An Overview on Additive Manufacturing Technology: Last Decade's Literature, Components, Generic Process, Printing Categories, Associated Materials, Advantages, Disadvantages, and Research Gaps

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Abstract: Remarkable advancements have been witnessed in the domain of additive manufacturing technology during the past few years. It is a technique that might enhance the manufacturing process by creating tiny layers of materials from digital three-dimensional designs that are built using modern CAD software. It has a myriad of applications and is already being applied in practically every aspect of life. Many industries, such as automotive, aerospace, healthcare, education, and art, have already embraced additive manufacturing technology for its power of customization, product's weight reduction, waste minimization, and capacity to cope with sophisticatedly designed components. For these reasons, it may be speculated that additive manufacturing technology may have an extensive influence on the next industrial revolution. Therefore, the purpose of this article is to present an overview of additive manufacturing technology: literature, components, general additive manufacturing steps, additive manufacturing categories, related materials, advantages, disadvantages, and research needs.

Keywords: 3D printing; additive manufacturing; rapid prototyping;

1. Introduction

By successively depositing material, three-dimensional additive manufacturing is capable of transforming a geometrical representation into physical objects [1]. To put it another way, additive manufacturing — also known as 3D printing or rapid prototyping [2] — is a process by which intricate components are created successively by the addition of layers by means of a computer-aided design model [3] [4] [5]. Back in 1956, when Otto Munz introduced one of the earliest concepts of this kind of technique, which was photo-glyph recording [6]. In contrast, numerous individuals today regard Charles Hull as the progenitor of additive manufacturing, given that his patent from the 1980s coined the term "stereolithography" and facilitated the commercialization of the first additive manufacturing instruments [1] [6] [7] [8].

In this modern era, because of additive manufacturing technology's availability for enhanced performance, complicated geometries, and easier production, additive manufacturing is currently accepted by a number of industrial sectors, e.g., automotive, aerospace, dental and medical treatment, education, art, culture, and so on [8]. Albeit it's growth and potential to be a feasible alternative to traditional manufacturing processes in certain circumstances, it might not seem entirely competitive at the present moment. Moreover, although it is hard to foretell exactly which sectors will be most significantly affected by additive manufacturing, the most probable candidate sectors in the foreseeable future are those that need low- volume productions of high-value, highly sophisticated parts, such as the aerospace industry [9] [10]. Since there are versatile domains where additive manufacturing technology may be employed, it provides new prospects and brings hope to many possibilities for companies trying to enhance manufacturing efficacy [1]. Moreover, it has the ability to revolutionize manufacturing industries with its capacity for mass customization of items on a huge scale [11]. In addition to its influence on manufacturing industries, this additive manufacturing breakthrough is a forthcoming household necessity; consequently, it offers a personally customizable environment [2]. Therefore, it may also give a new opportunity to revolutionize personalized customized manufacturing.

In addition to revolutionize manufacturing, it needs to be mentioned that Industry 4.0 is the expression of the smart thinking concept for manufacturing environments that was initially suggested by the Communication Promoters Group of the Industry-Science Research Alliance in 2011. Industry 4.0 is defined as the fourth industrial revolution, representing a new stage of coordination and supervision of entire value chains over the full lifespan of goods. In such a setting, additive manufacturing offers an appropriate technological solution for quick prototyping with agility in developing complicated designs and large-scale customization that requires low waste [12]. Thus, the widespread use of additive manufacturing would enable industries to incorporate the tenets of Industry 4.0 [13].

To wrap it up, additive manufacturing technology has evolved in contemporary era as a malleable and vigorous approach in advanced manufacturing firms. This technique has been disseminated and deployed in many countries, notably in the manufacturing industry. Therefore, the objective of this paper is to offer an overview of additive manufacturing technology: literature, components, generic additive manufacturing processes, additive manufacturing categories, associated materials, benefits, drawbacks, and research gaps.

2. Literature review

There are a number of fascinating potential novel additive manufacturing research works carried out in the last decades (during the period from 2014 to 2023). Some of those attempted to fabricate objects by incorporating gravity force; nevertheless, some of those tried to build a 3D printer free of gravity force for future manufacturing in space environment as mankind’s possible habitats might be space in the future. Besides, some researches have been attempted to conduct biodegradable materials in additive manufacturing on the earth to keep this planet livable by reducing soil pollution. In this literature review, the outline is constructed as follows: glass additive manufacturing and including gravity force along it; gravity-free additive manufacturing; and incorporating biodegradable materials in additive manufacturing.

2.1 Attempted to use glass or glass-like materials

To begin with Luo et al.’s study in 2014, the purpose of that research was to explore the application of Selective Laser Melting for depositing glass structures. The study's methodology includes irradiating glass powder with a carbon-dioxide laser beam to generate particles, scanning the powder bed to form continuous lines, and creating glass walls gradually. Experimental and numerical modeling studies demonstrated that the absorptivity of the glass powder stayed practically constant with shifting process parameters. The significance of that research was to illustrate the potential of Selective Laser Melting for creating transparent glass objects [14].

Another analogous investigation was carried performed by Fateri et al. in the following year 2015. That experimental investigation also used Selective Laser Melting for soda-lime glass powder. The process factors were examined using several test geometries, and a collection of optimum process parameters was developed and used to manufacture numerous objects. The morphological and mechanical characteristics of the manufactured pieces were also evaluated. The results revealed the feasibility of Selective Laser Melting method to successfully manufacture components from soda-lime glass powder for many purposes [15].

The laser powder bed fusion process was incorporated by Datsiou et al. to produce parts that were made of soda lime silica glass. That additive manufacturing process was optimized with the help of the mechanical and physical properties, such as porosity, opacity, and strength, of the manufactured parts. It was concluded that geometrically sophisticated shapes might be possible [16].

Marzi et al. worked on a hybrid additive manufacturing process in which a hybrid extrusion-photopolymerization process was developed for fabricating transparent glass components. By combining both, complex structures, for instance, honeycombs, were created by beginning with a suspension that merged silica particles and silicon alkoxides. Eventually, fabricated parts were nearly identical to the computer aided-design model. A heat treatment was required to ensure the formation of a completely silica glass [17].

Another work in light of silica glass materials was carried out by Mader et al. to convert transparent fused silica into transparent glass. In that study, both Fused Deposition Modeling and Fused Feedstock Deposition were conducted. It was found that wall thicknesses could be produced down to 250 µm along the high aspect ratio of glass structures. Multicolored glass parts might be possible via this approach [18].

There was one issue germane to glass manufacturing, which was bubble formation during additive manufacturing. Thus, Peters et al. used a custom-made glass additive machine in order to mitigate this problem. In addition to this, that study focused on regulating the melt pool temperature so that melting glass could be released at its desired location with high accuracy. Moreover, the glass machine was shown to have the ability to produce a thin-walled, multi-layer star pattern and a spring without the need of support structures, by printing the material in free-space [19].

Glass is a kind of material that is difficult to structure at the microscale. Therefore, potential research was needed to cure this issue. Kotz et al. worked on this problem and found a panacea. The work included the precise creation of detailed patterns on microfluidic chips made of clear fused silica glass using stereolithography and microlithography techniques. A silica nanocomposite with an amorphous structure was synthesized at ambient temperature utilizing stereolithography printers commonly found on workbenches, together with a microlithography system that was specifically designed and produced using a digital mirror device. Microlithography has the potential to enable the production of printed structures with a resolution in the range of tens of microns. Thermal de-binding and sintering were used to convert the printed parts into transparent fused silica glass [20].

Luo et al. depicted that glass parts could be manufactured by wire-fed additive manufacturing. During the procedure, a laser beam was used to create a molten pool, into which uncolored glass was fed via a wire. As the work piece was shifted in relation to the stationary laser beam, the molten glass solidified and formed the final product. It was demonstrated that the process parameters — the morphology, scan speed, feed rate and laser power — could produce optimum results [21].

Albeit glass material requires a high temperature to fabricate products, Baudet et al. printed chalcogenide glass pieces at significantly lower temperatures. The sample's chemical and thermal attributes were found to be comparable to the original glass. The study found that 3D printing could create intricate optical pieces from chalcogenide glass, such as multi-material fiber formed with unique geometry and structure [22].

Moore et al. have developed a new method for additive manufacturing multifunctional glass using a desktop digital light processing printer. In their process, UV light is employed to regulate the splitting and polymerization of liquid, which governs the porosity of the resulting multicomponent glass. In this procedure, Moore et al. injected a second stage of a miscible fluid or polymer precursor to cause zone separation during polymerization. A polymer with a self-generated nanostructure can be created by adjusting the fluid's miscibility. Subsequently, the second stage may be eliminated by evaporation or heat breakdown, which led to the creation of a porous shape for the polymer. The resultant nanostructured goods are determined by the stage splitting process, which relies on the blending ratio and polymerization circumstances of the forerunner [23].

Cooperstein et al. had created a sol ink utilized for the additive manufacturing of opaque silica objects. In that printing method, the item was initially printed using a commercial desktop digital light processing printer. Then, the printed item was dried at 50°C for five days. Eventually, following a sintering operation at 800°C for one hour, a translucent silica structure was formed [24].

Nguyen et al. combined silica nanoparticles with tetraglyme and hydroxyl-terminated dimethylsiloxane to produce an organic slurry and printed a predefined green piece using the Direct Ink Writing process;

subsequently, the piece was heat-treated and fired into glass parts. The findings demonstrated that the approach permitted the printing of glass components with varied microstructures [25].

Sasan et al. used 3D printing to create high-quality germaniasilica glasses. A technique was described for producing colloidal germanium dioxide elements that can be mixed with silica colloids to alter their refractive index. The colloidal particles were turned into inks, printed using Direct Ink Writing, and then transformed into glasses at various germania concentrations. The printed GeO2-SiO2 glasses were juxtaposed with conventionally prepared glasses based on chemical composition, optical transmission, and refractive index [26].

2.2 Incorporating of earth's gravity force

Although items made of glass could be created via a 3D printer, gravity force was not employed to feed the glass during additive manufacturing until 2015. In that year, Klein et al. presented a study piece in 2015 in order to portray optically transparent items that were generated using a 3D printer. A novel printing technique — gravity-fed glass additive manufacturing — was implemented in that research. One of the major aims of that research was to integrate additive manufacturing technologies with the creation of glass products with acceptable optical qualities. It was determined that light transmission had very little distortion due to a generally high degree of uniformity and strong adhesion between layers. It was also noted that if the roughness of layer surface was kept, it would permit light refraction and scattering, as well as the fabrication of very convoluted caustic patterns. As a result, the observed behavior gave fresh insights on light regulation and extra optical features for the printed items. Moreover, it was also discovered that samples printed in the heated chamber exhibited improved mechanical properties over those printed at ambient temperature. That new additive manufacturing technology offered glass production the freedom to find a full variety of unique uses in numerous sectors, such as art, architecture, and product design. However, there were some downsides. Firstly, gravity as a feed mechanism necessitated regular refilling of the crucible, which was needed to maintain the glass level nearly constant. That refilling process was accomplished manually by observing with the assistance of the naked eye. Therefore, that procedure altered the overall quality of the print. Secondly, the relatively moderate pressure drop was created by the gravity-fed system, which limited the printing speed and resolution [27].

Hence, the aforementioned breakthrough gravity-fed glass additive manufacturing method unveiled new possibilities in creating parts for scientific equipment, construction components, and art pieces. As a result, there is more interest in additional research to expand our understanding of nozzle design, high-temperature printer design, key process parameters, fluid flow modeling, and the constraints of the printed specimens. However, the melting temperature of glass is extraordinarily high (>1000°C); hence, the tools and procedures utilized for it are not only costly but also advanced. To tranquillize these challenges, Leung came up with a panacea in 2017: sugar additive manufacturing instead of glass additive manufacturing. Because sugar's (a blend of sugar and corn syrup) melting temperature (between 100 and 150°C) is quite low, it decreases pertinent hazards, costs, and knotty procedures. Moreover, another benefit of utilizing sugar is that the residual sugar in the reservoir and nozzle can be cleaned simply with water, allowing the nozzle and reservoir to be reused repeatedly in the lab. Further, both sugar and glass have several comparable properties: optical transparency, temperature-viscosity connection, solidification, and solid state at ambient temperature. So, sugar may be integrated in the lab as an equivalent material for investigating glass additive manufacturing and other molten material-fed additive manufacturing. Additionally, by doing sugar, numerous process factors may be explored, such as layer height, nozzle design, printing speed, multicolor material input, and so on. After producing items by utilizing a sugar 3D printer, it could be concluded that the produced object displayed complicated caustic patterns analogous to those observed in glass [28]. Therefore, sugar additive manufacturing may be employed for gravity-feeding additive manufacturing research purposes.

Yadavalli et al.'s research incorporated gravity force for producing monofilament nano- and microfibers of diverse diameters by additive manufacturing. The Gravity Fiber Drawing technique utilizes the gravitational force to form a single, elongated nanofiber by allowing a polymer solution droplet to freely fall. The study determined that the unique approach provided versatility in using various polymers and solvent systems, as well as straightforward production procedures and scalability benefits. Furthermore, the technology allowed for the creation of intricate geometric patterns, such as twisted, woven, and braided nanofiber textiles, by appropriately designing the scaffolding device [29].

2.3 Future space additive manufacturing

On the contrary, Wang et al. published very interesting anti-gravitational additive manufacturing research in 2017 that was undertaken to overcome the restrictions provided by gravity in conventional techniques. By integrating a magnetic platform and inserting polycaprolactone-bonded Neodymium Iron Boron (Nd-Fe-B) powder material into the printing filament in a Fused Deposition Modeling method, the research attempted to achieve printing independence of gravity. This revolutionary methodology opens up new possibilities for additive manufacturing applications in settings where typical gravity-dependent technologies may not be possible, such as in outer space or moving vehicles. In the research, the impacts of Nd-Fe-B concentration, printing angle, and magnetic flux density on magnetic, mechanical, and thermal characteristics were examined. Eventually, the findings of the produced components demonstrated improvements in tensile strength, magnetic characteristics, and thermal conductivity with the presence of magnetic force during additive manufacturing. This unique method broadens the application scenario for Fused Deposition Modeling additive manufacturing, bringing potential advantages for numerous sectors [30].

In addition to the immediately stated study above, another work carried out by Gu et al. extended that anti-gravitational additive manufacturing to the next stage in 2019. The research attempted to investigate how severe gravity and pressure circumstances may impact the Laser Metal Deposition process and the quality of metal components produced in space scenarios. A three-dimensional transient model was constructed using Gambit, and subsequently, Ansys Fluent software was utilized for Computational Fluid Dynamics simulation. Afterwards, the model was inserted into Ansys Fluent, a pressure-velocity coupling approach was employed to solve the equations that govern boundary constraints. It was shown that gravity had a considerable influence on the final deposition outcomes, particularly at non-flat areas on earth, resulting in dripping-shaped depositions owing to gravitational forces influencing the melt pool development. To acquire insides relevant to gravity, the gravity value was progressively dropped from 1g to nil g for the examination of future space applications. The simulation findings revealed that surface tension would rule the melt pool kinematics when gravity was lowered to empty or almost empty. The deposition anomaly seemed to be more obvious as the gravity value declined. When reducing the gravity from 2g to nil g, the contact angle would rise, but the aspect ratio would fall. Without gravity, the metal in liquid state would have the ability to form a sphere with an enhanced contact angle under the effect of a poor aspect ratio and a large melt pool volume and surface area, resulting in the inconsistency of the deposition becoming more noticeable. Moreover, the influence of pressure on deposition synthesis was explored for the hypothetical process environment in a space atmosphere with a lower pressure magnitude. It was observed that the vaporization temperature of material will drop with a fall in ambient pressure. It was also noticed that more vapor would be formed with a lower boiling point in a reduced-pressure environment, and as a consequence, less material would be deposited on the substrate. In order to alleviate the impact of reduced pressure on the method of deposition and to diminish vapor generation, it was recommended that lower laser power and/or higher scanning speeds ought to be employed to mitigate the melt pool temperature and hinder the material from vaporizing after achieving the melting point [31]. Overall, that research sheds light on the need to incorporate gravity and pressure effects into the Laser Metal Deposition processes for space applications and provides the framework for additional developments in additive manufacturing technologies for space exploration.

It can be inferred that the severe environment in space, for instance, microgravity, would modify the printing mechanisms dramatically compared with those on the earth, which will hamper the application of additive manufacturing in space. Therefore, another effort was begun in 2020 by Huang et al. to create a technology for Metal Droplet Deposition manufacturing in space by exploiting an anti-gravity electric field to regulate the trajectory of droplets for precision deposition on a vertical substrate. Metal droplet-based additive manufacturing was chosen because it is a potential approach for metal additive manufacturing in space due to its vast advantages, such as wide material applications (tin solder, copper, aluminum, and gold) and the capacity to produce complicated microstructures. In that work, a droplet horizontal generator (ejection setup) was employed to create and charge metal droplets. With the help of the generator, droplets were ejected horizontally and manipulated using charging and deflection voltages in an electric field. In order to expel droplets properly, computerized numerical control files were applied for deposition routes and coordinate control. Before printing, computer aided design models were first translated into stereolithography (STL) format model data. Then, the model was read into slicing software (custom-designed) and split into a sequence of parallel layers with a particular layer thickness. Meanwhile, the solid portions of a layer were filled by droplet-deposited routes. Finally, the droplet generator discharged droplets, and the deposition platform moved simultaneously under the supervision of the CNC file. As a result, a metal part with the necessary geometry was manufactured. Moreover, a flight trajectory model was built to study the droplet motion process, which demonstrated that the flight-controllable zone of the droplet was located in the top half of the electric field. It was concluded that under the control of the anti-gravity electrical field, droplets could precisely form on the desired vertical substrate and solidify into the norm morphologies even after struggling an extensive flying travel distance, which suggested the effectiveness of suppressing the gravity effects on the droplet deposition. It paved the groundwork for an applicable additive manufacturing approach in space. That work was pioneering for droplet-based space manufacturing [32].

It is known that the moon is the earth's only natural satellite. Therefore, when mankind will commence colonizing space, the moon may become the first extraterritorial dwelling. So, additive manufacturing under lunar gravity seems to be very engrossing, for which the manufacturing of habitats, spare components, tools, and other infrastructure is mandatory. While commercial manufacturing methods are already well engineered under normative circumstances — gravity and atmosphere—on earth, additive manufacturing under lunar gravitational settings has only been studied to a very limited extent. Thereby, in 2021, Reitz et al. [33] investigated the feasibility of additive manufacturing under lunar gravity and microgravity circumstances, specifically focusing on the selective melting of regolith simulants (these are synthetic lunar soils [34]) using a laser-based process. That pioneering additive manufacturing study in light of lunar gravity showcased consistent results in sample geometry, mass, and porosity across different gravitational conditions. That research was possible because the Einstein-Elevator — the drop tower of the next generation, based at the Hannover Institute of Technology of the Leibniz University Hannover, enables experimentation under adjustable gravity conditions for more effective space research on earth [35] [36] — provided a new capability to conduct experiments in customizable gravitational conditions, together with the required infrastructure and accessibility to modify these scenarios at a low expense [33].

Another research work was published for the concern of micro-gravitation additive manufacturing by Zocca et al. A parabolic flight effort was conducted to create the world's first 12-millimeter steel wrench using the Laser Beam Melting process in microgravity (μ-g) conditions. In addition to this, it was also determined that there were no substantial variations from a produced component compared to 1g circumstances [37].

Nonetheless, the moon’s gravity is micro; there are a lot of space objects that have massive gravity. Therefore, it is necessary to consider high gravitation for future additive manufacturing in space. Sugiura and Koike worked on this to investigate the high-gravitational influence on additive manufacturing — metal Powder Bed Fusion. In that research work, a high-gravitational — up to 10G — Powder Bed Fusion system was developed via the application of centrifugal acceleration. It was concluded that the surface quality, density, and hardness of the fabricated parts were improved [38].

During future exploration in space, microstructures may be required for many purposes. Waddell et al. published a research article whose aim was to use volumetric additive manufacturing in space. Computed Axial Lithography was employed in the work for volumetric additive manufacturing. According to that study paper, Computed Axial Lithography is a superior technique to produce parts in space than layer-based procedures since a level liquid-gas interface is not needed to be maintained during printing using Computed Axial Lithography. Computed Axial Lithography was not only capable of generating microstructures for space exploration, but also biological tissue, flexible seals, and stiff trusses, as well as fixing existing tools and components. It was observed that printed components exhibited less geometric distortion than those on earth under consideration of microgravity. A variety of materials in microgravity may be included into Computed Axial Lithography which was a strength of that approach [39].

2.4 Conducting biodegradable materials

Apart from unearthing the potential of additive manufacturing in space settings for future possible habitats and manufacturing solutions, it is also required to look forward to its use in environmentally friendly ways on earth, such as incorporating biodegradable materials — materials which are designed to deteriorate upon disposal by the activity of living organisms [40] — in order to diminish the earth's soil pollution. Catana and Mazurchevici observed that to attenuate the influence of human's pollution activities on the environment, biodegradable materials are viable alternatives to petrochemical-derived materials. Because biodegradable materials have vital functions in preserving the planet by lessening the use of petroleum-based raw resources and dwindled carbon dioxide emissions. In addition to biodegradability material solutions, additive manufacturing provides greater material savings than traditional procedures; hence, additive manufacturing can be regarded as a distributed manufacturing technique to escalate sustainability and the circular economy worldwide [41]. Furthermore, recycling is an essential theme brought up by the European Union with the circular economy plan for both the environment and the economy [42].

While plastics are primarily made from petrochemicals, there is a growing demand for polymers made from renewable resources as alternatives to petrochemically derived plastics. These novel competitive polymers are known as bioplastics, which are biobased, biodegradable, or both [43] [44] [45]. Three kinds of bioplastics are recognized by Andanje et al. [43]. Firstly, biodegradable bioplastics are created from biobased ingredients. For instance, polylactic acid, polyhydroxyalkanoates, thermoplastic starch, and poly butylene succinate [43] [46]. Secondly, biodegradable bioplastics are generated from petrochemical resources. For example, include poly butylene adipate terephthalate and polycaprolactone [43] [47]. Thirdly, non-biodegradable or partly biodegradable bioplastics are produced from biobased monomers and bioderived technical polymers. To illustrate, include bioPE, bioPET, and polytrimethylene terephthalate [43] [48]. Table 1 depicts bioplastics composition, properties and applications pertinent to these three categories.

In 2018, Zeidler et al. showed an approach of additive manufacturing by employing renewable biobased materials, with a focus on appropriate packaging for delicate components. Waste materials were used in that research that had no other usage besides burning or energy. Those waste materials were locally available materials with little or no transportation need and an inexpensive cost. Such materials were wood flour, miscanthus particles, fruit stone flour, rice husk, and seashell powder. Those components were converted into powder, and a binder was also added to stabilize the powder particles. To adapt the material properly, sifting and sizing were undertaken until the distribution curves agreed well with those of norm additive manufacturing. It was found that by mixing powder material and binder, mechanical properties may be widely modified. From that study, it was proven that additive manufacturing has applicability using renewable resources [49].

Morales et al. produced and characterized bio-composite filaments using recyclable polypropylene and rice husks. The fiber content ratio studied was 0, 5 and 10 wt. %, which was manually blended prior entering into the extruder for filament creation. The researchers evaluated how the fiber fraction ratio affected the physical, morphological, mechanical and thermal aspects of printed items utilizing the Fused Filament Fabrication technique. Due to the inclusion of lignocellulosic fiber parts thermo-gravimetric tests indicated that the breakdown procedure for the bio-composites started significantly sooner than it did for the clean recycled polypropylene [50].

To robust the use of biodegradable materials, research was needed to come with a competitor of petroleum-based materials. In 2020, McLaughlin et al. carried out research with such a competitor namely polylactic acid. In that research, polylactic acid was combined with wood flour into several matrices to examine the particle species (maple and pine), size effect, and concentration (wood flour quantity) in the biopolymer and component additive manufacturing performance. Mechanical, thermal, and structural characteristics were evaluated for the diverse matrices generated in that research. Results indicated the possibility of employing wood floor as an addition to improve bioplastics, maintain sustainability characteristics, and modify the biopolymer to be appropriate for additive manufacturing [51].

Another study was carried out by Estakhrianhaghighi et al. in order to create high-performance sustainable materials with improved properties through the integration of cellulose-based compounds into a biobased polymer. In that study, the biopolymer — polylactic-acid — was reinforced by a variety of waste wood fibers. That experimental investigation showed that several mechanical properties — strength, rigidity, flexural modulus, and failure strain — were significantly enhanced while composite coupon density was slightly dwindled. Overall, that research work introduced an excellent cellular composite for additive manufacturing [52].

Kariz et al. used varying amounts of wood powder as an element in adhesive combinations for additive manufacturing. Binders included polyvinyl acetate and urea-formaldehyde adhesives, and the optimal mixture was determined by calculating the extrusion forces. Bending strength was determined by how much wood powder was in the combination as well as the type of adhesive used. The additive manufacturing of wood-based bulk materials, however, was said to suggest weak mechanical characteristics, making it improper for structural applications [53].

To address the problem of poor mechanical properties, several better polymer filaments featuring lignocellulose were formed. Le Duigou et al. presented the Fused Deposition Modeling of wood fiber-reinforced biological composites with an industry-approved filament known as fine wood fill filament. The filament was made of polyhydroxyalkanoate and polylactic acid, reinforced with reused wood fibers. That study found that printing orientation (0 or 90◦) greatly impacts mechanical characteristics due to fiber anisotropy. The porosity of printed objects was modified by the printing width (100, 200, and 300%), affecting their mechanical properties. Other observations from the bio-composite printing process included high porosity, water absorption, and swelling [54].

Tao et al. produced polylactic acid and wood flour (5%) bio-composite filament for Fused Deposition Modeling. The paper claimed that the polylactic acid crack surface's microstructure was changed by the insertion of wood flour, thereby enhancing the composite's early deformation resistance. Furthermore, the composite's early thermal breakdown temperature was lowered somewhat [55].

Hence, biodegradable materials could be employed for making additive manufacturing products, therefore, it was time to optimize the additive manufacturing machine's parameters — such as printing speed, nozzle temperature, platform temperature, and layer thickness — to let the additive manufacturing machine provide high-performance for biodegradable materials. Because most of the 3D printers' parameters are optimized for non-biodegradable materials. It was the aim of Lyu et al.'s study conducted in 2021. Another purpose was to examine the mechanical characteristics and responses of biodegradable polymer products created by Fused Deposition Modeling. It was revealed that the ideal additive manufacturing goods had the lowest porosity and the best interlayer adhesion. Furthermore, the yield strength and elongation at break of samples were also raised. This study presented a novel way for increasing the interlayer adhesion of Fused Deposition Modeling and the mechanical qualities of Fused Deposition Modeling products [56].

Afterward, it was necessary to know the mechanical performance of polylactide specimens — produced by additive manufacturing — during degradation, therefore, Moetazedian et al. carried out a study pertinent to this concern. That work compared the degradation of the interface bond at different temperature — 37, 50, and 65 degrees Celsius. It was found that there was no deterioration of mechanical or thermal properties after 8 months when the components were kept at room temperature. A comparison of chemical and thermal characteristics demonstrated that crystallinity was the most influential factor during the early phase of degradation, while mechanical behaviors were primarily defined by the molecular weight and autocatalytic degradation at the later phase [57].

Table 1 depicts bioplastics composition, properties and applications.

Category	***Materials***	***Properties***	***Application***	***Reference***
Made from biobased ingredients.	Polylactic acid	- Dense matrix - Enhanced crystallinity - Reduced permeation to Oxygen and moisture	- Bakery packaging - Seafood packaging - Active packaging	[43] [58]
	Polyhydroxyalkanoates	- Good resistance to UV rays - Insolubility in water - Too rigid and brittle - Stiffness - High degree of polymerization - Thermoplasticity - High temperature stability - Low degree of surface porosity -	- Tissue engineering - Biomedical usage - Agricultural components	[59]
	Thermoplastic starch	- Improved polymer compatibility - Reduced tensile strength - Antimicrobial nature	- Fresh noodles	[43] [60]
	Poly butylene succinate	- Brittleness - Shiny look - Poor density and flexibility -	- Food packaging - Tableware - Biomedical	[61]
Generated from petrochemical resources.	Poly butylene adipate terephthalate	- Dense matrix - Enhanced crystallinity - Reduced permeation to Oxygen and moisture	- Bakery packaging - Seafood packaging - Active packaging	[43] [58]
	polycaprolactone	- low melting temperature nearly 60 °C -	- drugs’ encapsulation -	[62]
Produced from biobased monomers and	Bio-polyethylene	- Flexible - Good barrier properties	- Food packaging - Cosmetics - Personal care - Automotive - Toys applications	[63] [64]

bioderived technical polymers.	Bio-polyethylene terephthalate	- High melting temperature - Durability - Transparent	- Food packaging - Bottles and containers - Textile	[64][65][66]
	Polytrimethylene terephthalate	- High strength - High toughness - Good abrasion - Good heat resistance - Low creep at elevated temperatures - Good chemical resistance - Transparent - Amorphous thermoplastic	- Beverage bottles - Artificial fibers for textiles	[67]

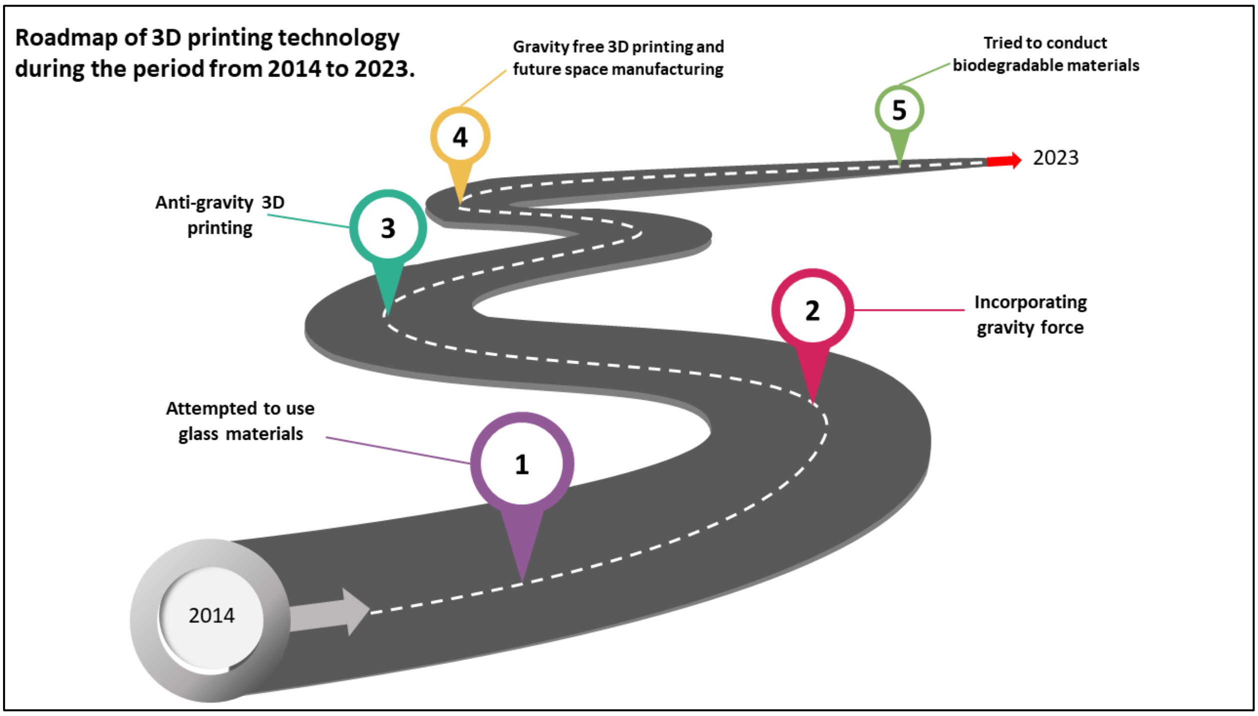

Fig. 1: Roadmap of additive manufacturing technology during the period from 2014 to 2023.

To summarize, in the last decade (2014–2023), there were so many studies carried out for various purposes. Fig. 1 illustrates that some works made use of glass as an additive manufacturing material; some studies tried to incorporate gravity force for material feeding; some research was conducted to get a gravity-free additive manufacturing solution; and eventually, some studies attempted to come up with a biodegradable additive manufacturing material.

3. Common components of the additive manufacturing machine

There are several common components that most additive manufacturing machines have, for instance, a nozzle, stepper motor, sensor, controller, power supply, display, and frame.

3.1 Nozzle or printer head

A nozzle is an important part for most of the 3D printers [68], from where molten material pours out in order to produce the continuous layers. The nozzle must be selected accordingly to the kind of material to be printed [69]. The larger the nozzle, the more mass and surface area available for transmitting heat to the filament enabling the process effective [70]. However, it may compromise accuracy.

3.2 Stepper motors

As the name indicates stepper motor travels one step at a time, in contrast to that of conventional motors, which rotates constantly. The stepper motor travels in particular number of steps as per the instruction supplied by the user according to the necessity [69] [71]. The motor spins in an incremental fashion that has number of pauses and stages [69]. Stepper motors are extremely vital elements for every 3D printer [68] [70], since it aids for controlling the nozzle's position. In other words, all three axis X, Y, and Z need three distinct stepper motors. Additionally, this motor is important for advancing the feeding materials for various 3D printers.

3.3 Sensors

Sensors are responsible for sensing different matrix like pressure, humidity, velocity, weight, and temperature [70]. Sensors send and receive feedback from the controller for a particular action.

3.4 Controller

The controller board is the 3D printer's brain. This board is in charge of the electronic operations of a 3D printer. The printer could not be capable of performing anything without the controller board; consequently, it is the most critical component of a 3D printer [70].

3.5 Power supply

It consists of a series of transformers, which lowers down the voltage to 12 or 24 volt DC correspondingly [70] [71]. The rated voltage: 110V @60Hz and 240V @50Hz AC for most of the additive manufacturing machine [70].

3.6 Display

As the name implies, it is used to show output. It is utilized to show the time required for printing, the left-over time for printing, and the speed of the fan [70].

3.7 Frame

A frame is a mechanical element which is composed of a steel or any other appropriate material for a stiff framework to retain the components [68] [70] [71]

4. The generic additive manufacturing process

From the CAD model to the actual part, additive manufacturing technology needs many steps to accomplish: CAD, STL convert, file transfer to machine, machine setup, build, remove, post-process, and application [72] [73] [74] [75] [76]. These steps are illustrated in Fig. 2.

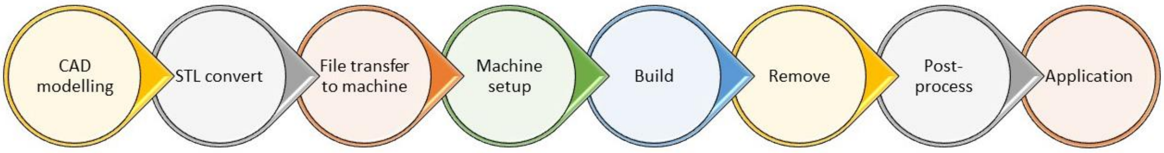

Fig. 2: The generic additive manufacturing process.

Firstly, all components must commence with a software model that completely represents the external geometry. This can entail the usage of practically any professional CAD modeling. Secondly, almost every additive manufacturing machine supports the STL file format, which is considered a norm, and almost every CAD system can export output that STL file format. This file represents the external closed surfaces of the original CAD model and is the foundation for calculation of the slices, software, but the output needs to be a 3D solid or surface representation. Thirdly, the STL file illustrating the part should be transmitted to the additive manufacturing equipment. Here, there might be few general processing of the file so that it is the correct position, size, and orientation for building. Fourthly, the additive manufacturing machine should be correctly set up before to the build process. Such settings pertain to the build factors such the layer thickness, the material restrictions, timings, energy source, etc. Fifthly, building the part is primarily an automated operation and the machine can mostly operate on with no supervision. Only cursory monitoring of the machine may require to take place at this period to ensure no problems have taken place including software glitches, running out of material, or power, etc. Sixthly, once the additive manufacturing machine finished its creation, the parts ought to be removed. It might need contact with the machine, there might be safety interlocks in place to check certain conditions, such as the operating temperatures are suitably low or there are no actively parts that are rotating. Seventhly, Once separated from the machine, pieces may require some amount of extra cleaning up before they are suitable for use. Parts may be weak at this point or they may have supporting features that must be eliminated. Eventually, pieces at this stage might be ready to use. Nevertheless, they might need further processing before they are deemed suitable for use. For example, they might need priming and painting to offer a satisfactory outermost layer's texture and finish. Treatments could be tedious and lengthy if the terminating standards are particularly exacting. They may also be needed to be joined together with other mechanical components to make a desired model or product [72] [73] [75] [76].

5. Classification of additive manufacturing and corresponding materials

There are so many kinds of additive manufacturing approaches available in this contemporary era, which results in the classification of additive manufacturing methods in order to comprehend them better. There are a number of systems for classifying additive manufacturing processes, such as the one proposed by the American Society for Testing and Materials (ASTM) F42 Committee, which divides the additive manufacturing into seven broad categories: Powder Bed Fusion, Directed Energy Deposition, Material Extrusion, Vat Photopolymerization, Binder Jetting, Material Jetting, and Sheet Lamination [1] [73] [74] [75] [76] [77] [78] [79][80]. On the other hand, additive manufacturing techniques are classified into four types depending on the beginning material used: liquid, filament/paste, powder, and solid sheet [77] [81]. In this article, the ASTM Committee's seven categories are described below.

5.1 Powder Bed Fusion

Powder Bed Fusion techniques make use either an electron beam or laser source to liquefy and bond material powder together [1] [72] [73]. In other words, thermal energy deliberately combines certain areas of a powder bed by fusing [73]. It entails the dispersion of the powdered substance onto existing layers. There are many materials can be used in this particular area of additive manufacturing such as metals [1] [73], polymers [1] [73], ceramics [1], and composite [1]. This Powder Bed Fusion approach has some merits and demerits. High resolution and good quality additive manufacturing can be achievable by this way although it is slow and expensive technique [82]. Several particular types of additive manufacturing fall under this category, including Electron Beam Melting [1] [73] [76], Direct Metal Laser Sintering [73], Selective Laser Sintering [1] [73] [76], Selective Laser Melting [72] [73] [76], and Selective Heat Sintering [1] [73].

5.2 Directed Energy Deposition

Directed Energy Deposition includes applying concentrated thermal energy to fuse materials by melting them while they are being physically deposited. This procedure provides for fine control over the deposition of materials, allowing complicated shapes to be created. A typical Directed Energy Deposition machine consists of a nozzle positioned on a multiple-axis arm, which distributes molten material onto the desired surface, where it solidifies. The nozzle may travel in numerous directions and is not fixed to a certain axis. The material, which can be formed from any angle due to 4 and 5 axis machines, melting occurs upon deposition using an electron or laser beam [73]. This method may be utilized with polymers and ceramics, but it is commonly employed with metals in the form of either powder or wire [1] [73]. While powder is more exact owing to the nature of no preformed shape, wire is more material efficient [72] [73]. There are some benefits and drawbacks of this category's additive manufacturing. This process needs relatively low cost and less time, but it has low accuracy, poor surface finish, limitation for complex shape printing [82]. Laser Metal Deposition [73], Laser Engineered Net Shape [73], Laser Beam Additive Manufacturing [76] are the example of Directed Energy Deposition additive manufacturing.

5.3 Material Extrusion

Material Extrusion involves purposefully distributing material via a nozzle or aperture to build up layers. To put it another way, this technique is analogous to additive manufacturing, where material is extruded and placed layer by layer to construct parts [73] In this technique, the material is introduced via a nozzle at constant pressure and in an uninterrupted flow. This pressure must be maintained stable and at a constant pace to ensure precise findings [72]. Polymers [1] [73] — notably popular for ABS plastic — may be utilized for material extrusion additive manufacturing [73]. Material Extrusion method has some advantages and disadvantages. It is cost effective and time efficient while outcomes of finished parts have poor mechanical properties [82]. Both Fused Deposition Modelling [73] [76] and Liquid Deposition Modelling [74] are most prevalent forms of Material Extrusion additive manufacturing.

5.4 Vat Photopolymerization

Vat Photopolymerization employs a vat of liquid photopolymer resin, out of which the finished piece is created layer by layer. An ultraviolet (UV) light is applied to cure or harden the resin where necessary, whereas a platform slides the item being created downwards after each successive layer is formed. As the procedure employs liquid to construct items, there is no support for structure from the material throughout the process of building [73]. In this Vat Photopolymerization technique, resins are cured via a process of photopolymerization [72] or UV light [83], where the light is focused over the surface of the resin with the aid of motor-controlled mirrors. Where the resin comes in touch with the light, it dries or solidifies. Only photopolymers materials [83] are suited for this Vat Photopolymerization. There are some positive and negative outcomes related to this technique. Vat Photopolymerization is unique for its high resolution and premium-quality results. But very few materials can be employed for this process [82]. Both Stereo Lithography and Digital Light Processing are Vat Photopolymerization sorts of additive manufacturing [73].

5.5 Binder Jetting

The Binder Jetting technique involves two ingredients: a powder-based substance and a binder. The binder serves as glue between powder layers. The binder is normally in liquid form, and the construction material is in powder form. A print head rotates horizontally along the x and y axes of the machine and deposits successive layers of the construction material and the binding substance. After each layer, the item being manufactured is lowered onto its construction platform. This kind of additive manufacturing enables color printing and employs polymers, ceramics (foundry sand), and metals [73]. There are some pros and cons of this process. It is a quick, simple and cheap technique; nevertheless, resulted items can be undergone shrinkage without infiltration [82]. Both Powder Bed-Inkjet Head and Plaster-Based additive manufacturing are under this Blinder Jetting category [73].

5.6 Material Jetting

In the Material Jetting category, material is jetted onto the construction surface or platform, where it hardens and the model is produced layer by layer. In other words, droplets are generated and positioned on the build surface in order to construct the item being printed, with subsequent droplets added to additional layers until the full thing has been built. In this style of additive manufacturing, material is deposited from a nozzle that travels horizontally over the build platform. The material accumulations are then dried or solidified using ultraviolet radiation. In the Material Jetting technology, not only polymers are included but also waxes may be employed [73]. This technique has also good and bad sides. Material Jetting is a quick additive manufacturing technique for colorful 3D creation; however, it suffers from exact color accuracy and uneven circumstances [84]. Multi-Jet Modeling [73] and Drop on Demand [76] are the instances of Material Jetting additive manufacturing.

5.7 Sheet Lamination

When sheets of material are combined to make an item, such a method might be termed the Sheet Lamination process. In this procedure, two sheets are joined together constantly until the required object is constructed by either ultrasonic welding (for metals) or adhesive (for paper). Both paper and metal are viable for this additive manufacturing category [73]. Sheet Lamination has some upsides and downsides. It provides opportunities for generating larger parts; however, it has low consistency of the surface and dimensional precision [82]. Laminated Object Manufacturing and Ultrasonic Additive Manufacturing are under Sheet Lamination Process [1] [73].

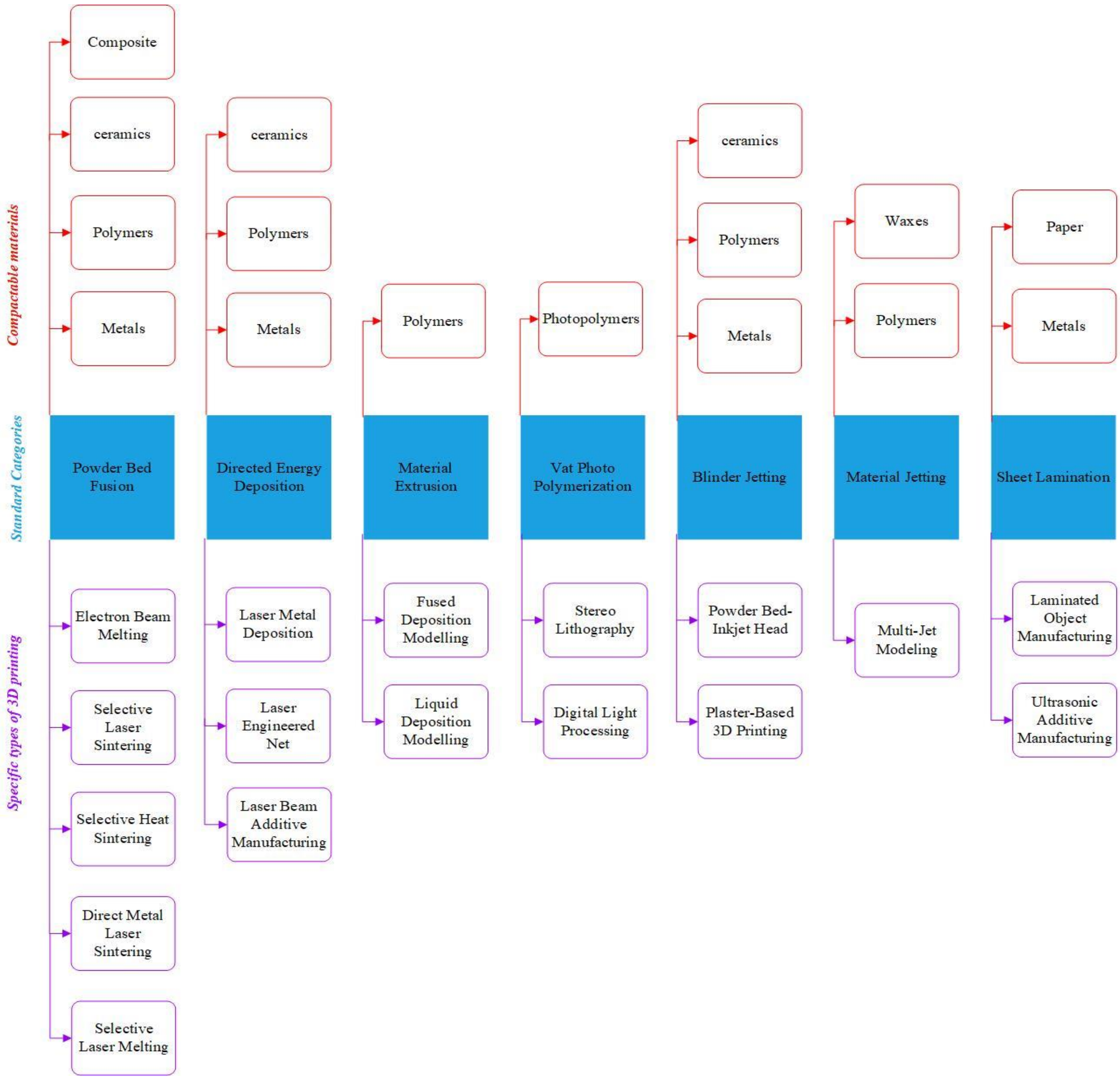

Fig. 3: Seven categories of additive manufacturing, corresponding materials, and additive manufacturing types.

Fig. 3 depicts all seven categories of additive manufacturing suggested by the ASTM F42 Committee. These seven categories have a blue color in the figure for visual purposes. Additionally, corresponding usable materials for each broad group are shown in red. Moreover, the types of additive manufacturing under each major category are also demonstrated by the purple color.

Furthermore, in light of the aforementioned description, it can be stated that different types of additive manufacturing processes require different materials. Among them, first and foremost, polymers are the most extensively utilized material in additive manufacturing manufacture. Most notably, nylon is a very extensively used polymer because it melts and binds better than other polymers [73]. Secondly, metals are another extensively utilized material for additive manufacturing. These metal materials include aluminum alloys [85], cobalt-based alloys [86] nickel-based alloys [87], stainless steels [88], and titanium alloys [89] [90] for additive manufacturing. Thirdly, additive manufacturing technology is capable of creating 3D printed item by employing ceramics and concrete without major pores or any fractures by optimization of the parameters and establish the excellent mechanical characteristics. Ceramic is robust, durable and fire resistant. By virtue of its fluid condition before setting, ceramics may be employed in nearly any geometry and form and particularly suited on the production of future structure and building [1]. Eventually, composites, as their name implies, are materials that are mixtures of two or more materials, either naturally (in nature) or created, that can be utilized for additive manufacturing [73] Composite materials with their extraordinary adaptability, lightweight, and tailorable features have been transforming high-performance industry sectors. Examples of composite materials include carbon fiber-reinforced polymer composites [91] and glass fiber-reinforced polymer composites [92]. Carbon fiber-reinforced plastic composite structures have high strength, specific stiffness, outstanding resistance to corrosion, and excellent fatigue performance [91]. At the same time, glass fiber-reinforced polymer composites are extensively employed for many purposes in additive manufacturing applications [92] and have tremendous prospective applications owing to their cost efficiency and high performance [93]. Fiberglass has a strong thermal conductivity and a relatively low coefficient of thermal expansion. Furthermore, fiberglass cannot ignite and is not influenced by the curing temperatures used in production procedures, thus, it is extremely ideal for use in the additive manufacturing industry [93]. The innovation or incorporation of novel technologies and materials will dominate the foreseeable future of additive manufacturing, and there is no doubt that additive manufacturing will have a prosperous future [94].

6. Advantage of additive manufacturing technology

There are plenty of benefits to using additive manufacturing technology over conventional manufacturing: sophisticated parts fabricating; reducing processes and resources; minimizing the weight of the parts; feasible to redesign parts; cutting toolless manufacturing; waste reduction; and eco-friendly production possibility.

Generally, knotty geometrical shapes are difficult to fabricate by conventional manufacturing process. However, the convoluted design components can be manufactured by means of 3D printers. Therefore, additive manufacturing gives the freedom of part design with full of complexity [95] [96] [97] [98] [99] [100] . Moreover, traditional manufacturing procedures would demand many iterative stages to be carried out like casting, rolling, forging, machining, drilling, welding, and so on, depending on the complexity of the objects. As you integrate more functions into a design, the number of these stages may expand rapidly. However, the number of processes and resources required might be greatly decreased when employing additive manufacturing [72]. Further, by being capable of printing a piece that is vacuous and has a thinner outer shell, which includes interior lattice structures instead of solid material all through, this drastically abates the quantity of material, weight, and build time [9]. So, additive manufacturing has the feature to build light weighting parts [95]. Besides, even a very small adjustment in the design could result in a large increase in the time required to manufacture using conventional methods [36]. In contrast, it is also feasible to redesign parts utilizing component optimization approaches; this permits the structure to be improved with a suitable durability to the cost ratio [9]. In addition, it has the potentiality to elimination of tolling [95]. Because it is an additive manufacturing process which does not require a cutting tool to subtract materials like conventional manufacturing process. Additionally, the wastage of materials can be annihilated by additive manufacturing method [101] because there is approximately no material waste during this process.

Since, there is nearly no waste production during the object creation, it is an eco-friendly approach [98] [99]. All of these benefits are illustrated in Fig. 4 by a cause-and-effect diagram.

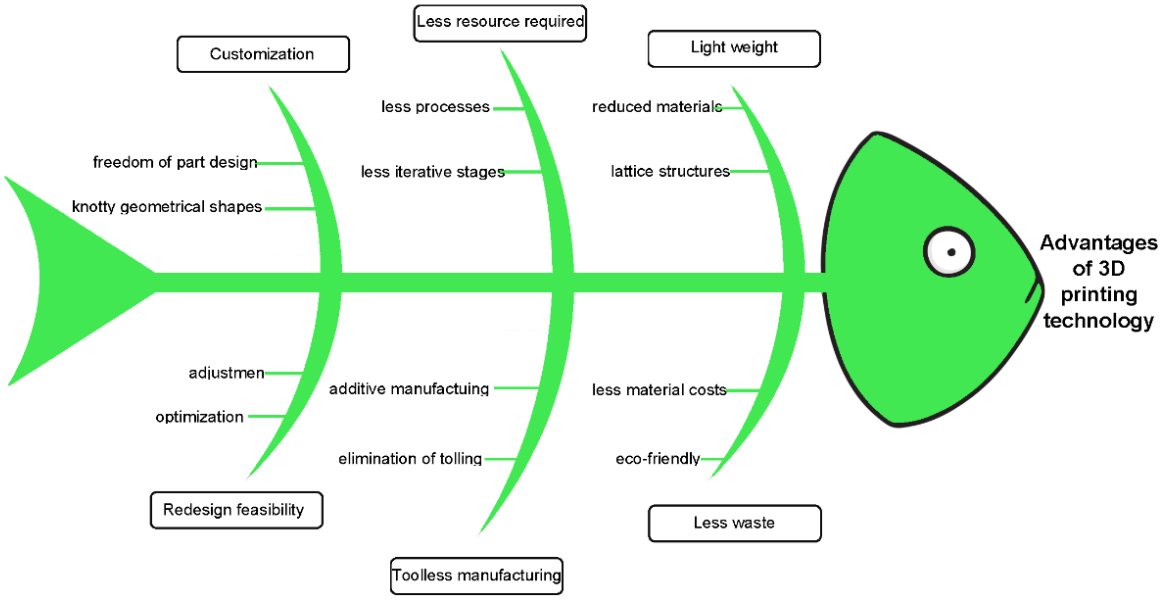

Fig. 4: Cause and effect diagram for demonstrating merits of the additive manufacturing technology.

7. Disadvantage of additive manufacturing technology

At the same time, there are several disadvantages to the adoption of additive manufacturing technology in the manufacturing industry. These limitations hamper the use of additive manufacturing technology as a replacement for conventional manufacturing.

For instance, the use of additive manufacturing technology will lead to a decrease in the need for manual labor in manufacturing. Consequently, this will have a significant impact on the economies of nations that heavily depend on a substantial workforce engaged in low-skilled employment [1]. Moreover, using additive manufacturing technology, individuals have the capability to fabricate a broad range of perilous objects [1] [102] including knives [1]. Hence, the utilization of additive manufacturing needs to be restricted exclusively to certain individuals in order to assuage undesirable actions [1]. In addition, anybody who gets a blueprint will have the ability to effortlessly produce counterfeit items. Because the simplicity of additive manufacturing technology lies in the process of drawing and inputting data into the machine, which then generates 3D things [1]. Furthermore, the capabilities of additive manufacturing technology are restricted in terms of the range of materials that can be used and the size of objects that can be built. Only a small number of materials can be processed and used to create the final goods [97] [99] [103] [104]. The 3D printer imposes significant constraints on the size of the object being built, such as limitations on the printing bed dimensions [99] [105] [106]. In some cases, certain components may require printing support during the additive manufacturing process, which necessitates cleaning after the printing operation has been completed. An important drawback of post-processing is the requirement for time-consuming tasks, which may lead to an increase in both production time and expense [94]. Apart from them, it is viable for low volume production compared to traditional manufacturing [99] [107]. Traditional manufacturing procedures, for instance, injection molding and compression molding, still dominate mass production [107]. It may be realized that the lack of repeatability [97] is one of the main challenges connected with additive manufacturing, owing to the tiny degree of accuracy involved in varying repeatability while making consecutive batches of identical components. In addition, the quality of surface finishing on the 3D-printed items is not satisfactory enough due to layer-by-layer fabrication [108] [109]. This layer-by-layer production gives the components lower strength, precision, and gloss on the surface [58] [59]. All of these drawbacks are presented in Fig. 4 by a cause-and-effect diagram.

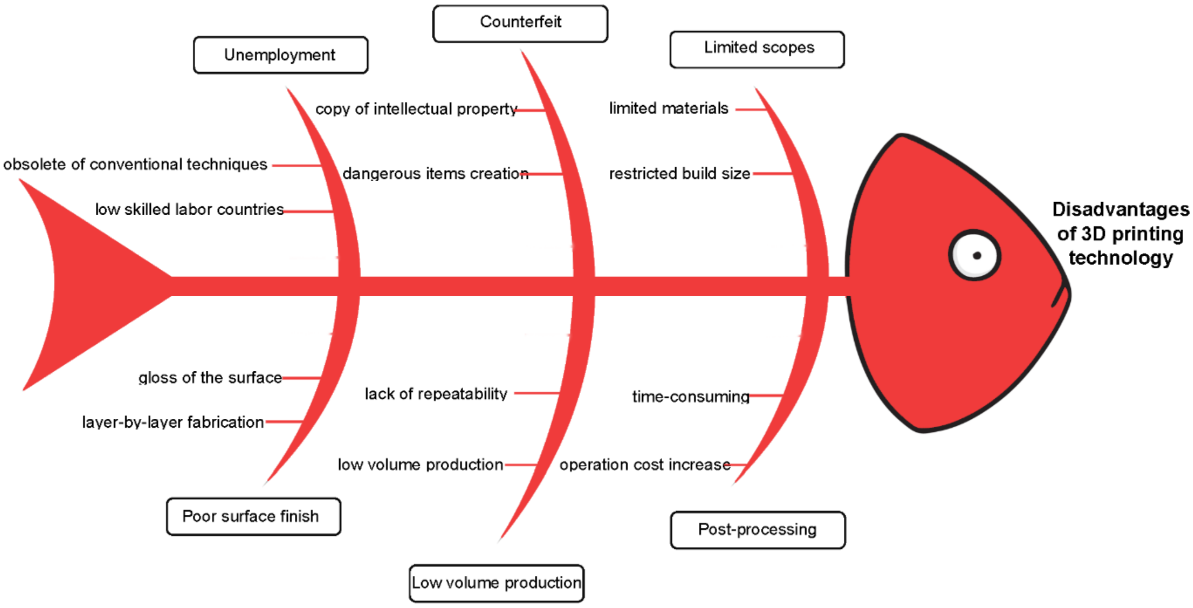

Fig. 5: Cause and effect diagram for demonstrating demerits of the additive manufacturing technology.

8. Research gaps and potential future works

1. In the work of Klein et al., gravity feed glass additive manufacturing was a need for regular recharging of the crucible, and it was executed manually [27], therefore an automated recharging way can be carried out in future work to get the better quality of output.
2. Furthermore, in light of Klein et al.’s study, it might be attempted to enhance the pressure of molten glass beside gravity feeding for higher printing speed and resolution in the forthcoming research.
3. Apart from Leung et al.’s work, additional empirical investigations are required to understand the factors in the sugar recipe that influence the viscosity and perhaps adjust the composition for a greater cooling rate and printing speed[28].
4. The printed sugar objects were particularly hygroscopic in Leung et al.’s examination. In the presence of humid air, the outermost layer turned sticky within hours and might even disintegrate in the moisture it absorbs. Thus, future studies may look at the use of an anti-inflammatory agent to decrease this undesired impact [28].
5. It is interesting to see the usage of such kinds of novel biodegradable materials by additive manufacturing in the forthcoming study, which materials will have durability for an acceptable product life.
6. As Current 3D printers can create dangerous items if the corresponding CAD file is given to them [1], thus, an artificial intelligent could be integrated on the additive manufacturing machine’s built-in operation system software.
7. To support the Gu et al.’s study, future research could focus on further refining the computational models to account for additional complexities in the Laser Metal Deposition process under extreme gravity and pressure conditions. As that study was based on Computation Fluid Dynamics simulation instead of actual experiment in the space, therefore, more supporting cross studies are needed in order to validate the proposition.
8. In addition to Huang et al.'s study on Metal Droplet Deposition fabrication using an anti-gravity electric field, more research is needed to examine optimal deposition parameter configurations, improve surface roughness of fabricated components, and eradicate porosity content under vacuum and microgravity [32]
9. additive manufacturing technology has lack of repeatability [97], so future research may focus to come out with a feature for repeatability. So that identical parts can be made.

9. Conclusion

Remarkable advancements have been witnessed in the domain of additive manufacturing technology during the past few years. From the literature review of the last decade, it can be noticed that many novel research studies pertinent to additive manufacturing techniques have been conducted for using glass materials, incorporating gravity force to feed the printing materials, unearthing the independence of gravity, ignoring atmosphere pressure for future manufacturing in space, and employing biodegradable materials for environmentally friendly production.

There are some common modules for the additive manufacturing machine, and there are eight generic steps involved in the printing process. Moreover, additive manufacturing methods can be classified into seven broad categories, each with corresponding materials. Additionally, albeit there are some advantages to this additive manufacturing technique, several considerable disadvantages also exist. Therefore, to apply additive manufacturing technology more widely, many significant future research projects are essential.

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Credit authorship contribution statement

Md Nazmul Hasan Dipu wrote this entire manuscript and created all necessary figures.

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Reference

[1] N. Shahrubudin, T. C. Lee, and R. Ramlan, “An overview on 3D printing technology: Technological, materials, and applications,” in *Procedia Manufacturing*, Elsevier B.V., 2019, pp. 1286–1296. doi: 10.1016/j.promfg.2019.06.089.

[2] S. M. Saptarshi and Dr. C. Zhou, “Basics of 3D Printing,” in *3D Printing in Orthopaedic Surgery*, M. Dipaola and F. M. Wodajo, Eds., Elsevier, 2019, pp. 17–30. doi: 10.1016/B978-0-323-58118-9.00002-6.

[3] L. Qi, J. Luo, H. Shen, and H. Lian, *Metal Micro-Droplet Based 3D Printing Technology*. Singapore: Springer Nature Singapore, 2023. doi: 10.1007/978-981-99-0965-0.

[4] C. W. J. Lim, K. Q. Le, Q. Lu, and C. H. Wong, “An Overview of 3-D Printing in Manufacturing, Aerospace, and Automotive Industries,” *IEEE Potentials*, vol. 35, no. 4, pp. 18–22, Jul. 2016, doi: 10.1109/MPOT.2016.2540098.

[5] S. A. M. Tofail, E. P. Koumoulos, A. Bandyopadhyay, S. Bose, L. O’Donoghue, and C. Charitidis, “Additive manufacturing: scientific and technological challenges, market uptake and opportunities,” *Materials Today*, vol. 21, no. 1, pp. 22–37, Jan. 2018, doi: 10.1016/j.mattod.2017.07.001.

[6] S. Pollack *et al.*, “Polymer-Based Additive Manufacturing: Historical Developments, Process Types and Material Considerations,” in *Polymer-Based Additive Manufacturing*, Cham: Springer International Publishing, 2019, pp. 1–22. doi: 10.1007/978-3-030-24532-0_1.

[7] P. Holzmann, R. J. Breitenecker, A. A. Soomro, and E. J. Schwarz, “User entrepreneur business models in 3D printing,” *Journal of Manufacturing Technology Management*, vol. 28, no. 1, pp. 75–94, Feb. 2017, doi: 10.1108/JMTM-12-2015-0115.

[8] Z. Lv, “Stories From China,” *IEEE Electrical Insulation Magazine*, vol. 39, no. 6, pp. 35–37, Nov. 2023, doi: 10.1109/MEI.2023.10286138.

[9] D. J. Thomas and T. C. Claypole, “3-D Printing,” in *Printing on Polymers: Fundamentals and Applications*, Elsevier Inc., 2015, pp. 293–306. doi: 10.1016/B978-0-323-37468-2.00018-X.

[10] Ö. Keleş, C. W. Blevins, and K. J. Bowman, “Effect of build orientation on the mechanical reliability of 3D printed ABS,” *Rapid Prototyp J*, vol. 23, no. 2, pp. 320–328, Mar. 2017, doi: 10.1108/RPJ-09-2015-0122.

[11] C. Schubert, M. C. Van Langeveld, and L. A. Donoso, “Innovations in 3D printing: A 3D overview from optics to organs,” *British Journal of Ophthalmology*, vol. 98, no. 2, pp. 159–161, Feb. 2014, doi: 10.1136/bjophthalmol-2013-304446.

[12] A. Sachdeva, R. Agrawal, C. Chaudhary, D. Siddhpuria, D. Kashyap, and S. Timung, “Sustainability of 3D printing in industry 4.0,” in *3D Printing Technology for Water Treatment Applications*, Elsevier, 2023, pp. 229–251. doi: 10.1016/B978-0-323-99861-1.00010-2.

[13] A. Malik, M. I. Ul Haq, A. Raina, and K. Gupta, “3D printing towards implementing Industry 4.0: sustainability aspects, barriers and challenges,” *Industrial Robot: the international journal of robotics research and application*, vol. 49, no. 3, pp. 491–511, Apr. 2022, doi: 10.1108/IR-10-2021-0247.

[14] J. Luo, H. Pan, and E. C. Kinzel, “Additive Manufacturing of Glass,” *Journal of Manufacturing Science and Engineering, Transactions of the ASME*, vol. 136, no. 6, Dec. 2014, doi: 10.1115/1.4028531.

[15] M. Fateri and A. Gebhardt, “Selective Laser Melting of soda-lime glass powder,” *Int J Appl Ceram Technol*, vol. 12, no. 1, pp. 53–61, Jan. 2015, doi: 10.1111/ijac.12338.

[16] K. C. Datsiou, F. Spirrett, I. Ashcroft, M. Magallanes, S. Christie, and R. Goodridge, “Laser powder bed fusion of soda lime silica glass: Optimisation of processing parameters and evaluation of part properties,” *Addit Manuf*, vol. 39, p. 101880, Mar. 2021, doi: 10.1016/j.addma.2021.101880.

[17] A. De Marzi, G. Giometti, J. Erler, P. Colombo, and G. Franchin, “Hybrid additive manufacturing for the fabrication of freeform transparent silica glass components,” *Addit Manuf*, vol. 54, p. 102727, Jun. 2022, doi: 10.1016/j.addma.2022.102727.

[18] M. Mader *et al.*, “Melt-Extrusion-Based Additive Manufacturing of Transparent Fused Silica Glass,” *Advanced Science*, vol. 8, no. 23, Dec. 2021, doi: 10.1002/advs.202103180.

[19] D. Peters, J. Drallmeier, D. A. Bristow, R. G. Landers, and E. Kinzel, “Sensing and control in glass additive manufacturing,” *Mechatronics*, vol. 56, pp. 188–197, Dec. 2018, doi: 10.1016/j.mechatronics.2018.06.002.

[20] F. Kotz, B. E. Rapp, and D. Helmer, “Additive manufacturing of microfluidic glass chips,” in *Microfluidics, BioMEMS, and Medical Microsystems XVI*, B. L. Gray and H. Becker, Eds., SPIE, Feb. 2018, p. 9. doi: 10.1117/12.2287654.

[21] J. Luo *et al.*, “Wire-Fed Additive Manufacturing of Transparent Glass Parts,” in *Volume 1: Processing*, American Society of Mechanical Engineers, Jun. 2015. doi: 10.1115/MSEC2015-9377.

[22] E. Baudet, Y. Ledemi, P. Larochelle, S. Morency, and Y. Messaddeq, "3D-printing of arsenic sulfide chalcogenide glasses," *Opt Mater Express*, vol. 9, no. 5, p. 2307, May 2019, doi: 10.1364/OME.9.002307.

[23] D. G. Moore, L. Barbera, K. Masania, and A. R. Studart, "Three-dimensional printing of multicomponent glasses using phase-separating resins," *Nat Mater*, vol. 19, no. 2, pp. 212–217, Feb. 2020, doi: 10.1038/s41563-019-0525-y.

[24] I. Cooperstein, E. Shukrun, O. Press, A. Kamyshny, and S. Magdassi, "Additive Manufacturing of Transparent Silica Glass from Solutions," *ACS Appl Mater Interfaces*, vol. 10, no. 22, pp. 18879–18885, Jun. 2018, doi: 10.1021/acsami.8b03766.

[25] D. T. Nguyen *et al.*, "3D-Printed Transparent Glass," *Advanced Materials*, vol. 29, no. 26, Jul. 2017, doi: 10.1002/adma.201701181.

[26] K. Sasan *et al.*, "Additive Manufacturing of Optical Quality Germania–Silica Glasses," *ACS Appl Mater Interfaces*, vol. 12, no. 5, pp. 6736–6741, Feb. 2020, doi: 10.1021/acsami.9b21136.

[27] J. Klein *et al.*, "Additive Manufacturing of Optically Transparent Glass," *3D Print Addit Manuf*, vol. 2, no. 3, pp. 92–105, Sep. 2015, doi: 10.1089/3dp.2015.0021.

[28] P. Y. V. Leung, "Sugar 3D Printing: Additive Manufacturing with Molten Sugar for Investigating Molten Material Fed Printing," *3D Print Addit Manuf*, vol. 4, no. 1, pp. 13–18, Mar. 2017, doi: 10.1089/3dp.2016.0045.

[29] N. S. Yadavalli, D. Asheghali, A. Tokarev, W. Zhang, J. Xie, and S. Minko, "Gravity Drawing of Micro- and Nanofibers for Additive Manufacturing of Well-Organized 3D-Nanostructured Scaffolds," *Small*, vol. 16, no. 11, Mar. 2020, doi: 10.1002/smll.201907422.

[30] J. Wang *et al.*, "Anti-gravitational 3D printing of polycaprolactone-bonded Nd-Fe-B based on fused deposition modeling," *J Alloys Compd*, vol. 715, pp. 146–153, 2017, doi: 10.1016/j.jallcom.2017.04.210.

[31] H. Gu and L. Li, "Computational fluid dynamic simulation of gravity and pressure effects in laser metal deposition for potential additive manufacturing in space," *Int J Heat Mass Transf*, vol. 140, pp. 51–65, Sep. 2019, doi: 10.1016/j.ijheatmasstransfer.2019.05.081.

[32] J. Huang, L. Qi, J. Luo, L. Zhao, and H. Yi, "Suppression of gravity effects on metal droplet deposition manufacturing by an anti-gravity electric field," *Int J Mach Tools Manuf*, vol. 148, Jan. 2020, doi: 10.1016/j.ijmachtools.2019.103474.

[33] B. Reitz *et al.*, "Additive Manufacturing Under Lunar Gravity and Microgravity," *Microgravity Sci Technol*, vol. 33, no. 2, Apr. 2021, doi: 10.1007/s12217-021-09878-4.

[34] L. A. Taylor, C. M. Pieters, and D. Britt, "Evaluations of lunar regolith simulants," *Planet Space Sci*, vol. 126, pp. 1–7, Jul. 2016, doi: 10.1016/j.pss.2016.04.005.

[35] C. Lotz, T. Froböse, A. Wanner, L. Overmeyer, and W. Ertmer, "Einstein-Elevator: A New Facility for Research from µg to 5g," *Gravitational and Space Research*, vol. 5, no. 2, pp. 11–27, Dec. 2017, doi: 10.2478/gsr-2017-0007.

[36] C. Lotz, Y. Wessarges, J. Hermsdorf, W. Ertmer, and L. Overmeyer, "Novel active driven drop tower facility for microgravity experiments investigating production technologies on the

example of substrate-free additive manufacturing," *Advances in Space Research*, vol. 61, no. 8, pp. 1967–1974, Apr. 2018, doi: 10.1016/j.asr.2018.01.010.

[37] A. Zocca *et al.*, "Enabling the 3D Printing of Metal Components in µ-Gravity," *Adv Mater Technol*, vol. 4, no. 10, Oct. 2019, doi: 10.1002/admt.201900506.

[38] Y. Sugiura and R. Koike, "High-gravitational effect on process stabilization for metal powder bed fusion," *Addit Manuf*, vol. 46, p. 102153, Oct. 2021, doi: 10.1016/j.addma.2021.102153.

[39] T. Waddell *et al.*, "Use of volumetric additive manufacturing as an in-space manufacturing technology," *Acta Astronaut*, vol. 211, pp. 474–482, Oct. 2023, doi: 10.1016/j.actaastro.2023.06.048.

[40] R. A. Gross and B. Kalra, "Biodegradable Polymers for the Environment," *Science (1979)*, vol. 297, no. 5582, pp. 803–807, Aug. 2002, doi: 10.1126/science.297.5582.803.

[41] M. Catana and S.-N. Mazurchevici, "CHARACTERIZATION OF BICOMPONENT 3D PRINTING TECHNOLOGIES OF BIODEGRADABLE MATERIALS," *International Journal of Manufacturing Economics and Management*, vol. 2, no. 2, pp. 18–37, Dec. 2022, doi: 10.54684/ijmem.2022.2.2.18.

[42] J. Pakkanen, D. Manfredi, P. Minetola, and L. Iuliano, "About the Use of Recycled or Biodegradable Filaments for Sustainability of 3D Printing," 2017, pp. 776–785. doi: 10.1007/978-3-319-57078-5_73.

[43] M. N. Andanje, J. W. Mwangi, B. R. Mose, and S. Carrara, "Biocompatible and Biodegradable 3D Printing from Bioplastics: A Review," *Polymers (Basel)*, vol. 15, no. 10, p. 2355, May 2023, doi: 10.3390/polym15102355.

[44] S. Mangaraj, A. Yadav, L. M. Bal, S. K. Dash, and N. K. Mahanti, "Application of Biodegradable Polymers in Food Packaging Industry: A Comprehensive Review," *J Packag Technol Res*, vol. 3, no. 1, pp. 77–96, Mar. 2019, doi: 10.1007/s41783-018-0049-y.

[45] G. Fredi and A. Dorigato, "Recycling of bioplastic waste: A review," *Advanced Industrial and Engineering Polymer Research*, vol. 4, no. 3, pp. 159–177, Jul. 2021, doi: 10.1016/j.aiepr.2021.06.006.

[46] J. Medeiros Garcia Alcântara, F. Distante, G. Storti, D. Moscatelli, M. Morbidelli, and M. Sponchioni, "Current trends in the production of biodegradable bioplastics: The case of polyhydroxyalkanoates," *Biotechnol Adv*, vol. 42, p. 107582, Sep. 2020, doi: 10.1016/j.biotechadv.2020.107582.

[47] S. M. Emadian, T. T. Onay, and B. Demirel, "Biodegradation of bioplastics in natural environments," *Waste Management*, vol. 59, pp. 526–536, Jan. 2017, doi: 10.1016/j.wasman.2016.10.006.

[48] M. H. Rahman and P. R. Bhoi, "An overview of non-biodegradable bioplastics," *J Clean Prod*, vol. 294, p. 126218, Apr. 2021, doi: 10.1016/j.jclepro.2021.126218.

[49] H. Zeidler, D. Klemm, F. Böttger-Hiller, S. Fritsch, M. J. Le Guen, and S. Singamneni, "3D printing of biodegradable parts using renewable biobased materials," *Procedia Manuf*, vol. 21, pp. 117–124, 2018, doi: 10.1016/j.promfg.2018.02.101.

[50] M. Morales, C. Atencio Martinez, A. Maranon, C. Hernandez, V. Michaud, and A. Porras, “Development and Characterization of Rice Husk and Recycled Polypropylene Composite Filaments for 3D Printing,” *Polymers (Basel)*, vol. 13, no. 7, p. 1067, Mar. 2021, doi: 10.3390/polym13071067.

[51] K. McLaughlin, A. Webb, K. Brätt, and D. Saloni, “Bioplastic Modified with Woodflour for Additive Manufacturing,” 2020, pp. 86–94. doi: 10.1007/978-3-030-51981-0_11.

[52] E. Estakhrianhaghighi, A. Mirabolghasemi, L. Lessard, and A. Akbarzadeh, “3D printed wood-fiber reinforced architected cellular composite beams with engineered flexural properties,” *Addit Manuf*, vol. 78, p. 103800, Sep. 2023, doi: 10.1016/j.addma.2023.103800.

[53] M. Kariz, M. Sernek, and M. K. Kuzman, “Use of wood powder and adhesive as a mixture for 3D printing,” *European Journal of Wood and Wood Products*, vol. 74, no. 1, pp. 123–126, Jan. 2016, doi: 10.1007/s00107-015-0987-9.

[54] A. Le Duigou, M. Castro, R. Bevan, and N. Martin, “3D printing of wood fibre biocomposites: From mechanical to actuation functionality,” *Mater Des*, vol. 96, pp. 106–114, Apr. 2016, doi: 10.1016/j.matdes.2016.02.018.

[55] Y. Tao, H. Wang, Z. Li, P. Li, and S. Q. Shi, “Development and Application of Wood Flour-Filled Polylactic Acid Composite Filament for 3D Printing,” *Materials*, vol. 10, no. 4, p. 339, Mar. 2017, doi: 10.3390/ma10040339.

[56] Y. Lyu, H. Zhao, X. Wen, L. Lin, A. K. Schlarb, and X. Shi, “Optimization of 3D printing parameters for high-performance biodegradable materials,” *J Appl Polym Sci*, vol. 138, no. 32, Aug. 2021, doi: 10.1002/app.50782.

[57] A. Moetazedian, A. Gleadall, X. Han, A. Ekinci, E. Mele, and V. V. Silberschmidt, “Mechanical performance of 3D printed polylactide during degradation,” *Addit Manuf*, vol. 38, p. 101764, Feb. 2021, doi: 10.1016/j.addma.2020.101764.

[58] P. Klinmalai, A. Srisa, Y. Laorenza, W. Katekhong, and N. Harnkarnsujarit, “Antifungal and plasticization effects of carvacrol in biodegradable poly(lactic acid) and poly(butylene adipate terephthalate) blend films for bakery packaging,” *LWT*, vol. 152, p. 112356, Dec. 2021, doi: 10.1016/j.lwt.2021.112356.

[59] V. Sharma, R. Sehgal, and R. Gupta, “Polyhydroxyalkanoate (PHA): Properties and Modifications,” *Polymer (Guildf)*, vol. 212, p. 123161, Jan. 2021, doi: 10.1016/j.polymer.2020.123161.

[60] J. Wangprasertkul, R. Siriwattanapong, and N. Harnkarnsujarit, “Antifungal packaging of sorbate and benzoate incorporated biodegradable films for fresh noodles,” *Food Control*, vol. 123, p. 107763, May 2021, doi: 10.1016/j.foodcont.2020.107763.

[61] S. A. Rafiqah *et al.*, “A Review on Properties and Application of Bio-Based Poly(Butylene Succinate),” *Polymers (Basel)*, vol. 13, no. 9, p. 1436, Apr. 2021, doi: 10.3390/polym13091436.

[62] L. McKeen, “The effect of heat aging on the properties of sustainable polymers,” in *The Effect of Long Term Thermal Exposure on Plastics and Elastomers*, Elsevier, 2021, pp. 313–332. doi: 10.1016/B978-0-323-85436-8.00001-1.

[63] M. Burelo, J. D. Hernández-Varela, D. I. Medina, and C. D. Treviño-Quintanilla, “Recent developments in bio-based polyethylene: Degradation studies, waste management and recycling,” *Heliyon*, vol. 9, no. 11, p. e21374, Nov. 2023, doi: 10.1016/j.heliyon.2023.e21374.

[64] V. Siracusa and I. Blanco, “Bio-Polyethylene (Bio-PE), Bio-Polypropylene (Bio-PP) and Bio-Poly(ethylene terephthalate) (Bio-PET): Recent Developments in Bio-Based Polymers Analogous to Petroleum-Derived Ones for Packaging and Engineering Applications,” *Polymers (Basel)*, vol. 12, no. 8, p. 1641, Jul. 2020, doi: 10.3390/polym12081641.

[65] T. Tiso *et al.*, “Towards bio-upcycling of polyethylene terephthalate,” *Metab Eng*, vol. 66, pp. 167–178, Jul. 2021, doi: 10.1016/j.ymben.2021.03.011.

[66] L. T. Sin and B. S. Tueen, “Eco-profile of plastics,” in *Plastics and Sustainability*, Elsevier, 2023, pp. 45–89. doi: 10.1016/B978-0-12-824489-0.00010-6.

[67] L. T. Sin and B. S. Tueen, “Plastics and environmental sustainability issues,” in *Plastics and Sustainability*, Elsevier, 2023, pp. 1–43. doi: 10.1016/B978-0-12-824489-0.00006-4.

[68] Md. M. Hoque, Md. M. H. Jony, Md. M. Hasan, and M. H. Kabir, “Design and Implementation of an FDM Based 3D Printer,” in *2019 International Conference on Computer, Communication, Chemical, Materials and Electronic Engineering (IC4ME2)*, IEEE, Jul. 2019, pp. 1–5. doi: 10.1109/IC4ME247184.2019.9036538.

[69] P. Sevvel *et al.*, “Design and Fabrication of Innovative Desktop 3D Printing Machine,” *Mater Today Proc*, vol. 22, pp. 3240–3249, 2020, doi: 10.1016/j.matpr.2020.03.284.

[70] S. Kiranlal, V. M. Brathikan, B. Anandh, and S. Vikash, “A Review on Electrical and Electronics Part of 3D Printer,” *IOP Conf Ser Mater Sci Eng*, vol. 1228, no. 1, p. 012007, Mar. 2022, doi: 10.1088/1757-899X/1228/1/012007.

[71] Krishnanand, S. Soni, and M. Taufik, “Design and assembly of fused filament fabrication (FFF) 3D printers,” *Mater Today Proc*, vol. 46, pp. 5233–5241, 2021, doi: 10.1016/j.matpr.2020.08.627.

[72] I. Gibson, D. W. Rosen, and B. Stucker, *Additive Manufacturing Technologies*. Boston, MA: Springer US, 2010. doi: 10.1007/978-1-4419-1120-9.

[73] K. Reddy and S. Tolcha, “ADDITIVE MANUFACTURING TECHNOLOGIES,” *International Journal of Management, Information Technology and Engineering*, vol. 4, no. 7, pp. 89–112, Apr. 2019.

[74] Y. W. Adugna, A. D. Akessa, and H. G. Lemu, “Overview study on challenges of additive manufacturing for a healthcare application,” *IOP Conf Ser Mater Sci Eng*, vol. 1201, no. 1, p. 012041, Nov. 2021, doi: 10.1088/1757-899X/1201/1/012041.

[75] R. Kawalkar, H. K. Dubey, and S. P. Lokhande, “A review for advancements in standardization for additive manufacturing,” *Mater Today Proc*, vol. 50, pp. 1983–1990, 2022, doi: 10.1016/j.matpr.2021.09.333.

[76] E. M. Sefene, “State-of-the-art of selective laser melting process: A comprehensive review,” *J Manuf Syst*, vol. 63, pp. 250–274, Apr. 2022, doi: 10.1016/j.jmsy.2022.04.002.

[77] M. D. Toksarı and G. Toğa, “Single batch processing machine scheduling with sequence-dependent setup times and multi-material parts in additive manufacturing,” *CIRP J Manuf Sci Technol*, vol. 37, pp. 302–311, May 2022, doi: 10.1016/j.cirpj.2022.02.007.

[78] S. Karimi, S. Kwon, and F. Ning, “Energy-aware production scheduling for additive manufacturing,” *J Clean Prod*, vol. 278, p. 123183, Jan. 2021, doi: 10.1016/j.jclepro.2020.123183.

[79] V. Mohanavel, K. S. Ashraff Ali, K. Ranganathan, J. Allen Jeffrey, M. M. Ravikumar, and S. Rajkumar, “The roles and applications of additive manufacturing in the aerospace and automobile sector,” *Mater Today Proc*, vol. 47, pp. 405–409, 2021, doi: 10.1016/j.matpr.2021.04.596.

[80] K. Nyamuchiwa, R. Palad, J. Panlican, Y. Tian, and C. Aranas, “Recent Progress in Hybrid Additive Manufacturing of Metallic Materials,” *Applied Sciences*, vol. 13, no. 14, p. 8383, Jul. 2023, doi: 10.3390/app13148383.

[81] S. Singh and S. Ramakrishna, “Biomedical applications of additive manufacturing: Present and future,” *Curr Opin Biomed Eng*, vol. 2, pp. 105–115, Jun. 2017, doi: 10.1016/j.cobme.2017.05.006.

[82] A. Jandyal, I. Chaturvedi, I. Wazir, A. Raina, and M. I. Ul Haq, “3D printing – A review of processes, materials and applications in industry 4.0,” *Sustainable Operations and Computers*, vol. 3, pp. 33–42, 2022, doi: 10.1016/j.susoc.2021.09.004.

[83] Z.-X. Low, Y. T. Chua, B. M. Ray, D. Mattia, I. S. Metcalfe, and D. A. Patterson, “Perspective on 3D printing of separation membranes and comparison to related unconventional fabrication techniques,” *J Memb Sci*, vol. 523, pp. 596–613, Feb. 2017, doi: 10.1016/j.memsci.2016.10.006.

[84] J. Yuan, C. Chen, D. Yao, and G. Chen, “3D Printing of Oil Paintings Based on Material Jetting and Its Reduction of Staircase Effect,” *Polymers (Basel)*, vol. 12, no. 11, p. 2536, Oct. 2020, doi: 10.3390/polym12112536.

[85] J. H. Martin, B. D. Yahata, J. M. Hundley, J. A. Mayer, T. A. Schaedler, and T. M. Pollock, “3D printing of high-strength aluminium alloys,” *Nature*, vol. 549, no. 7672, pp. 365–369, Sep. 2017, doi: 10.1038/nature23894.

[86] L. Hitzler *et al.*, “Additive Manufacturing of Cobalt-Based Dental Alloys: Analysis of Microstructure and Physicomechanical Properties,” *Advances in Materials Science and Engineering*, vol. 2018, pp. 1–12, Nov. 2018, doi: 10.1155/2018/8213023.

[87] L. E. Murr, “Frontiers of 3D Printing/Additive Manufacturing: from Human Organs to Aircraft Fabrication†,” *J Mater Sci Technol*, vol. 32, no. 10, pp. 987–995, Oct. 2016, doi: 10.1016/j.jmst.2016.08.011.

[88] T. DebRoy *et al.*, “Additive manufacturing of metallic components – Process, structure and properties,” *Prog Mater Sci*, vol. 92, pp. 112–224, Mar. 2018, doi: 10.1016/j.pmatsci.2017.10.001.

[89] F. Trevisan *et al.*, “Additive manufacturing of titanium alloys in the biomedical field: processes, properties and applications,” *J Appl Biomater Funct Mater*, vol. 16, no. 2, pp. 57–67, Apr. 2018, doi: 10.5301/jabfm.5000371.

[90] E. Uhlmann, R. Kersting, T. B. Klein, M. F. Cruz, and A. V. Borille, “Additive Manufacturing of Titanium Alloy for Aircraft Components,” *Procedia CIRP*, vol. 35, pp. 55–60, 2015, doi: 10.1016/j.procir.2015.08.061.

[91] W. Hao, Y. Liu, H. Zhou, H. Chen, and D. Fang, “Preparation and characterization of 3D printed continuous carbon fiber reinforced thermosetting composites,” *Polym Test*, vol. 65, pp. 29–34, Feb. 2018, doi: 10.1016/j.polymertesting.2017.11.004.

[92] T. Sathishkumar, S. Satheeshkumar, and J. Naveen, “Glass fiber-reinforced polymer composites – a review,” *Journal of Reinforced Plastics and Composites*, vol. 33, no. 13, pp. 1258–1275, Jul. 2014, doi: 10.1177/0731684414530790.

[93] Z. Liu *et al.*, “Modification of Glass Fiber Surface and Glass Fiber Reinforced Polymer Composites Challenges and Opportunities: From Organic Chemistry Perspective,” *Curr Org Chem*, vol. 19, no. 11, pp. 991–1010, Jun. 2015, doi: 10.2174/138527281911150610100914.

[94] Y. Tian *et al.*, “A Review of 3D Printing in Dentistry: Technologies, Affecting Factors, and Applications,” *Scanning*, vol. 2021, pp. 1–19, Jul. 2021, doi: 10.1155/2021/9950131.

[95] T. Duda and L. V. Raghavan, “3D Metal Printing Technology,” in *IFAC-Papers Online*, Elsevier B.V., 2016, pp. 103–110. doi: 10.1016/j.ifacol.2016.11.111.

[96] V. Tambrallimath and R. Keshavamurthy, “Glimpses of 3D Printing in the 21st Century,” 2023, pp. 1–8. doi: 10.4018/978-1-6684-6009-2.ch001.

[97] S. Kumar, “Advantage and Disadvantage,” 2023, pp. 1–60. doi: 10.1007/978-3-031-34563-0_1.

[98] B. Pavan Kalyan and L. Kumar, “3D Printing: Applications in Tissue Engineering, Medical Devices, and Drug Delivery,” *AAPS PharmSciTech*, vol. 23, no. 4, p. 92, May 2022, doi: 10.1208/s12249-022-02242-8.

[99] S. Kholgh Eshkalak, E. Rezvani Ghomi, Y. Dai, D. Choudhury, and S. Ramakrishna, “The role of three-dimensional printing in healthcare and medicine,” *Mater Des*, vol. 194, p. 108940, Sep. 2020, doi: 10.1016/j.matdes.2020.108940.

[100] J.-Y. Park, H.-Y. Kim, J.-H. Kim, J.-H. Kim, and W.-C. Kim, “Comparison of prosthetic models produced by traditional and additive manufacturing methods,” *J Adv Prosthodont*, vol. 7, no. 4, p. 294, 2015, doi: 10.4047/jap.2015.7.4.294.

[101] R. Sheng, “3-D printing in healthcare,” in *3D Printing*, Elsevier, 2022, pp. 111–120. doi: 10.1016/B978-0-323-99463-7.00013-X.

[102] H. Nazha and S. Szabolcs, “An Overview about Using the 3D Printing Technology,” *International Research Journal of Multidisciplinary Scope*, vol. 03, no. 01, pp. 01–03, 2022, doi: 10.47857/irjms.2022.v03i01.064.

[103] S. K. Sinha, “Additive manufacturing (AM) of medical devices and scaffolds for tissue engineering based on 3D and 4D printing,” in *3D and 4D Printing of Polymer Nanocomposite Materials*, Elsevier, 2020, pp. 119–160. doi: 10.1016/B978-0-12-816805-9.00005-3.

[104] H. N. Chia and B. M. Wu, “Recent advances in 3D printing of biomaterials,” *J Biol Eng*, vol. 9, no. 1, p. 4, Dec. 2015, doi: 10.1186/s13036-015-0001-4.

[105] J. R. Mark Co and A. B. Culaba, “3D Printing: Challenges and Opportunities of an Emerging Disruptive Technology,” in *2019 IEEE 11th International Conference on Humanoid, Nanotechnology, Information Technology, Communication and Control, Environment, and Management (HNICEM)*, IEEE, Nov. 2019, pp. 1–6. doi: 10.1109/HNICEM48295.2019.9073427.

[106] S. Beretta and S. Romano, “A comparison of fatigue strength sensitivity to defects for materials manufactured by AM or traditional processes,” *Int J Fatigue*, vol. 94, pp. 178–191, Jan. 2017, doi: 10.1016/j.ijfatigue.2016.06.020.

[107] T. Pereira, J. V Kennedy, and J. Potgieter, “A comparison of traditional manufacturing vs additive manufacturing, the best method for the job,” *Procedia Manuf*, vol. 30, pp. 11–18, 2019, doi: 10.1016/j.promfg.2019.02.003.

[108] S. Wilson, R. Thomas, N. Mary, E. T. Bosco, and A. Gopinath, “Development and fabrication of fused deposition modelling 3D printer,” *IOP Conf Ser Mater Sci Eng*, vol. 1132, no. 1, p. 012019, Apr. 2021, doi: 10.1088/1757-899X/1132/1/012019.

[109] C. R. Garcia, R. C. Rumpf, H. H. Tsang, and J. H. Barton, “Effects of extreme surface roughness on 3D printed horn antenna,” *Electron Lett*, vol. 49, no. 12, pp. 734–736, Jun. 2013, doi: 10.1049/el.2013.1528.