An Overview on 3D Printing Technology: Technological, Materials, and Applications

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Abstract

By layering on materials one after the other, digital fabrication technology—also known as 3D printing or additive manufacturing—manufactures actual itemsfrom geometric representations. One rapidly developing technology is 3D printing. These days, 3D printing is employed all over the world. The application of 3D printing technology is expanding in the fields of agricultural, healthcare, automotive, locomotive, and aviation. It is utilized for mass modification and fabrication of various open-source designs.

With the use of printing technology, a computer-aided design (CAD) model can be used to print an object layer by layer through material deposition. The varieties of 3D printing methods, their applications,and the materials utilized for 3D printing in the industrial industry are all summarized in this paper.

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1. Introduction

By adding material piece by piece, 3D printing may turn a geometric representation into a tangible thing [1]. Many have witnessed a remarkable growthin this 3D procedure in recent years.
Charles Hull first commercialized 3D printing techniques in 1980 [2]. At the moment, 3D printing is mostly utilized to create prosthetic heart pumps [3], jewelry lines [4], 3D printed corneas [5], PGA rocket engines [6], the Amsterdam steel bridge [7], and other items associated withthe food and aviation industries.

The process of fabricating three- dimensional (3D) structures layer by layer using computer-aided design (CAD) drawings is where 3D printing technology first emerged [8]. The really inventive and adaptable 3D printing technology has become a major technological advancement. It offers hope for numerous possibilities and creates new opportunity for businesses trying to increase production effectiveness. Currently, materials that can be manufactured using 3D printing technology include metal, ceramics, graphene-based materials, and conventional thermoplastics [9]. The manufacturing line and several industries could undergo a revolution thanks to 3D printing technology. By using 3D printing technology, manufacturing speeds will riseand costs consumer demand will exert a greaterinfluence over production.

Customers have more control over the finished product and can ask for it to be made according to their specifications. Inthe interim, 3D printing technology facilities will be situated nearer to the customer, enabling a more adaptable andresponsive manufacturing process in addition to enhanced quality control.
Moreover, the demand for international transportation is greatly reduced when 3Dprinting technology is used. This is due tothe fact that fleet tracking technology canhandle all distribution when production facilities are situated closer

to the final destination, saving both time and energy. Finally, the company's logistics may alteras a result of the implementation of 3D printing technology. The companies' logistics may oversee the entire process and provide more thorough, end-to-end services [10].

In the modern world, 3D printing is extensively utilized. The usage of 3D printing technology is growing in the fields of agriculture, healthcare, the automobile sector, and aerospace for masscustomization and manufacture of open- source designs [11].

However, there are a number of drawbacksto the manufacturing sector using 3D printing technology. For example, the use of 3D printing technology will lessen the need for manufacturing labor, which will inevitably have a significant impact on theeconomies of nations that rely heavily on low-skill occupations. Furthermore, users can create a wide variety of objects, including weapons, knives, and hazardous materials, utilizing 3D printing technology. Thus, only specific individualsshould be able to use 3D printing in order to stop terrorists and criminals from bringing guns into their homes undetected.At the same time, it will be simple for someone to counterfeit goods if they manage to obtain a blueprint. This is due to the fact that using 3D printing technology just requires basic drawing anddata entry into the printer to produce 3D things [12].

In summary, 3D printing technology has become a versatile and potent tool in the advanced manufacturing sector in recent years. Many nations have made extensive use of this technology, particularly in the manufacturing sector. Thus, an overview of the many types of 3D printing methods,their applications, and the materials utilized for 3D printing in the manufacturing business are presented in this paper.

2. Types of 3D Printing

Diverse 3D printing technologies have been developed, each serving a distinct purpose. As per ASTM Standard F2792 [13], the organization categorized seven kinds of 3D printing technologies: vat photopolymerization, sheet lamination, powder bed fusion, material extrusion, binding jetting, and directed energy deposition. There are no arguments over whether device or technology is superior because each one has certain uses in mind.These days, 3D printing technologies are being used more and more to create a widerange of items, not just prototypes [14].

2.1. Binder jetting

Binder jetting is a quick prototyping and 3D printing technique where powder particles are joined by selectively depositing a liquid binding agent. In orderto create the layer, the binder jetting method sprays chemical binder over the dispersed powder [9]. Binder jetting is used in the production of casting patterns,unfinished sintered goods, and other such large-scale sand products. Numerous materials, including as metals, sands, will fall. Simultaneously,

polymers, hybrids, and ceramics, can beprinted using binder jetting. Certain materials, like sand, don't need to be further processed. Furthermore, becausepowder particles are bonded together, binder jetting is an easy, quick, and inexpensive operation. Finally, printing very huge items is another capability ofbinder jetting.

2.2. Directed energydeposition

A more intricate printing method called directed energy deposition is frequently utilized to enhance or repair already-existing components [8]. Directed energy deposition can create high-quality objects and offers a great degree of control over grain structure. Although the nozzle in directed energy deposition is not fixed to asingle axis and can move in numerous directions, the technique is conceptually comparable to material extrusion. In addition, the procedure can be applied to ceramics and polymers, but metals and metal-based hybrids in the form of wire or powder are the most common applications.Laser deposition and laser-engineered net shaping (LENS) are two examples of this technique [8]. The newest technique, laser deposition, can be utilized to create or fix items with dimensions ranging from millimetres to meters.

Because it offers scalability and a variety of capabilities in a single system, laser deposition technology is becoming more and more popular in the oil and gas, aerospace, machining, and transportation industries [15]. In the meantime, thermal energy can be used by laser LENS to meltobjects during casting and after [16].

2.3. Materials extrusion

Plastics, food, and live cells may all be printed in several colors and materials using material extrusion-based 3D printingtechnology [17]. This procedure is fairly inexpensive and has been used extensively.Additionally, this method can create completely functional product components[8]. A material extrusion system's initial example is fused deposition modeling (FDM). Polymer is the primary material used in FDM, which was created in the early 1990s [18]. By heating and extrudingthermoplastic filament, FDM constructs parts layer by layer from the bottom to the top. The following is how FDM operates:

I. Thermoplastic is heated to a semi-liquid state and then deposited along the extrusionpath in minuscule beads [19].

II. The 3D printer deposits a detachable material that serves as scaffolding where support orbuffering is required. For instance, in order to create 3D bone models, FDM requires hard plastic material [19].

2.4. Materials jetting

ASTM Standards define material jetting asa 3D printing technique wherein build material is selectively deposited drop by drop. substance jetting is a process where aprinter distributes droplets of a photosensitive substance that solidifies under ultraviolet (UV) light, layer by layerconstructing a part [20]. Material jetting also produces products with excellent dimensional precision and a very smooth surface finish. Material jetting offers a broad variety of materials, including biologicals, polymers, ceramics, composites, and hybrids, as well as multi- material printing [8].

2.5. Powder bedfusion

The electron beam melting (EBM),selective laser sintering (SLS), and selective heat sintering (SHS) printing techniques are all part of the powder bed fusion process. In this procedure, the material powder is melted or fused togetherusing a laser or an electron beam. Metals, ceramics, polymers, composite materials, and hybrid materials are a few examples ofthe materials employed in this procedure. The most common example of powder- based 3D printing technology is selective laser sintering (SLS). In 1987, Carl Deckard created SLS technology. SLS is a high-accuracy, fast-functioning 3D printingmethod with variable surface finishes [21].Metal, plastic, and ceramic objects can all be produced with selective laser sintering [22]. SLS created a 3D product bysintering powdered polymers with a high intensity laser. SHS technology, on the other hand, is a different aspect of 3D printing technology that melts thermoplastic powder using a head thermalprint to produce 3D printed objects. Finally,melting with an electron beam improves thematerial's ability to heat an energy source [22].

2.6. Sheet lamination

Sheet lamination is defined by the ASTMas the 3D printing technique wherein sheets of materials are bonded together tocreate a portion of an object [20].

Ultrasonic additive manufacturing (UAM) and laminated object manufacture (LOM) are two examples of 3D printing technologies that make use of this procedure [8]. The benefits of this method include full-color printing capabilities, lowcost, ease of material handling, and the ability to recycle extra material by sheet lamination. Complex geometrical parts canbe produced using laminated object manufacturing (LOM) at a cheaper cost of fabrication and in less time spent on operations [23]. A novel process called ultrasound additive manufacturing (UAM)uses sound to combine metal layers that are taken from featureless foil stock.

2.7. VatPhotopolymerization

Photopolymerization, which generally refers to the curing of photo-reactive polymers by means of a laser, light, or ultraviolet (UV), is the primary 3D printing technology that is commonly used [24]. Two examples of photopolymerization-based 3D printing technologies are digital light processing (DLP) and stereolithography (SLA). The photo initiator, the specific irradiation exposure circumstances, and any additional UV absorbers, pigments, or dyes all had an impact on the SLA [18].

Digital light processing, on the other hand,uses photopolymers in a manner akin to stereolithography. The primary distinctionis the light source. A more traditional lightsource, like an arc lamp with a liquid crystal display panel, is used in the DigitalLight Process. It is often faster than stereolithography since it may cover the entire surface of the photopolymer resin vat in a single pass [25]. The exposure period, wavelength, and power supply are crucial Vat Photopolymerization factors. When the liquid is subjected to ultraviolet light, the materials that were previously employed as liquids will solidify.

Photopolymerization can be used to createhigh-end products with fine details and a smooth surface [17].

3. Materials Used for 3DPrinting Technology in Manufacturing Industry

To create consistently high-quality products, 3D printing requires high-qualitymaterials that adhere to rigorous specifications, much like any other manufacturing process. The suppliers, buyers, and end users of the material develop protocols, specifications, and agreements on material controls to guarantee this. Fully functioning pieces made of a variety of materials, such as ceramic, metals, and polymers, as well as their mixtures to make hybrids, composites, or functionally graded materials (FGMs), can be produced using 3D printing technology [8].

3.1. Metals

Due to the benefits this technique offers, metal 3D printing technology is receiving a lot of attention in the manufacturing, automotive, aerospace, and medical sectors[26]. Metal has good physical qualities andcan be employed in sophisticated manufacturing processes, such as printing aeronautical parts or human organs.
Aluminum alloys [27], cobalt-based alloys[28], nickel-based alloys [29], stainless steels [30], and titanium alloys [31–32] area few examples of these materials. An alloy based on cobalt is appropriate for usein dental applications that are 3D printed. This is as a result of its high levels of elongation, particular stiffness, resilience, and heat-treated conditions [28].
Moreover, the use of nickel base alloys in3D printing technology allows for the production of aeronautical parts [29]. Utilizing nickel base alloys, 3D printed objects can be utilized in hazardous conditions. This is due to its strong resistance to corrosion and its ability to withstand temperatures as high as 1200 °C[26]. Lastly, titanium alloys can also be used by 3D printing technology to producethe thing. Titanium alloys are extremely rare and feature qualities like low density, excellent corrosion and oxidation resistance, and ductility. It is utilized in high-stress environments with high operating temperatures, such as in the biomedical industry [32] and in aerospace components [31].

3.2. Polymers

The manufacture of polymer components, from prototypes to functional constructions with challenging geometries, is facilitated by the widespread usage of 3D printing technology [33]. Through the deposition of consecutive layers of extruded thermoplastic filament, such as polylactic acid (PLA), acrylonitrile butadiene styrene (ABS), polypropylene (PP), or polyethylene (PE), fused deposition modeling (FDM) can be used tocreate a 3D printed object [33]. More recently, PEEK and PMMA thermoplastic filaments, which have greater melting temperatures, have been able to be utilizedas 3D printing materials [34].
The 3D printing industry makes extensiveuse of liquid polymer materials or those with low melting points because of their affordability, light weight, and ease of processing [35]. Most typically used as inert materials, polymer materials have a significant impact on biomaterials and medical device products by facilitating thedevices' smooth operation and offering mechanical support in many orthopedic implants [28].

3.3. Ceramics

These days, 3D printing technology can create objects utilizing ceramics and concrete that have small pores or no cracksby setting up the right mechanical qualitiesand optimizing the parameters [37].

Ceramic is robust, long-lasting, and fireproof. Ceramics may be applied in almost any geometry or shape because of its fluid state before setting, which makes it ideal for creating future structures and buildings [37]. Ceramic materials are important in dentistry and aerospace applications, according to [38]. These materials include, for example, zirconia [41], bioactive glasses [40], and alumina [39]. For example, alumina powder may beprocessed using 3D printing technology.
Excellent ceramic oxide alumina finds extensive use in the chemical, microelectronics, adsorbent, catalyst, and aerospace industries, among other high- tech industries [42].

Alumina has a very difficult curing process [38]. Complexly formed alumina pieces with high green density and high density after sintering can be manufacturedwith 3D printing technology [39].

Additionally, in a subsequent experiment,glass-ceramic and bioactive glass were processed into dancing parts using a Stereolithographic (SLA) machine.

It greatly increases the material's bendingstrength. Increasing the mechanical strength will allow for the application of bioactive glass in clinically relevant structures like bone and scaffolds.

It is likely to be possible to create solidbulk ceramics with high densities, veryhomogeneous microstructures, high compression strengths, and bending byemploying Stereolithographic Ceramic

Manufacturing (SLCM) [40]. In the meantime, zirconia is the primary building material used in the nuclear power industryfor element tubing. Because of its low thermal neutron absorption and low radiation susceptibility, hafnium-free zirconium is ideal for this purpose [41].

3.4. Composites

Composite materials have revolutionized high-performance sectors with their remarkable adaptability, low weight, and adaptable qualities. Glass fiber reinforced polymer composites [44] and carbon fiber reinforced polymer composites [43] are two instances of composite materials. The aerospace sector makes extensive use of carbon fiber reinforced polymer compositestructures due to their high specific stiffness, strength, excellent corrosion resistance, and exceptional fatigue performance [43]. In addition, because of their high performance and affordability, glass fiber reinforced polymer composites are extensively utilized in a variety of 3D printing applications [44, 45]. Fiberglass has a low coefficient of thermal expansionand a high thermal conductivity.Fiberglass is also highly ideal for use in the 3D printing applicant since it does notburn and is unaffected by curing temperatures used in manufacturing procedures [45].

3.5. Smart materials

The ability of a material to change an object's geometry and shape in response toexternal factors like heat and water is known as smart material [46]. A couple ofexamples of 3D printed objects made withintelligent materials include soft robotics systems and self-evolving structures.

Materials for 4D printing can also be categorized as smart materials. Shape memory alloys [47] and shape memory polymers [48] are two instances of groupsmart materials. Certain shape-memory alloys, such as nickel-titanium [47], haveapplications ranging from microelectromechanical devices [37] to biological implants. The key factors in producing nickel-titanium 3D printed items are microstructure repeatability, density, and transformation temperatures. In the meantime, Shape Memory Polymer (SMP) is a class of functional material thatreacts to various stimuli such as heat, light,electricity, and chemicals [48]. The complex shape of shape memory polymer might be produced simply and conveniently with the use of 3D printing technology. Part density, surface roughness, and dimensional correctness are used to evaluate this material's quality [48].

3.6. Specials materials

The examples of special materials are:

- Food materials, such as chocolate, meat,sweets, pizza, spaghetti, sauce, and so forth, can be processed and used by food 3D printing technology to create the required shape and geometry [49].

Because this technology allows consumersto change the materials' contents without lowering the nutrients and taste of the foods, 3D-food printing can manufacture nutritious meals [50].

- The direct production of multi-layered items from lunar dust via a 3D printing technology holds potential for use in futuremoon settlement [51].

- Textile: The advancement of 3Dtextile printing technology will highlight the apparel and jewelry industries. Short product processing times, lower packagingcosts, and lower supply chain expenses aresome benefits of 3D printing technology for the fashion sector [16].

4. 3D Printing'sUses in Manufacturing Technologies

4.1. Aerospace industry

Unmatched creative freedom is possible incomponent and production design thanks to 3D printing technology. 3D printing technology offers the ability to produce lightweight components with enhanced and complicated geometry in the aerospaceindustry, hence lowering energy requirements and resource consumption [52]. In addition, the adoption of 3D printing technology might result in fuel savings since less material is needed to make aircraft parts. Additionally, a lot of aircraft components, like engines, have spare parts made possible by 3D printing technology. Engine parts need to be replaced on a regular basis because they are prone to deterioration. As a result, 3D printing technology offers a practical way to get these replacement parts [53]. Nickel-based alloys are highly favored in the aerospace industry because of their tensile qualities, resistance to oxidation and corrosion, and ability to withstand damage [54].

4.2. Automotive industry

These days, 3D printing technology has drastically transformed our industry's ability to create, develop, and produce newgoods. The application of 3D printing technology has revolutionized the car industry by enabling the rapid creation of lighter and more intricate structures. For example, in 2014, Local Motor produced the first electric car using 3D printing technology. In addition to automobiles, Local Motors produced a 3D-printed bus known as OLLI, expanding the broad use of 3D printing technology. OLLI is a 3D printed, electric, recyclable, and incredibly intelligent bus. Additionally, Ford is a pioneer in the application of 3D printing technology, using it to create prototypes and engine parts [55].

BMW also produces hand tools for automobile testing and assembly using 3Dprinting technology. In the meantime, SLM Solution Group AG and AUDI worked together to build prototypes and replacement components in 2017 [56].

As a result, the automobile industry's use of 3D printing technology allows businesses to test out many options and prioritize early in the improvement process, leading to the creation of optimal and efficient car design. Simultaneously, the technique of 3D printing can minimizematerial waste and consumption.
Additionally, 3D printing technology cansave money and time, making it possibleto test new ideas quickly [57].

4.3. Food industry

The food business is one that has benefitedgreatly from 3D printing technology in addition to the aerospace industry. The demand for food that is specially made for people with specific dietary needs— athletes, kids, pregnant women, patients, and so on—is rising at the moment. These people need different amounts of nutrients,so food manufacturers are trying to reduce the amount of unnecessary ingredients while increasing the amount of healthy ones [58]. Nevertheless, the creation of personalized meals needs to be done with great care and creativity, which is where 3D food printing comes into play. Food layer manufacturing, sometimes referred toas 3D-food printing, is the process of creating food by physically depositing layers upon layers that are generated from computer-aided design data [49].
Certain materials can be combined and processed into a variety of intricate structures and shapes utilizing 3D printing technology [59]. You can make new culinary items with intricate and fascinating shapes and designs by combining ingredients like sugar, chocolate, pureed food, and flat foods likepasta, pizza, and crackers.

Food production can now produce food with excellent energy efficiency, cheap cost, and good quality control thanks to 3Dprinting technology. Because 3D printing opens up new possibilities for food customisation and can adapt to individual needs and preferences, it can be beneficial to human health. Dietary restrictions that don't require exercise could be achieved byenabling meal preparation and ingredient adjustments based on consumer information [49].

4.4. Healthcare and medical industry

In addition to printing 3D skin [60], it can also be used to print bone and cartilage [62], replacement tissues [63], organs [22], drugs and pharmaceutical research [61], printing for cancer research [64], and models for communication, teaching, and visualization. The following are some benefits of 3D printing technology for biomedical products:

- At a lesser cost, 3D printing technology can imitate the skin's natural structure. Products related to chemicals, cosmetics, and pharmaceuticals can all be tested on 3D printed skin. Thus, testing the items onanimal skins is not necessary. As a result, it will assist the researcher in obtaining precise results by employing skin replication [65].Drugs can be printed withgreater efficiency, precise control over dosage and size drops, excellent repeatability, and the ability to create dosage forms with intricate drug-release patterns thanks to 3D printing technology [22].

- Cartilage and bone can be printed using3D printing technology to fill up skeletalholes created by trauma or illness [66]. Using in vivo bone growth, maintenance,and function is the major goal of this treatment, setting it apart from auto- andallograft alternatives.

- The function of tissues can be improved,maintained, restored, or replaced with the application of 3D printing technology. The3D printed replacement tissues feature a network of interconnected pores, are biocompatible, have the right surface chemistry, and exhibit good mechanical qualities [63].

- Similar organ failure brought on by serious issues including illness, accidents,and congenital deformities can also be printed using 3D printing technology.

- 3D printing technologies have the potential to significantly speed up cancerresearch by creating highly controlled models of cancer tissues. More accurate and dependable data may be provided topatients through the use of 3D printing technology.

- 3D printing models can be used to assist neurosurgeons in learning surgical techniques during the learning process. Because a 3D model simulates a real patient's pathological condition, it can increase accuracy, save the trainer time while doing clinical procedures, and offer chances for hands-on training for surgeons.

4.5. Architecture, building,and construction industry

The technique of 3D printing offers infinite possibilities for the fulfillment of geometric complexity and can be regardedas an ecologically friendly derivative. 3D printing technology is utilized in the construction industry to generate completebuildings or individual construction parts. Better use of 3D printing technologies willbe made possible by the rise of Building Information Modeling (BIM). Building

information modeling is a digital depictionof a building's functional and physical attributes that allows for the sharing of data and expertise on three-dimensional buildings. Throughout its life cycle, from original conception to demolition for building construction or design, it can serve as a trustworthy source of information [67]. The built environment may be designed, created, and maintained more effectively with the help of this creative and cooperative technology.

Businesses can use 3D printing technologyto quickly and affordably design and produce a building's visual, prevent delays,and identify trouble areas. Construction engineers and their clients can converse more effectively and clearly thanks to 3D printing technology. A lot of what customers expect is based on an idea, and 3D printing makes it easier to manifest ideas than the antiquated process of drawing them on paper [68]. The Apis CorPrinted House in Russia [67] and the CanalHouse in Amsterdam [68] are two instances of 3D printed buildings.

4.6. Fabric and FashionIndustry

3D printed shoes, jewelry, consumer products, and clothing [69] are starting to appear on the market as a result of the introduction of 3D printing technology into the retail sector. Fashion and 3D printing may not seem like a good match, but this is beginning to change and becomeubiquitous worldwide. Large corporations such as Adidas, New Balance, and Nike, for example, are working to develop 3D printed shoes that can be produced in largequantities. These days, 3D printed sneakers, custom shoes, and athlete's shoesare made [70].
Additionally, the technology of 3D printing can expand fashion design's

creative potential. In fact, it enables the creation of shapes without the need for molds. The fashion industry may design and manufacture clothing using mesh systems and print embellishments for traditional textiles by utilizing 3D printingtechnologies. Furthermore, the fashion industry is not the only sector where 3D printing technology is being used; it can also be used to manufacture leather items.

4.7. Electric and Electronic Industry

As 3D printing becomes more widely available to the scientific, technological, and manufacturing communities, firms are beginning to grasp the myriad of intriguingways in which its potential might be utilized. By embedding conductors into 3D printed devices, various 3D printing methods are already widely employed for structural electronic devices, such as electrodes, active electronic materials, and devices with mass customisation and adaptive design [74].
Utilizing the Fused Deposition Modelling method of 3D printing, the production process for the 3D electrode offers an economical and expedient method for mass generating electrode materials. In contrast to standard electrodes made of copper, aluminum, or carbon, the 3D electrode's surface area and design are easily customizable to fit a specific need. Additionally, the highly precise and fully automated 3D printing procedure for the electrode allowed for the completion of thefabrication of eight electrodes in just thirtyminutes [75].

Furthermore, any electronic equipment orcomponent having the ability to enhance and regulate the electric current flow charges is considered an active electroniccomponent. In addition, gadgets with the ability to produce power are considered active. Light-emitting diodes (LEDs),

batteries, transistors, diodes, operational amplifiers, and silicon-controlled rectifiersare a few examples of active electronic components. Because of their extensive capabilities, these components typically require more complex fabrication procedures than passive components [76]. The processing of a product and its electronics can benefit from 3D printing technology. The efficiency of electronic systems may be used in Industry Revolution 4.0 with the help of multi- material printing technology, allowing for the creation of more creative designs in a single procedure [37].

5. Summary

This evaluation covers a wide range of 3D printing applications in the manufacturing sector. The manufacturing sector is currently utilizing 3D printing technology, which has numerous advantages for individuals, businesses, and the government. Thus, further data is required to advance the discussion of strategies to improve the uptake of 3D printing technology. More knowledge about 3D printing technology will assist the government and businesses in modernizingand strengthening the infrastructure supporting this technology. This study aims to provide an overview of the many types of 3D printing technologies, the materials utilized in the manufacturing industry for 3D printing technology, and the applications of 3D printing technology.In the future, scientists can do research on the different kinds of 3D printers and the materials that work best for each kind of printer.

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