# Additive Manufacturing and 3D Printing Technology

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**Abstract.** With the growing use of technology in the manufacturing industry, additive technology has its contribution and potential for further advancements. This paper will discuss the various additive manufacturing processes and the potential of additive manufacturing and 3D printing technology in the 21st-century manufacturing industry. Additive manufacturing and 3D printing technology have been around for decades, but their applications and capabilities rapidly expand. A thorough analysis of additive manufacturing and 3D printing technology is reviewed, focusing on recent advancements made by several researchers and industries. The paper explores the current state of the technology and its potential applications in the future as Industry 4.0 continues to advance. Challenges that can hinder the technology from reaching its full potential are also discussed.

**Keywords:** Additive Manufacturing · 3D Printing · Technology

## 1 Introduction

3D printing is a digital fabrication process that creates physical objects from a geometrical model by adding materials layer by layer. In additive manufacturing, material may or may not be added in layers. 3D printing technology and additive manufacturing are rapidly transforming how products are designed and manufactured [7]. The technologies have been around for decades, but their applications and capabilities rapidly expand. 3D printing is a technology that has revolutionized how we design, create, and produce products and can potentially transform the global manufacturing industry. In this case, 3D printing technology integrates the processes and elements required for manufacturing. Consequently, the technology impacts the supply chain, saves on the cost of production, and reduces complexities. According to Parupelli and Desai (2019), in the coming decades, Industry 4.0 will advance largely due to additive manufacturing, helping to shape the future of the global industrial sector. Additive manufacturing and 3D printing technology enable us to create products quickly and with fewer resources, creating cost-effective, efficient, and sustainable solutions. In addition, the technology can be used to produce complex structures, which can be used in various industries across the globe [15].

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Despite showing great promise in several areas, 3D printing has a variety of limitations that keep them from realizing their full potential. Through a comprehensive review of past literature in relevant fields, this paper seeks to address the following areas concerning the development of additive manufacturing and 3D printing:

1. What is the potential of additive manufacturing and 3D printing in the manufacturing industry?
2. What are the challenges of realizing the full potential of additive manufacturing and 3D printing in the manufacturing industry?
3. What implication do the possible challenges pose to applying additive manufacturing and 3D printing in different fields?
4. What can be done to address these obstacles?

### 1.1 Additive Manufacturing Processes

Additive manufacturing processes, or 3D printing technology, uses digital technology to create three-dimensional objects from digital models. The process begins with creating a digital model of the desired object, which is then sent to a 3D printer. The printer then prints the object layer by layer from the model, using various materials such as plastics, metals, or even ceramics [2]. Furthermore, the process can also produce components with multiple materials, such as metal and plastic. Table 1 below shows different additive manufacturing processes, including the technology applied, materials, layer resolution, and building volume.

According to Parupelli and Desai (2019), the most used additive manufacturing processes are Fused Deposition Modeling (FDM) and Stereolithography (SLA) [15]. While FDM uses a filament of plastic material, which is heated and extruded through a nozzle, layer by layer, SLA uses a liquid resin that is cured by a U.V. laser, layer by layer [7]. FDM is relatively inexpensive and is widely used to create prototypes and end-use products. The materials used in FDM are also widely available, making it a great choice for prototyping and small-scale production. On the other hand, SLA is highly accurate and can produce extremely detailed objects. It is also one of the fastest processes, making it ideal for rapid prototyping. These processes are generally relatively quick and cost-effective, making them attractive to small businesses and hobbyists.

Another typical 3D printing procedure is selective laser sintering (SLS). SLS 3D printing can create durable, useful parts for engineers and manufacturers from various industries, including design, automotive, aerospace, and engineering (Gibson et al., 2021). A powerful laser is used in this procedure to sinter tiny polymer powder particles into a solid structure based on a 3D model [5]. The method is perfect for various applications, including rapid prototyping and small-batch, bridge, or bespoke manufacturing, because of its low cost per part, high productivity, and well-established materials. SLS printing is now available to a wider range of organizations thanks to recent equipment, materials, and software advancements. In the past few years, these technologies could only be used by a few high-tech enterprises. The process of how SLS works is presented in Fig. 1 below.

**Table 1.** Additive manufacturing processes [7]

| Process | Technology | Materials | Minimum layer resolution | Max. Build volume (LxWxH-mm$^3$) and Applications |
|---|---|---|---|---|
| Photo-polymerization | Stereolithography (SLA)<br>Digital Light Processing (DLP)<br>Continuous Liquid Interface Production(CLIP)<br>Scan, Spin and Selectively Photocure (3SP) | Photopolymers | 50–100 µm<br>25–150 µm<br>50–100 µm<br>25–100 µm | 1500x750x550<br>192x120x230<br>190x112x325<br>266x175x193<br>Rapid prototypes tooling end user parts and mold patterns |
| Extrusion Based Systems | Fused Deposition Modeling (FDM) | Thermoplastics (PLA, ABS, HIPS, Nylon, PC) | 10–100 µm | 1500x1100x1500<br>Spare parts, automotive, testing tool design and jigs |
| Powder Bed Fusion | Selective laser sintering (SLS)<br>Electron Beam Meling (EBM)<br>Selective laser melting (SLM)<br>Selective heat sintering (SHS)<br>And Direct metal laser sintering (DMLS) | Polymers, Metals and Ceramic powder | 80 µm<br>70 µm<br>20–50 µm<br>100 µm<br>20–40 µm | 381x330x460<br>6096x1194x1524<br>300x300x300<br>160x140x150<br>250x250x325<br>Aerospace, automotive, dental, rapid prototyping and jewelry |
| Materia Jetting | Multi-jet Modelling, Drop on Demand, Thermo-jet printing and Inkjet printing | Polymers, Plastics and Waxes | 13 µm | 300x185x200<br>Casting patterns, prototypes and electronics |
| Binder Jetting | 3D printing | Polymers, Waxes, Metals and Foundry sand | 90 µm | 2200x1200x600<br>Prototypes, casting patterns and molds |
| Directed Energy Deposition | Laser Engineering Net Shape(LENS) | Metals | 50–100 µm | 1500x1500x2100<br>Aerospace, military, repair metal objects and satellites |
| Sheet Lamination Processes | Laminated Object Manufacturing (LOM) | Metals, Paper, Plastic film | 100 µm | 256x169x150<br>Prototypes, plastic parts and end user parts |

(*continued*)

**Table 1.** (*continued*)

| Process | Technology | Materials | Minimum layer resolution | Max. Build volume (LxWxH-mm$^3$) and Applications |
|---|---|---|---|---|
| Hybrid snd Direct Write AM | Combination of microextrusion, droplet based, laser and UV cutting, CNC machining, etc | Ceramic materials and Metal alloy | 50 µm | 734x650x559 Structural components and embedded 3D structures |

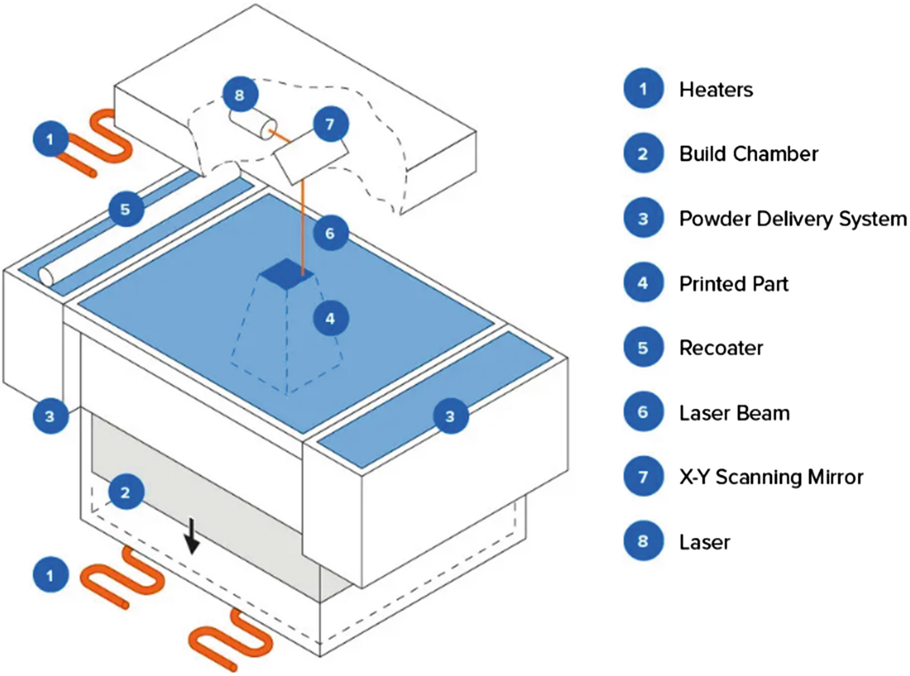

**Fig. 1.** Overview of SLS 3D printing [5].

## 1.2 The Potential of Additive Manufacturing and 3D Printing Technology

Additive manufacturing and 3D printing technologies have emerged as potential game-changers in the manufacturing industry. 3D printing technologies such as stereolithography and sintering have the potential to revolutionize the global economy. First, technology enables us to create products quickly and with fewer resources, resulting in cost savings [7]. The potential of additive manufacturing and 3D printing technologies is further enhanced by their ability to reduce lead times and costs. Additive manufacturing and 3D printing technologies can produce complex parts within a fraction of the time and cost compared to traditional manufacturing processes [15].

Additive manufacturing and 3D printing technologies can produce parts with high precision and accuracy, which can lead to improved product quality. Additionally, additive manufacturing and 3D printing technologies can produce parts with fewer defects, which can lead to reduced manufacturing costs. Fewer defects refer to ensuring the efficiency and quality of products by lessening the interval between pressing cycles, minimizing errors resulting from negligence, and ideal placement of elements. The production of fewer defective products by 3D printing proves more efficient than traditional manufacturing.

Wimpenny et al.‘s (2017) study also emphasizes how additive manufacturing technology may be utilized to create complex structures used in various sectors, including research, the aerospace, automotive, medical, building, fashion, food, and oceanographic industries. Additive manufacturing uses layer technology to slice any object into layers and reconstruct it using those layers, regardless of how complex its geometry is, to create the desired shape by adding material, preferably by stacking contoured layers on top of one another [20]. Figure 2 below is an example of how the principle of layer technology is applied in processing sculpture puzzles.

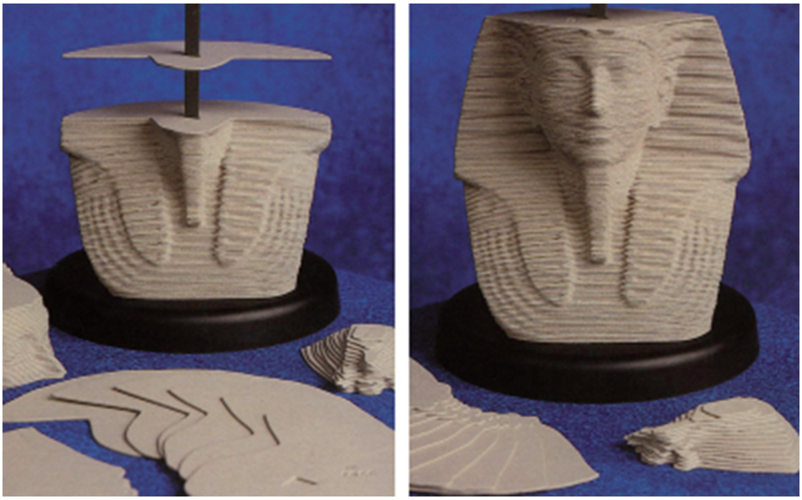

**Fig. 2.** Doing a sculpture puzzle using the principle of layer technology [6].

In terms of sustainability, additive manufacturing, and 3D printing technology has the potential to reduce the environmental impact of manufacturing. Gebler et al. (2014) conducted a sustainability-based study to assess the current state of the art of 3D printing in the context of sustainability in industrial manufacturing. These technologies require less material and energy to produce parts than traditional manufacturing processes [8]. In this case, 3D printing and additive manufacturing use less material by recycling materials such as scrap metals and use of biodegradable materials. Furthermore, 3D printing technologies can produce parts with fewer defects, which can reduce waste and improve resource efficiency. According to the study, using 3D printing in manufacturing has altered the input and output dynamics of production processes for low-volume, highly customized, and valuable products, such as tooling, aerospace manufacturing, and medical components [4]. By reducing the amount of resources used in the production process, 3D printing can reduce the amount of waste generated and energy consumed.

### 1.3 Challenges to the Adoption and Implementation of 3D Printing Technology

Although additive manufacturing and 3D printing technologies have great potential, obstacles must be removed before they can be used fully. These challenges range from the availability and affordability of the materials required, technical issues in using the technology, the formation of voids, and environmental concerns brought about by the type of materials used in the manufacturing process.

## 2 Methods

### 2.1 Materials Used

The limitations of conventional materials are one of the primary issues with additive manufacturing technologies. In addition, certain materials may require special printing techniques or may not be suitable for certain additive manufacturing processes. Therefore, it is vital to develop appropriate materials that can be used for 3D printing. It also requires more effort to enhance the mechanical qualities of 3D-printed products. According to Ngo et al. (2018), additive manufacturing processes are limited to materials that can be printed, such as polymers, metals, ceramics, and concrete, and these materials have certain limitations in terms of strength and durability, which can limit the range of applications for which additive manufacturing can be used [14]. Table 2 summarizes the primary applications, benefits, and obstacles of the primary materials for additive manufacturing/3D printing.

**Polymers:** The most prevalent and easily accessible materials are polymers. Polymers are regarded as the most often utilized materials in the 3D printing industry due to their flexibility and versatility in different 3D printing procedures [12]. However, more materials are being developed due to technological advancement. Materials are often produced as wire feedstock or powders; however, this changes over time. Polymers have traditionally been the primary material used in 3D printing due to their ease of production and handling. Polymer and composite 3D printing has been studied for many years in various industrial applications, such as the aerospace, architectural, toy-making, and medical fields [14]. However, because they lack pure polymer goods' strength and fundamental functionality, most additive-manufacturing polymer products are currently used as samples rather than fundamental components, restricting the technology's extensive industrial application.

**Metals/Alloys:** The subject of metal additive manufacturing is constantly developing, with new methods, alloys, and uses emerging more frequently. Faster production speeds and noticeable quality improvements result from alloys. Microscale additive manufacturing integrates metals with various microstructures and plastic or elastic properties and materials of crystalline & dense microstructure with ideal mechanical properties

**Table 2.** Main materials used in 3D printing [12].

| Materials | Main Applications | Benefits | Challenges |
|---|---|---|---|
| Metals and alloys | Aerospace and Automotive<br>Military<br>Biomedical | Multifunctional optimization<br>Mass-customization<br>Reduced material waste<br>Fewer assembly components<br>Possibility to repair damaged or worn metal parts | Limited selection of alloys<br>Dimensional inaccuracy and poor surface finish<br>Post-processing may be required (machining, heat treatment or chemical etching) |
| Polymers and composites | Aerospace and Automotive<br>Sports<br>Medical<br>Architecture<br>Toys<br>Biomedical | Fast prototyping<br>Coste-effective<br>Complex structures<br>Mass-customisation | Weak mechanical properties<br>Limited selection of polymers and reinforcements<br>Anisotropic mechanical properties (especially in fibre-reinforced composites) |
| Ceramics | Biomedical<br>Aerospace and Automotive<br>Chemical industries | Controlling porosity of lattices<br>Printing complex structures and scaffolds for human body organs<br>Reduced fabrication time<br>A better control on composition and microstructure | Limited selection of 3D-printable ceramics<br>Dimensional inaccuracy and poor surface finish<br>Post-processing (e.g., sintering) may be required<br>Layer-by-layer appearance<br>Anisotropic mechanical properties |
| Concrete | Infrastructure and construction | Mass-customization<br>No need for formwork<br>Less labour required<br>especially useful in harsh environment and for space construction | Poor inter-layer adhesion<br>Difficulties in upscaling to larger buildings<br>Limited number of printing methods and tailored concrete mixture design |

[17]. Metals are used in the 3D printing of intricate electrical and electronic circuitry components, structural and mechanical parts, and functionally essential parts. They can be sintered or melted from powder or deposited in liquid form using high-temperature procedures [12]. Metals commonly used in 3D printing include steel, gold, silver, aluminum, cobalt-chrome alloy, titanium, and stainless steel [9]. The time it takes for the

entire process to be finished is one of the main problems with metal additive manufacturing. Most additive manufacturing techniques use both heating and cooling. Traditional manufacturing processes are often much faster, with machines capable of producing parts in minutes.

In contrast, 3D printing can take hours or even days to finish a single part. This can be especially problematic for industries where speed and precision are essential. Additionally, some metals are more difficult to 3D print than others due to their physical properties, which can further complicate the process.

**Ceramics:** 3D printing is now a flexible production option due to the quick advancements in additive manufacturing that allow it to print ceramics in addition to a wide range of polymers. Ceramics are frequently used in bulked additive manufacturing techniques based on powder [3]. Due to ceramic materials' very high melting temperatures and the preparation of feedstock, 3D printing of ceramics is more challenging than printing with polymers and metals [12]. High melting temperatures are required to melt the bulk ceramic powder. The processing requirements for ceramic materials (in terms of feedstock and sintering) are quite difficult, making them difficult to process using 3D printing technology.

**Concrete:** Concrete, glass, metal, and wood are among the materials that are printed using additive manufacturing and 3D printing technologies in the construction sector. In the building business, additive manufacturing was only used for residential construction for the first time in 2014, according to [21]. To build structures and other infrastructure, one needs to have access to large-scale 3D printers. These printers can produce large quantities of concrete rushes that harden quickly. Traditional building is extremely time-consuming and expensive since it requires experienced employees to mix and pour concrete. According to a study by Wu et al. [21], the requirements for mass customization, the lack of widespread implementation, the life cycle cost of the printed projects, and the advancement of building information modeling were the main barriers to the adoption of 3D printing technology in the construction industry.

## 3 Technical Issues

Some technical challenges still need to be addressed for the technology to be used more widely. Traditional manufacturing processes, such as injection molding and machining, are well-established and are well-suited for mass production. On the contrary, additive manufacturing requires specialized printing techniques and materials [14]. For instance, resolution, surface quality, and layer bonding issues with micro-scale 3D printing occasionally necessitate post-processing methods like sintering [1]. Increasing the effectiveness and precision of additive manufacturing processes requires advanced printing technologies. As Lu et al. [11] claim, by implementing the five "any"—using practically any material to create any product, in any quantity and everywhere, for any industrial field—3D printing technology will be able to advance the revolution of fabrication modes and usher in a new era of personalized fabrication. Fusing 3D printing technology and procedures with conventional manufacturing methods will drive innovations in material, design, and fabrication processes [11].

### 3.1 Environmental Issues

There are environmental and safety concerns. Additive manufacturing processes use energy and materials, which can harm the environment. 3D printers consume more energy at the process or machine levels than similar conventional processes for most additive manufacturing processes. In addition, additive manufacturing processes produce fine particles and hazardous waste, which must be safely managed and disposed of. Moreover, additive manufacturing processes involve using chemicals and materials, such as metals, that are hazardous to human health.

### 3.2 Creation of Voids

Developing voids between succeeding layers is one of the main issues with 3D printing components. This kind of problem develops due to inadequate layer bonding, which leads to inadequate mechanical performance. For instance, voids develop between the created layers using extrusion-based additive manufacturing methods like FDM. This leads to delamination and anisotropic mechanical properties [16]. In reality, the amount of permeability brought on by void generation largely depends on the kind of additive manufacturing technique used and the material used [13]. A limited build volume is another issue that the user of additive manufacturing technology must deal with. It is regarded as some of the most important shortcomings of additive manufacturing expertise. Huge portions are usually reduced or divided into smaller amounts, which requires time and effort. In most cases, scaling down the model is also not practical or efficient. The assembly of the subparts gets weaker when adhesives are used and bulkier when mechanical fasteners are used. AM has not yet demonstrated viability in extensive industrial applications [10].

## 4 Results and Implications

### 4.1 Results

This paper has involved a comprehensive review of additive manufacturing and 3D printing technology literature. The review considered various studies (most recent or less than ten years old) that focused on the technology. The results reveal that additive manufacturing and 3D printing technology have a huge potential to revolutionize the manufacturing industry. It was also recognized that 3D printing technology had been used in various fields like medicine, automotive, aerospace, and construction. In each industry, technology has been used to advance production and increase efficiency. However, the review showed that some limitations and obstacles must be eliminated to allow the 3D printing technology to realize its full potential in whichever industry. For instance, the literature review revealed that although 3D printing technology was recently introduced in the construction sector, its potential is constrained by the absence of widespread use, the advancement of building information modeling, the demands of mass customization, and the lifetime costs of printed projects. Almost in every sector, past studies show that the key challenges involve tough processing requirements like in ceramics, expensive materials, sometimes highly regulated processes, poor mechanical performance, environmental concerns, and the technicalities needed for effectiveness and precision.

### 4.2 Implications

The implications of additive manufacturing processes on the future of the manufacturing industry are extensive. The introduction of additive manufacturing processes is likely to significantly impact employment, as it is likely to reduce the need for traditional manufacturing processes. In addition, additive manufacturing processes are likely to disrupt existing supply chains, as manufacturers will no longer be able to rely on traditional suppliers. Finally, introducing additive manufacturing processes will likely require new business models and strategies, as manufacturers will need to adapt to the changing landscape.

## 5 Conclusion

Additive manufacturing and 3D printing technology can potentially revolutionize the global economy. This technology enables us to create products quickly and with fewer resources, resulting in cost savings. In addition, the technology can be used to produce complex structures, which can be used in various industries such as aerospace, automotive, medical, and many more. Furthermore, the technology can be used to create custom products, enabling companies to meet the needs of their customers better. While the potential of additive manufacturing is vast, it also carries with it certain challenges that need to be addressed, like environmental and safety concerns, limitation of materials used, void formation, and the required new technical knowledge. Despite the challenges, the potential implications of this technology are immense and will continue to be explored as the technology develops.

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