Application and Standing of 3D Printing

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Abstract. Three dimensional (3D) printing, also referred to as additive manufacturing, has established itself as a transformative technology in several manufacturing industries. 3D printing builds objects directly from a digital model by constructing it layer by layer. This paper explains the fundamental mechanisms of 3D printing, and highlights the five key methods: material extrusion, vat photopolymerization, power bed fusion, binder jetting, and directed energy deposition. This paper reviews the industries where 3D printing plays an integral role in, including aerospace, automotive, healthcare and more. The paper will examine how 3D printing is involved in these industries and how it challenged conventional means of production. 3D printing offers possibilities for these industries to achieve shorter time-to-market, material efficiency, and lower costs. The paper also addresses the challenges of 3D printing, such as its slower speed when compared to subtractive processes, and the expensive cost for high-precision machinery. Finally, the paper will cover future trends and potential developments of 3D printing in fields including integrating ne materials, large scale productions, and entering new industries. 3D printing is a potent tool that is reshaping manufacturing by prompting innovations and more efficient development, the constant technological advancements in 3D printing will continue to change manufacturing.

1 Introduction

Additive manufacturing, also known as 3D printing, is a manufacturing technology that creates objects using a geometric representation by adding material successively. In the 1980s, Charles Hull first commercialized the 3D printing technology [1]. 3D printing is a novel concept in comparison to traditional means of production. Unlike formative or subtractive methods, where material is shaped using a mold or removed,3D printing builds the object from the bottom layer by layer using a computer aided design (CAD) model [2]. Ever since its emergence in 1980, 3D printing has developed from an obscure tool for quick prototyping to a concrete method of manufacturing that has its applications in many industries such as aerospace, automotive, food, and health industries. 3D printing has the potential to thoroughly change the modern day manufacturing process.

In 1983, Charles W. Hull, or more commonly known as Chuck Hull, created the first ever 3D printed part. Hull coined and defined the term stereolithography as “a method and apparatus for making solid objects by successively printing thin layers of the ultraviolet curable material one on top of the other” [1]. The process of 3D printing can be divided into

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three parts, pre-processing, production, and post-processing. The pre-processing is the part where the digital model of the desired object is created. The model can be created using CAD software or 3D scanner. The computer generates a digital version of the object through analyzing and collecting the data of the shape, appearance and texture of the object. Based on this information, the printer uses it as a blueprint to produce the modellin or scanned object. Another crucial step before printing a 3D model is processing it through a software called a "slicer". This software converts the 3D model into a set of very thin layers. Because 3D printing is a layer by layer construction of the desired object, the printer relies on these series of cross-sectional planes of the model to create the object [3]. During the production process, the 3D printer uses these smaller blueprints, each layer, to deposit material layer after layer, fusing them together to create the final object. After the production process, the completed object is removed from the printer and the post-processing process begins. Many designs require additional support structure during the printing process, so they would need to be removed or washed away. Furthermore, in order to achieve even higher resolution and precision in certain applications, it is common to print out a slightly larger model of the object and use subtractive methods such as polishing to attain the final product [3].

Ever since Hull claimed his patent for stereolithography in 1986, many other categories of 3D printing has emerged [2]. The American Society for Testing and Material (ASTM) declares seven types of 3D printing, five of which will be thoroughly discussed below as they hold particular importance in modern day manufacturing. Each of these techniques have unique characteristics that make them more suitable for certain applications and materials. The five types of 3D printing technologies that will be discussed are material extrusion, vat photopolymerization, powder bed fusion, binder jetting, and directed energy deposition.

Material extrusion is one of the most commonly used methods and can be best described by fused deposition modelling (FDM). During the FDM process, a thermoplastic material such as polylactic acid or other types of polymer is heated and extruded out a small hole of a nozzle, then that melted plastic will be deposited layer by layer to complete the object. In some scenarios where a support material is needed, a removable piece can be deposited as scaffolding and the melted material will build on top of it. The material extrusion method "can be used to print multi-materials and multi-colour printing of plastics, food or living cells" (An Overview on 3D Printing Technology: Technological, Materials, and Applications). Not only is this method very versatile, it is also relatively low cost, making it rather accessible [2].

Vat photopolymerization is another major category of 3D printing, processes such as stereolithography and digital light processing both fall under this category. Photopolymerization works by curing photo-reactive polymer using a light source such as laser of ultraviolet light [4]. The materials used are initially in liquid form, but will then harden after it is exposed to the light source [2]. A major advantage of this method is that it can produce objects with higher resolution, smoother surfaces, and more intricate geometries.

Power bed fusion is another type of 3D printing that uses laser or electron beam to produce high temperature in order to fuse powdered material [5]. Subcategories of this type of 3D printing includes selective laser sintering (SLS), electron beam melting (EBM), and selective heat sintering (SHS). SLS uses a laser to sinter powdered material such as metal or polymer. EBM and SHS works similarly in that they direct the heat source to melt and fuse powdered material to build the object [2].

Binder jetting is a different and unique type of 3D printing that involves depositing a liquid binding agent onto a bed of powdered material, using the agent for bind powdered material together to form each layer of the object. Binder jetting offers a cheap and fast way to glue powdered material such as metal, ceramics, or sand together for high volume production [2].

Directed energy deposition is a comparatively more complex process of 3D printing that is commonly used to repair or add parts onto existing parts. The fundamental principles of directed energy deposition is similar to that material extrusion, where the material is heated and pushed through a nozzle. However, in directed energy deposition, the nozzle is not fixed to a certain axis, but rather has the ability to move and point in different directions. This allows for greater freedom when printing, making it an apt choice for repairing components that would require printing on an irregular surface [2]. Its increased freedom in the nozzle permits a higher level of precision, producing objects with greater resolution.

2 Applications

Since 3D printing's first appearance in the early 1980s, it has evolved and developed greatly from a niche prototyping tool to a rapidly advancing mean of manufacture that is challenging tradition subtractive and formative methods. 3D printing provides unparallel freedom compared to conventional methods of manufacture, making it an outstanding option in many industries nowadays.

The aerospace industry gas greatly benefitted from 3D printing's capacity to produce small, lightweight, intricate, and customized components. The industry often needs components that are highly precise and highly complicated in design [3]. The automotive industry has employed 3D printing as a way to accelerate the design process. 3D printing allows engineers to design and create prototypes more efficiently, prompting better design development by allowing companies to try an array of different prototypes in a quick and cheap manner. Large automobile corporations such as Ford, BMW, and Audi have all been using 3D printing to create prototypes or certain car parts [2]. Another industry that has been utilizing 3D printing are the medical and dental industries, greatly aiding clinical and product development [4]. 3D printing is used to create patterns for metal casting of dental crowns, as well as dental aligners [3]. 3D printing has also been a potent tool beyond dentistry, as it has the ability to reproduce biological parts, such as skin, bone, tissues, and organs. 3D printing has been used to make drugs with high precision in pharmaceutical research, to create tissue models in cancer research, and to make detailed anatomical models for surgical education and training [2]. The jewellery business in particular has been using CAD to model and design new products [3]. The additive process allows the business to unlock more freedoms in design rather than to be restrained to conventional subtractive methods which relies heavily on the shape of the raw material. 3D printing provides a simpler alternative that often eliminates several intermediary processes during production. The architecture and construction have also taken advantage of the unprecedented versatility provided by 3D printing. The industry embraced the 3D printing technology to produce accurate architectural models in a fast and economical manner. This helped engineers better visualise designs especially CAD data as well as the printed result using technologies such as FDM. Not only is 3D printing a potent tool in the architectural developing process, companies such as Apis Cor have taken a further step to create entire buildings using 3D printing as well as the Canal House in Amsterdam [2]. This shows that 3D printing is taking concrete steps from creating concept models to actually functional structures. The fashion industry has rapidly adopted 3D printing as a tool for designers to fully realize their innovative and audacious plans. The industry uses 3D printing as a tool both for design and production. Accessories such as shoes, hats, and bags have been produced using 3D printing as improvements in detail and material allow greater flexibility. Large brands such as Nike, Adidas, and New Balance have begun exploring the possibilities of mass production 3D printed shoes [2]. However, 3D printing does not solely act as an alternate mean of production for already-existing products. The high customizability of 3D printing enables the production of unique personalized items that vastly lower the cost especially for low volume productions. Finally, the food industry has used 3D

printing technologies to open up many new possibilities. Simpler examples include customized chocolates and pasta that are made into innovative shapes, but more complicated food designs for personalized nutrition have also been achieved [2]. The ability to construct structures and shapes without using molds allows greater creative applications in the food industry. The essential involvement of 3D printing in the various industries aforementioned shows that 3D printing is expanding rapidly and is becoming an integral part of manufacturing today.

3 Advantages

The rapid rise and the ability to consolidate its essential position in a variety of industries is driven by its concrete advantages over traditional means of manufacturing. The additive process enables faster development, cheaper costs, and supports greater levels of freedom [6].

Its key feature, dramatically reduced time-to-market, allows companies to realize an idea into a tangible prototype very quickly. In comparison to traditional formative methods, where a company would have to design a product, make a new mold for it and then make it, 3D printing shortens the process where engineers can design using CAD and print out the prototype within the same day, vastly shortening the design and development cycle [6].

Another outstanding advantage that 3D printing has over traditional manufacturing that it is cost effective. Traditional subtractive manufacturing involves the removal of excess material through cutting and polishing, which can generate a considerable amount of waste in material. The additive process builds out the object using a digital model, allowing designers to optimize digital designs reducing material waste. For instance, General Motors has developed a safety belt using 3D printing technology. As a result, this design is 40% lighter and 20% stronger than the previous design, as they combined eight parts of the belt into one using 3D printing [6]. Furthermore, 3D printing serves to reduce risk during the designing process. Since designers are able to thoroughly test their prototypes before committing to production which also reduces the potential cost producers would waste on failed designs [3].

Beyond cost savings and risk reduction, the efficiency of 3D printing allows feedback from the market before mass production begins. Because 3D printing can produce a prototype in very short time, it will allow manufacturers to promptly present their ideas with buyers, and demonstrate their product at shows. 3D printing also provides an unparalleled opportunity for developers to properly assess the ergonomics and practicality of the prototype, they are able to interact with a physical prototype and test it in ways unachievable solely with a digital model [3].

Another important advantage of additive manufacturing is personalization and customization. In traditional manufacturing methods, identical parts are produced in bulk, 3D printing allows custom tailored products to be made for individual customers at a far cheaper cost. Unlike the conventional formative method, manufacturers would not need to produce a new molds for every custom request. The high customizability makes 3D printing a significant technology in the medical sector, where tailored implants can be produced to fit the patient's exact needs. Similarly, 3D printing offers a much greater design freedom, where intricate shapes and complicated geometries can be produced just as easily as a simple cube. The nature of additive manufacturing permits greater creativity in engineering and design [3].

4 Disadvantages

3D printing presents many outstanding advantages over traditional production methods, but also has many disadvantages that have greatly hindered its wider application. First, while the

additive manufacturing process can be more cost effective as it saves material and mitigates production of poor designs, the initial investment is more expensive. The high cost of purchasing a 3D printer with high resolution discourages many households and small workshops from using it despite optimistic investment returns in the future. Furthermore, one printer usually does not suffice the needs of most producers. Different printers are needed for different object types, and printers that can print colors are more expensive than monochrome ones. The purchase of several printers for different needs will increase the initial cost even more [7]. Given the current technology of 3D printing, size and material limitations also pose a challenge to its wider use. 3D printers are incapable of producing very large objects, and that it only supports around 100 materials, a number miniscule compared to that of traditional manufacturing. 3D printing often needs post processing to remove excess material on the surface. Printing duration has also been a major shortcoming in this technology [3]. The printing process may take some hours or even days depending on the size and quality of the final product, which is significantly slower than formative or subtractive methods, not mentioning that errors during the printing process may lead to restarting the entire process. Finally, there are concerns about the possibility of individuals to produce dangerous items that would otherwise be prohibited to purchase [3]. The potential of misusing the technology for dangerous matters such as 3D printed guns pose challenges for governments to regulate 3D printing effectively [8].

5 Conclusion

The future of 3D printing holds profound and expansive potentials in manufacture. At the moment, manufacturing is developing towards a more decentralized model, where the traditional model of supply chains may be reduced and replaced by locally sourced materials. 3D printing offers the manufacturing industry a peek into a future where a nearly completely automated manufacturing system replaces the traditional assembly line used today. The greater capacity of complexity allows developers to imagine more audacious designs that would be unattainable through traditional methods. Nevertheless, there are many uncertainties in the future of 3D printing. While it is unlikely that 3D printing will completely replace traditional manufacturing, the potency and potential of 3D printing even at this preliminary stage already makes it a powerful tool. In the decades to come, the transformation of the manufacturing industry will be fully seen, where 3D printing will play an essential role.

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