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Research Article

An Overview of Extensive Analysis of 3D Printing Applications in the Manufacturing Sector

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3D printing (additive manufacturing) is one of the revolutionary technologies that are transforming manufacturing and industrial processes. Additive manufacturing (AM) technology is being used for extensive customization and production of all types of open-source designs in farming, medical, automotive, locomotive, aerospace, and construction industries. The advantages of 3D printing for industrial applications include little material waste, simple production, minimal human participation, minimal postprocessing, and energy efficiency. There are limited articles on the scope and future possibilities of AM technologies. This article explains numerous AM techniques, uses for technology, and substances used in the manufacturing firm. The numerous materials that may be used with every type of 3D printing process are explained in depth. The numerous settings whereby every processor kind is used are also listed in the study. The original study findings indicate that, while 3D printing technology has made great advances, there are still challenges that need to be addressed; however, the obstacles appear to vary: the cost of preprocessing and postprocessing, a restricted selection of materials, and technological constraints are the most significant 3D printing challenges. Readers will be benefitted from the new dimension added by explanation of the many aspects of additive manufacturing and the identification of potential new research fields in this review. The processes may be enhanced and modified to operate with a range of materials through further research, whereas if the range of applications for 3D printing technology components is to be increased, more effort should be made into developing economical printing procedures and supplies that function with these printers.

1. Introduction

3D printing, also known as additive manufacturing, has rapidly emerged as a transformative technology in the manufacturing sector. Its ability to create complex and customized objects with precision has opened up a world of possibilities for industries ranging from aerospace and automotive to healthcare and consumer goods. This article provides an in-depth analysis of the various applications of 3D printing in the manufacturing sector and explores its impact on efficiency, innovation, and sustainability. The utilization of 3D printing technology is significantly transforming the manufacturing industry through the provision of inventive approaches to product development, customization, optimization of supply chains, and the promotion of sustainability. As the development of this technology progresses, it is anticipated that it will become an essential component of the manufacturing sector, facilitating improvements in efficiency, innovation, and sustainability across diverse industries. Manufacturers who actively adopt and adjust to these transformations are well positioned to maintain competitiveness and assume a leadership role within their particular markets. 3D printing technology uses three-dimensional model data to produce a wide range of complex structures [1]. Some industries that employ additive manufacturing include prototype, construction, and biomechanics technology. Despite the benefits of 3D printing, including such adoption, automation, and decreased wastage, progress in the construction sector has indeed been slow and uneven [2]. The additional costs associated with product creation have lowered because of the usage of AM technology. On the other side, AM has recently gained popularity in many industries, from initial designs to finished goods. Because of the considerable expenses associated with producing traditional goods for end customers, product offering has proven to be a challenge for entrepreneurs. In addition, additive manufacturing allows for the affordable 3D printing of small quantities of customized goods [3].

Prototyping and product development

(i) One of the earliest and most widely adopted applications of 3D printing in manufacturing is rapid prototyping. Manufacturers can quickly and cost-effectively create prototypes of their products, allowing for faster iteration and design improvements. This significantly reduces the time and cost associated with traditional prototyping methods, such as CNC machining or injection molding.

Customization and personalization

(ii) 3D printing enables manufacturers to offer highly customized and personalized products to consumers. Whether it is tailored orthopedic implants, custom-fit shoes, or personalized consumer electronics, 3D printing allows for efficient production of one-of-a-kind items, fostering customer satisfaction and brand loyalty.

Supply chain optimization

(iii) Traditional manufacturing relies on complex and often global supply chains, leading to long lead times and high transportation costs. 3D printing can disrupt this paradigm by enabling on-demand production, reducing the need for warehousing and transportation. Companies can produce parts and products locally, minimizing inventory and responding quickly to market fluctuations.

Complex geometries and lightweight structures

(iv) 3D printing can create intricate and lightweight structures that are difficult or impossible to achieve with conventional manufacturing methods. In aerospace, for example, 3D printing is used to produce complex engine components, reducing weight and improving fuel efficiency. In automotive, it enables the creation of lightweight yet strong components, enhancing vehicle performance and fuel economy.

Tooling and jigs

(v) Manufacturers often require specialized tools, jigs, and fixtures for assembly and quality control. 3D printing allows for the rapid production of these items, reducing lead times and costs. Moreover, these tools can be optimized for specific tasks, increasing efficiency on the factory floor.

Reduced material waste

(vi) Traditional subtractive manufacturing methods, such as milling or turning, generate significant material waste. In contrast, 3D printing is an additive process, which means it only uses the material required to build the final product. This reduces material waste and contributes to sustainability efforts in manufacturing.

Spare parts and aftermarket services

(vii) 3D printing can revolutionize the way manufacturers handle spare parts and aftermarket services. Instead of maintaining large inventories of spare parts, companies can produce them on-demand, reducing storage costs and ensuring the availability of parts for older products.

Sustainability and environmental benefits

(viii) 3D printing's potential for reducing material waste and energy consumption aligns with global sustainability goals. By using more sustainable materials and optimizing designs for minimal environmental impacts, the manufacturing sector can contribute to a greener future.

While 3D printing offers numerous advantages, it also faces challenges such as material limitations, quality control, and intellectual property concerns. As technology continues to evolve, these challenges are being addressed, opening up even more possibilities for its application in manufacturing.

In the present era, 3D printing is extensively utilized around the globe. A growing number of businesses, including those in farming, healthcare, the automobile industry, and aerospace, are using 3D printing methods to manufacture anything that is open source and to mass-customize it [4]. The 1980s saw the development of the 3D printing technique, often known as AM. The popularity of 3D printing has grown dramatically, and it has emerged as a cutting-edge production technique. As a result, it received widespread acceptance in a variety of industries, including designing jewels, polymeric printed materials, applicable autonomy and mechanization, tissues and structures, and gadgetry things. A couple of 3D printing's attributes, such as its quick turnaround time, low labor need, ability to customize, and ability to use fewer materials, suggest that technology has aided some application industries [5]. In addition, because AM technology is in a dynamic stage of mechanical growth, it offers the potential to advance the evolution of manufacturing, creative methods, and fabrication techniques [6].

Straightforwardly from CAD models, the initial AM technology was utilized to produce a three-dimensional assemblage layer by layer [7]. A cutting-edge technique that has demonstrated that it is quite versatile is 3D printing. It broadens options and pushes initiatives meant to increase industrial production. Nowadays, ceramics, alloys, standard thermoplastics, and graphene-based substances may all be produced using the process of 3D printing. Utilizing digitized information obtained from a computer, the item is constructed layer by layer utilizing numerous materials, including composites, polymers, ceramics, and metals pastes, based on what is needed [8]. In order to swiftly generate models and prototypes, the initial phase of additive manufacturing (AM) was introduced. The first method to develop in the late 1980s was stereolithography (STL). Consequently, quick production was coined as this technology developed to produce finished goods [9]. AM is an innovative technology that has the potential to completely transform the world of production. Figure 1 depicts the global increased level of 3D printing technology from 2014 to 2021.

3D printing (additive manufacturing (AM)) is a quick prototyping method without the need for molds. The process involves printing material deposition in succession on top of one another. Advancements include inkjet printing; fusion depositing models, contour carving, and powder bed fusion appeared shortly after stereolithography (SLA) [12]. A variety of processes, materials, and equipment are used in 3D printing, which has developed over time and has the potential to change the manufacturing and logistical sectors. The number of industries that employ additive manufacturing for prototype building, construction, and biomechanics technology has increased over the past few decades. Despite the benefits of 3D printing, which include adoption, automation, and decreased wastage, the progress in the construction sector has indeed been slow and uneven since it requires optimization [2]. This technology has several drawbacks, such as limitations in material build size, constraints on the type of build material, occasional resolution issues, and increased costs (including processing and post-processing) for product creation. On the other side, AM has recently is gaining popularity in industries, from initial designs to finished goods. Because of the considerable expenses associated with producing traditional goods for end customers, product offering has proven to be a challenge for entrepreneurs. In addition, additive manufacturing allows for the affordable 3D printing of small quantities of customized goods [3]. Researchers are constantly working on shortcomings to make it an ideal manufacturing technology.

Currently, 3D printing is extensively utilized worldwide. A growing number of businesses, including those in farming, healthcare, the automobile industry, and aerospace, are using 3D printing methods to manufacture anything that is open source and to mass-customize it [4]. The 1980s saw the development of the 3D printing technique, the popularity of 3D printing has grown dramatically, and it has emerged as a cutting-edge production technique. As a result, it received widespread acceptance in a variety of industries, including designing jewels, polymeric printed materials, applicable autonomy and mechanization, tissues and structures, and gadgetry things. A couple of 3D printing's attributes, such as its quick turnaround time, low labour need, ability to customize, and ability to use fewer materials, suggest that technology has aided some application industries [5]. In addition, because AM technology is in a dynamic stage of mechanical growth, it offers the potential to advance the evolution of manufacturing, creative methods, and fabrication techniques [6].

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The use of AM in production has the potential to change and transform the manufacturing industry. Production will be expedited and costs will be reduced using AM technology [13]. Requirements from customers will also have a bigger influence on production at this time. Consumers could customize an item to be developed as per their specifications, and they have more influence over the outcome. Eventually, AM facilities will be situated nearer to the user, permitting a quicker, greater flexible process of production along with better quality control [14]. Furthermore, the utilization of AM technology greatly decreases the need for overseas travel. This appears to be because fleet surveillance technology can manage complete dispersal whenever manufacturing plants are near the ultimate destination, preserving both energy and time. Using AM technology might also affect how the company handles its logistics [15]. The firms' logistics department may oversee the whole process and offer more comprehensive, end-to-end services [16].

3D printing (AM) features more tightly regulated procedure restrictions and a more active connection between material quality and technique parameters than conventional production processes. The kind of AM process employed depends on several factors, including material preparation, layer production techniques, phase variability incidence, types of material, and application requirements. The three main stages of the AM procedure are the testing process, the design process, and the execution process [17].

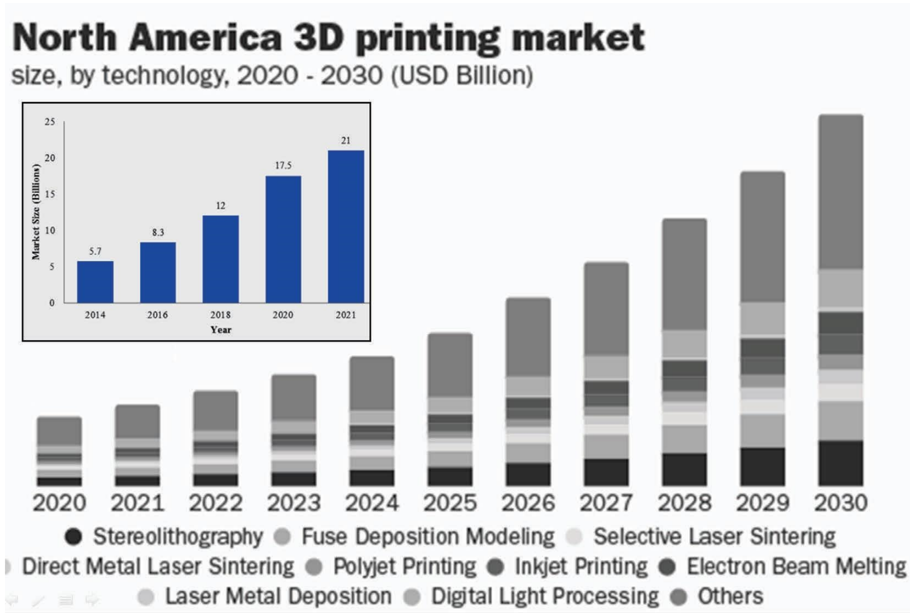

FIGURE 1: The global market for 3D printing and the estimation for the current decade. The market for 3D printing was estimated to be worth USD 16.75 billion in 2022, and from 2023 to 2030, it is expected to expand at a compound annual growth rate (CAGR) of 23.3%. Inset shows a globally increased 3D printing technology range [10, 11].

Compared to conventional and subtractive production technologies, AM offer several advantages. Large amounts of design flexibility [18], effectiveness, complexity, and adaptability [19], less assembling and reliable manufacturing, assistance for green production efforts, and exact physical replication are a few of the significant advantages. Because of the technology's quick progress, AM has expanded its usage to a variety of industries, including building, healthcare, aerospace, fashion, farming, automotive, oceanographic, and education [20]. We began the research with the product's fundamental layout as 3D printers are fundamentally a process of additive manufacturing [21]. Utilizing computer programs capable of being linked to 3D printing, the layout was developed. A unique type of file is then produced by this program and transmitted to the printers. After reading the data, the 3D printer builds the object by adhering layers on top of one another [22]. To create a component in a 3D printing process, layers are used almost often. Instead of reading the pieces as an entire portion, 3D printers examine them as a solitary two-dimensional layer at a moment [23]. Future-proofing features of 3D printing include its low environmental impact and ability to produce complicated parts for relatively little money, even with minimal postprocessing. Other sustainable features of 3D printing include its capacity to recycle waste plastic and reduce pollution [24]. The technique may also produce geometric patterns that are complex and well optimized, helping to produce lighter parts with an improved strength-to-mass ratio. As a result, 3D printing is used to create sustainable designs [25].

The usage of AM technology has the potential to revolutionize business and manufacturing. The use of AM technology will lead to simplify the production process and make it less expensive. Consumer requests will simultaneously have a greater influence on manufacturing [26]. The end product will be more customizable for the consumer, and they may ask for it to be produced according to their exact specifications. Conversely, clients will be served by 3D printing operations that are situated nearer to them, allowing for a more adaptable and accessible manufacturing technique as well as greater quality management [27]. Also, technology for AM technology reduces the requirement for foreign transportation. This is because entire supplies might well be done using fleet monitoring technologies whenever production facilities are closer to the end objective, saving both energy and time [28]. Last, the firm's logistics may be impacted by the use of AM technology. Businesses' logistics teams can oversee the entire path and provide further comprehensive, end-to-end services [29]. The development of the sector depends on cutting-edge and creative research projects connected to industrialized processes, resources, and product plans [30]. Today's manufacturing processes are related to requirements for items that are more complicated, have shorter life spans and faster distributing times, need fewer customizations, and require fewer qualified employees in addition to the conventional requirements for low expense and excellent superiority. The reality is that making today's commodities is difficult. As an outcome, there is a pressing requirement to create, evaluate, and use innovative manufacturing methods [31].

1.1. 3D Printing in Biomanufacturing, Textile, and Construction Industries. 3D printing is reshaping biomanufacturing, textile, and construction industries, offering customized solutions, sustainability benefits, and innovative designs. With ongoing research and development, the potential for this technology is boundless, promising a future where production is more efficient, sustainable, and tailored to individual needs. As 3D printing continues to evolve, its impact on these industries will only grow stronger, heralding a new era of manufacturing and design. In the case of biomanufacturing, 3D printing is a sustainable method to create biological items and systems with preprogramed behavior used in synthetic biology. As a result of the widespread genetic engineering of microbes as cell factories for the fermentation-based biosynthesis of chemicals, 3D printing of living materials utilizing these cells may usher in a new paradigm for biomanufacturing. Currently, the 3D printing development addresses a critical event to assist medication and clinical associations with creating more unambiguous prescriptions, facilitating a speedy formation of clinical installs, and altering how authorities and experts prepare strategies. The growth of 3D printing addresses a substantial event that will assist medication and clinical associations in producing more specific prescriptions and clinical inserts as well as altering how professionals and experts construct techniques. 3D printing enables us to vividly depict the intricate structures of living organisms and produce precise models for enhanced comprehension, careful assistance, as well as the development of stents, prosthetics, drug delivery systems, and more. The benefits of biomodeling, 3D printing, and cautious partners are evident in practice, particularly when a comparable expert who participated in the virtual cautious organizing operated.

The application of 3D printing in biomanufacturing has opened new horizons for the field of medicine and the production of biopharmaceuticals. 3D printing enables the creation of patient-specific prosthetics and implants. By using biocompatible materials, healthcare professionals can design and produce implants tailored to an individual's unique anatomy. This not only improves patient comfort but also enhances the success of surgery. Bioprinting, a subfield of 3D printing, has made significant progress in generating complex tissue structures. Researchers are exploring the possibility of printing organs and tissues for transplantation, reducing the demand for donor organs and the risk of rejection. 3D printing has the potential to revolutionize drug delivery systems by producing personalized medication formulations. This allows for precise dosages and release mechanisms, optimizing treatment outcomes.

The textile industry is experiencing a revolution driven by 3D printing, leading to innovation in materials, production processes, and design. 3D printing enables the creation of personalized clothing items, shoes, and accessories. Customers can provide their measurements, and manufacturers can produce garments that fit perfectly, reducing waste from mass production. By using eco-friendly materials and reducing waste in production, 3D printing is contributing to sustainability efforts in the textile industry. Companies are experimenting with recycled plastics and other sustainable materials to create fashionable items. 3D printing allows for the production of intricate and complex textile patterns that were previously impossible or extremely labor-intensive to create using traditional methods. This opens up new avenues for designers and artists.

The development in the 3D printing technique represents a significant step in drug and clinical associations by making more explicit descriptions, involving a rapid formation of clinical installs, and modulating the way that authorities and experts plan strategy. The advancements in 3D printing technology contribute to the creation of precise models, careful assistants, stents, prosthetic development, and drug delivery devices, among other applications. The advantages of 3D printed systems, biomodeling, and cautious associates are clear in operation, especially when a specialist who has operated in the virtual environment. The magnitude of tomography-based 3D printed understanding aids in full-scale knee arthroplasty [32]. Many systems subject to 3D printing have been drawn with magnificent results. Numerous systems that are compliant to visualization and 3D printing have been rendered with excellent results, but orchestrating and creating interestingly planned associates and plates are occasionally tedious and expensive. 3D print devices that were earlier only conceptual would now have the option to be made practically in effective and sufficient quantities.

3D food printing has the potential to revolutionize the food industry. In additive manufacturing strategies, food-grade needles clasp the printing material which is then saved through a food-grade spout layer by layer. The food can be customized with personalized flavor, or sustenance, which makes it precious in various fields, for example, space exploration and wellbeing care. The principle of 3D food printing involves expulsion-based printing and inkjet printing of food materials; for example, the combination of sugar, gelatine, and chocolate put together regarding rheological estimations of their rigidities gives a great improvement in dimensional soundness of 3D food items.

Since a decade ago, analysts, material scientists, fashion designers, makers, and retailers have been collaborating to develop 3D printing technology. Innovation is significantly beneficial in lowering production and assembly costs which are important for fiber-reinforced composites. Polymer deposits on synthetic textures offer greater adaptability and economic viability than material functionalization techniques such as inkjet printing. Several advantages in the material domain can be achieved by using techniques, such as physical and chemical alterations of material surfaces. Utilizing these in the material will reduce labor and external additions.

Significant innovations in solid 3D printing technologies have increased production in the construction industry. This technique has been successfully used in a wide range of enterprises, including aviation and the automobile industry. Solid extrusion-based 3D printing offers fantastic openings for a broad reach in the development sector. Development records, preferences, safe work practices, reduced development time, and cost have all been completely altered by 3D printing. This strategy is an effective way to reinforce printed layers. The usage of load-bearing dividers in small homes will help to reduce the impact of natural development materials. A cutting-edge technology for creating useful smart devices is 4D printing. 4D printing refers to the fusion of 3D printing with intelligent material. The additional dimension, which alludes to time, allows for the printed part's shape to change over time. A common method for 3D printing thermoplastic polymers is FDM [33]. Innovations in 3D printing technology involve the use of statistical methods. Nearly, all manufactured goods employ statistical models for quality control and assurance, streamlined for industry professionals. The degree of variety in customers' demands and wants is measured using statistics [34]. The most popular statistical technique for enhancing the mechanical characteristics of 3D-printed parts is the Taguchi methodology, which is followed by Weibull analysis and factorial design [35].

However, there are several limitations to the use of 3D printing in the industrial sector. For example, the adoption of 3D printing technology would diminish the need for manufacturing workers, which will immediately have a significant impact on the economies of nations that relied heavily on low-skill occupations. In addition, consumers of 3D printing technology may manufacture a wide variety of objects, including knives, firearms, and other hazardous goods [35]. As a result, the usage of 3D printing ought to be restricted to a small group of people to stop terrorists and criminals from bringing firearms into the country undetected. In addition, anyone with access to a blueprint will be able to produce fake goods with ease. This is due to the ease of use of 3D printing technology, which just requires a drawing and the setting of data for the mechanical printing of 3D items. Understanding the advantages and disadvantages of employing 3DP in business is necessary. While 3DP is a frequently discussed subject, there are still very few applications of 3DP in the industry. There are clear barriers preventing 3DP from obtaining a larger-scale use. Since the technology is already developed, difficulties may lie on the application's side. As a result, this article provides an overview of the 3D printing technology's production process, its applications, and finally the materials that are utilized in the manufacturing sector.

While 3D printing holds immense promise in these industries, there are challenges to overcome, including material limitations, regulatory hurdles, and scalability issues. The cost-effectiveness and sustainability of 3D printing materials also need further improvement. As technology advances, it is likely that 3D printing will continue to disrupt and transform biomanufacturing, textiles, and construction. Innovations in materials, automation, and software will drive progress and expand the applications of this versatile technology.

The various AM methods, applications for the technology, and materials utilized in the manufacturing company are described in this article. In-depth explanations are provided for the various materials that can be utilized with each sort of 3D printing method. The report also lists all of the various settings for each type of processor. The results of the initial study indicate that although 3D printing technology has advanced significantly, there are still problems that need to be fixed, such as the cost of materials and differences. The review's explanation of many facets of additive manufacturing and identification of prospective new study areas may be helpful to readers. Through additional research, the procedures might be improved and adjusted to work with a variety of materials, whereas if the range of applications for 3D printing technology components is to be increased, more effort should be made into developing economical printing procedures and supplies that function with these printers.

This article describes many AM techniques, technological applications, and materials used in the manufacturing industry. The different materials that can be used with each type of 3D printing technique are thoroughly explained. The report also includes a list of every parameter for every processor type. The review describes several aspects of additive manufacturing and the identification of potential new research fields. The processes may be enhanced and modified to function with a range of materials through further study.

2. Industrial Manufacturing Materials

Similar to any other manufacturing process, AM requires good materials (including high-quality 3D printers with good resolution and high-quality software) that conform to rigorous specifications to reliably create significant items. To accomplish this, manufacturers, purchasers, and end consumers of the materials adopt norms, requirements, and agreements on material handling. Using a diversity of substances including polymers, metals, ceramics, and their combinations to create hybrids, composites, or functional grading materials (FGMs), AM technology may create completely functioning components [14]. Table 1 depicts the manufacturing material properties, applications, advantages, and disadvantages.

2.1. Metals. The benefits provided by the application of 3D technology in metal printing have attracted great interest in automotive and aerospace industries [36]. Different metals have exceptional physical properties that make them appropriate for use in a range of complex production processes, such as the production of human parts of the body and plane parts. Examples of this material include titanium, aluminium alloys, nickel, cobalt, and stainless steel. For 3D-printed dental restorations, a cobalt-based metal is suitable. This is due to its high intrinsic flexibility, durability, great manageability, elongation, and heat-treated conditions [37]. Bar dissolving, folio streaming, and bound powder ejection are examples of 3D metal-engraving techniques. Metal-printed items are stronger, harder, and occasionally more adaptable than conventionally manufactured parts.

Moreover, the process of 3D printing may be used to create aeronautical components utilizing nickel-based alloys [38]. AM products made of nickel-based alloys can be utilized in hazardous surroundings. It does so because of their excellent resistance to corrosion and capacity to sustain temperatures of up to 1200°C. Last, AM might be utilized to construct the object using titanium. Flexibility, great

Table 1: Manufacturing materials' properties, merits, and demerits and their application.

Materials	Properties	Advantage	Disadvantage	Application
Metals	Higher mechanical qualities	Their melting points are greater	They are costlier	Applicable in smart structures
Ceramics	Heat resistance, suitable thermal conductivity, chemical and physical stability, strength, and hardness	Relatively lightweight	Low tensile strength	Foundry and forging industries
Composites	Excellent modulus, minimal density, outstanding fatigue resistance, etc.	Greater strength-to-weight ratio	Rising expenses for raw materials	Construction industry
Polymers	Excellent heat conductivity and sticky tack	They combine several features into one	Mechanical strength is low	Paper industry

durability against corrosion and oxidation, and low density of titanium are their distinguishing characteristics. It is used, for example, in aircraft structures and the healthcare industry, where there are tremendous stresses, high temperatures, and significant stresses [39].

2.2. Ceramics. Contemporary AM technology can produce 3D-printed ceramic and concrete items that do not have numerous holes or cracks by modifying circumstances and arranging suitable mechanical properties. Ceramics are dependable, durable, and flame-resistant. Ceramics are perfect for the creation of upcoming constructions and structures since they can be put in almost any geometry and shape before settling [40]. A ceramics substance, they stated, is effective in both dentistry and aeronautical applications. Instances of this substance include zirconia, bioactive glasses, and aluminium. For example, 3D printing can handle alumina powder. Good ceramic oxide alumina has several uses, such as a catalyst, adsorbent materials, microelectronic devices, chemicals, the aircraft sector, and other high-tech industries [41]. It takes a lot of sophistication to cure alumina. Complexly formed, very dense following sintered, and highly dense greenish alumina pieces may be manufactured utilizing 3D printing technology. In another study, bioactive glass and glass-ceramic were processed into dancing portions using stereolithographic (SLA) machinery. The bending strength of these composites is greatly improved. The possibility to use bioactive glasses in pertinent therapeutic designs such as scaffolding and bones will increase with tensile characteristics. By using stereolithographic ceramic production, it is feasible to produce solid bulk ceramics with significant concentrations, very homogeneous microstructures, improved compressive, and excellent bending power [42]. In the nuclear power industry, zirconium serves as the main construction material for constituent tubing [43].

2.3. Composites. Rising sectors have been transformed by the lightweight and tailorable features of synthetic structures and outstanding adaptability. Glass fiber-reinforced polymer composites and carbon fiber-reinforced (CFR) composite materials are two instances of synthetic structures. Because of their large specific elasticity, outstanding fatigue behavior, and superior corrosion resistance, CFR plastic composite frameworks are frequently employed in the aerospace region [44]. Also, because of their outstanding effectiveness and simplicity, glass-reinforced composites are often used in several AM operations and have a wide range of potential usages. Fiberglass is characterized by higher heat conductivity and moderate excellent thermal properties. Fiberglass is a great material to employ for 3D printing usage since it is also fireproof and undisturbed by the curing temperatures used in manufacturing procedures [45].

2.4. Polymers. A typical use of AM technology is the manufacturing of polymeric material, from prototypes to operational structures with complex geometries. A 3D-printed item can be produced using fused deposition modeling by applying successive layers of extruded thermoplastic filaments such as acrylonitrile butadiene styrene (ABS), polypropylene (PP), and polylactic acid (PLA); a 3D-printed object may be created utilizing fused deposition models (FDMs) [46]. Recently, thermoplastic filaments with extremely high melting points, including PEEK and PMMA, are currently employed as materials for 3D printing because of their inexpensiveness, 3D printing polymer materials in liquid form, low weight, and operational versatility [47]. The majority of the time, polymer materials played a significant role in medical device goods and biomaterials, frequently acting as inert materials. These materials helped the devices work effectively and provided mechanical protection for numerous orthopedic applications.

3. 3D Printing Techniques

Traditional manufacturing methods rely on CAD software to print products using a variety of substances, which drastically reduces the amount of supply chain management. They additionally require a great deal of effort to automate 3D printing. After everything has been discussed and accomplished, 3D printing is a cheap method since it does not require any costly molds or tools for machining, building, or punching. Numerous manufacturing methods for 3D printing exist based on supplies. Every one of the approaches can be used depending on how elements are applied. The categories of the 3D printing operation process are displayed in Figure 2.

3.1. Powder-Based Systems. The most common manufacturing process for 3D printing is the powder-based approach. Inkjet print heads that are common and conventional are used to create the parts. The four main types of powder-based methods are LMD, EBM, DMLS, and SLM.

3.1.1. Laser Metal Deposition (LMD). In the additive manufacturing process known as laser metal deposition (LMD), a laser beam is employed to create a molten pool of evaporating materials outside a metallic substrate. Subsequently, powder is introduced into this pool using a gas mixture. On the surface, the swallowed metal powder resembles a shop. Rehabilitation of metallic components, such as valves, worm screws, and gauges, is a frequent use. A laser beam is used to illuminate substrates initially, forming a liquefied puddle that collects and liquefies the powdered components that are passed up a nozzle. Several elements are used in LMD, and clay powder particles may be evenly combined to create a variety of composites with desirable qualities. Figure 3 represents the experimental setup for the LMD process. The powder is then combined using a fly of argon gases. The liquid pool hardens when the laser source retracts due to heat dispersing through propagation, circulation, and power. The affidavit top, which has powdered nozzles and optics for delivering a laser beam, is placed next to the characterized route, enveloping the substrates with a layer. Soon after, the head moves up to the solitary depth to place the supplementary level. To assist arrange the bottom layer and serve as

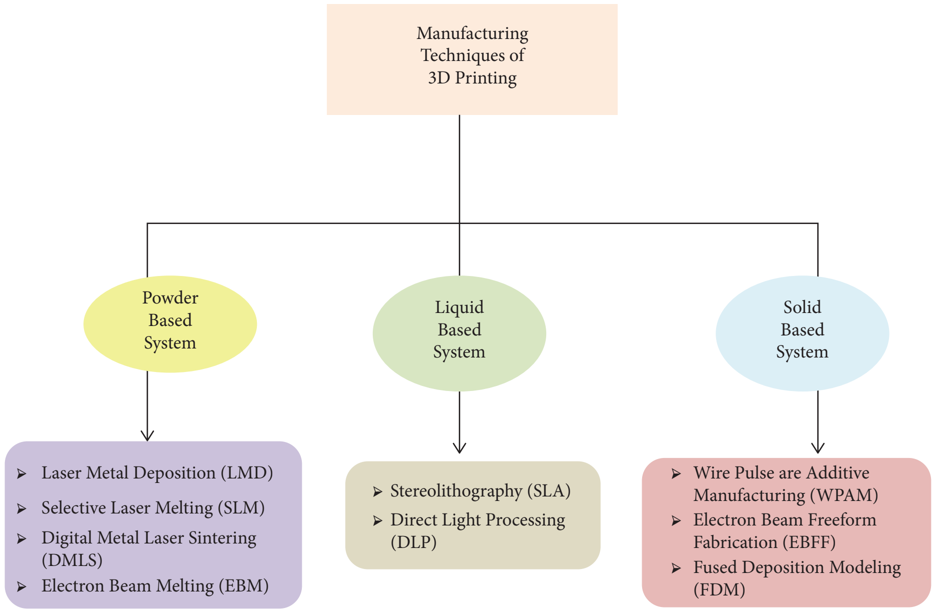

FIGURE 2: Various production/manufacturing techniques of 3D printing technology.

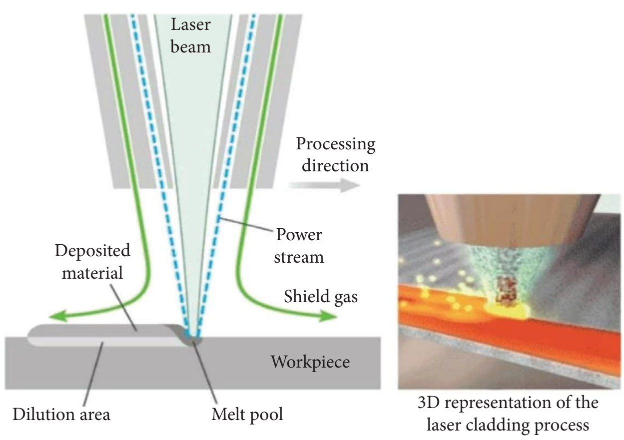

FIGURE 3: Diagrammatic representation of the experimental setup for the LMD process [48].

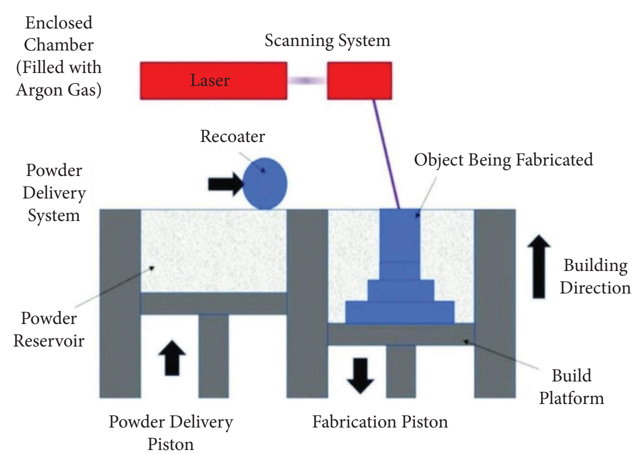

FIGURE 4: Process flow diagram for SLM [51].

another "adsorptive," the upper surface in LMD is substantially reliquaries. A simulation model in a standardized setting is created using the CAD system [49].

3.1.2. Selective Laser Melting (SLM). A maximum force depth laser is used in the SLM 3D printing technique to liquefy and mix metallic particles. Powders are specially dissolved and woven between layers to function as a portion. The SLM process, also recognized as straight discriminating laser curing, straight metal laser sintering, and laser cutting, has been shown to yield components that are almost identical in form up to 99.9% relative thickness. This enables the approach to operate with practically all practical components and offers respectable financial benefits [50]. Figure 4 depicts the schematic representation of the SLM process. Table 2 depicts the comparative study of various 3D printing process merits and demerits.

3.1.3. Electron Beam Melting (EBM). Electron beam melting (EBM) is a valuable additive manufacturing technique that offers unique advantages for producing high-quality, complex metal parts, especially in industries where precision, performance, and lightweight materials are critical. Some other AM fabrication method that is acknowledged to change the manufacturing industry is EBM. The method liquefies the metal powder by using EB energy. The accompanying beam of electrons is used as the primary energy source for the whole procedure, which takes place in a hoover chamber. The absence of oxygen in the hoover environment ensures exceptional cleanliness while reducing the risk of hydrogen. A temperature of 700°C is consistently upheld in the chambers during the fabrication of components to minimize residual stresses, consequently preventing distortion and warping. With a faster sweeping velocity, the EB first prewarms the powder layer before vaporizing it by the geometry described in the CAD documentation. Figure 5

Table 2: Comparative study of various 3D printing process merits and demerits.

Procedure	Benefits	Drawbacks
Powder bed fusion	Minimal cost, no need for outside assistance, a broad variety of material options, and powdered recycle	It is necessary to postprocess. Materials created by this procedure have poor structural qualities and the procedure that takes a long time
Laminated object manufacturing	External assistance is not necessary. Cost-effective, fast to complete, and appropriate for huge portions	Poor dimensional accurateness, poor surface finish, the need for postprocessing, and the difficulty of manufacturing complex components are all factors
Binder jetting	Large surface polish and high-resolution minimal postprocessing are necessary; several printings may be performed at once and across a big area	There are a few things available, the components have low strength, and the substrate is necessary for printing
Fused deposition modeling	Low initial capital costs, large surface quality is simple to create complex forms, no waste is produced, and flexibility	A lengthy procedure, albeit the length of time, will vary depending on the component being produced. It is not of high quality as SL or SLS
Selective laser sintering	SLS makes it simple to produce complex pieces that the previous two methods cannot produce. It does not need outside assistance, in line with mass manufacturing	Because of the substantial production expenses and the need for postprocessing, big surfaces and small holes are challenging to create precisely
Direct energy deposition	The construction of denser portions is feasible, enables for the directional solidification of elements, and successfully used for refurbishing and restoring parts	The procedure takes a long time, has a poor surface quality, and has a restricted supply of material
Stereolithography	Excellent surface polish, ease of manufacturing complex products, precision, and thermal endurance	Massive price of the first expenditure. Manufacturing components with overhangs is challenging. The photosensitive resin is challenging to work with

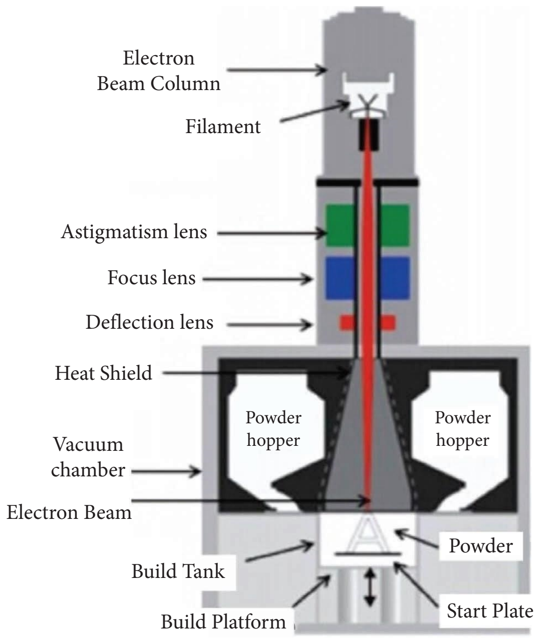

Figure 5: Schematics representation of the EBM process [48].

depicts the schematic representation of the EBM process. In EBM, every level of a segment is operated on in two phases. The powders within the form are dissolving along these boundaries to complete one layer. The exterior boundary of the component is initially produced, a process referred to as molding. This process continues until the perfect 3D thing is fully completed [52]. EBM employs an electron beam to heat and melt the metal powder. This electron beam offers high-energy density and can penetrate deeper into the powder bed. EBM operates in a vacuum or low-pressure environment to prevent contamination and oxidation of the metal powder, which is crucial for creating high-quality parts, especially with reactive materials such as titanium. Similar to other 3D printing techniques, EBM builds parts layer by layer, with each layer fusing to the one beneath it. This layer-wise approach allows for the creation of complex geometries that would be difficult or impossible to achieve with traditional manufacturing methods.

EBM is categorized as a powder bed fusion technique. It works by spreading a layer of metal powder (typically titanium or other high-performance alloys) on a built platform, and then, an electron beam is used to selectively melt and fuse the powder particles together according to the 3D design. Several variables, including the power of the laser, scanning speed, and powder properties, affect the microstructure of metal items manufactured using EBM or SLM. Parts made with EBM/SLM can have a variety of microstructures, such as dense, fine-grained frameworks that have certain residual stress and porosity. Though subsequent processing may be necessary, the mechanical characteristics of metal objects printed with EBM/SLM can be good, with great strength and resistance to fatigue [53].

EBM machines can be expensive to acquire and maintain, making them more suitable for industries where benefits outweigh costs. Postprocessing steps are often required to achieve the desired surface finish and mechanical properties of EBM parts. High-quality metal powders can be expensive, adding to the overall cost of EBM-produced parts. Overall, electron beam melting (EBM) is a valuable additive manufacturing technique that offers unique advantages for producing high-quality, complex metal parts, especially in industries where precision, performance, and lightweight materials are critical.

3.1.4. Direct Metal Laser Sintering (DMLS). It is a procedure that allows the fabrication of complicated objects from powder-based materials, as per AM computational modeling. In general, the machine fabricates the item by distributing out progressively thicker layers of the creating components on a movable stage. The device deploys a powdered coating with a specific thickness for each layer (0.1 mm). A powerful laser light then is focused on powder particles and modified to intertwine metallic particles which already exist in their central region, creating a thin steel coating, as per a computer-aided conceptual design. Figure 6 depicts the schematic representation of the DMLS process. A new powdered coating is added when the phases are reduced to the desired layer thickness, and succeeding deposition is softened by exposure to the laser's light to ensure it accommodates the layer that came before it. Thus, until the component is produced, the procedure is repeated, applying levels as required [55].

3.2. Liquid-Based Systems. Whenever a powerful laser strikes the tar, a photosensitive polymer is reduced in size or solidified (the liquid-based technique). The main type of 3D printer creates item levels by precisely hardened photopolymer, a fluid substance that solidifies when exposed to a laser beam or other lighting effects. Regardless of photo polymerization, 3D printing builds object layers inside fluids tanks. Furthermore, before the subsequent layer is applied, another fly with a single level of pitching and ultraviolet light is used to fix it firmly. Some 3D printers use the aforementioned technology and can combine several photograph polymers in a single print job, enabling them to generate things made of various elements. The direct light process (DLP) and stereolithography (SLA) are the primary groups under which the liquid-based method may be categorized [56].

3.2.1. Stereolithography (SLA). In the latter half of the 1980s, the stereolithography process became better known. While several other techniques have been developed since then, stereolithography remains a much more spectacular and flexible technique. The range of materials that may be managed is growing, and it has the greatest notable degree of production accuracy. Stereolithography is an additional substance creating method that permits the manufacturing of portions from a CAD file, similar to the majority of other creative production processes. To create 3D objects using stereolithography, fluid tar must be precisely manipulated to harden by photo polymerization. An instance is brightened on the exterior of tar using computerized lighting projected with a PC-driven

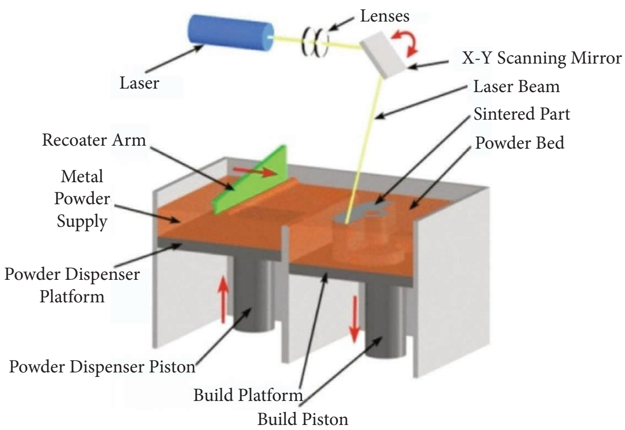

FIGURE 6: Schematics representation of the DMLS process [54].

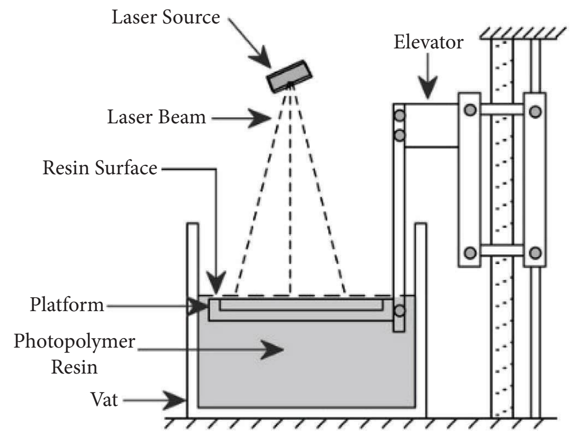

FIGURE 7: Schematic representation of the SLA process [57].

structural phase. As a result, the example's pitching is fixed to a defined profundity, which enables it to cling to a supporting framework. The staging is pulled out of the surface following photography of the polymers of the main layer, and the formed level is then recoated with fluid tar. Figure 7 depicts the schematic representation of the SLA process. The next layer then restores an instance. More adhesion to the primary layer is ensured by the restoration's depth being somewhat stronger than the phase step stature. To create a solid, three-dimensional item, these techniques are recycled. An as-built building is obtained after the sufficient pitch has been used up and washed off [26].

3.2.2. Direct Light Processing (DLP). Projection lighting is used in digital light processor (DLP)-based 3D printers to polymerize reaction materials and obtain the predesigned structures. The printed objective, printed skill, and working environment are this method's crucial focus areas. As a result, it might provide the things a lot of wonderful highlights. Printed techniques help diffuse photo polymerization reactions with the aid of DLP and laser. Those 3D printing phases feature significant differences in the printed tool, velocity, material choice, and objective. This technology makes extensive use of chipsets that are optically and electromechanically shrunk for the light sources of photosensitive substances. The main operational module is a computerized small-scale reflective system that includes an assortment of micron-sized, programmed reflections. The mirror rotates to direct the flow of lighting, which it then does by passing onto the photosensitive material. Figure 8 depicts the schematic representation of the DLP process. The typical shows contain a staggering amount of mirrors—between a million and over two million. Yet, the tiny size reflecting pixel dispersion is only a few to 12 microns. The purpose of DLP was to create a 3D printer that was dependent on the plane surface that was balanced between DMD and the focus point. The DLP (digital light processing) printing process operates at a micron scale, utilizing precise light patterns to cure and solidify photopolymer resin layer by layer, enabling high-resolution and intricate 3D Printing technology [59].

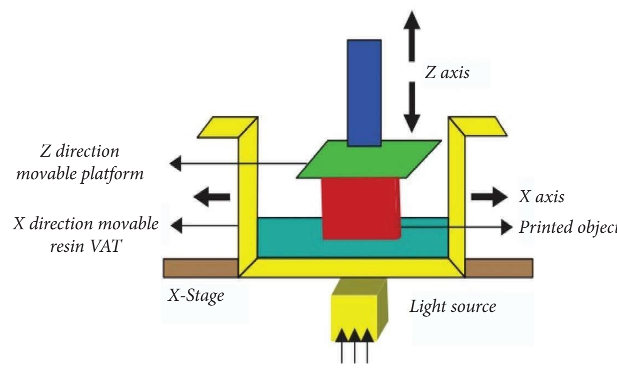

FIGURE 8: Schematic representation of the DLP process [58].

3.3. Solid-Based Systems. A specific type of 3D printing manufacturing procedure is a solid-based technique. Solids are the primary building block for every part or model created using solid-based 3D printing techniques. It differs greatly from the fluid-based image restoration procedure. They are also different from one another in that the primary type of high-quality materials might appear as fibers, wire, sheeting, or rollers in some applications, while pellets may be used in others. A unique collection of powerful 3D printing techniques that use powders as the intermediary will be individually protected. WPAAM, FDM, and EBFF are the three main categories for the solid-based system.

3.3.1. Electron Beam Freeform Fabrication (EBFF). At present in development is a cross-cutting technique called EBFF that yields conceptual metal pieces. The technique may be used to create complex, integrated components in a layer-added material approach, but it produces parts more quickly when used to add details to segmentation made from enhanced casts, forgings, or plating products. A strong beam of electrons operating in a narrow domain is used in EBFF. Therefore, to issues managing powdered in a vacuum, wire feeding is used. Meanwhile, the beam of electrons will ionize the transporter gas that is used to aid in the transportation of the powders. Working in a hoover ensures a pristine operating environment and eliminates the need for an expensive shielding gas, which is typically used in laser ablation techniques. Figure 9 depicts the schematic representation of the EBFF process.

The feedstock usage efficiency of the EBFF technique is close to 100%, and its power utilization efficiency is close to 95%. Every electrical conductor substance, including composites made of fundamentally clever materials such as aluminium and copper, interacts effectively with the beam of electrons. With EBFF, a variety of weldable materials may be created. To determine when nonweldable pairings may also be maintained, more advancement is necessary. Having EBFF, the shown affidavit values ranged from 330 to 2500 cm^3/hr, with a lesser aim in the ability to gather small details. Examinations are set up with narrow wires to try to build tiny details and wide distances between wires to increase affidavit rates. For the incorporation of the production criterion, EBFF provides appropriate solutions to the problems of testimonial rates, required to effectively manage, and material resemblance [60].

3.3.2. Wire Plus Arc Additive Manufacturing (WPAAM). Because of its ability to fabricate complex with a large throughput rate and about 100% material consumption, this technology has recently attracted the attention of manufacturing companies. To achieve the last goal, WAAM is a layer-over-layer technique for affidavits of liquid metal. Due to the growing need in the marketplace for novel designs that may be developed with significant profitability while generating little wastage of materials and incurring minimal hardware costs, this improvement uses an electric curvature as a warming supply to soften the metal wire [61]. Figure 10 depicts the schematic representation of the WPAAM process. Periodic welding consists of joining metallic filler wires together to maintain the top of the framework heated. Periodic welding involves connecting metallic filler wires to keep the top of the framework heated. An example of this is using a gas metal arc welding machine. The procedure has revealed several interesting points, such as the higher BTF fraction in comparison to conventional assembly aspects, the potential absence of dimensional breaking points for sequence production, and the effectiveness of the technique in comparison to powder-based techniques when substantial expenditure material is taken into consideration [63].

3.3.3. Fused Deposition Modeling (FDM). In the FDM technique, the layering of substances is printed in three dimensions using a constant filament made of thermoplastic. After being warmed by the edges of the nozzle to the point of semiliquidity, the fibers are briefly dumped on the stage or the head of the subsequent generated stages. The thermoplasticity of the polymer filaments, which enables the filament to consolidate while printed and thereafter set at room temperature afterward, is a significant feature of this technique. The key setting parameters that affect the mechanical qualities of printed components are deposition fatness, filament widths and courses, and air openness. The primary source of structural instability was assumed to be wandering amid layers. The main attractions of FDM are its

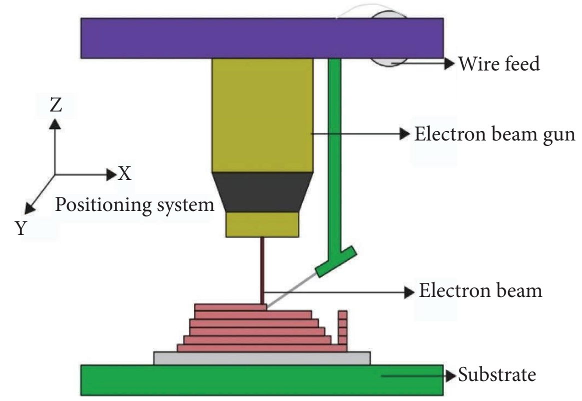

Figure 9: Schematic representation of the EBFF process [58].

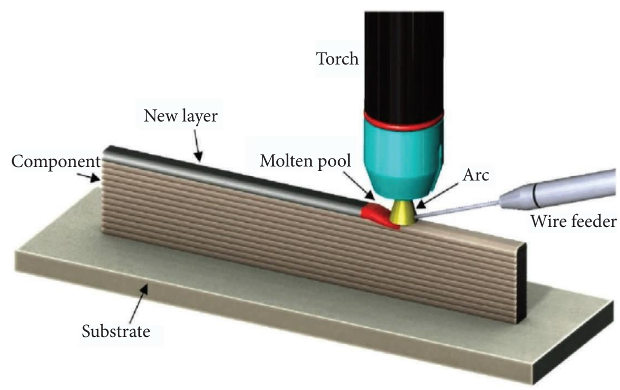

Figure 10: Schematic representation of the WPAAM process [62].

quick and simple operating methods. The fundamental flaws of FDM, on the contrary, are its poor mechanical behaviors, layer-by-layer arrivals, helpless surface integrity, and predetermined quantity of thermoplastics. The advancement of FDM-based fiber-enhanced materials has enhanced the mechanical characteristics of 3D parts [64]. Figure 11 presents the schematics representation of the FDM process.

3.3.4. 3D Printing Challenges. 3D printing has several benefits, including flexible design options, the capability of printing intricate assembly, ease of use, and product customization. Technologies for 3D printing have still not developed to the point where they can be put to real use. In addition to technical development, there have been downsides and obstacles that need to be examined [66]. The creation of overhanging areas, elephant foot, layering misaligned, spaces in the upper layers, underextrusion, pillowing, distortion, poor precision, limited production effectiveness, high prices, and anisotropy mechanical characteristics are only a few of the issues that require being handled progressively [67].

The development of voids among succeeding levels represents one of the main issues with 3D printing parts. This kind of problem occurs as a consequence of inadequate layer binding, which leads to inadequate mechanical effectiveness. Devices for 3D printing that rely on extruded, such as fused deposition modeling, induce voids to form among

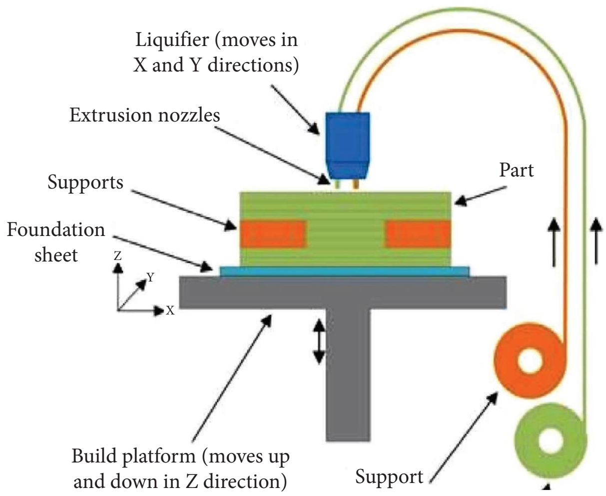

Figure 11: Schematic representation of the FDM process [65].

the created layers, leading to deformation and anisotropy mechanical properties [68]. In reality, the amount of permeation brought on by void generation is largely based on the kind of AM technique utilized and the substance employed [69]. A constrained building area must also be overcome by the consumer of 3D printing technologies. It is considered one of the most important shortcomings of the expertise of 3D printers. Large servings are usually reduced in size or split into more manageable amounts, which requires time and effort. In most cases, scaling down the concept is also not practicable or efficient. The assembling of subparts loses power whenever adhesives are employed, while assemblage grows bulkier whenever mechanical fastening is included. 3D printing has not yet demonstrated its viability in extensive industrial uses [70].

A 3D printer can be very expensive to purchase initially, particularly high-end industrial models. When contemplating implementing technology for 3D printing, people or organizations may find the upfront outlay to be a barrier. Maintenance regularly for 3D printers is necessary, and it involves cleaning, calibrating, and changing out worn-out parts [71]. Furthermore, as technology advances, it could be necessary to improve the printer or some of its parts, which would raise the entire cost. When compared to conventional manufacturing materials, the materials utilized in 3D printing, such as filaments, powders, resins, or metals, might be costlier. Whenever determining the entire costs of 3D printing, it is crucial to take material prices into account because the price of these consumables might vary based on the kind, excellence, and brand [72]. The largest obstacles for respondents in the 2017 survey were linked to expenses (of system equipment, preprocessing and postprocessing, and materials), whereas the greatest difficulties for respondents in the survey for 2019 were connected to 3D printing material concerns. The major 3D printing problems for 2021, however, appear to be the expense of preprocessing and postprocessing, the restricted availability of materials, and technological constraints. Figure 12 shows the challenges with 3D printing in 2017, 2019, and 2021.

4. Benefits of 3D Printing

4.1. A Higher Level of Precision and Accuracy. Conventional production processes cannot be compared to 3D printing's precision and accuracy whenever it comes to industrial production. Components with exquisite features and incredibly strict specifications may be made using 3D printing. This allows for the creation of components that are identical to those made utilizing conventional techniques but with a far better level of accuracy [74].

4.2. Improved Speed. The faster production of components is among the main advantages of 3D printing for the industrial sector. The production cycle might last weeks or even months when using conventional techniques such as machining or injection molding [75]. Yet, components may be produced using 3D printing in a couple of hours, some even seconds! Because of this, manufacturing project lead times are drastically shortened, and businesses can launch their goods more quickly than at any time before.

4.3. More Customization and Design Versatility. The increased design versatility it provides in comparison to more conventional techniques such as machining or injection molding is another significant advantage of the 3D printing method in the manufacturing of industrial products [76]. Developers may now construct sophisticated designs and frameworks that were impractical since they are no longer restricted by the constraints imposed by these earlier technologies.

4.4. Lower Production Costs. The ability to dramatically reduce expenses is among the most important benefits of 3D printing for industrial production. Oftentimes, producing items using 3D printing may be done for far less money than using more conventional techniques [77].

4.5. Prospective Issues with Additive Manufacturing. While AM has many advantages for the industrial sector, ongoing issues prevent its widespread use. One difficulty is getting the component to have the necessary strength by design optimization. An additional challenge is determining the physical characteristics and microstructure of products made via 3D printers. Understanding the material properties of the AM parts, such as densities, tensile, and hardness, is necessary for them to meet the necessary criteria [76].

4.6. Rapid Prototyping. The process of creating prototypes is sped up by the ability of 3D printing to produce parts in a couple of hours. This makes it possible for every phase to finish sooner. Whenever compared to machining prototypes, 3D printing is less costly and more effective at producing components since the item may be produced in hours, permitting every layout alteration to be accomplished at a much more rapid pace [78].

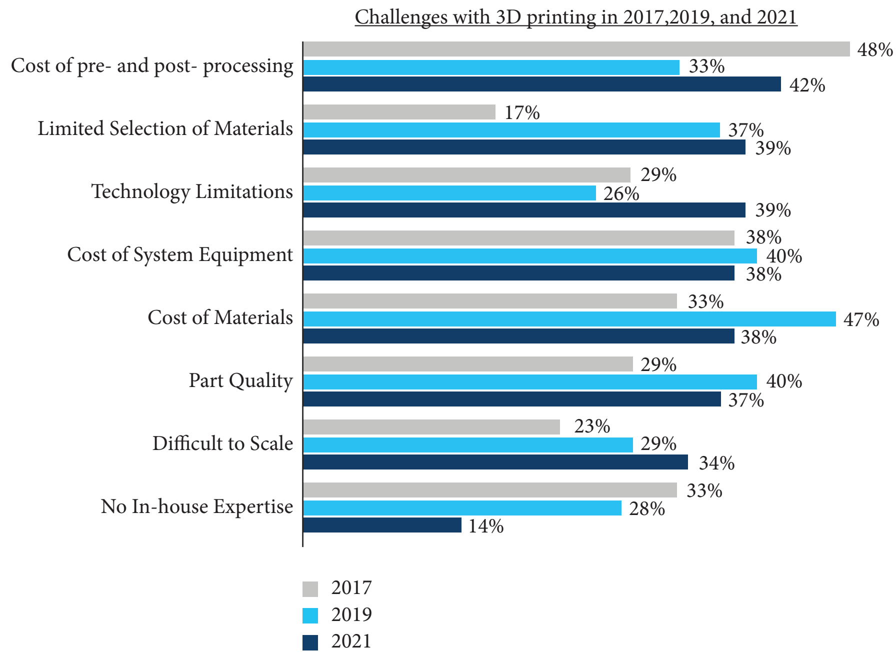

FIGURE 12: Challenges with 3D printing in 2017, 2019, and 2021 [73].

4.7. Lightweight and Strong Parts. While various metals may also be utilized, plastic is the primary material for 3D printing. Yet, as plastics are more lightweight than their metal counterparts, they have benefits. This is crucial in sectors such as automotive and aircraft where weight reduction is a concern and can result in higher fuel economy. In addition, components can be made from substances that have been specially designed to offer particular qualities such as heat resistance, increased strength, or repellent to water [79].

4.8. Fast Design and Production. Compared to molding or machining components, 3D printing may produce an object in a couple of hours, based on the part's difficulty and layout. By 3D printing, time may be saved not only during the part's production but also during the design phase by producing STL or CAD files that are prepared for printing [80].

4.9. Reducing Waste. Compared to conventional procedures, which involve cutting big pieces of materials that are not recyclable, the manufacturing of components only uses the resources required for the part itself, with little to no waste. In addition to conserving resources, the procedure also lowers the price of the materials required [81].

5. Limitation of 3D Printing [82]

5.1. Fewer Materials. However, a variety of metals and polymers may be used in 3D printing to construct objects, and the selection of raw resources is still not extensive. This is because various polymers and metals may be 3D printed under control of temperature. Moreover, the vast majority of these printed materials cannot be recycled, and a tiny portion of them cannot be used in food. The problem of ecological contamination is a serious one since it is crucial to use sustainable technology that does not harm the environment in the medium or long term [83].

5.2. Restricted Size of Construct. The number of pieces that may be produced is constrained by the printing areas of 3D printers. Greater components must first be printed individually and then assembled after manufacturing. To create bigger items, the printer must be able to print additional components. Because they must be put together and linked to form a single part, this will raise the price and time needed. Also, the thing will be completed by assembling each of these components. Moreover, physical effort will be required throughout the procedure [84].

5.3. Sizeable Volumes. In contrast to the injection molding process, which can create huge volumes at a lesser price, the 3D printer has a set expense. While 3D printing is costlier than other production techniques, the unit price does not decrease in the same manner as with the injection molding process if scales up the production to big volumes for large-scale production [85].

5.4. Defects in the Design. The kind of procedure or equipment utilized is a third potential issue with 3D printers. Certain printers can produce components that are inconsistent with the original concept because of their poorer constraints. It ought to be mentioned that while this may be fixed in postprocessing, it will lengthen manufacturing time as well as expenses more [86].

5.5. Structural Limitations. 3D-printed things could not be as strong and long-lasting as conventionally made ones. Anisotropic characteristics, in which the strength changes in various directions, can be produced through layered design. Some applications may be constrained by this restriction, particularly those requiring great integrity of structure [87].

5.6. Intellectual Property Concerns. Concerning intellectual property obligations, 3D printing raises difficulties. It becomes simpler to duplicate or purchase counterfeit goods, which might result in copyrights or patent infractions [88].

5.7. Health and Safety Risks. Certain 3D printing techniques, especially those that use specific substances or resins, might release noxious fumes or particulates. To reduce the health and safety concerns connected with 3D printing, proper ventilation and safety measures are required [89].

6. Applications of 3D Printing

The manufacturing of things in the shortest amount of time with the lowest amount of waste is made feasible through every one of the procedures that have been mentioned so far. Furthermore, the techniques make it incredibly simple to create complicated structures of the best standard. With the aid of 3D printing, sectors are being upgraded and transformed. Conventional production methods are rapidly giving way to unconventional ones in production. It necessitates in-depth familiarity with the characteristics of various materials. Utilizing 3D printing, various adjustments have been made to the conventional methods utilizing the current understanding of the components and procedures. Figure 13 depicts the various applications of 3D printing technology. The study will briefly go through a few of the procedures that have been applied in this part that have been covered thus far.

6.1. Uses of Stereolithography. A novel innovative method for producing healthy, functioning heart valve tissues from autologous cells reflects the development of heart valve tissues through bioengineering. A polymeric substance is utilized to create heart valve scaffolding. The tissue engineering of the heart valve includes SL as a key approach. It creates plausible tissues that are capable of developing within the human body like that of real cells. Utilizing X-ray computerized tomography as well as other tools, biocompatible and biodegradable scaffolding is constructed for stereolithic specimens. They resemble humans and are readily absorbed by the human body. Nowadays, mechanical valves that cannot develop are employed, which increases the likelihood that a body may reject them. Thereby, this novel method gets over these restrictions [90].

Natural teeth reflect, absorbed, and relay light to some extent, giving them a certain amount of translucency. The construction of all-ceramic structures was prompted by the especially glaring and undesirable transparency problems in metallic ceramics in the preceding industry. For individualized and aesthetically pleasing restorations, materials comprising glasses and ceramics are typically employed in the dentistry sector. Lithium disilicate is often treated using the AM technique, resulting in very dense (>99 percentage), whole ceramics parts that fulfil the requirements of being utilized for dental restorations. By melting the SiO_2-Li_2O-Al_2O_3-K_2O-P_2O_5 glass structure and heating pretreatment specimens to the glass's crystallization temperature, lithium silicate glass-ceramic may be created. Superior mechanical features of the produced glasses, including such high tensile strength, enable reproducible print and crowns and debinding of bridges, particularly in the anterior tooth region [91].

6.2. Uses of Fused Deposition Modeling. The phrase "drug transmission" encompasses techniques, formulation, methods, and technology that utilize nanoparticles that are employed to effectively and securely disperse pharmaceuticals throughout the body as needed to produce the required therapeutic effect while maintaining good health. FDM-based 3D printing offers significant benefits in the production of customized tablets, including streamlining manufacturing procedures, enhancing intrinsic qualities, and distributing dose kinds. FDM is a low-cost method of 3D printing, depending on extrusion that creates solid shapes by layering materials. As FDM is a thermo-based technique, melting polymeric rheology and thermal heat properties must be taken into account while choosing materials. Because of their low melting point, thermoplastics predominate in FDM usage. Polyvinyl alcohol has become the most popular polymer utilized in FDM systems for drug delivery [92].

Today's consumers' demands for high-quality, low-cost elements that can be delivered quickly provide a significant problem that necessitates streamlining the operational parameters of the corresponding machinery. Commercial castings have successfully employed the FDM technology to make wax and wax shapes at competitive rates. Great surface quality and dimensional accuracy are essential for castings and component assembly. Whichever material condition the master design displays, molding replicates it. As a result, the master's design produced by FDM has to have an excellent surface polish to produce decent casting. Acrylonitrile butadiene styrene serves as the maximum common nonwax substance utilized to create casting models in FDM. With only minor adjustments to the foundry's standard procedures, the wax produced utilizing the FDM scheme has both shown to be successful in heating out the ceramic shell. In investment casting, wax gates and vents are manufactured as an inherent element of the patterns and joined by the foundry by ABS design [93].

6.3. Uses of Powder Bed Fusion. Direct laser metal sintered, commonly referred to as laser fusion on a powder bed, is a type of AM procedure that uses a laser source to directly produce near net-shaped objects utilizing CAD data by melting multiple layers altogether. With only a few completing stages needed, metals manufactured using near-

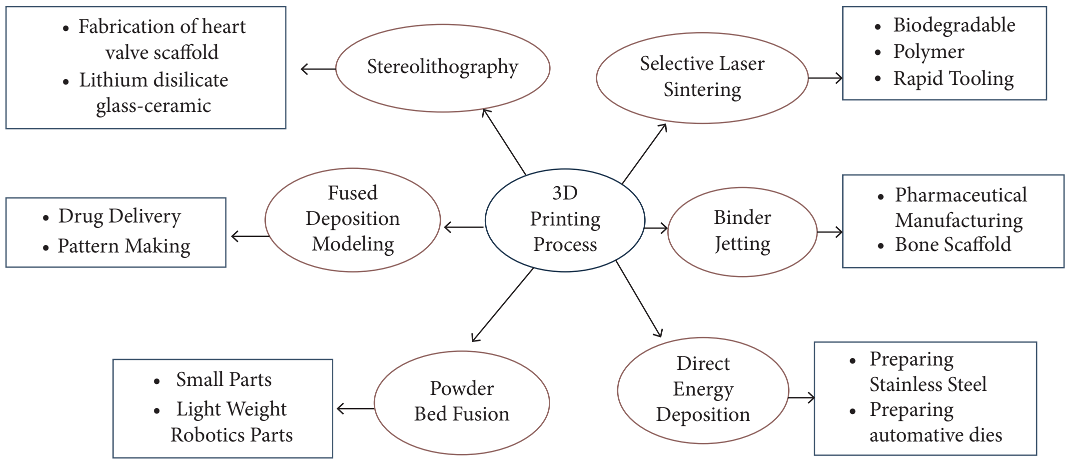

Figure 13: Various applications of 3D printing technology.

net-type modern techniques produce products that are almost similar to the ultimate shape and size. This technique is employed for producing lighter robotic parts out of an aluminium alloy. Substantial stiffness and strength have been attained, as well as other highly interesting mechanical characteristics, due to the extremely tiny structure. The compact finger exoskeleton with bolts was created in a solitary phase of creation. Furthermore, it is formed with all the required mechanical characteristics [94].

Power device modules with built-in sensors or other intelligent parts can provide input on how the real-time system is operating and allow for on-the-ground inspection. Appropriate surface contacting and cavity sensing have a greater chance of interfering with the normal operation of power systems because of developments in the structural parts required for sensor location. It will be feasible to adaptably embed a sensor into a building utilizing additive manufacturing (AM) technologies without compromising the structure or functioning. Sensing may be put inside a component at any chosen place owing to the layer-by-layer technique, giving unmatched accessibility to previously unreachable regions inside the dimension of a component. To improve the production process for smart parts, problems such as part registering and bonding strengths of the interfaces brought on by the stop-and-go procedure are additionally being researched. By allowing integrated sensors to offer function to delicate sections of a component that are often exposed to elevated temperatures, additive manufacturing (AM) technologies will transform the development of metal components [95].

6.4. Uses of Direct Energy Deposition. PBF, a 3D printing method, is widely used for producing components made of stainless steel 316L. Traditional repair procedures can be helpful in cases when these PBF parts have suffered severe degradation or wear throughout operations. These methods do have many drawbacks, though, including the creation of a sizable heat-affected region and repairing flaws. DED, on the other hand, produces a limited heat-affected zone, minimum diluting, and robust metallurgical bonding. The repaired region's structure is mostly made up of intricate dendritic formations because of the region's uneven nucleation. Moreover, the microhardness of the depositing region is equivalent to that of the PBF samples and higher than that of the initial hot-rolled samples [96].

Traditionally utilized for die repairs, tungsten inert gas (TIG) welding only endures 20.8% of the die's lifespan before necessitating further repairs. An additive reconstruction method known as powder-blown DED is used to remove broken sections and subsequently rebuild them. The longevity of the traditional die as well as the DED-repaired die was identical. DED maintenance decreased the need for urgent fixes and unforeseen line shutdowns because additional assistance was needed sooner. Due to this technology, the repaired DED dies now have the same cycle life as the initial die [97].

6.5. Uses of Selective Laser Sintering. Explosive growth has become a key enabler for reducing the time it takes for a product to reach the market and as a productive output strategy. Among the most popular methods for fast prototyping is the SLS procedure. The modules are swiftly prototyped with the SLS methodology utilizing several methods. Copper polyamide is the material utilized to construct tooling inserts, whereas all nylon-based substances are utilized to create production prototypes or components with special attributes such as hinges, chips, and other characteristics. A small number of prototype components may be made with identical materials and manufacturing processes as the finished product components using the same SLS approach that was employed to manufacture copper polyamide tooling inserts. The quick instrument approach demands an in-depth understanding of design attributes to be used effectively [98].

Because of the potential of using biological replacements to restore damaged or destroyed organs, tissue engineering has advanced. This branch of biomedicine is growing in complexity and importance. For anchorage-based types of cells, temporary three-dimensional scaffolding is frequently utilized to control cell growth. Computer-controlled

Table 3: Various techniques, merits, and demerits of 3D printing.

Techniques	Materials	Uses	Advantages	Disadvantages
Fused deposition modeling	Thermoplastic continuous filament and continual polymeric reinforced with fibers	Sophisticated composite toys and components with quick prototyping	Cheaper, faster, and simpler to use	Constrained materials and poor mechanical characteristics
Binder jetting	Granular-shaped materials, such as metals, sands, and ceramics	Creation of broad sand casting cores and molds and full-colour prototypes	Cheap, fast, easy, and rapid	Low density, no infiltrating shrinkage
Powder bed fusion	Elements made of finely ground compressing powder, a few polymers, and metals and alloys	Pharmaceuticals, electronics, aircraft, and lightweight construction	Great quality and resolution	Sluggish printing, high porosity, and increased price
Stereolithography	A combination of photoactive resin monomers, polymers, and ceramics	Biomedical simulations	Excellent resolution, top-notch outcomes	Few such materials, sluggish printing, and high expenses
Laminated object manufacturing	Ceramics, metal rolls, polymer, metal-filled tapes, and composites	Smart constructions, the foundry industry, and papermaking	Simplified tooling, cost-effective, ideal for producing bigger systems	Poor dimensional accuracy and surface uniformity, which limit the manufacturing of complex structures
Selective laser sintering	Flame-resistant nylon, thermoplastic nylon	Connections, packing, and electronics	High-complexity functional components with long-lasting geometry	Manufacturing defects include warp, shrinkage, hard surfaces, and thermal distortion
Direct energy deposition	Ceramics, polymers, and alloys in terms of wire	Renovation, maintenance, aerospace, cladding, and biomedicine	Minimal time and expense requirements, strong mechanical characteristics, and precise compositional regulation	Poor precision, a lacklustre surface appearance, and restrictions on intricate printing with tiny details and forms

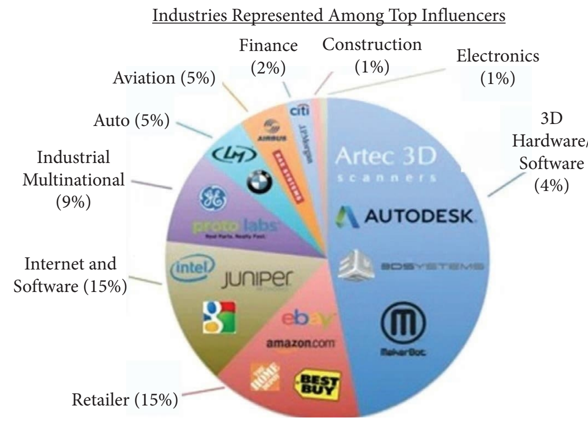

FIGURE 14: Application of 3D printing in various sectors [101].

	Traditional model making	Machining	3D printers
Iterations	1/part	1/part	10/part
Costs (incl. initial outlay, materials)	\$3,000/part	\$500/part	\$15-\$17/part
Delivery time	40 hrs/part	3 - 4 weeks	12-24 hrs/part
Post-processing*	5-8 hrs/part	4-7 hrs/part	6-9 hrs/part

* Post-processing (sanding, painting, finishing, rework, installation) is an important stage in the production process as the parts are used as final components in the car.

Cost and time savings from 3D printing reported by Tucci Hotrods

FIGURE 15: Quantitative illustration on how 3D printing can do cost savings [103].

production processes such as rapid prototyping methods have been acknowledged as having a benefit compared to traditional manual-based scaffolding production techniques because of their capacity to construct structures with complicated macroarchitectures and microarchitectures. Commonly produced rapid prototyping model substances are not biocompatible and are not the best for primary function in scaffolding production, regardless of the enormous rapid prototyping processor speed for scaffolding assembly. One of the biocompatible polymers becoming manufactured is hydroxyapatite, a bioceramic. Other biocompatible polymers include polyester ether ketone, polycaprolactone, polyvinyl alcohol, and polylactide. To deal with these substances, the SLS technology's settings have been adjusted. Scaffolding samples produced by SLS are examined under scanning electron microscopy. Microscopy demonstrates their applicability in creating tissue engineering scaffolding and the ability of the SLS approach to produce very porous scaffolds [99].

6.6. Uses of Binder Jetting. The most potential 3-dimensionalprinting method used to date in the pharmaceutical business is binder jet printing. The FDA modified the binder jet procedure in 2015 to make it easier to produce Spritam as a substitute mass fabrication method. Anticipating binder jet printing is to have a significant impact on formulating manufacturing during the coming ten years. Particularly with binder jet printing, producers may create oral dosage preparations with a variety of releasing properties, from quick-dissolving to systems for sustained release. Even though it has many benefits, there are also downsides [100].

Scaffoldings are biocompatible 3-dimensionalframeworks that imitate the characteristics of the extracellular matrix (physical supporting, cell function, and protein synthesis), and they operate as a support system for the development of bone cells and cell attachment. Their conclusions are supported by data on biochemistry, high porosity, pore diameter, and mechanical strength. Utilizing the binder jet AM process, a hybridization made of tricalcium phosphate and stainless steel is employed in different volume concentrations to create portions with different densities.

Among commonly employed biomaterials for implantation include alloys and metals, ceramics, and polymeric. The most biocompatible and closely related one to the genuine bone in terms of characteristics is calcium phosphate. Its weak toughness and tensile strength, therefore, restrict its use as bioimplants. The following is the major production approach for the binder jet procedure: The STL files are created by separating each level of the CAD system into its individual file. Every layering begins with a small distribution of powders thrown across a powder bed's surface. Utilizing inkjet printing techniques, a binding agent binds particles just where the result is to be generated. A piston that covers the powder bed and lowers the active component enables the extension and selected joining of the subsequent powder sheet. Level by level, this process brings out till every part is finished. The unbound particle is extracted during heat processing, and the metal powder is fused altogether [97]. Table 3 depicts a list of the numerous AM technology uses, benefits, and demerits [35].

FDM is potentially helpful for production on a small scale where molding by injection may be costlier or altogether out of reach owing to the concerned party's tiny scale. Because of their introduction, 3D printers have made significant strides towards being more affordable and therefore more affordable to "mom-and-pop" customers who might not have been qualified for production processes at all. Figure 14 depicts the 3D printing application in various sectors. It appears that manufacturers of FDM technology are targeting enhancements at decreasing costs rather than significantly developing the technology to target the marketplace for decentralized and maybe smaller-scale industrial applications.

7. Conclusion

The manufacturing industry has undergone a significant transformation in recent years, largely due to the advent of 3D printing technologies, also known as additive manufacturing. This revolutionary approach to production has opened doors to innovative applications, promising cost savings, design freedom, and enhanced efficiency. 3D printing has developed over the years from a specialized industrial technique to a commonplace technology with a wide range of uses [102]. The valuation of the global 3D printing market in 2022 amounted to USD 16.75 billion, with a predicted compound annual growth rate (CAGR) of 23.3% from 2023 to 2030 [11]. In 2022, North America dominated the market and brought in over 33.34% of worldwide revenue, with Europe coming in second. For the next ten years, the Asia Pacific region is expected to grow at the fastest rate of growth. The Asia Pacific manufacturing industry's advancements and modernizations are responsible for AM's quick acceptance in the area [11].

TCT Magazine gives an example of how a firm was able to achieve a $50,000 quarterly reduction in production expenses. A case study describing how Volkswagen Autoeuropa was able to cut the manufacturing costs of specially designed assembly tools by 91% (or €325,000/year) is another illustration of a large cost decrease. The modeling and machining time for custom autoparts was reduced from three to four weeks to less than twenty-four hours by Tucci Hot Rods. With the focus on small, intricate metal components, 3DEO was able to produce parts at the volume required by their clients at a reasonable cost. The better postprint surface quality of 3DEO not only eliminates the need for tooling or upfront costs but also significantly lowers postprocessing costs. Half of the price of 3D printing goes towards postprocess or secondary activities. Through attaining a superior surface polish as printed, 3DEO can considerably reduce the cost of secondary procedures for the client [103]. Figure 15 shows the quantitative illustration on how 3D printing can do cost savings.

The process of 3D printing provides many benefits for consumers, enterprises, and the government alike as it moves into the industrial sector. As a consequence, an additional study is needed to determine the best ways to promote the use of AM technology. Knowing more about AM technologies will help businesses and the government build the sector's infrastructure. This article's goal is to give a general understanding of the numerous 3D printing procedures, manufacturing materials, and uses. Researchers are going to get a chance to conduct more research on many types of prototyping equipment and the best components to use for each. For such a manufacturing industry to progress, new research in manufacturing parts, processes, and product development is required. With increasing product complexity, new and innovative manufacturing techniques are needed. In the end, 3D printing technology has opened up new opportunities in a variety of industries, including manufacturing, healthcare, and design. It is a promising technology for the future since it can support quick prototyping, personalization, and environmentally friendly manufacturing. It is anticipated that technology will continue to shape industries and alter how to design and produce things as a greater amount of it becomes available.

Data Availability

The data that support the findings of this study are available from the corresponding authors upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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