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3D Printing: Current Trends in Technology

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ABSTRACT:

Additive manufacturing with proper geometry is a pressing priority for its ecofriendly unit material use. Three-dimensional printing is just like fabricating our creative power by manufacturing contemporaneous objects by depositing layer after layer of filaments. 3-D printing is gaining importance in every capacity of healthcare system and most importantly the biomedical application has taken a tremendous leap forward. 3-D printing helps us in designing a more efficient patient based treatment by facilitating customized manufacturing, hence overcoming the old theory, "one size fits all". This review abridge various applications of 3-D printing in healthcare system, including organ grafting, drug delivery systems, implants, etc. demonstrating different materials and technologies used in 3-D printing, and furthermore, a detailed listing of the challenges associated with this technology is adequately mapped in this review. The objective of this review is to explore the current scenario of 3-D technology for achieving its well-shaped utilization by researcher in coming days.

1. Introduction

Digital progress is propelling the world to unprecedented heights, as technological advancement rapidly unfolds. A multitude of headway in technology, encompassing both software and hardware capabilities, along with evolving productivity, are occurring swiftly. The ongoing transformations in principles, including the rise of cloud technology and the impact of the Internet of Things (IoT), are currently navigating the embrace of a ubiquitous system. This system aims to deliver rapid and efficient revolution, pliable resource allotment, latest connected security, and expandability [1].

People inhabit a period dominated by computers and technology. The assured progression of technology, software, and their expansion is inevitable in coming days. In this rapidly evolving world, the healthcare sector is accelerating its efforts to integrate new machineries for the well-being of patients and to explore challenging frontiers. Technology continually surprises us with novel trait that enhances user-friendliness and complements the existing methods. This remarkable development creates fresh opportunities to enhance fruitful outcome in various sectors [2].

One remarkable development making strides across various healthcare sectors is 3D printing. It seamlessly combines medical and technological exercise, addressing the current requirements of the healthcare system. The inception of 3D printing, initially known as stereolithography in the late 1980s, rapidly clinched traction.

This revolutionary technology is based on the principles of fabrication science, employing diverse manufacturing techniques to sequentially build various substances of requirement (inks) layer after layer in various shapes. It follows a simple design focused on additive manufacturing (AM) and rapid prototyping. While traditional preparation techniques played a

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crucial role in the industrialization of our society, it has inherent drawbacks that require innovative directions. Additive manufacturing comprises a set of new technologies that construct items, one split sheet at a time [3].

The global requirement for three-dimensional (3D) printing is experiencing rapid growth and is anticipated to continue expanding in the coming many years. This developing technology finds applications in various sectors, most importantly medical and healthcare sector. The distinct advantages of 3D printing encompass open-ended development, structured and feasible output, and a low timeframe from hypothesis to production compared to traditional methods. A widely utilized and efficient 3D printing technology, which simplifies the production of intricate components in the additive manufacturing process, is fused deposition modeling (FDM) or fuse filament fabrication (FFF). FDM builds objects in layer manner from digital 3D model information. Both FDM and 3D printing have developed demand in near time due to their rapid, flexible, and cost-effective approach to manufacturing things with composite forms and shapes [4].

A wide range of outcome and utility utilize 3D printers to produce tangible duplicates of designs prepared by computer technology. Toys and medical implants to intricate maps and historical artifacts are some of the items to be mentioned among many. Various raw materials, such as plastic, plaster, metal, and even fruit, can be employed to craft these prototypes [5].

The fundamental inquiry regarding manufacturing revolves around the process of creating items, from raw materials to the final usable, purchasable, or consumable product. The initial approach is machining, where the production starts with raw materials and progresses towards the desired outcome. Another method is fabricating, where substances experience transformation in measurements when after application of energy. Molding, the third type of manufacturing, involves melting of solid raw material into liquid form, and then pouring the liquid material into a specific mold to give shape the object.

The fourth preparation technique is Additive Manufacturing (AM), where the final shape is obtained by placing layer on top of layer. AM and 3D printing are terms encompassing a variety of processes for constructing three-dimensional image and construction from documents generated digitally. Construction of product by layer after layer deposition of extremely fine divisions with the help of designs generated digitally serves as the foundation for additive technologies, thus overcoming the barriers of traditional methods [6].

A machine qualifies as a 3D printer if it possesses main properties like being three-dimensional, additive, and layer-based. In an additive process, different substances are combined to create the desired substance. If we look into an example, while preparing food, we add different ingredients unless we are ready with the final product—illustrating an additive method. Same way, a subtractive process involves starting with a larger entity and removing unnecessary elements. Like what we do in case of shaping any object from big piece of marble [7].

This has become a revolutionary method of formulation in the global market. Computer added designs containing software based information is employed, commanded to the printer and then produced. This method is more efficient, particularly suitable when the outcome need to be of outmost quality and energy consumption is also low. Formulation manufacturer grapples with significant challenges and is transitioning to advanced manufacturing techniques due to technological advancements. Modern production system includes advanced methods, methodology, and script aimed at enhancing the rate of formulation. Now formulation has a comprehensive term, primarily focuses on technologies used in formulation and its feasibility. Increasing requirement has prompted industries to embrace advanced techniques to fulfil the demand adequately.

2. Methods:

Current Scenario

Geocement: Activated alkali cement encompasses medium possessing pozzolanic qualities paired with other activating materials. These systems facilitate the reuse of by-products collected from production unit, thereby curbing the use of energy and less harm to the surrounding, contingent upon their constitution [8]. Materials crafted from these binders may exhibit heightened resistance against chloride ion and corrosion caused by acid compared to Portland cement due to the unique attributes of the moisturized material. Moreover,

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owing to their network structures akin to nature of becoming rigid naturally when exposed to heat, they are often termed "geocement" or "geopolymers" [9]. Geocement, essentially three-dimensional network-structured aluminosilicate substances having the ability to become rigid, consist of SiO4 and AlO4 tetrahedral units formed through the fusion of charred elements or leftovers from manufacturing units with alkali activators [10]. The genesis of geocement unfolds in three steps: (i) dissolution of Silicon, Aluminium monomers, (ii) rebuilding the monomers, and (iii) formation of polymer by chemical condensation [11]. The aluminosilicate precursors of geocement can be further categorized based on the calcium content of the source materials: without calcium, less-calcium and more-calcium. Geocement have found applications in 3D printing as an eco-friendly substitute substance, aiming to mitigate waste production and diminish reliance on Portland cement [12].

The utilization of 3D printing in creating composite materials from natural fibres and their derivatives, alongside degradable polymers, marks a significant advancement in biomaterials. These alternatives to conventional petroleum-based polymers like polyethylene, polypropylene, and polystyrene are gaining considerable traction due to their commendable performance and environmentally friendly nature. A notable breakthrough in this field was the development of green biomass flax fibre/polypropylene composite materials by Oksman and colleagues in the early 21st century [13]. They utilized polylactide (PLA) as a matrix, flax fibre as reinforcement, and triglyceride as a plasticizer, resulting in PLA composite materials exhibiting mechanical strength approximately 50% higher than polypropylene (PP) composites. This superior performance has led to their widespread application. Subsequent research efforts, both in China and globally, have focused on enhancing and applying degradable polymer/natural fibre-based composite materials. However, challenges such as inadequate mechanical properties due to poor interfacial bonding and mismatched thermal properties between matrix and fibres remain common. Nevertheless, significant strides have been made in recent years to address these issues, particularly in improving the interface between matrix and reinforcement, as well as enhancing mechanical and thermal properties [14]. Additionally, the incorporation of additives has led to the development of smart materials with unique responsiveness. This study delves into the prominent natural fibre materials and their derivatives, providing comprehensive insights into macro-level composite materials comprising polymers and natural fibres, as well as micro-level considerations concerning xylem cellulose. Specific considerations for the 3D printing of natural fibre-degradable polymer-based composite materials are also discussed [15].

The Fundamental Use of 3D printing in Conventional Apparel: With the advancement of 3D printing technology, its application in clothing and textiles has gradually expanded. Research on materials for 3D-printed clothing has also made initial progress Cakar conducted experiments on printed samples using polylactic acid (PLA soft), PLA+ (hard), and Filaflex (TPE, or Thermoplastic Elastomer) [16]. The findings indicate that Filaflex is the most suitable material for 3D printing. Moreover, optimizing printing parameters can minimize air cavities formed during printing, while adjusting printing load can control residual stress in Filaflex materials. Kim compared the properties of TPU (thermoplastic polyurethane elastomers) and ABS (acrylonitrile butadiene styrene) when combined with traditional textile fabrics [17]. ABS, with its solid structure, yields high-quality outputs but requires post-processing due to high surface roughness. It is more suited for circular structures in apparel production. On the other hand, flexible TPU offers smoother surfaces and is better suited for connection patterns in clothing, such as hinge structures, owing to its inherent characteristics. Spahiu utilized FDM printing to create a dress with arrow geometric structures, reinforced with fixed belts for ease of wear, entirely made of Filaflex flexible filament for enhanced flexibility Nonetheless there still exist a gap between the properties of 3D-printed materials and those of traditional textile materials [18].

Technology for creating bone tissue engineering using 3D printing: Currently, the technology for 3D printing bone tissue engineering scaffolds primarily involves various methods such as Fused Deposition Modeling (FDM), Selective Laser Sintering (SLS), Stereolithography (SLA), Electron Beam Melting (EBM), 3DP technology, and biological 3D printing. These techniques have garnered significant attention in recent years.

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Printing Biological material using 3D: While the traditional 3D printing methods mentioned earlier excel in precise control over the structure and form of 3D products, they face limitations in integrating scaffold materials with cells, growth factors, and other components due to high temperatures or specific material treatments during the printing process. In recent years, advancements in 3D printing technology have led to increased attention towards bio-3D printing. This approach, based on absorbable materials, cells, and active factors, offers a promising solution. Currently, bio-3D printing encompasses three main methods: inkjet bioprinting, extrusion bioprinting, and laser-assisted bioprinting.

In the realm of bone tissue engineering scaffold materials, among the three fundamental components (seed cells, scaffold materials, and growth factors), scaffold materials hold unquestionably significant importance. They serve as carriers for signalling molecules or target cells while also providing a framework for new bone formation. In the field of bone tissue engineering, the ideal scaffold material is expected to meet the following criteria:

Osteoconductivity: The ability of the material to provide a channel or medium for the growth of new tissue.

Osteoinductive: The material can stimulate the growth of bone tissue.

Good biocompatibility: The material can promote the adhesion, proliferation and differentiation of seed cells.

Good biodegradability.

Sufficient mechanical properties.

Three-dimensional porous structure: can provide space for the growth of seed cells

Simple to process and sterilize [19].

And for the design of scaffolds, the following three aspects should be considered:

It can provide the basis for cell adhesion, differentiation, proliferation and migration. The pore size and structure, porosity, and surface chemistry of scaffolds are influencing factors.

Have suitable mechanical strength.

Conform to the anatomical morphology of the replacement part [20].

Moreover, it is commonly acknowledged that the porosity of 3D bone scaffolds should exceed 40%–60% to facilitate swift cell diffusion, nutrient flow, and cell transfer. Hence, when designing and fabricating scaffolds, careful consideration should be given to the requirements of bone tissue engineering scaffolds, and the most suitable materials should be chosen. Table 3 elucidates the relationships between scaffold properties (porosity, surface area, and elastic modulus) and mechanical and biological factors [21]. Presently, commonly utilized 3D printing materials encompass metal materials, bioceramics, and composite materials comprising multiple substances [22].

Metallic material: Metal materials represent one of the most prevalent choices in 3D printing applications within clinical settings. Among these, titanium alloy stands out as a common selection, owing to its lightweight nature and high durability, making it extensively utilized in treating clinical bone defects. A notable characteristic of medical implant materials is their substantial individual variations in size, shape, intricate structures, and intricate details. Traditional manufacturing methods often struggle to precisely match the unique characteristics of patients with metal scaffolds. However, 3D printing technology, enabled by computer simulations and direct printing based on desired object macro/micro features, offers rapid, efficient, and finely detailed fabrication. Such technology holds immense promise in clinical treatment, given its ability to tailor implants to specific patient needs. Porous bone scaffolds crafted from titanium alloy exhibit excellent biocompatibility and effectively promote osteoblast proliferation and differentiation. Choi et al. utilized CT scans to construct patient-specific head models, devised surgical plans accordingly, and successfully implanted 3D-printed pre-fabricated titanium implants into defective skulls, achieving effective fixation and significantly reducing operation time without postoperative complications such as infection [23]. The patient demonstrated satisfactory postoperative healing. Figure 9 illustrates images of the 3D printed titanium alloy prosthesis both pre- and post-implantation. Despite the widespread use of metal materials, the printing process necessitates

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high temperatures, warranting further research to ensure prolonged cell activity and functionality.

Non-metallic materials:

Bio ceramics: Bioceramic materials, such as tricalcium phosphate, calcium phosphate, and hydroxyapatite, are notable bone repair agents due to their strong osteoconductivity. These materials, whose main components closely resemble the inorganic constituents of human bone, possess excellent degradability and the ability to stimulate new bone formation [24]. Bone scaffolds crafted from biphasic calcium phosphate, a blend of hydroxyapatite and tricalcium phosphate, demonstrate exceptional efficacy in promoting cellular osteogenic differentiation [25]. Wang et al. utilized 3D printing technology to create a hydroxyapatite/chitosan composite porous scaffold, incorporating type I collagen. Animal studies revealed that this scaffold significantly elevated alkaline phosphatase secretion and facilitated osteogenesis.

Polymer materials, categorized into natural and synthetic polymers, constitute another significant category. Natural polymers, derived from living organisms, such as collagen, chitosan, hyaluronic acid, sodium alginate, and fibrin, undergo degradation into carbon dioxide and water by microorganisms. These biomaterials provoke mild inflammatory responses in vivo, boast good biocompatibility, and offer abundant sources and easy accessibility [26].

To fulfil the demands for optimal 3D-printed bone repair materials, composite materials combining various elements like high molecular weight polymers, metals, and bioceramics have emerged as a novel breakthrough. Bone tissue scaffolds comprising high molecular weight polymers and bioceramics are extensively employed in 3D printing for bone repair due to their similarity to the natural bone matrix. Matsuo et al. employed synthetic polymer polylactic acid and hydroxyapatite to fabricate absorbable porous scaffolds for mandibular reconstruction. Comparative analysis revealed that these Polylactic acid/hydroxyapatite scaffolds outperformed traditional titanium alloy scaffolds in terms of repair efficacy [27].

High-fidelity physical organ models serve as crucial aids in both clinical treatment and medical education. Traditional manufacturing methods such as casting or forging often entail time-consuming processes and the expense of preparing costly tooling, overlooking individual patient differences [28]. In contrast, 3D printing offers rapid production of customized medical models at a reduced cost, as it eliminates the need for tooling. These 3D printed organ models primarily facilitate surgical analysis and preoperative training for medical professionals. Customized medical models with intricate shapes, created through 3D printing, serve as effective communication tools between doctors and engineers, aiding in surgical planning and diagnosis. For applications such as medical models and in vitro equipment used for preoperative planning, prosthesis design, and testing standards, there is no requirement for material biocompatibility since the printed parts do not enter the body.

Commonly used permanent medical implants in dentistry and orthopaedics necessitate non-degradable biomaterials and must provide excellent biocompatibility post-surgery. In comparison to conventional machining techniques for implant fabrication, 3D printing enables personalized, real-time manufacturing of intricate implants with precise dimensions and short production cycles. Traditional metallic implants used in bone treatments often lead to stress-shielding phenomena due to their higher stiffness compared to bone, which can eventually compromise bone integrity. The integration of topology-optimization designs with 3D printing represents a novel and efficient approach to crafting lightweight custom implants with tailored stiffness [29]. This technology seamlessly aligns with the widespread use of digital measuring devices, facilitating data conversion and spatial compatibility.

Creating localized bioactive and biodegradable scaffolds involves two potential methods for manufacturing tissues and organs, depending on whether cells are directly manipulated during the formation process. The first method, known as tissue engineering or indirect cell assembly, begins with the creation of a 3D scaffold, followed by the seeding of cells. Biocompatible materials, growth factors, and physical factors can be employed alone or in combination with living cells to produce a biomimetic tissue-like microarchitecture scaffold [30]. The second method, termed direct cell assembly, entails integrating both cells and materials into a composite structure [31].

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This approach involves encapsulating a mixture of cells and gel into 3D scaffolds made of another type of gel with robust mechanical strength or directly printing them to control the spatial distribution of cells and potentially achieve in situ repair.

Printing tissues and organs directly involves encapsulating cells into biodegradable scaffolds through traditional tissue engineering methods, but this approach may not ensure precise implantation of cells into inner scaffolds. Additionally, growth factors typically only affect the growth and differentiation of surface cells. Consequently, researchers have explored cell and growth factor direct-printing technology with the ultimate aim of generating tissues and organs. In 2000, Professor Thomas Boland of Clemson University in the USA introduced a novel concept known as "cell and organ printing," which marks the inception of modern 3D bioprinting technology. This approach involves layer-by-layer printing of various materials and "biological ink" containing seed cells, growth factors, and nutritional components to create tissue structures with physiological functions. Subsequently, the printed tissue or organ is cultured to promote maturation [32].

Bioprinting: Bioprinting, a method within biofabrication, employs a noncontact technique to create 3D printed constructs layer by layer by depositing ink drops onto successive layers. Inkjet printing enables the precise deposition of very small droplets containing multiple cells or proteins onto specific spatial positions, facilitating the production of well-structured 3D printed constructs. The initial inkjet printers were adaptations of commercially available 2D ink-based printers, wherein the ink cartridges were substituted with biological materials, and the paper was replaced with an electronically controlled elevator stage to enable control over the z-axis [33].

Microneedles: These are miniature needle devices designed for minimal invasiveness, fabricated from a range of materials such as biomaterials, metals, polymers, ceramics, and composites [34]. They are specifically engineered to penetrate the skin's stratum corneum layer for various applications. The primary purpose of microneedles is the delivery of bioactive materials, vaccines, and pharmaceutical agents, as well as the collection of bio-signals and substances from the body with minimal invasiveness.

Conventional drug administration via the gastrointestinal tract has proven inefficient due to poor drug absorption and pharmacokinetic activities, often resulting in only a fraction of the drug achieving therapeutic effects. An alternative approach involves creating micron-scale pathways through the skin's outermost layer, the stratum corneum, using microneedles made from materials like silicon, metal, or polymers. Microneedle arrays hold promise for transdermal drug delivery applications, offering a pain-free route to the rich blood supply in the lower dermal layers, enabling easy and efficient delivery of various medications [35].

Key advantages of microneedles include painless administration, faster healing, ease of use, and precise control over drug delivery rates. Microneedle patches are classified into five types: solid microneedles, coated microneedles, dissolvable microneedles, hollow microneedles, and hydrogel-based microneedles, each with specific fabrication processes and application areas. The term "microneedle" was first documented in 1921 by Chambers as a means of micro-dissecting echinoderm eggs [36].

Implants: Additive manufacturing enables the production of custom-printed implants tailored to each patient's unique needs. Dinesh et al. utilized 3D printing technology to create a more cost-effective alternative to pre-formed, personalized implants and a more precise option compared to bone cement. After performing hemicraniectomy or skull resection, the team obtained a high-resolution CT scan of the patient's brain, from which they generated a model of the skull and a corresponding mould using computer software. Both the model and mould were then fabricated using a fused deposition method of additive manufacturing. The resulting pattern was utilized to shape an acrylic implant, which was seamlessly fitted to the skull model without requiring additional adjustments, showcasing its accuracy.

The symmetry of the model skull post-implant fitting was assessed by overlaying one half of the skull with a mirror image of the other half and calculating the percentage of overlapping area, yielding a symmetry result of 96.2%. This further underscores the precision

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of the moulded implant. This approach combines the advantages of using bone cement and patient-specific implants to achieve an outcome that is both accurate and cost-effective [37]. Figure 1 indicates various medical applications of 3D printing.

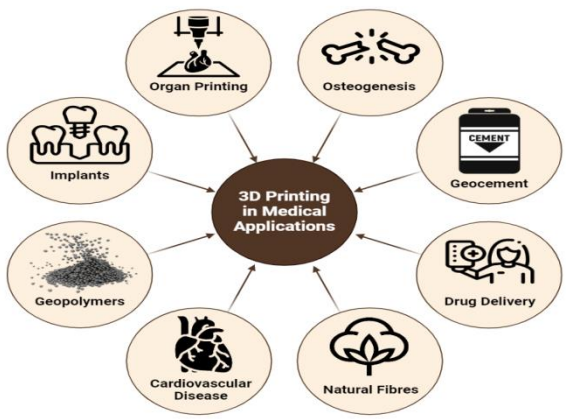

Figure 1: Application of 3D Printing in Medical and Healthcare system

Cardiovascular medicine: Additive manufacturing serves as a valuable asset in cardiology as well. Utilizing this technology, 3D models of a patient's heart can be generated, facilitating effective communication between doctors and patients regarding their individual medical conditions. Moreover, these models aid doctors in better preparing for medical procedures by providing a comprehensive understanding of a patient's unique anatomy. Likewise, such models are beneficial in medical training programs for surgeons. Additive manufacturing offers a relatively rapid and cost-effective approach to producing 3D anatomical heart models, thereby enhancing surgical planning and treatment outcomes [38].

Orthopaedics: Similar to its applications in other medical fields, additive manufacturing is revolutionizing the production of orthopaedic aids, making them more precise, automated, and cost-effective. Molnár and Morovi detail the utilization of 3D modelling and additive manufacturing techniques to fabricate custom-fit orthopaedic corsets for lower back support. Initially, the patient underwent scanning, and a digital model was generated using an active triangulation method, which produces a series of points representing a surface. The data obtained from the scan was then utilized to design a personalized orthopaedic corset using CAD software. The corset was subsequently printed employing a fused deposition modelling approach. In selecting the material for the corset, considerations for biocompatibility and printability were paramount, leading to the choice of polyethylene terephthalate glycol and polylactic acid [39].

Analyte Deposition and Calibration Purposes: Considering the unique capabilities of inkjet printing technology, one particularly advantageous feature is its ability to precisely dispense tiny amounts of materials onto predefined areas of a substrate. Conventional nozzle-based systems can accurately dispense volumes as small as 20pL or even less, with high reproducibility. This characteristic renders inkjet printing a suitable tool for reliably calibrating analytical instruments and validating the quantitative detection capabilities of devices. For instance, Browne et al. employed inkjet printing to deposit precise amounts of artificial sweeteners, facilitating the calibration of an ion mobility spectrometer for quick and efficient quantification of sweetener content in food [40]. Numerous other examples in the literature demonstrate the use of inkjet printing to generate calibration curves for various analytes and applications, including mass spectrometry (MS).In addition to its straightforward application for dispensing minute and accurate amounts of substances, inkjet printing can address more complex issues by integrating it into sample preparation processes, devices, or analytical instruments [41].

3D printing of geopolymers: At the micro scale, the synthesis of geopolymer involves two primary stages that occur simultaneously: dissolution and polycondensation [42]. Upon contact with the aluminosilicate binder, the alkaline activator initiates the dissolution stage by breaking the surface bonds of the binder (such as Si-O-Si and Al-O-Al bonds in fly ash (FA)), resulting in the dissolution of aluminate and silicate components and the formation of reactive ionic species [43]. The concentration of the alkaline activator significantly influences the degree of dissolution [44]. The ionic species generated during the dissolution stage contain various Si-OH and Al-OH groups, which subsequently undergo condensation during the polycondensation stage to form the 3D aluminosilicate gel. It should be noted that the aforementioned reactions

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are greatly affected by the properties of the binders [45].

The literature reviewed in this paper, highlights the raw materials, curing conditions, and measured properties relevant to the synthesis of geopolymer. The most commonly used binder type in 3D printed geopolymer (3DPG) is typically a blend of low calcium FA, ground granulated blast-furnace slag (GGBS), and silica fume (SF) [46]. Other binder types, such as limestone (LS) [47], metakaolin (MK) [48], steel slag (SS) [49], and calcium carbonate (CC) [50], are also utilized in combination with FA or GGBS. Typically, the content of FA, GGBS, and SF falls within the ranges of 60–96.7%, 1.67–30%, and 1.67–30% (by mass of the total binder), respectively. The alkaline activator may be employed in either liquid or solid form, with the commonly used type being a combination of NaOH and Na2SiO3. The activator modulus (SiO2/Na2O or K2O) varies across different studies, ranging from 0.5 to 2.0 [51].

Similar to the production of 3D printed cementitious materials, fine aggregates with relatively small sizes (less than 2 mm) are typically used in the development of 3DPG, while coarse aggregates are often avoided due to difficulties in passing through existing hoses and nozzles in 3D printing systems [52].

3D printing of tissue engineering scaffolds: The process of 3D printing tissue engineering scaffolds typically follows a layered approach using various solid freeform fabrication (SFF) methods. This method generally involves several steps:

a. Creating a 3D computer model, this can be generated from medical imaging data like CT scans or X-rays.

b. Slicing the 3D computer model into a build file consists of 2D images, by using software.

c. Fabricating the build through, this is a computer-controlled layer-by-layer process.

d. Concluding with any necessary post-processing, such as surface modification for nano-architecture.

Complex three-dimensional features such as internal voids, cantilevers, undercuts, and narrow tortuous paths are simplified into a series of common two-dimensional features like circles, lines, and points, without being constrained by tooling path restrictions. While initially developed for industrial applications, these additive technologies are increasingly attractive for biomedical engineering due to their ability to create complex three-dimensional shapes [53, 54].

Various SFF techniques have been introduced to produce objects with controlled macroarchitecture and microstructures, catering to biomedical and tissue engineering needs. The flexibility in shape, coupled with suitable material deposition technology, allows for precise control over the tissue engineering triad, directing the spatial distribution of cells, signals, and scaffolding substrates during fabrication. Moreover, these technologies facilitate integration between digitized medical imaging data and computer-aided design models, enabling the aseptic manufacturing of tissue engineering grafts precisely matching a patient’s contours. Ultimately, these advancements enable the fabrication of multifunctional scaffolds meeting structural, mechanical, and nutritional requirements based on optimized models [55].

Electrochemical Sensors, Ready-to-use sensing elements- For the purpose of this review, "ready-to-use" sensing elements, such as electrodes and membranes, are defined as those that remain untreated or unmodified (e.g., not activated, complex, coated, etc.) prior to utilization [56,57]. The integration or inclusion of these "as-printed" sensing elements into a device or sensor housing does not negate their classification as "ready-to-use." As previously noted, the advent of 3D printing has revolutionized various fields by enabling the rapid incorporation and printing of inexpensive materials to produce customizable structures and devices [58, 59, 60].

In the domain of analytical electrochemistry, 3D printing initially found application in creating electrode housings, scaffolds, and structures, primarily due to the simplicity with which rigid and nonconductive materials could be printed [61,62]. However, over the past approximately five years, 3D printing has made significant strides in the field of electro analysis, facilitated by advancements in the printability of conductive polymers and plastics [63]. This technology has streamlined the fabrication of conductive electrodes and, more recently, ion-selective membranes (ISMs).

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Among 3D printing techniques, FDM (Fused Deposition Modelling) has emerged as a frontrunner in fabricating electrochemical sensing elements, owing to its capacity to introduce conductive materials (such as carbon fibre, metallic nanoparticles, etc.) into extrudable plastics with ease. Particularly noteworthy is the work of the Kokkinos group, which showcased this capability through a dual extrusion process [64]. Their study involved the fabrication of a fully 3D printed sensor, utilizing a nonconductive PLA filament for the holding platform and a carbon-based PLA filament for the working, counter, and reference electrodes.

Upon fabrication, the device was employed for detecting caffeine and paracetamol in pharmaceutical tablets and urine samples. Utilizing the electrochemical technique of differential pulse voltammetry (DPV), the Kokkinos group achieved detection limits of 2.01 μM for caffeine and 2.84 μM for paracetamol, respectively. The robustness of this device was demonstrated by simultaneously measuring both compounds in pharmaceutical formulations (with recoveries of 96% for caffeine and 101% for paracetamol) and urine samples (with recoveries of 97% for caffeine and 103% for paracetamol).

Post-modified sensors— The utilization of conductive polymers, nanomaterials, and biological recognition elements (such as enzymes, antibodies, aptamers, etc.) to modify electrode surfaces has proven highly beneficial in developing electrochemical sensors that exhibit both sensitivity and selectivity toward specific target analytes [65]. Consequently, electrochemical sensors have found application in detecting a wide range of analytes in diverse matrices, including biological fluids (such as blood, urine, saliva, sweat, and tears) and environmental samples.

The versatility and rapid prototyping capabilities offered by 3D printing enable researchers to efficiently address significant societal concerns. One noteworthy example is the profound impact of the COVID-19 pandemic on global society. The urgent need for rapid and accurate diagnosis of COVID-19 prompted many researchers in the field of analytical chemistry to innovate in this area. Leveraging their expertise in 3D printing and immunosensing, Munoz and Pumera developed a 3D printed immunosensor tailored for the detection of COVID-19 [66].

Automotive: Original equipment manufacturers (OEMs) in the automotive sector have traditionally utilized additive manufacturing (AM) primarily for rapid prototyping purposes. However, advancements in AM technology have gradually transformed the way end-use parts are conceived, manufactured, and distributed in recent times. Deloitte's study on the potential of 3D printing in the automotive industry indicates that companies prefer evolutionary rather than revolutionary changes in their supply chains and product offerings when adopting AM. The primary utilization of AM lies in facilitating design iterations, enhancing quality through cost-effective prototyping, and crafting customized tooling components. Nonetheless, alternative AM methodologies within the automotive sector exist, which bring about more profound alterations to goods and supply chains.

The forthcoming discussion will delve into the additive manufacturing's influence on the automotive sector, exploring its diverse impacts. As per projections from SmarTech Analysis, the revenue generated solely from the production of end-use parts through automobile 3D printing is anticipated to reach $9 billion by 2029, a significant increase from $1.39 billion recorded in 2019 [67]. This prompts the question: what is the current standing of AM in the automotive industry?

In any industry, expediting the product design phase during new product development holds paramount importance. In this regard, 3D printing offers a viable alternative to the expensive and time-consuming CNC production method. Specifically, it enables designers to iterate through multiple design variations at a minimal cost before finalizing the production of the end product, a process commonly referred to as rapid prototyping.

Bio-filaments: Bio-filaments crafted from polymers have garnered considerable attention due to environmental concerns, leading to a focus on producing and utilizing biodegradable or bio-derived polymers. While biodegradable polymers possess several desirable traits, such as environmental friendliness, they often fall short in comparison to traditional polymers regarding mechanical and thermal properties required for 3D printing [68]. For instance, although PLA is recognized for its biodegradability, it degrades relatively slowly under typical conditions, lasting several years in a standard environment without

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significant degradation induced by sunlight or ultraviolet light. Consequently, PLA and other biodegradable polymers like PHA, HPMC, PBSA, and PBS are being explored for 3D printing applications [69]. Researchers have experimented with various biodegradable polymers to create biofilaments, focusing on understanding their rheological and thermal characteristics, particularly in the context of filament fabrication via the FFF method [70]. Optimal filament quality has been achieved for PBS and PBSA, aligning with their rheological properties. Studies have delved into the impact of layering on thermal, molecular weight, and mechanical properties, with PLA and its variants like impact PLA Grey and HD PLA Green undergoing examination for tensile strength [71]. While PLA exhibited consistent tensile strength, its variants showed lower values. Additionally, researchers have investigated the manufacture of semisolid theophylline tablets using HPMC hydrogels through extrusion-based semisolid 3D printing, noting variations in yield stress, hardness, and storage modulus based on hydrogel composition [72]. The tensile properties of PLA have been analyzed under slow strain rates, revealing improved tensile strength and elongation properties [73]. However, the incorporation of PHA into PLA led to significant reductions in elongation at break, indicating embrittlement [74]. Furthermore, the surface of printed PLA samples remained un-degraded under simulated marine conditions.

Bio-filaments using composites- Similar to the attention given to biodegradable polymers, significant research efforts are directed towards developing biofilaments with polymer composites. Researchers are exploring various polymer composites to meet the biodegradability requirements of 3D printing filaments. Different raw materials, such as soy protein and cocoa shell waste, are being combined with various polymers and plasticizers to assess their potential as biofilaments for 3D printing. Incorporating these bio fillers into polymers not only enhances the significance of bio fillers but also reduces the reliance on petroleum-based polymers. Biocomposite filaments for FDM 3D printing are developed by combining CNF with PLA, showing improved thermal stability and offering new potential for CNF utilization in high-value consumer product applications [75]. Various physical strengthening methods are being investigated to enhance the mechanical properties of soy protein-based bioplastics without compromising their functionality [76]. Moreover, PLA/316L composite scaffolds with varying stainless steel particle contents (ranging from 5vol% to 15vol%) are manufactured using the FFF process [77]. The results indicate enhanced dimensional accuracy and reduced coefficient of thermal expansion compared to pure PLA scaffolds [78].

Conductive nanomaterials: The properties of conductive nanomaterials play a crucial role in regulating the electrical conductivity and other characteristics of polymeric composites in which they are integrated. Achieving uniform distribution of nanomaterials within the flexible matrix is essential for forming multiple electrically conductive networks. This arrangement facilitates the smooth transport of electrons along the established pathways. The morphology, initial electrical conductivity, and dispersal of nanomaterials significantly impact the minimum loading required to establish percolated networks within the polymer matrix. A lower percolation threshold is preferred as it allows for minimal filler concentration, thereby preserving the intrinsic physical and chemical properties of the host polymer and ensuring cost-effectiveness of the final products. Moreover, intrinsically conducting polymers, characterized by their unique structures, can also be utilized to transmit electrical currents effectively.

Carbon nanomaterials: Carbon serves as the foundational component for numerous materials, as its atoms can arrange themselves in diverse configurations, giving rise to various carbon allotropes with distinct morphologies and properties [79]. These allotropes encompass a broad spectrum of material characteristics, including thermal conductivity, electrical conductivity, mechanical strength, and optical properties, ranging from conductive to insulated, hard to soft, and opaque to transparent [80]. Consequently, these carbon allotropes have garnered significant attention from both academic and industrial sectors in recent years [81].

Regarding electrically conductive allotropes, carbon nanomaterials can be classified based on their dimensionality into 0D carbon black (CB), 1D carbon nanotubes (CNT) and carbon nanofibres (CNF), and 2D graphene and its derivatives. CB consists of aggregates of spherical carbon particles, typically 10–100 nm in

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diameter, produced through the thermal decomposition of hydrocarbons. Its structure comprises an amorphous core surrounded by a shell of 2D stacked graphitic layers [82]. CB, known for its abundance, low cost, reasonable electrical conductivity, and excellent stability, serves as filler widely employed to enhance the electrical conductivity of elastomeric composites [83]. However, achieving satisfactory electrical conductivity often requires high fractions of CB. Nonetheless, resulting composites find applications in various fields, including supercapacitors, batteries, and wearable devices [84].

Metallic nanomaterials: While carbon nanomaterials offer chemical and thermal stability, their inherent electrical conductivity is contingent upon factors like size, quality, and morphology. In contrast, metallic nanomaterials such as silver (Ag), copper (Cu), and gold (Au) present themselves as superior options for creating conductive polymer composites due to their unique electrical conductivity properties. By adjusting the concentrations of metallic nanomaterials within the host matrix, these composites can be tailored to produce a wide array of devices, ranging from highly sensitive sensors to stretchable conductors capable of maintaining stable electrical conductance even under significant deformations [85, 86]. Various wet chemical methods have been documented for fabricating metallic nanostructures in particle, wire, sheet, and rod forms [87,88]. Among these, metallic nanowires stand out for their high aspect ratios, flexibility, and conductivity compared to nanoparticles and nanosheets [89]. Consequently, they can effectively establish robust conductive pathways within polymers while minimizing filler-to-filler contact resistance [90].

Methods:

Material Extrusion (ME) via Polymer Filaments: Material extrusion operates by depositing flexible drug formulations through one or multiple nozzles/openings onto a platform in a step-by-step manner, resulting in a three-dimensional structure [91]. This process encompasses various subtypes including Fused Deposition Modelling (FDM), Semisolid Extrusion (SSE), Direct FDM, and Embedded 3D Printing (e-3DP) [92].

FDM-Fused Deposition Modelling: Essentially, FDM stands for Fused Deposition Modelling, a technique employing a thermoplastic filament coil as its primary material input, commonly ABS (Acrylonitrile Butadiene Styrene). In this method, the thermoplastic filament is heated within an extruder until it reaches its melting point, then extruded layer by layer to construct a 3D solid object. Scott Crump introduced FDM technology in the early 1990s through Stratasys INC, USA. FDM printers feature a movable support base for vertical movement, alongside an extruder responsible for heating and extruding the filament through a nozzle to create the desired object. The extruder operates in all three directions (x, y, and z). The term "fused deposition modelling" refers to the fusion of adjacent layers as the extruder deposits material, with the 3D printer modelling the object accordingly [93].

Powder bed fusion (PBF): A PBF (Powder Bed Fusion) technique utilizes a fine layer of powder to form a base, and an energy source, such as a laser or an electron beam, is employed to fuse the powder according to the shape of the component being produced [94]. This method enables the laser to selectively melt powders layer by layer, resulting in three-dimensional structures. PBF processes distribute powdered material over the previously fused layer, preparing it for the next layer's treatment, resulting in a discrete rather than continuous output (though each layer is bonded to adjacent layers). A container delivers the powdered material, which is then evenly spread across the powder bed to establish a platform surface using a roller or brush. The optimal thickness of each layer of distributed powder is determined by process conditions and the type of material being used [95].

SLS- Selective Laser Sintering: Essentially, Sintering involves using a laser beam to melt and solidify a photopolymerizable polymer mixture containing therapeutic drugs, heated just below its melting point, to fuse the powder together and create a solid object. Selective Laser Sintering (SLS) is an additive manufacturing technology pioneered by Dr. Carl Deckard and Dr. Joe Beaman of the University of Texas at Austin in the mid-1980s. This method utilizes polymeric powder to fabricate 3D objects, with various materials such as thermoplastics, ceramics, glass, and metals being used, though plastics, particularly Nylon 11 and Nylon 12, are predominantly employed. In SLS, a CO2 laser, connected to a computer, precisely traces the desired geometries, heating the powder just below

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its melting point within chambers, where it then fuses together to form a solid object [96].

SL- Stereo-lithography: The era of 3D printing emerged in the late 20th century, with Stereolithography (SL) being the earliest 3D printing process introduced to the market. The initial 3D printers put into operation were stereolithographic (SL) machines used for manufacturing 3D models, prototypes, parts, and patterns. Although research in 3D printing was conducted in the 1970s, this specific process was patented by Charles Hull in 1984. It enables the production of 3D printed parts from liquid resin polymer, transforming them into solid objects. This method utilizes a specialized polymer called photopolymer, which undergoes a chemical reaction altering its physicochemical properties upon exposure to UV/IR light. Despite offering potential advantages such as excellent surface texture and high-resolution printing, SL technologies have notable drawbacks including brittleness, low impact strength, and limited longevity due to degradation of physical properties over time.

To understand Stereolithography (SLA), it's essential to grasp its operational principles. The process involves four key components: UV Curable Photopolymer Liquid contained in a tank, a perforated table, a laser source, and a computer controlling the movement of the laser source and perforated table. Once a CAD file is prepared, it is converted into an STL file, which serves as the input for the 3D printer. The SLA process employs a laser to heat the upper surface of the photopolymer liquid, causing it to harden instantly. This laser can move in various shapes to create the desired design of the object being printed [97].

Selective Laser Melting (SLM): Selective laser melting (SLM) belongs to the subset of powder bed fusion technology, sharing this category with SLS. This method involves employing a bed of powdered granules with specified density. Thermal sources are utilized both to fuse the particles and to control the fusion process. Laser light is directed onto the powder bed, generating heat energy that melts the construction material. As the temperature decreases, the molten material solidifies, shaping the desired object. A portion of the powder bed remains un-melted, providing support for the object being produced. Once the fabrication of the object is complete, the unused powder bed is removed [98].

Inkjet 3D Printing: Inkjet printing involves depositing a specific quantity of material, often referred to as ink (polymer), onto a substrate to form a layer. The printing process is initiated by commands from computer software, prompting ink to be ejected from the printer's reservoir. Inkjet printers are classified based on their ink ejection modes, which can be continuous or drop-on-demand (DOD). In continuous ejection systems, pressure is used to initiate jet formation, exerted on ink flowing continuously from the printer. Pressurized jets are then used to break the stream into precise droplets. DOD printers are further divided into piezoelectric and thermal printers, depending on the actuator mechanism. In this setup, an actuator generates pulses that lead to the ejection of a single droplet with a predetermined volume of ink [99].

Bioprinting: As the term suggests, bioinks play a central role in this manufacturing process. The primary application area for this technique lies within tissue engineering and organ generation, with a particular emphasis on addressing fractures and defects in bone tissue. Bioink technology shows significant promise in various aspects such as implanting metal prostheses, bone grafting, promoting biomineralization, and inducing osteogenesis. The main focus of this method is to reduce costs, waste, and production time compared to synthetic methods. Bioink technology can be categorized into extrusion or laser-based methods, with the former utilizing mechanical or pneumatic sources to deposit layers, while the latter involves laser sources for thermal stimulation [100,101].

Binder Jetting: Binder jetting is a 3D printing technique that utilizes a binding liquid agent to selectively deposit onto powder particles, fusing them together. This process is commonly used for rapid prototyping. In binder jetting technology, a chemical binder is jetted onto the spread powder to create each layer. This method offers advantages such as speed, cost-effectiveness, and simplicity, making it suitable for printing large-sized products [102].

This printer operates by directing liquid binding agents through a nozzle, which sprays droplets onto a thin layer of powdered drug formulation on a build plate [103]. Subsequently, an additional layer of powder is

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lowered from a reservoir and rolled onto the ongoing drug product(s). This process of binding and layering is repeated until all necessary layers are bound together according to the specifications of the 3D model. Binder Jetting technology has demonstrated its capability to manufacture both immediate and extended-release dosage forms, including drug capsules with multiple compartments to separate active drug components [104]. Notably, Binder Jetting has already produced an FDA-approved medication, Spritam. However, significant challenges exist with Binder Jetting 3D printers, including their size, cost, limited availability, and apparent suitability primarily for large-scale manufacturing. Additionally, the resulting drug product must undergo curing to strengthen its form before being separated from the unbound powder [105].

Material Extrusion (ME) without Polymer Filaments: Material extrusion can be accomplished without the use of filaments through methods like direct powder extrusion printing or single-process 3D printing [106]. In this technique, powder or pellets are loaded into a chamber or syringe of the printer, and then the drug formulation materials are melted or heated steadily in the chamber or nozzle until they reach a printable semisolid ink state [107]. The ink is selectively deposited onto packaging or previous layers with the help of a screw, ram, or plunger within the chamber [108]. This printing process resembles FDM but doesn't require filaments. Challenges with direct powder extrusion include: (i) the need for a heated chamber to contain the ink formulation directly, necessitating cleaning and reuse of the chamber for each formulation or batch, (ii) inability to print with semisolids or liquids; the printer can only handle pellets and powders melted into semisolid form during printing, (iii) akin to FDM, this technique generally doesn't yield dosage forms with immediate release characteristics, necessitating channels in the dosage form design to facilitate faster drug release [109].

Material Extrusion (ME) without Application of Heat: Material extrusion without the use of heat is achievable through semisolid extrusion, also known as 3D micro-extrusion, Pressure-assisted micro-syringe extrusion, Extrusion-based Bioprinting [110], and the Melting Solidification Printing Process (MESO-PP). In this process, a syringe, cartridge, or chamber is filled with a paste, gel, or solid substance that melts at low temperatures (around -49°C) to serve as the drug formulation ink. Pressure, either with or without heat, is then applied to extrude this ink onto a build plate, which may or may not be heated, and onto previous layers to construct a 3D formulation.

Non-heated extrusion 3D printers are versatile and can handle a wide range of semisolid materials as ink. Some models even offer the option of using disposable syringes to deposit the drug formulation, minimizing contact between the drug ink and the printer to address sterility concerns for the printed product. However, a significant challenge with non-heated extrusion is that the printed product often requires an extended period to dry before it can be handled directly to prevent damage. Strategies to address this issue include printing directly into commercially available capsules [111], printing onto packaging to allow indirect handling during drying, and adjusting drying times between printed layers to reduce overall drying time [112].

Semisolid ink formulations can undergo changes in temperature and viscosity during printing, affecting ink flow characteristics and reducing consistency and repeatability with each layer over time. Thus, maintaining a consistent temperature, such as through a heated jacket or other temperature control methods surrounding the syringe or cartridge body, may be necessary to address this issue [113].

Embedded 3D Printing (e-3DP): Embedded 3D Printing (e-3DP) represents a fusion of FDM and semisolid extrusion printing technologies, offering the convenience of swallowing extended-release formulations and the flexibility to customize flavouring or appearance without affecting drug release characteristics. In this method, a paste or gel drug formulation is extruded into the centre of an edible liquid gelatine- or jelly-based matrix, which solidifies upon cooling. The resulting gelatine- or jelly-coated dosage forms created by embedded 3D printing are easier for elderly and paediatric patients to swallow. Importantly, these dosage forms do not necessitate modifying the formulation of the external matrix for each drug-containing core. The design of appearance and flavour is independent of the drug-containing core design, allowing for more creative exterior forms without compromising medication behaviour. Additionally, this dosage form facilitates the separation

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of multiple drugs within the same dosage form while keeping them contained [114]. Figure 2 indicates Techniques and Quality Assessment of 3D Printing.

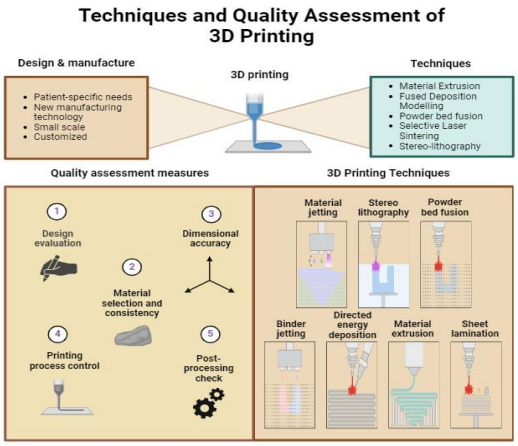

Figure 2: Techniques and Quality Assessment of 3D Printing

Challenges of 3D printing technology:

Despite advancements in computerized processes like 3D printing, variations can arise in printed objects originating from the same 3D computer-aided design (CAD) model due to factors such as the age or quality of ink materials, adjustments in slicer program-based printer settings, alterations to the stage level or angle, and wear and tear of components. This underscores the necessity for efficient analytical tools capable of quickly assessing whether the intended medication was successfully printed, including aspects like uniformity, release profile, and concentration of each drug [115]. Some propose leveraging Artificial Intelligence or predictive models for this purpose, while others advocate for employing portable Near-Infrared Spectrometers with calibration models generated through partial least squares (PLS) regression to verify multiple drug dosages within polypills [116].

The optimal 3D printer chosen for implementation in a pharmacy environment should possess user-friendly features, require minimal setup and training, streamline the compounding process compared to traditional methods, effectively utilize approved pharmaceutical ingredients, and have the capability to produce a wide range of medications relevant to the pharmacy's needs. While certain printers may approach achieving most of these objectives, others may excel in addressing specific ideal qualities either presently or with further advancements [117].

Contamination is a significant concern in the 3D printing of edible products, including drugs. It is imperative that all 3D drug printers are designed for easy cleaning, particularly in areas where they come into contact with edible printed products and their ingredients. Reusing drug formulation materials from one printing task to the next can introduce additional contamination risks, as these materials may have been exposed to previously used drug formulation ink or processing conditions. Printer parts themselves can also pose a contamination risk; for instance, FDM printers often come with brass nozzles containing lead as a default standard, necessitating an upgrade to stainless steel nozzles for medical applications to mitigate this risk [118].

Many of the polymers typically utilized in traditional pharmaceutical compounding exhibit poor printing performance, leading to the utilization of non-pharmaceutical grade polymers in numerous studies involving thermoplastic polymer-based printers like FDM. Alterations to formulations are frequently required when printing different drugs, which can consequently yield varying release characteristics. To enable a diverse array of medications to be produced by each 3D printer while minimizing the required pharmaceutical ingredients and accurately predicting drug release with modified excipients, optimized formulas are essential. Artificial Intelligence can play a pivotal role in forecasting the effects of excipient modifications on the release pattern of the final product [119].

It is imperative to identify the training needs of pharmacists and technicians who will utilize 3D printers or provide guidance to patients regarding medications created by 3D printers to ensure compliance with USP 795 standards. Those adept at drafting are typically individuals skilled in 3D Computer Aided Design, particularly in building and printing models, with some acquiring specialized knowledge in biomedical applications. Becoming proficient in drafting for manufacturing industries usually entails up to two years of training, although certain 3D modelling software can be intuitive for those lacking formal training. The

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American Design Drafting Association (ADDA) offers a general certification for professional drafters to demonstrate proficiency in 3D modelling standards, along with certifications in various drafting specialties. Collaborating with pharmacy leaders, the ADDA could potentially introduce pharmacy drafting as a specialized certification, thereby establishing standardized practices for 3D modelling and printing medications in pharmacy environments [120].

When selecting a 3D printer for producing medications, it's crucial to factor in the printer's quality, particularly in relation to the size and concentration of the desired drug products. Various printer models come with different tolerance ranges, affecting the precision of the printed drug items. For instance, a printer may have a tolerance of +/-0.1 mm, meaning the dimensions of the drug product can deviate by up to 0.1 mm shorter or longer than specified by the 3D model. Typically, printers with smaller tolerance ranges tend to be more expensive [121].

The utilization of multiple materials in additive manufacturing (MMAM) does not guarantee that the benefits of each material can always be effectively harnessed for desired applications. In certain instances, researchers have leveraged the drawbacks of combining different materials, such as inadequate bonding between bi-materials and the presence of residual stress at interfaces. The control of the additive manufacturing process poses challenges due to limitations in the mixing and wetting behaviours of diverse materials, as well as variations in their properties like thermal conductivities, expansions, and melting points122. Discrepancies in coefficients, whether materials are similar or dissimilar, as seen in bi-material systems such as metals–plastics or metals–ceramics, can lead to significant mismatches, resulting in defects like cracks, pores, and residual stresses that impact component integrity, dimensional stability, crack resistance, and mechanical properties in real-world applications. Hence, future research should prioritize material selection, design, and manufacturing aspects of MMAM parts, particularly focusing on understanding and mitigating residual and surface stresses generated during the additive manufacturing of metallic parts. This involves comprehending the composition and optimal distribution of suitable materials, reaction kinetics mechanisms, bonding behaviour, residual stress management, and cracking mechanisms, which are crucial for the effective design of MMAM components [123].

Conclusion From this review a wide utilization of 3D printing is distinctly evident. Apart from the conventional uses, novel applications of this technology have brought recent attention of the researchers. The use of sustainable resources makes it economic and ecologically sound. Even though 3D technology is blessed with supremacy, many more lacunae still prevails in current scenario. Hence an in-depth learning in order to make the technology nonpareil by overcoming the challenges has become requisite. Updating depth information on applications of 3D printing with researched data will serve as a very good platform for industries to set up futuristic facilities for manufacturing.

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