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A Review on Processes, Types, Applications and Recent Trends of 3D Printing Technology

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Abstract: ***The established rules of manufacturing and design have undergone a fundamental shift as a result of 3D printing, often known as additive manufacturing. By building objects sequentially using successive layers of material based on digital 3D models, 3D printing differs from typical subtractive manufacturing procedures that involve the removal of material from a solid block. This review examines the most recent developments in 3D printing technology over the previous five years in terms of processes, types, applications, and recent trends. Quite a few study papers are examined in order to find the most recent trends in development. This article will act as a handy point of reference for exploring its historical development, technological advances, and unexplored research potential in the years to come.***

Keywords: 3D Printing, Additive Manufacturing, Fused Deposition Modelling (FDM), CAD, Industry4.0

1. Introduction

The traditional approaches of manufacturing and design have been reimagined by 3D printing, commonly referred to as additive manufacturing. Instead of cutting or molding material from a solid block as is the case with traditional subtractive manufacturing techniques, 3D printing builds products layer by layer from digital 3D models. This method offers unmatched flexibility and accuracy for building delicate, complicated structures, enabling businesses from a variety of sectors to generate specialized parts, working prototypes, and even finished products with unmatched speed and adaptability. 3D printing, one of the most exciting technological advancements of the twenty - first century, is upending a number of sectors, including consumer goods, healthcare, aerospace, and automotive (Wohlers & Caffrey, 2020).

The capacity of 3D printing to modify production processes is at the core of its revolutionary power.3D printing transformed production by enabling the layer - by - layer fabrication of three - dimensional items, eliminating previous limitations and complications. Its capacity for rapid prototyping and on - demand production is challenging conventional mass production methods, fostering a new era of customization, efficiency, and cost - effectiveness (Anderson & Pérez, 2019).

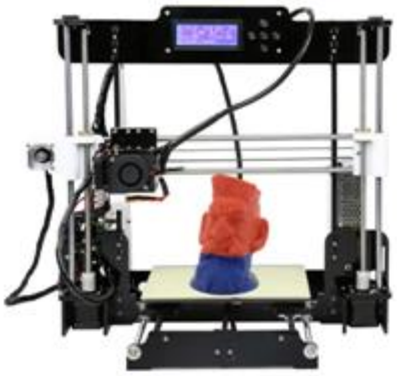


Figure 1: Commercial 3D printer [25]

3D printing's transformational impact extends to healthcare, where it has brought about a paradigm shift in patient - specific care. Customized implants, prosthetics, and anatomical models are just the beginning. The technology has opened doors to intricate surgical planning, drug delivery systems, and even the potential for bioprinting of tissues and organs. These applications are enhancing patient outcomes and challenging conventional medical practices (Ventola, 2020).

In the aerospace industry, 3D printing has ushered in a new era of aircraft design and manufacturing. Components that were once assembled from multiple parts can now be printed as single, lightweight structures. This not only reduces fuel consumption but also enhances the structural integrity of aerospace components, making air travel safer and more efficient (Gardan et al., 2018).

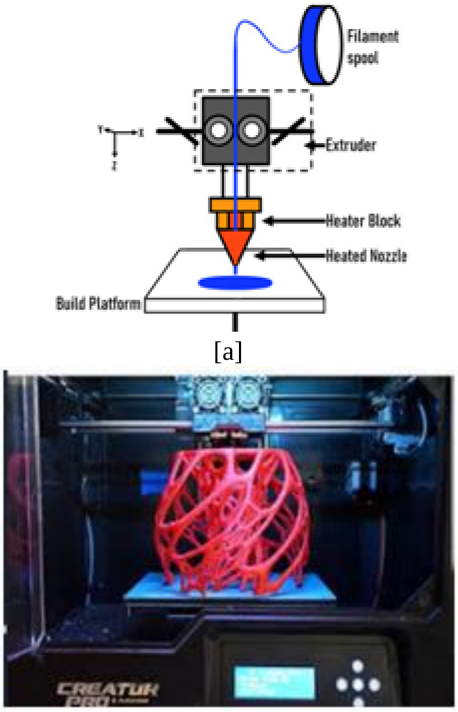
2. Types of 3D Printing Processes

Some of the popular 3D printing processes are reviewed below:

2.1 Fused Deposition Modeling (FDM)

FDM was introduced by Scott Crump in the early 1990s, stands as a pioneering technology within the additive manufacturing domain (Crump, 1992). FDM is predicated on a simple yet revolutionary concept, where thermoplastic filaments are heated to their melting point and extruded layer by layer through a nozzle, following precise instructions from computer - aided design (CAD) models. This additive layering process grants FDM its distinctive edge, offering an exceptional blend of accessibility, cost - efficiency, and adaptability that has democratically opened the doors to 3D printing for both small - scale innovators and global corporations (Berman, 2021).

In aerospace, FDM's transformative potential has become evident as it facilitates the production of intricate, lightweight components (Gardan et al., 2018). The aerospace industry's stringent demands for precision and material integrity find alignment with FDM's capabilities, leading to the manufacturing of parts with improved structural performance while reducing overall weight and production time. These advantages position FDM as a valuable asset in the aerospace sector's pursuit of efficiency and innovation (Gardan et al., 2018).



[a]

[b]

Figure 2: [a] FDM sketch, [b] FDM machine [26]

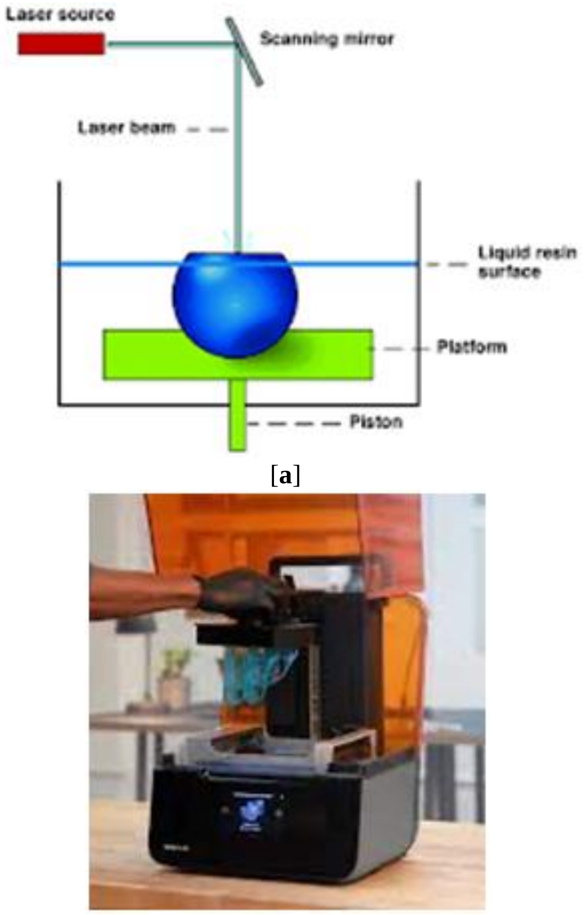
In the realm of healthcare, FDM has emerged as a disruptive force, enabling patient - specific solutions that were once unimaginable. From customizable surgical instruments to anatomical models used for surgical planning, FDM has propelled medical innovation forward (Ventola, 2020). These applications are not confined to theoretical constructs but are being actively employed in clinical practice, enhancing patient outcomes and redefining the boundaries of medical possibility (Ventola, 2020).

2.2 Stereolithography (SLA)

Stereolithography (SLA), an additive manufacturing technology introduced in the mid - 1980s by Chuck Hull, represents a pioneering stride in the realm of 3D printing (Hull, 1986). This transformative method capitalizes on the photopolymerization principle, where liquid resin is solidified layer by layer, guided by a computer - generated ultraviolet (UV) laser, ultimately culminating in the creation of intricate 3D objects. SLA's inherent precision and capacity for producing high - resolution models have solidified its reputation as a groundbreaking technology in the additive manufacturing landscape.

In aerospace, SLA's transformative potential becomes evident in the production of complex, lightweight components requiring exceptional precision (Gardan et al., 2018). Its ability to craft intricate, aerospace - grade parts with exceptional surface finish and dimensional accuracy is highly valued. These parts, previously a manufacturing challenge, are now realized with ease, contributing to improved aircraft performance and safety (Gardan et al., 2018).

Within the healthcare sector, SLA's transformational impact has been profound. This technology enables the creation of detailed anatomical models and patient-specific medical devices, transcending the limitations of conventional manufacturing techniques (Ventola, 2020). Surgeons utilize SLA - produced anatomical models for pre - surgical planning, allowing for a deeper understanding of complex cases. Customized prosthetics and dental implants fabricated with SLA are further testimony to the technology's ability to improve patient care and outcomes (Ventola, 2020).



[**a**]

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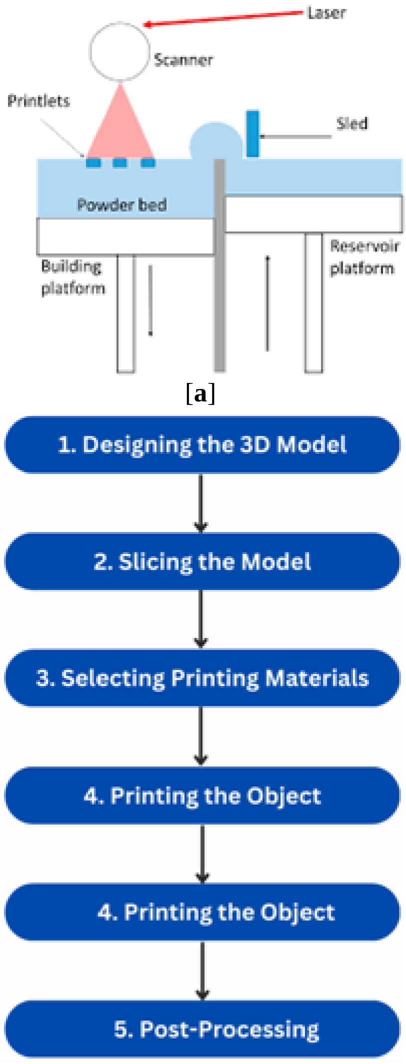
Figure 4: [a] SLA sketch, [b] SLA machine [27]

2.3 Selective Laser Sintering (SLS)

It is a transformative additive manufacturing technique, has evolved significantly since its inception in the late 1980s (Deckard, 1989). SLS leverages a high - powered laser to selectively sinter powdered materials, including polymers, metals, and ceramics, layer by layer, ultimately yielding intricate 3D objects. This process showcases SLS's exceptional precision and material versatility, making it a pioneering force in additive manufacturing.



[**a**]

[**b**]

Figure 5: [a] SLS sketch, [b] SLS machine [28]

In the aerospace industry, where precision and material performance are paramount, SLS has demonstrated its transformative potential (Kärger et al., 2020). SLS's capacity to fabricate lightweight, robust, and intricate components using aerospace - grade materials aligns perfectly with the sector's demands. Complex geometries that were once challenging to produce are now attainable with ease, revolutionizing aircraft and spacecraft manufacturing (Kärger et al., 2020).

Within healthcare, SLS has emerged as a revolutionary technology, enabling the creation of patient - specific implants and intricate surgical instruments (Bose et al., 2013). The precision and material versatility offered by SLS have opened doors to innovations like customized orthopedic implants and biocompatible devices tailored to individual patients, revolutionizing healthcare practices and enhancing patient outcomes (Bose et al., 2013).

3. Basic Procedures of 3D Printing

Although each 3D printing technology has different procedures, however the basic steps remains the same.

Figure 6: Basic Procedures of 3D Printing

Some of them are as listed:

3.1 Designing the 3D Model

The inception of any 3D printing endeavor commences with the design of a digital 3D model. CAD software plays a pivotal role in crafting this virtual representation, enabling precise control over the object's dimensions, intricacies, and functionality (Wohlers, 2019).

3.2 Slicing the Model

Once the digital design is perfected, it undergoes the critical process of slicing, converting the 3D model into a format comprehensible to the 3D printer. Slicing software dissects the model into discrete horizontal layers, as highlighted by Campbell and Griffiths (2019). Each layer is then translated into a set of instructions, often in G - code format, which the printer uses to execute the precise deposition of material. The slicing process permits fine - tuning parameters like layer height and infill density, allowing for tailored control over the final print's quality.

3.3 Selecting Printing Materials

The choice of printing material is a pivotal consideration in the 3D printing workflow. It depends on both the printer's capabilities and the intended application of the final object. Plastics, metals, and resins are commonly employed materials, each imparting distinct characteristics to the printed object (Gibson et al., 2014). The selection process involves weighing material properties against the desired outcome.

3.4 Printing the Object

With the model sliced and the material selected, the 3D printer embarks on the transformative printing process. The printer's nozzle or laser, as elucidated by Hull (1986), meticulously follows the G - code instructions, depositing or solidifying material layer by layer. This additive layering technique lies at the core of 3D printing, and the material is often heated to ensure adequate adhesion between layers. The complexity and scale of the object determine the print duration, ranging from minutes to hours, exemplifying the flexibility of 3D printing across various temporal scales.

3.5 Post - Processing

Upon the printer's completion of the object, post - processing steps may be necessary to refine the final result. This can encompass the removal of support structures, a technique described by Chua et al. (2015) as essential for overhanging features. Sanding or smoothing rough surfaces, a process highlighted by Campbell and Griffiths (2019), may also be required. Furthermore, finishing touches such as painting or the assembly of multiple printed parts may be incorporated, as underscored by Rengier et al. (2010). The extent of post - processing hinges on the intended end result and aesthetic considerations.

(Include one flow diagram of the processes)

4. Applications of 3D printing Technologies

4.1 Health

The integration of 3D printing technology into healthcare has ushered in a new era of personalized patient care and innovative medical solutions (Ventola, 2020). One significant application lies in the creation of patient - specific anatomical models, generated from medical imaging data (Tam et al., 2017). Surgeons utilize these 3D - printed models for preoperative planning and practicing complex procedures, leading to more precise surgeries (Chae et al., 2015). Additionally, 3D printing enables the development of customized prosthetic limbs and implants, enhancing comfort and functionality for patients (Ventola, 2020). Surgical guides and instruments, tailored to individual anatomies, contribute to improved surgical precision and reduced risks (Tack et al., 2016). Bio - resorbable devices, such as 3D - printed airway splints, offer innovative solutions in pediatric cases, gradually dissolving and eliminating the need for additional surgeries (Zopf et al., 2013). Furthermore, 3D printing has even extended its influence to drug delivery systems, potentially revolutionizing personalized medicine by tailoring drug doses and release profiles to individual patient needs (Ventola, 2020).

These applications highlight the transformative potential of 3D printing in healthcare, offering tailored solutions that improve patient outcomes and streamline medical procedures (Ventola, 2020; Chae et al., 2015; Tam et al., 2017; Tack et al., 2016; Zopf et al., 2013). The technology's versatility in creating customized anatomical models, implants, surgical guides, and even bio - resorbable devices signifies a paradigm shift in the medical field, underlining its capacity to enhance patient care (Ventola, 2020).

4.2 Automotive Industry

The potential of 3D printing has been fully realized in the automobile sector, which now uses it to spur innovation, optimize production methods, and improve vehicle performance. Rapid prototyping of automobile parts, including as engine parts, interior elements, and exterior panels, is one common use (Rosen, Harrysson, & West, 2015).3D printing allows for the swift creation of complex prototypes, facilitating design iterations and reducing development lead times. This capability not only accelerates product development but also enables engineers and designers to test and refine components before final production, leading to improved product quality and performance.

Another impactful application lies in the manufacturing of customized and low - volume parts.3D printing technologies like Selective Laser Sintering (SLS) and Fused Deposition Modeling (FDM) have been employed to produce specialized automotive components tailored to unique specifications (Ashcroft, Hague, & Hague, 2013).

This is particularly valuable in the production of luxury and high - performance vehicles, where customization is a key selling point.3D printing allows for the efficient creation of intricate and bespoke parts, contributing to the automotive industry's ability to meet the diverse demands of consumers.

4.3 Consumer goods

3D printing has disrupted the consumer goods industry by offering customization, rapid prototyping, and cost - effective manufacturing solutions. One prominent application is the creation of personalized consumer products. With the ability to design and acquire goods that suit their own preferences, from custom - fitted eyewear to personalized home decor, customization has become a defining feature of 3D printing (O'Connell & Akintoye, 2018). This degree of personalisation not only improves the customer experience, but it also creates new opportunities for businesses to interact with their clients and satisfy the needs of specialized markets.

Additionally, small - scale production and prototyping in the consumer goods sector have been made easier by 3D printing. The time to market can be greatly shortened by manufacturers through speedy testing and iterations of new product designs (Berman, 2012).

Small businesses and startups can compete with larger organizations in the quick - moving consumer market because to this adaptability, which is extremely valuable to them. Additionally, 3D printing technology have made it possible to produce replacement components on - demand, cutting waste and providing sustainable options for consumer goods (Schneider et al., 2018). We can anticipate seeing 3D printing used to create many more consumer goods as technology develops.

5. Recent advancement trends in 3D printing technology

5.1 Evolvement of advanced printing materials

In the realm of 3D printing, the continuous evolution of advanced materials has been a key driver of innovation. Recent developments have led to materials with enhanced properties, paving the way for the creation of more sophisticated and functional printed objects. For instance, researchers have been exploring advanced polymer materials that offer improved strength, durability, and flexibility (Vaezi, Seitz, & Yang, 2013). These materials are particularly valuable in industries such as aerospace and automotive, where high - performance parts are essential. Additionally, advancements in biocompatible materials have opened up new possibilities in the field of medical 3D printing. Biocompatible polymers and ceramics are being used to produce patient - specific implants and tissue scaffolds with enhanced compatibility and integration within the human body (Salmi et al., 2017).

Another significant development is the utilization of nanomaterials in 3D printing. Incorporating nanoparticles into printing materials enhances properties such as electrical conductivity, thermal conductivity, and mechanical strength (Dai, Rustom, & Derby, 2018). This breakthrough has unlocked applications in electronics, where 3D - printed conductive materials are employed in the production of intricate circuits and sensors. Furthermore, developments in composite materials have allowed for the creation of hybrid structures, combining the advantages of multiple materials into a single printed object (Ravindran, 2018). These advancements are pushing the boundaries of what can be achieved with 3D printing, leading to the production of highly functional and complex components across various industries.

5.2 Industry 4.0 Integration

The integration of 3D printing with Industry 4.0, characterized by the convergence of digital, physical, and cyber - physical systems, has witnessed significant advancements in recent years. The emergence of smart factories and the Industrial Internet of Things (IIoT) has transformed 3D printing processes. One notable development is the implementation of real - time monitoring and control systems for 3D printers (Dai, Xue, & Hao, 2019). These systems utilize sensors and data analytics to continuously assess print quality, detect anomalies, and optimize printing parameters in real - time. Such capabilities enhance the reliability and efficiency of 3D printing in industrial settings.

Furthermore, the integration of Artificial Intelligence (AI) and Machine Learning (ML) has played a pivotal role in improving the performance and quality of 3D - printed objects. AI algorithms can analyze large datasets of design and printing information, identifying patterns and optimizing designs for cost - efficiency and performance (Gao et al., 2019). Additionally, AI - driven quality control systems can detect defects or inconsistencies during the printing process, reducing waste and ensuring the production of high - quality parts. These recent developments in Industry 4.0 integration not only streamline 3D printing workflows but also contribute to the broader goal of autonomous and adaptive manufacturing.

5.3 Distributed Manufacturing

Distributed manufacturing, enabled by 3D printing technology, has experienced remarkable progress in recent years. It involves the decentralized production of goods, where 3D printing plays a central role in localized manufacturing. One significant development is the emergence of distributed manufacturing networks (DMNs) that connect 3D printers across various geographic locations (Parthasarathy et al., 2017). These networks allow for the efficient sharing of design files and the on - demand production of parts closer to the point of need. It has implications for reducing transportation costs, minimizing lead times, and enabling rapid response to changing demands, making it particularly valuable in industries like aerospace and healthcare.

Additionally, advancements in material sciences and multi - material 3D printing have expanded the capabilities of distributed manufacturing. Researchers have been working on developing new materials and composites with tailored properties for specific applications (Smith et al., 2019). For instance, the integration of conductive materials within printed objects has paved the way for the production of electronic components closer to the end - user, reducing the need for centralized electronics manufacturing (Smith et al., 2019). These developments signify a shift toward more sustainable and localized production processes, aligning with the principles of distributed manufacturing.

6. Conclusion

With the advancement of science and technology, the applications of 3D printing expands to almost all branches of engineering and health. It also have significant use in business for cost reduction and complexities of operations.

Moreover, the recent developments in 3D printing field itself are vast and promising and present Research and Development (R&D) has yet to expand its flexibility and scope. This brief review about the 3D printing technology will serve the purpose of handy references in imparting various history and development as well as open future research opportunities.

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