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3D printing: A catalyst for innovation in modern industries

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Abstract. 3D printing, also known as additive manufacturing, has the potential to revolutionize various areas of society. This technology uses a layer-by-layer approach to transform digital designs into physical objects, allowing individuals and small businesses to easily produce prototypes, custom products, and replacement parts. This significantly reduces the barriers to entry that previously existed in the manufacturing industry. The democratization of product creation through 3D printing has significant implications for intellectual property and manufacturing. There are concerns about the ease with which 3D printing can be used to reproduce copyrighted designs, leading to debates on how to protect intellectual property rights in the digital age. Additionally, the technology may disrupt established manufacturing processes and threaten jobs in traditional manufacturing industries. Despite these concerns, the benefits of 3D printing cannot be ignored. The technology allows for efficient and cost-effective production of complex geometries that would be difficult or impossible to create using traditional manufacturing techniques. It also enables the creation of customizable and personalized products, reducing waste and increasing sustainability. To maximize the potential benefits of 3D printing while addressing its challenges, policymakers, stakeholders, and researchers are working together to develop solutions. These include developing new intellectual property laws and regulations, designing new manufacturing processes that combine traditional techniques with 3D printing, and promoting education and training programs to help ensure that individuals and businesses have the necessary skills to use 3D printing technology effectively.

Keywords: 3D printing, additive manufacturing, manufacturing innovation.

1. Introduction

By using digital design data, 3D printing enables the direct production of physical objects, opening up new opportunities for design creativity, customization, and modification of existing products or manufacturing techniques [1]. It is widely expected by researchers that the customer-centric approach of 3D printing will lead to the localization and democratization of manufacturing activities, allowing smaller companies to compete with or even surpass larger corporations. Entire supply chains can be shortened, reducing the environmental impact of moving goods around the world, while standardizing production capacity will dramatically reduce the complexities associated with modern planning processes [2]. However, this shift toward decentralized, on-demand manufacturing also raises important questions about intellectual property, product safety, and the displacement of traditional manufacturing jobs. This essay will explore the origins, advancements, and long-term implications of 3D printing on the economy, society, and the many emerging industries that will experience it most powerfully [3].

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2. Relevant principles

The following text will explore the historical development and technical concepts of 3D printing as it lays the groundwork for understanding how the technology works and how it has evolved over time.

3D printing technology is an advanced manufacturing technology based on digital models that can transform digital models into physical objects. Unlike traditional manufacturing methods, 3D printing technology uses a layer-by-layer stacking process. This advanced manufacturing method has been widely used in fields such as medicine, industrial design, and art, and has become one of the hotspots in the development of the manufacturing industry [4]. The principle of 3D printing technology is to manufacture objects by layer-by-layer stacking materials. First, a three-dimensional model needs to be established. This model can be created using computer-aided design software (CAD) or downloaded from the internet. Then, the three-dimensional model is imported into slicing software for processing, setting related parameters, and generating G-code files. Next, the G-code file is input into the 3D printer, which will parse the file and start working.

Inside the 3D printer, there is a heater that can heat the material to above its melting point. Then, the material is gradually sprayed or extruded out by a nozzle or extrusion device. After each layer is processed, it moves down one layer and repeats the process until the entire object is completed.

The materials used in 3D printing machines are usually plastics, metals, ceramics, and other materials. These materials are heated to above their melting point and then gradually sprayed or extruded out of the 3D printer using a nozzle or extrusion device. After coming into contact with the air, these materials quickly cool and solidify, forming a hard object [5].

In summary, the principle of 3D printing technology is to establish a digital model and transform it into a physical object. Its advantages are that it can manufacture high-quality products with high precision and reliability. Compared with traditional manufacturing methods, 3D printing technology has higher flexibility and production efficiency. Moreover, various materials and colors can be used in 3D printing technology to create a variety of products.

However, 3D printing technology also faces some challenges. One of the main challenges is that the printing speed is too slow. Since materials need to be stacked layer by layer, it takes a long time to produce a single object. In addition, some special materials may be difficult to adapt to the requirements of 3D printing technology. Furthermore, the price of 3D printers is relatively high, which may not be practical for many people.

In conclusion, the principle of 3D printing technology is advanced and useful. Although there are some challenges, this manufacturing method has become an important component of modern industrial design and medicine [6]. With the continuous development of technology, 3D printing technology is expected to have more extensive applications and bring us more possibilities.

In terms of the technical principles that govern the functionality of 3D printing, the process begins with the creation of a digital model using software designed specifically for the printer. The software then slices the 3D model into thin, two-dimensional layers and converts them into machine instructions for the printer to execute [7]. The printer then builds the object layer by layer. There are several types of 3D printing technologies, each with their own advantages and disadvantages. The ISO/ASTM 52900 standard classifies 3D printing processes into seven groups, including tank photopolymerization, material extrusion, sheet lamination, directed energy deposition, material flow, binder flow, and powder bed fusion. The first category is Watt photopolymerization, which uses a photopolymer resin cured by an ultraviolet light source to create an object. There are three forms of this technique, including stereolithography, digital light processing, and continuous liquid interface fabrication.

The second category is material extrusion, which uses a heated nozzle to melt a solid thermoplastic filament and place it on a build platform. The third category is sheet lamination, which uses paper and plastic as a construction material to reduce printing costs. The fourth category is directed energy deposition, which uses a nozzle to deposit a metal powder melted by a laser, plasma, or electron beam onto a build platform to form a solid. The fifth category is material sputtering, which applies a light-sensitive material in droplets through a small-diameter nozzle, which is then cured by ultraviolet light to build a layer-by-layer part. The sixth category is binder spraying, which uses two materials: a powder

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base material and a liquid binder. Finally, the seventh category is powder bed fusion, which involves spreading a thin layer of powder over a build platform and selectively melting or sintering it to form a solid.

Each 3D printing technology has its own strengths and weaknesses in terms of cost, speed, material properties, and geometric limitations [8]. Although the process can produce almost any structure, the printed object often requires post-processing to achieve the optimal surface finish. In addition, one of the main limitations of 3D printing is the lack of a one-size-fits-all solution due to the diversity of materials and applications [7].

3. Application analysis

3.1. Aerospace manufacturing

The use of 3D printing in the aerospace industry has many implications and applications that make it an attractive option for manufacturing. Compared to traditional manufacturing methods, 3D printing reduces the need for supply chain management and machinery, making it more cost-effective. It also reduces waste material with a 40% reduction in metal applications, and most waste materials can be recycled. 3D printing also reduces manufacturing time and cost without sacrificing performance [9].

One of the most attractive advantages of 3D printing in the aerospace field is the potential for fuel savings due to the lighter weight of parts. This can reduce annual fuel costs by up to $3,000 per kilogram of material saved. In addition, 3D printing reduces resource consumption, energy demand, and process-related CO_2 emissions per unit of GDP, making it a sustainable choice for long-term manufacturing in the aerospace industry. Furthermore, nanocomposites are an attractive material option due to their ability to combine the properties of nanomaterials with those of the host matrix. Incorporating nanoparticles into the base material can improve mechanical properties, thermal and electrical conductivity, and dimensional accuracy, and lower the sintering temperature. There are two methods of incorporating nanomaterials into a 3D printed object: intermittent stops during printing to add the nanomaterials to the base matrix material.

While unmanned aerial vehicles and experimental aircraft can quickly adopt 3D printing due to lower regulatory scrutiny, operational aircraft that remain in service long after production ends can also benefit. Supporting hard-to-find parts for these aircraft is no longer a problem.

Despite ongoing research in additive manufacturing (AM), the aerospace industry's adoption of 3D printing has been slow. This can be attributed to strict certification requirements critical to the safety of aircraft and spacecraft, and testing and safety standards for AM, which are still under development. The various AM technologies are not yet fully mature and a number of certification rules are difficult to define. Additionally, high energy requirements, sometimes times more than traditional production [10].

Moreover, it enables the production of lattice structure parts, which helps to reduce the weight of aircraft and improve fuel efficiency. With an increased reliance on unmanned aerial vehicles, AM has become an essential part of cost-effective production, especially for prototypes and small production runs. However, challenges remain, such as the need for certification and qualification of parts for commercial use and the understanding of fatigue and aging in AM alloys. Despite these challenges, AM has proven to be a valuable tool in the aerospace industry, and its applications continue to grow, even extending to the automotive industry, where it offers opportunities for lighter, safer, and environmentally friendly cars with reduced production lead times and costs [10].

3.2. Pharmaceutical field

3D printing has emerged as a valuable tool for pharmaceutical manufacturing in recent years. This technology enables the production of complex solid dosage forms with high precision and accuracy, on-demand production, and affordability. Personalization and customization of drugs with individually adjustable doses is also possible with 3DP, making it an attractive option for pharmaceutical manufacturing, nozzle-based deposition systems, and laser-based writing systems. Among these, the piezoelectric DOD method is more suitable for pharmaceutical applications because it can be operated with less volatile and more biocompatible liquids at room temperature. DOD technology can be further divided into two subtypes, which are called droplet deposition and droplet powder deposition [11]. The former method involves printing droplets on top of previously deposited droplets, while the latter method involves depositing droplets onto a bed of powder.

The most investigated applications of 3DP in pharmaceuticals, tablets have been the most studied 3DP dosage form. Single active pharmaceutical ingredient (API) tablets and multiple API tablets are the two main categories of 3DP tablets. The choice of materials and manufacturing methods significantly affect the physical properties of 3DP tablets, including drug release profiles. In addition, 3DP technology is applied to the production of immediate release, extended release and modified release tablets. While FDM is a popular method for producing 3DP tablets, other methods such as SLS and IJ have also shown potential. Overall, 3D printing technology has shown great potential in the pharmaceutical industry, especially in the production of customized transdermal delivery systems and 3D tissue models for drug discovery and development. It also offers possibilities for the fabrication of biomimetic constructs, DNA biosensors, and targeted delivery of anticancer drugs. However, there are still technical and regulatory challenges that need to be addressed before 3D printing becomes a standard method for commercializing a pharmaceutical product [12].

3.3. Building construction

The construction industry has been exploring the use of three-dimensional (3D) printing technology for over 25 years. Recently, technology has led to increased interest in the industry. Two main techniques used in 3D printing of concrete structures have been identified: binder jetting and material deposition method (MDM). There is MDM as a central production process. Bond jetting allows for the printing of complex geometries and encourages designs to have voids and overhangs; layer thickness must be carefully controlled to ensure proper bonding, and the process may be difficult to use for on-site construction applications [13].

Self-compacting concrete (SCC) is widely used in conventional concrete structures due to its advantages in reducing time and eliminating the need for vibration. However, the higher deposition flux of SCC may not be suitable for 3D printing. Researchers have used different 3D printing materials with different compositions and properties in 3DCP., increasing safety and allowing the construction of more complex structures. Conventional construction processes require skilled labor, two-dimensional (2D) drawings, and scale models to construct any form of free-form structure [14]. However, 3D printing technology combined with Building Information Modeling (BIM) can streamline the process of creating highly customized building components and facilitate the construction of more complex designs. By eliminating the need for molds in the construction of concrete structures, 3D printing technology can reduce construction time at no additional cost. 3D printing in construction has potential benefits beyond cost reduction and improved safety. Technology can provide a competitive advantage while supporting the global push to reduce carbon emissions. Technology enables innovative construction solutions that can pave the way for sustainable construction.

3.4. Intelligent textile

Additive manufacturing has the potential to revolutionize the textile industry by offering a new way of designing, prototyping and manufacturing textile products. Unlike traditional manufacturing, 3DP can create complex 3D structures efficiently and cost-effectively, making it attractive for textile customization and innovation[15].

Several 3DP technologies are available for the textile and fashion industry. Material extrusion is one of the most common 3DP techniques for textiles. Direct ink printing is another 3DP technique that can be used to produce complex and customizable textile structures. Electrohydrodynamic direct writing is a special inkjet-based 3DP method that can print conductive materials onto textiles for wearable electronics. 3DP technology in textiles also has several advantages over traditional manufacturing, such as flexible design, rapid prototyping, on-demand printing, waste minimization, and advanced healthcare. However, there are also some disadvantages, such as limited material selection, limited construction

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size, post-processing requirements, large production volume, and part structure limitations. Comfort remains an important issue in creating flexible parts such as chain link structures using 3DP technology. In addition, due to limitations in raw materials, and it is necessary to develop low-cost designs for everyday wear [16]. Finally, the lack of a uniform test standard makes it difficult to compare the properties and capabilities of different 3DP textiles. However, with further research and development.

4. Conclusion

As the Internet does, it will take some time to reach its full potential, but it is already having an impact by reducing costs and enabling personalization. With the ability to print on-demand goods, companies will no longer need to hold inventory, saving them money, while consumers will be able to print what they need, reducing reliance on traditional suppliers. Moreover, 3D printing allows the customer to print objects in remote locations, uses materials with improved properties and requires a low level of human interaction. As more industries adopt this technology, we could see significant economic consequences as production moves closer to the end consumer and more personalized products are produced.While there are some concerns about safety and cost, the benefits of 3D printing far outweigh the drawbacks. One of the main limitations is the lack of legislation and regulations governing its use. For example, there have been cases where 3D printing has been used to create guns and weapons. In addition, 3D printing can be expensive and time-consuming, and some materials may not be suitable for use in certain applications. In addition, the technology has not yet reached the level of accuracy and speed required for mass production, and technical limitations such as the size of printable objects. The 3D printing revolution is happening, and those who can adapt to this new trend will benefit, while those who stick to traditional methods will be left behind. It is clear that 3D printing represents a paradigm shift and we will have to be patient and see the snowball roll in the right direction.

References

[1] Matias E, Rao B. 3D printing: On its historical evolution and the implications for business. In 2015 Portland International Conference on Management of Engineering and Technology (PICMET) 2015 Aug 2 (pp. 551-558). IEEE.
[2] Jiang R, Kleer R, Piller FT. Predicting the future of additive manufacturing: A Delphi study on economic and societal implications of 3D printing for 2030. Technological Forecasting and Social Change. 2017 Apr 1;117:84-97.
[3] Su A, Al'Aref SJ. History of 3D printing. In3D Printing Applications in Cardiovascular Medicine 2018 Jan 1 (pp. 1-10). Academic Press.
[4] Pîrjan A, Petroşanu DM. The impact of 3D printing technology on the society and economy. J. Inf. Syst. Oper. Manag. 2013 Dec;7(2):360-70.
[5] Savini A, Savini GG. A short history of 3D printing, a technological revolution just started. In2015 ICOHTEC/IEEE international history of high-technologies and their socio-cultural contexts conference (HISTELCON) 2015 Aug 18 (pp. 1-8). IEEE.
[6] Bastawrous S, Wu L, Liacouras PC, Levin DB, Ahmed MT, Strzelecki B, Amendola MF, Lee JT, Coburn J, Ripley B. Establishing 3D printing at the point of care: basic principles and tools for success. Radiographics. 2022 Mar;42(2):451-68.
[7] Shahrubudin N, Lee TC, Ramlan RJ. An overview on 3D printing technology: Technological, materials, and applications. Procedia Manufacturing. 2019 Jan 1;35:1286-96.
[8] Al Jassmi H, Al Najjar F, Mourad AH. Large-scale 3D printing: the way forward. InIOP Conference Series: Materials Science and Engineering 2018 Mar 1 (Vol. 324, No. 1, p. 012088). IOP Publishing.
[9] Joshi SC, Sheikh AA. 3D printing in aerospace and its long-term sustainability. Virtual and physical prototyping. 2015 Oct 2;10(4):175-85.
[10] Karkun MS, Dharmalingam S. 3D Printing Technology in Aerospace Industry–A Review. International Journal of Aviation, Aeronautics, and Aerospace. 2022;9(2):4.

DOI: 10.54254/2755-2721/9/20230103

[11] Park BJ, Choi HJ, Moon SJ, Kim SJ, Bajracharya R, Min JY, Han HK. Pharmaceutical applications of 3D printing technology: current understanding and future perspectives. Journal of Pharmaceutical Investigation. 2019 Nov;49:575-85.
[12] Trenfield SJ, Awad A, Goyanes A, Gaisford S, Basit AW. 3D printing pharmaceuticals: drug development to frontline care. Trends in pharmacological sciences. 2018 May 1;39(5):440-51.
[13] Tay YW, Panda B, Paul SC, Noor Mohamed NA, Tan MJ, Leong KF. 3D printing trends in building and construction industry: a review. Virtual and Physical Prototyping. 2017 Jul 3;12(3):261-76.
[14] Hossain MA, Zhumabekova A, Paul SC, Kim JR. A review of 3D printing in construction and its impact on the labor market. Sustainability. 2020 Oct 15;12(20):8492.
[15] Chatterjee K, Ghosh TK. 3D printing of textiles: potential roadmap to printing with fibers. Advanced Materials. 2020 Jan;32(4):1902086.
[16] Spahiu T, Grimmelsmann N, Ehrmann A, Piperi E, Shehi E. Effect of 3D printing on textile fabric. Engineering and Entrepreneurship. 2017 Nov;1(1):1-7.