3D printer can print components with various materials at the time, which is an outstanding feature of the printer. Regarding the technical specifications, the build area of the printer is 342x342x200 mm according to data given on the website of company. Additionally, the AC power requirements are 100-120 VAC, 50-60 Hz, 13.5 A, and 1 phase. The printer can be used in many applications such as Visual prototypes, medical models, or injection molds, besides them, with different types of materials such as biocompatible, tango, vero family, and others.

Figure 5.3 3D printer F900, source: Stratasys[68]

F900 is the most powerful 3D printer among other printers in Stratasys company, and it is used basically for large-scale production. GrabCAD Print and Insight software are integrated into the printer and work perfectly. With respect to technical specifications, the power requirement of 230 VAC (three phases), 50-60 HZ, and 40 Amp circuit, additionally, the accuracy of the printer is +/- 0.89 per mm. The one of advantages of the F900 is that only one operator is enough, and his task is to start and stop the printer. There are many materials that can be used for manufacturing with F900, such as ABS-ESD7, ASA, PPSF, and ST-130.

Figure 5.4 3D printer H350, source: Stratasys[69]

H350 is a powder bed fusion 3D printer. It gives customers an opportunity to manufacture high-volume components and parts, and human interaction and repair of the printer are minimized. With fewer limitations on this printer, it is possible to reuse the powders and lower the manufacturing costs. H350 is integrated into SAF(Selective Absorption Fusion) technology which provides high accuracy and the ability for rapid prototyping and printing. Regarding the technical specifications, the printer requires more energy consumption than the printers that we have already introduced above, 400 VAC, 16A, and built time is around 11.62 hours, and the weight is 825 kg. With respect to the software used with H350, there is not much software being used with that printer, only GrabCAD Print, which is also used with F900, and Siemens NX according to data given on the company's official website. Additionally, the company is working on new types of 3D printers and making innovations for the development of current printers in order to stay competitive in the market.

5.2 External Analysis

Additive manufacturing technologies are becoming an important part of many industries such as automotive, aerospace, medical, dental, consumer products, and others due to their many advantages for those industries. Therefore, the competition among 3D printer manufacturers is so high that it is quite hard to stay in the market and compete with already established big companies for new entrants. First of all, let us understand what actually External Analysis means. External analysis means the environment of the given company, which factors affect the industry from outside of the company, such as political, economic, social, or technical, and any substitutes for products, or new entrants. By analyzing these factors, and eliminating or dealing with these issues, the company can create value and make improvements. In this part, Porter's five forces will be discussed and analyzed regarding the Stratasys company.

5.2.1 Porter's 5 Forces

The analysis of Porter's 5 forces is used to analyze the competition among industries. With help of Porter's 5 forces, the profitability of the company can be also increased. Porter's 5 forces were published by Michael E Porter in 1979 according to Investopedia. These 5 forces consist of the following competitors:

Vertical competitors:

1. Suppliers
2. Buyers

Horizontal competitors:

1. New entrants
2. Substitutes
3. Rivals

It is also shown in Figure 5.5. In order to increase its profitability and check the power of competitors in the industry, a company should analyze Porter's five forces one by one.

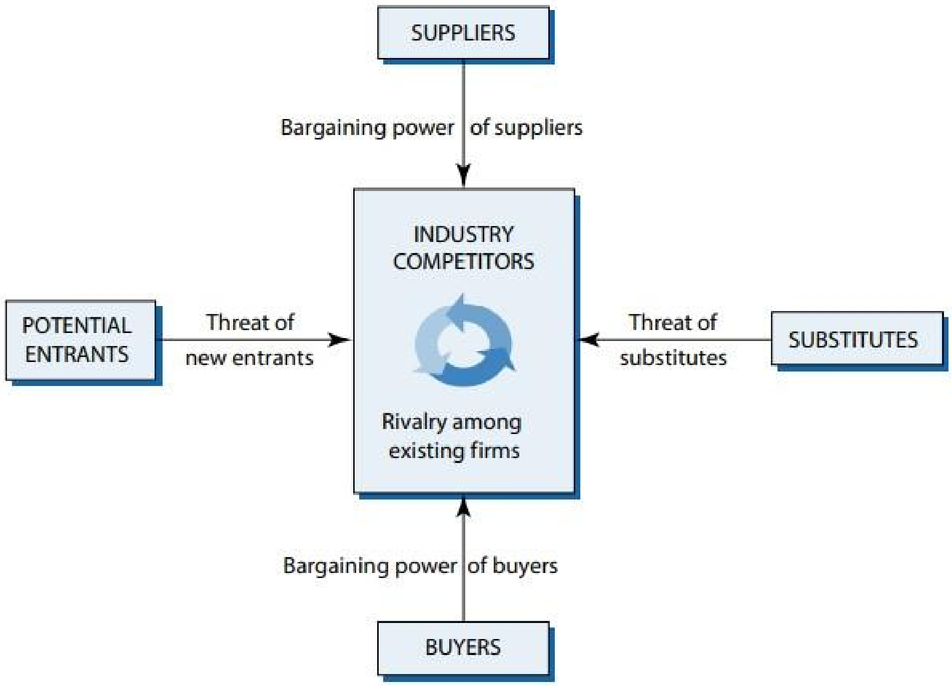

Figure 5.5 Porter's Five Forces, source [70]

The bargaining power of Suppliers. The bargaining power of suppliers means how much power suppliers have in the market, namely, the ability to sell their products at the price they want. In additive manufacturing, there are many suppliers, and for Stratasys, the suppliers are software and material production companies. As we have analyzed materials used in additive manufacturing processes, the materials are mainly divided into metal, plastic, resin, and composite materials. Material production for 3D printers is quite a difficult and expensive process, and also it gives restrictions to the manufacturing of 3D printers since different parts of printers require different materials, and collaborating with external suppliers may have a negative impact on printer manufacturing due to delays with delivering materials. Therefore, in order to eliminate and reduce these limitations, Stratasys both buys materials from other suppliers and produces them themselves also. Regarding the software suppliers, they play a major role in the manufacturing of 3D printers, and there are many software development companies, besides that, Stratasys has its own software also to use. With the help of software, it is possible to reduce the time to print components and produce more complex parts. Overall, with respect to the bargaining of suppliers, suppliers of Stratasys have weak bargaining power due to the fact that Stratasys has also its own material manufacturers and software developers.

The bargaining power of buyers. The term "Bargaining power of buyers" means how much buyers have the opportunity to receive a higher quality product. The buyers are usually consumers or customers, and so the customers of Stratasys are mostly in the automotive, aerospace, medical, or dental industries, and there are many 3D printer companies that are competing with Stratasys, and one of them is 3D Systems. 3D Systems is one of the biggest competitors of Stratasys, and its headquarter is located in Rock Hill, South Carolina, it was founded in 1986, and it offers many different types of 3D printers. Besides that, there are other many competitors also, such as SLM Solutions, Protolabs, Luxexcel, ExOne, and others. Therefore, customers have many other alternative companies to Stratasys, that's why buyers have strong bargaining power, and they can choose easily one of the 3D printers based on their requirements, and technical specifications.

The threat of new entrants. The term "the threat of new entrants" means that if new companies enter the market, and they offer the same product, it will be a threat to incumbents since they may lose their customers. The additive manufacturing industry is already a mature industry, and there are many barriers to entry. However, due to the high demand for 3D printers, and high profitability and perspective, the number of new entrants is increasing. New entrants can be developed easily and quickly if they get invested and given developed technologies, and they try to make innovations and keep developing new technologies to stay in the market. Besides that, new entrants may try to lower the costs as much as they can in order to attract customers, and also take other actions such as advertising. However, although new entrants may compete on the cost of 3D printers, they may not provide as good quality as rivals do since new entrants do not have economies of scale and learning. For example, Stratasys has almost 35 years of experience in additive manufacturing technologies and already gained a high market share in the industry. Additionally, incumbents can make high barriers, for instance, they can make patents for technologies, or industrial standards also. Overall, we can understand that the threat is low for incumbents due to high barriers.

The threat of substitutes. When it comes to the threat of substitute products, we can understand those substitute products are alternative ones that customers can use instead of products offered by incumbents. Substitute products for 3D printers are other technologies, mostly traditional methods, for instance, CNC, injection molding, Plastic forming, and others. These technologies are also currently being used by some manufacturing industries due to their low-cost production, and other reasons. However, the demand for more complex shapes and high-strength components is increasing, and nowadays only 3D printers are capable of producing these types of components, and customers are moving to 3D technologies. Besides that, one of the biggest issues for additive manufacturing companies is the cost of the 3D printers, and therefore, they have to find ways such as making innovations, managing the supply chains, or having more economies of scale in order to lower the costs. Overall, we can say that there is a low threat of substitutes.

The Rivalry. When it comes to Rivalry, the term “Rivalry” means competition among existing companies and their profitability according to Robert M. Grant [70]. Companies compete differently depending on the industry., for example, some industries compete on cost while others compete on quality and product differentiation. Since 3D printing companies have already set high barriers to entering the market, and it requires high capital investments, it is really hard to enter the market, and therefore, in the additive manufacturing industry, mostly, existing companies compete. There are many already existing companies in the industry, such as 3D systems, Protolabs, ExOne, and Stratasys. These companies are competing for both cost and product differentiation. Overall, the competition is so high in the 3D printer industry.

5.3 Internal Analysis

First of all, it is better to understand the meaning of Internal Analysis, and its role in the industry. The term “Internal Analysis” means the analysis of internal resources, components, or capabilities of the company, and this is used to evaluate and analyze the strength of the company. With the help of Internal analysis, we can identify the strengths and weaknesses of our companies, then we can increase our profitability. In this part, SWOT analysis will be discussed

5.3.1 SWOT analysis

SWOT analysis has been proposed by Albert Humphrey in 1960, and it stands for the strengths, weaknesses, opportunities, and threats. It is used to assess the competitiveness of the company, and the external and internal sides of the company. SWOT is divided into two parts[70]:

External factors include

1. Opportunities
2. Threats

Internal factors include

1. Strengths
2. Weaknesses.

SWOT analysis will be discussed in Table 5.6, and with the figure, we can understand how much the strengths, weaknesses, opportunities, and threats Stratasys have in its company

Strengths: 1. Different types of printers for different industries 2. Partnership with big companies such as Volvo, Ford, Airbus 3. Lower costs of 3D printers 4. Possibility of using a wide range of materials 5. Availability of Global service in 13 countries	**Weaknesses**: 1. Most products have a low market share compared to competitors 2. highly centralized decision process 3. Lower rate of investments than competitors
Opportunities: 1. Core competence 2. Decrease in transportation due to global manufacturing 3. Online trading 4. Increase in the demand for complex-shaped products.	**Threats:** 1. Increasing number of new entrants to the market 2. Imitation of products by competitors 3. Competition 4. Currency rate due to Global trading

Figure 5.6 SWOT analysis for Stratasys

5.4 Conclusion

In this chapter one of the global leader in additive manufacturing technology companies has been introduced, Stratasys, Ltd. It was founded by S. Scott Crump. The history of Stratasys goes back to 1989, and it is clearly seen that the company has more than 30 years of experience. Additionally, in this chapter, how Stratasys interacted with other companies in order to develop, for example, the company made partnerships, mergers, and acquisitions. Furthermore, some products of the company, such as Objet350 Connex 1-2-3, and F900, also have been introduced, and also technical specifications have been provided. Those 3D printers are used widely in different manufacturing industries, such as automotive, aerospace, and others. Additionally, external and internal analyses of the company have been also analyzed. Regarding the external analysis, Porter's five forces have been analyzed, and we can understand that since the bargaining power of buyers is so high, the company should outstand from competitors, and attract more customers, therefore, the company is investing more every year to stay competitive in the market. With respect to the internal analysis, SWOT has been introduced, and we can see that there are some crucial threats to the company, for instance, the highly centralized decision process which impacts manufacturing processes. In order to achieve faster production processes, the company has to decentralize the organization, and the company is better to give freedom to middle managers and technologies in the industry.

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