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Applications of 3D printing technology and limitations-An update

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Abstract

3D printing, also called Additive Manufacturing (AM), has the potential to be a technological revolution in the manufacturing industry. 3D printing technology is divided into different types, Stereolithography (SLA), digital light processing (DLP), and fused deposition modeling (FDM). Polymers are the materials that are frequently utilized in 3D printing due to their versatility, affordability, and ease of use. The materials used in 3D printing technology include thermoplastics, metals, ceramics, and composites. Bioinks are materials used in 3D bioprinting to create tissues and organs. They act as a support system for living cells during 3D printing. 3D printing has revolutionized various industries by enabling the production of complex. designs and shapes. Some of the examples of application of 3D printing technology are healthcare, building construction, fabric fashion designing, aerospace, auto- industries, agriculture, food, and plant science. The cost and speed of 3D printing technology remain significant challenges. While the average cost of 3D printers has decreased in recent years, the cost of materials and maintenance remains high. However, while 3D printing technology has advanced significantly in recent years, there are still many challenges that need further development rather than investigation.

Keywords: Additive Manufacturing (AM); Agriculture and Food Industries; Bioprinting; Organ and Tissue Printing; Polymer; 3D Printing; Stereolithography (SLA)

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1. Introduction

3D printing technology provides the advantages of customization, prototyping, various fabrication techniques, and complex geometries at a low cost in a short timeframe [1, 2]. Recently, the potential of new materials in 3D printing has led to an exponential increase in the technology's applications [1-26]. Additive manufacturing technology has come a long way since its inception when Chuck Hull, co-founder of 3D Systems, developed the first 3D printer in 1983[1-15]. 3D printing has revolutionized various industries by enabling the production of complex. designs and shapes [1-26]. According to Iftekar et al., (2023) [2], apart from medicine, three-dimensional printing has a wide variety of applications in almost every sector [1-26]. This versatile technology can be used to produce goods from fashion items, food items, toys to complex parts for aircraft and even entire rocket bodies and engines [2]. In addition to its various applications, 3D printing has revolutionized various fields of medicine, including orthopedics, surgery, and even human organs [1-50]. It has enabled the production of precise surgical guides, patient-specific implants, prosthetics that can be tailor-made to fit the individual's unique anatomy, three-dimensional tissues, and even entire functional organs and organisms [1-26]. Technology has shown great potential in addressing the growing need for organ transplantation, as it allows for the creation of customized, patient-specific replacement organs [1-26]. However, despite these advancements, the technology still faces significant challenges, including high costs, low printing speeds, limited part sizes, and strength. Furthermore, the use of 3D printing technology has considerably reduced the need for worldwide transportation, saving both energy and time [1-26]. According to Iftekar et al., (2023) [2], additive manufacturing is expected to continue advancing and improving, but it will take some time to overcome the challenges, particularly those related to the cost and speed of 3D printing. As technology becomes more efficient, faster, and cost-effective, it will become more accessible to a wider range of users worldwide [1-26]. Additionally, the industry will focus on sustainability, developing eco-friendly materials, and adopting circular economy models [1-26]. Iftekar et al., (2023) [2] are of the opinion that the future of additive manufacturing looks promising, and it will be fascinating to witness the emergence of innovations and applications in the years to come [1-27].

2. 3D Printing: Types

3D printing technology is divided into different types [1-27]. These types of 3D printing technologies offer unique capabilities that serve a wide range of businesses and applications. Following are the few unique types of 3D printing [1-27].

1) Stereolithography (SLA): In the field of 3D printing, stereolithography (SLA) uses a UV laser to solidify liquid photopolymer resin layer by layer, producing solid objects with excellent surface polish and high resolution [1-27]. According to Iftekar et al., (2023) [2], it operates particularly well for designing complex prototypes and small-batch productions. Significant advancements have been made in stereolithography (SLA), which now offers greater accuracy, quicker print times, and a wider variety of materials [1-27]. The development of resin compositions has led to the creation of biocompatible resins for use in medical applications [1-27].

2) Digital light processing (DLP): Similar to stereolithography (SLA), digital light processing (DLP) uses photopolymer resin and ultraviolet light [1-27]. However, instead of a laser, it uses a digital light projector, which makes it possible to simultaneously cure a complete layer [1-27]. Digital light processing (DLP) technology prints more quickly than stereolithography (SLA), although its resolution may be slightly poorer [2-27]. According to Iftekar et al., (2023) [2], research on digital light processing (DLP) technology has mostly focused on increasing the material possibilities, decreasing the layer thickness, and enhancing the resolution [2-27]. Rapid prototyping, jewelry casting, dental applications, and the creation of personalized consumer goods are all areas in which this technique is used [1-27].

3) Fused deposition modeling (FDM): According to Iftekar et al., (2023) [2], one of the most used 3D printing procedures is melt extrusion, commonly referred to as fused deposition modeling (FDM) [1-27]. To build the desired object, multiple layers of hot thermoplastic filament are melted and extruded through a heated nozzle [1-27]. Various materials, such as polylactic acid (PLA), metal–polymer composites, fiber-reinforced polymer composites, ceramicmaterials, andmany different kinds ofmaterials, can be produced using this technique [1-27]. A large variety of filaments with various properties, including strength, flexibility, temperature resistance, and conductivity, is now available. Hence the development of fused deposition modeling (FDM) technology concentrated on printer design, extruder technologies, and material possibilities [1-27]. Due to its adaptability, FDM can be used for quick prototyping, functional components, tooling, architectural models, and instructional applications even in the aerospace and healthcare sectors [2-27].

3. 3D Printing: Polymers

According to Iftekar et al., (2023) [2], polymers are the materials that are frequently utilized in 3D printing due to their versatility, affordability, and ease of use [1-27]. They are composed of materials that can be melted and extruded into different shapes, such as plastics, resins, and rubber-like substances [1-2-27]. Fused deposition modeling (FDM) technology is the most popular method for polymer-based 3D printing [2-27]. There are several types of polymers used in 3D printing, each with its own unique characteristics and applications [2-27]. One of the most popular polymer materials is polylactic acid (PLA). This material that rules the world of desktop 3D printing [2-27]. The applications of PLA in 3D printing include prototyping, models, DIY projects, artistic objects, household items, low-wear toys, packaging, and biomedical applications [2-27]. It offers advantages such as simple printing, a wide variety of colors and patterns, and being "biodegradable [2-27]. It also has some drawbacks, such as being brittle and having weak mechanical properties [1-2-27]. The most crucial characteristic of PLA (polylactic acid) material for 3D printing is its widespread use in FDM technology due to its low melting point, lack of toxicity, lack of irritation, and biocompatibility [1-2-27].

Flexible polymers used in 3D printing include thermoplastic elastomers (TPE), thermoplastic polyurethane (TPU), and thermoplastic copolyester (TPC) [2-27]. These materials are extremely flexible and durable, and they have rubber-like qualities [2-27]. They are frequently utilized in products such as automotive components, home appliances, and medical supplies that require parts that can bend or compress [2-27]. According to Iftekar et al., (2023) [2], TPE, TPU, and TPC can be challenging to print and consider under certain printing conditions [2-27]. High-impact polystyrene (HIPS) is a copolymer that combines the tensile strength of rubber and the hardness of polystyrene [2-27]. It is frequently used in protective packaging and containers and, when combined with ABS, as a support material in 3D printing. HIPS has the advantage of being a reliable 3D printer filament and an appropriate support material [1-2-27].

An increasing popular material for 3D printing is polyethylene terephthalate glycol (PETG), a variation of polyethylene terephthalate (PET) [1-27]. PETG is appropriate for applications, including mechanical parts, printer parts, and protective components since it is flexible, strong, and simple to print [2-27]. However, polyethylene terephthalate glycol (PETG) is prone to dampness and is easily scratched. A common polymer used in powder bed fusion 3D printing is nylon, sometimes referred to as polyamide (PA) [2-27]. Water-soluble polyvinyl alcohol (PVA) is frequently used as a support material in intricate 3D printing with overhangs. PVA filament is an excellent support material, although it may be tricky to work with and is moisture sensitive [2-27]. The rise of polyvinyl alcohol in 3D/4D printing is due to its appropriate flowability, biodegradability, and cost effectiveness, among other qualities [2-27]. Acrylonitrile styrene acrylate (ASA) is a material that can withstand environmental conditions and is ideal for practical uses, particularly in the automobile sector [2-27]. Due to its superior UV resistance, thermal stability, and durability, ASA filament is perfect for a variety of applications, such as sections exposed to sunshine and severe settings because it can survive external conditions without significantly degrading [2-27]. According to Iftekar et al., (2023) [2], another popular polymer for 3D printing is ABS, or acrylonitrile butadiene styrene [2-27]. ABS is ideal for a variety of applications, including phone covers, high-wear toys, tool handles, automotive trim components, and electrical enclosures due to its good mechanical qualities, such as its impact, heat, chemical, and abrasion resistance [2-27]. ABS must be printed on a heated print bed with bed glue since it is prone to warping. One of the toughest and most resilient polymers utilized in 3D printing is polycarbonate (PC). It can withstand temperatures up to 110 ^{o}C and is resistant to heat and physical damage [1-27]. Polycarbonate is frequently employed in applications such as electrical, mechanical, or automotive components, where strength and toughness are essential [2-27]. The layer thickness and infill density parameters for 3D printing have a big impact on the performance of the polycarbonate pieces that were manufactured utilizing the material extrusion technique. Engineering plastics and food packaging both use durable, flexible, chemically resistant, and food-safe polypropylene (PP) polymers [2-27]. The strong mechanical qualities, high chemical resistance, and low friction make PP filament ideal for functional parts that need to be durable, resistant to chemicals, and wear resistant [1-27]. Another new polymer material called as polymethyl methacrylate (PMMA), is also used in 3D printing [1-27].

4. 3D Printing: Metals

According to the literature survey by Iftekar et al., (2023) [2], the most frequently used materials in 3D metal printing include cobalt–chromium alloy, stainless steel 316L, aluminum 6061, titanium, copper, silver, gold, titanium, nickle, chromium, tungston alloys [2]. These metals are widely used in healthcare, aerospace and automation industries [2-27].

5. 3D Printing: Fiber Composite

According to the literature survey by Iftekar et al., (2023) [2], composite materials are composed of two or more substances with combined properties that are different from the original components [2-27]. They typically consist of a matrix and a reinforcement, such as carbon fiber or fiberglass [2]. This combination of materials allows composites to outperform thermoplastics while maintaining a low density. In fact, many carbon fiber layups are stronger than steel at one-tenth the weight [2-27]. One of the major advancements in 3D printing has been the development of new materials. Previously, 3D printing was restricted to plastic materials [2-27]. However, a wide range of materials can now be used to produce high-quality parts and products [1-2-27].

6. 3D Printing: Smart Materials

According to the literature survey by Iftekar et al., (2023) [2], smart materials can be used in 3D printing processes such as stereolithography (SLA) and fused deposition modeling (FDM) to create objects with shape memory capabilities [2-27]. Nitinol, an alloy consisting of nickel and titanium, is a well-known shape memory material. It is included in surgical instruments and implantable medical equipment [1-27]. Ferrofluid: Ferrofluid is a substance composed of minute magnetic particles floating in a liquid is also used as a new smart material in 3D printing [2-27]. Magnetorheological (MR) fluids: Similar to ferrofluids, magnetorheological (MR) fluids are composed of tiny magnetizable particles [2-27]. Electroactive polymers (EAPs): When exposed to an electrical field, EAPs, which are intelligent materials, alter their structure, size, or volume [2-27]. Piezoelectric materials: These clever materials can convert mechanical energy into electrical energy and vice versa [2-27]. They are commonly employed in sensors, actuators, transducers, and energy harvesting devices [2-27]. Chromogenic materials: These materials have the capacity to alter their color or optical characteristics in response to a variety of external stimuli, including electric fields, heat, light, and mechanical stresses [2-27]. Sunglasses with photochromic lenses, which get dark when exposed to UV light, is a well-known example [2-27]. Chromogenic materials are used in security inks, temperature-sensitive paints, and smart windows, as well as a few other applications. Smart materials have numerous product advantages, from self-healing materials that automatically fix themselves when damaged to smart fabrics that can warm or cool humans when necessary [2-27]. Ceramics can now be explored in 3D printing due to recent developments in additive manufacturing technologies that have removed these barriers [2-27]. Ceramic powders or pastes are used as feedstock materials in ceramic 3D printing, sometimes referred to as ceramic additive manufacturing [2-27]. Ceramics' high temperature resistance, hardness, and electrical insulating qualities have long been valued in conventional production [2-27]. Due to their brittleness and demanding fabrication requirements, ceramics materials caused difficulties for 3D printing [2-27]. Ceramics can now be explored in 3D printing due to recent developments in additive manufacturing technologies that have removed these barriers [2-27]. The ceramic material is deposited and shaped layer by layer using a variety of processes, including selective laser melting, stereolithography, and binder jetting [2-27]. Additionally, ceramic 3D printing provides customization and design optimization options, enabling the fabrication of ceramic components with specialized qualities and functions [2-27]. The performance, density, and strength of the printed ceramic pieces can be further improved by post-processing methods such as sintering [2-27].

7. 3D Printing: Bioinks

According to the literature survey by Iftekar et al., (2023) [2], bioinks are materials used in 3D bioprinting to create tissues and organs [2]. They act as a support system for living cells during printing [2-27]. Hydrogels such as alginate and gelatin as well as synthetic polymers such as PCL and PLA, are common bioink materials [2-27]. Cell-laden bioinks involve mixing cells with a carrier material such as a hydrogel or using cell aggregates [2-27]. The application of bioink has great potential in personalized therapies with increased concentration for controlling drug releases, drug screenings for cancer treatment, studying the possible side effects, and analyzing the behavior of tumor cells, etc. [2-27]. The use of biocompatible and biodegradable ingredients, together with the inclusion of cells within bioink, make it possible to print customized structures or tissues with minimal healing time as well as minimal chances of implant rejection and other immune responses [2-27]. At present, 3D bioprinting has enabled the in vitro production of complex tissues, including skin, cartilage, bone, lung, and heart [2-27].

8. 3D Printing: Applications

8.1. Following are the few examples of applications of 3D printing technology

1) Three-dimensional (3D) bioprinting, also known as additive manufacturing (AM), is a rapidly evolving field, with a focus on fabricating organ and tissue constructs by layering organic materials, living cells, and biochemicals according to a given digital mode [1-28-49] 3D printing, also called Additive Manufacturing (AM), has the potential to be a technological revolution in the manufacturing industry [1-28-49]. Some of the applications of 3D printing technology in plant science are bioprinting of plant cells, plant tissue cultured cell production, plant tissue culture lab-ware, production of plant secondary metabolites without plants, plant derived compounds for nozzle design, plant phenomics, plant phenotyping, ecological research, as a botany teaching tool, green bioprinting, and printing laboratory equipment [28-49]. Plant bio-printing may improve understanding of plant shape and morphogenesis, and could serve for the mass production of desired tissues or plants, or even the production of plant-based biomaterial for industrial uses [28-49]. Bioprinting is the ultimate and the most progressive step of engineering applied to plant cell culture [28-49]. However, plant bioprinting may be difficult due to rigid plant cell walls, unlike animal cells that do not have a cell wall, although plant cells have a distinct advantage, totipotency, which allows a plant cell, under strict environmental conditions, to develop a tissue scaffold that serves as the precursor for an organ, and the whole plant itself, organogenic steps that are under strict genetic control [28-49]. The culture methodologies of bioprinted plant cells could be assimilated to the culture of immobilized cells [28-49]. Additionally, sustainable practices, and the potential impact of factors influencing 3D printing must be considered [28-49].

2) The application of 3D printing technology in the aerospace and automotive industries has been widely recognized [2-27]. When compared to traditional manufacturing methods, AM creates stronger and lighter products with excellent mechanical properties [2-27]. This technology has also been applied in the automotive sector, enabling the production of lighter car parts, components, and prototypes with faster turnaround times [2-27]. Furthermore, 3D printing can also manufacture replacement and spare parts more efficiently [2-27].

3) Organ 3D printing has demonstrated significant progress in both animal and human models, paving the way for potential developments in transplantation and regenerative medicine [2-27-50]. The technology has also been used to produce personalized medicine, such as customized pills with specific dosages and active ingredients [2-27].

4) The automotive industry is using 3D printing to create lighter and stronger parts for cars, leading to improved fuel efficiency and performance [2-27]. The technology also allows for the rapid prototyping and testing of new designs, minimizing the time and expenses required to launch a new product [2-27]. Additionally, custom, and specialized parts are being manufactured using 3D printing to maintain unique and vintage cars, offering owners a more convenient option for vehicle preservation [2-27].

5) According to the literature survey by Iftekar et al., (2023) [2], using 3D printing to produce energy conversion technologies could be a major shift [2-27]. It could be a low-cost strategy that allows for the manufacturing of complicated designs and improved performance per unit of mass and volume [2-27]. It can be used to create intricate and customized components for renewable energy systems, such as wind turbines and solar panels [2-27]. Additionally, it is possible to reduce waste and improve efficiency in energy production by enabling the creation of precise and optimized components[2-27-50].

6) Advances in 3D printing have been embraced by the fashion industry to create unique and innovative clothing and accessories [2-27]. Printing 3D designs onto fabric eliminates the need for glue, and the bonding between the fabric and printing materials is primarily due to physical locking rather than chemical bonding. [2-27-111]. From light and complex parts to unique and innovative clothing and accessories, 3D printing has created new opportunities to produce customized and personalized clothing [2-27-111].

7) According to the literature survey by Iftekar et al., (2023) [2], 3D printing has revolutionized the architecture and construction industries by allowing for the rapid prototyping of building designs and the creation of complex and intricate structures [2-27]. Technology is also being used to create customized and unique building components, such as wall panels and tiles, which would be impossible to produce using conventional methods [2-27]. With the ability to create precise and intricate structures, 3D printing has the potential to change the way buildings are designed and built [2-27]. New and novel construction methods are necessary to accomplish the worldwide aim of lowering carbon dioxide emissions [2-27]. These technologies should not only promote green building practices but also reduce the costs of creating and managing facilities while maintaining a competitive advantage [2-27].

8) The food industry has embraced 3D printing technology to create new and innovative food products [2-27]. Overall, 3D printing allows for the creation of intricate shapes and designs that would otherwise be difficult to achieve through traditional methods [2-27]. This has resulted in the development of novel and unique snacks, desserts, and even complete meals that are both aesthetically pleasing and delicious [2-27]. The technology also has the potential to produce complex geometrical shapes in a shorter period, making it easier to produce healthier food products with precise control over the used ingredients [2-27].

9) Industrial *Cannabis sativa* (hemp or fibre) is mainly used to produce paper, ropes, food, medicines, cosmetics, hempcrete, leather, bioplastic, biochar, 3D printing and textiles [8, 50-102]. Hempcrete is a building construction material made from Industrial hemp fibres, lime and water [8, 50-102]. Hempcrete is a cost effective and sustainable properties which makes as a promising material in both new projects and those involving renovation [8, 50-102]. 3D printing, also known as additive manufacturing, is a method of creating a three-dimensional object layer-by-layer using a computer created design [8, 50-102]. 3D printing or additive manufacturing is a process of making three dimensional objects from a digital file [8, 50-102]. The process works by laying down thin layers of material in the form of liquid or powdered plastic, metal or cement, and then fusing the layers together [8, 50-102]. Hemp has been applied in filaments for 3D printing [50-102]. Hemp filament is a promising and sustainable alternative to traditional 3D printing materials [8, 50-102]. The 3D printing industry has been integrating hemp into its technology [8, 50-102]. Hemp can be transformed into filament to be used for 3D printing. 3D printing is used to apply computer-aided design (CAD) files of 3D objects, which are digitally designed for use in different applications or obtained by scanning an existing object through therapeutic prototyping or rapid manufacturing [8, 50-102]. The building construction with 3D printing technologies could be a game-changer and **Tvasta** Manufacturing Solutions, Chennai, with IIT Madras, Tamilnadu, India has constructed the first 3D printed buildings in India [8, 50-102]. The efficiency of 3D printing outpaces traditional building times and methods [8, 50-102]. As the world of 3D printing continues to evolve, hemp filament is emerging as a viable and eco-friendly alternative [8, 50-102]. Hemp filament shares many printing properties with polylactic acid (PLA), making it easy to use for various 3D printing applications [8, 50-102]. One of the biotechnology companies, Makeinica at Bengaluru, Karnataka, India has developed manufacturing process, and practical applications of hemp filament in 3D printing, with a focus on its potential for 3D printing services in India [8, 50-102]. Several companies have developed their versions of hemp 3D printer filament, contributing to the growing market for biodegradable and sustainable materials [8, 50-102].

10) 3D printing, or additive manufacturing, involves creating three-dimensional objects layer by layer using various materials such as plastics, metals, and composites [8, 102-111]. In India, the application of 3D printing in agriculture has revolutionized the agriculture and food industries [8,102-111]. The recent release of **Apollo 350 SLS** by IISC, Bengaluru, Karnataka, India is not just a machine; it's a game-changer for India's polymer 3D printing industry [8, 102-111]. Apollo 350 SLS revolutionary 3D printer sets the stage for self-reliance and industrial transformation in India [102-111]. Among the various innovations reshaping this industry, 3D printing stands out as a game-changer [102-111]. 3D printing is a potential technology that can revolutionize the agriculture industry by impacting the design and performance of agricultural machinery, manufacture equipment and tools on-demand, water management, phenotyping, and pest control [8, 102-111]. 3D printing can offer cost reduction, availability, improvement, customization enhancement, and performance improvement for agricultural machinery, benefiting both farmers and consumers [102-111]. On the other hand, 3D food printing also plays a beneficial role in food manufacturing. 3D food printing (3DFP) is a technology by which customized food items can be 'printed' layer by layer, as the nozzle releases the 'food ink' in a pre-programmed design [102-111]. Foods can be digitally designed and physically prepared using the layer-by-layer deposition of food components, rewarding opportunities to deliver nutritionally personalized food [102-111]. However, 3D printed food technology also faces challenges such as consumer acceptability, food safety and regulatory concerns [102-111]. Possible adverse health effects due to over consumption or the ultra-processed nature of 3D printed foods are major potential pitfalls [102-111]

9. Conclusion

3D printing technology has become common place in a variety of industries, including healthcare, aerospace, automotive, and manufacturing. Its major applications include rapid prototyping, tooling, and end-use part production. Furthermore, 3D printing can solve societal problems, such as food scarcity and homelessness, by enabling the government to fund the production of free foods and homes for people in need. However, the development of this technology is still in its early phases, and more research is needed to explore its full potential. The materials used in 3D printing technology include thermoplastics, metals, ceramics, and composites. Despite the wide range of materials available, there is still a need to develop high-strength and high-temperature materials that are more affordable. The research on materials is continuously advancing, but there is still a considerable way to go. The cost and speed of 3D printing technology remain significant challenges. While the average cost of 3D printers has decreased in recent years, the cost of materials and maintenance remains high. In addition, when compared to conventional manufacturing methods, the speed of 3D printers is still slow. More experimentation and innovation will be needed to cut prices and increase the speed of 3D printing technology. The 3D printing industry is focused on sustainability by developing eco-friendly materials and adopting circular economy models. This is a crucial area of research that desperately needs to be explored further. Overall, 3D printing technology has advanced significantly in recent years, there are still many challenges that need further development rather than investigation. Many studies in the field of 3D printing technology have been criticized for providing insufficient details and clarity in their explanations. Future research should aim to provide more detailed and transparent reporting of the research methodologies and results.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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