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

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Abstract

By gradually adding materials, digital fabrication technology—also known as 3D printing or additive manufacturing—creates tangible items from a geometric representation. A rapidly developing technology is 3D printing. The use of 3D printing is very common these days. In the fields of agricultural, healthcare, the automotive, locomotive, and aviation sectors, 3D printing technology is increasingly employed for mass modification and fabrication of any kinds of open source designs. Layer by layer, material can be deposited to create an object using 3D printing technology and a computer-aided design (CAD) model. The overview of the various 3D printing technologies, applications of the technology, and materials utilised in the manufacturing business are all covered in this article.

Keywords: Additive manufacuting, 3D Printing, manufacturing industy

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1. Introduction

By adding material in layers, 3D printing may turn geometric representations into actual physical objects [1]. Many 3D processes have seen amazing growth in recent years. Charles Hull launched the first 3D printing businesses in 1980 [2]. PGA rocket engine [6], steel bridge in Amsterdam [7], artificial heart pump [3], jewellery collections [4], 3D printed cornea [5], and other goods connected to the aviation and food industries are among the current applications of 3D printing.

Layer-by-layer production of three-dimensional (3D) structures starting with computer-aided design (CAD) drawings is the origin of 3D printing technology [8]. The development of 3D printing technology has been incredibly inventive and adaptable. For businesses trying to increase industrial efficiency, it offers up new possibilities and provides encouragement for many others. The materials that can currently be manufactured using 3D printing technology are conventional thermoplastics, ceramics, materials based on graphene, and metal [9]. The production line could shift and be revolutionised by 3D printing technology. The introduction of 3D printing technology will boost the production speed while cutting expenses. The consumer's demand will also have more of an impact on production at the same time.

Consumers have greater input in the final product and can request to have it produced to fit their specifications. At the meantime, the facilities of 3D printing technology will be located closer to the consumer, allowing for a more flexible and responsive manufacturing process, as well as greater quality control. Furthermore, when using 3D printing technology, the need for global transportation is significantly decreased. This is because, when manufacturing sites located nearer to the end destination, all distribution could be done with fleet tracking technology that saves energy and time. Lastly, the adoption of 3D printing technology can change the logistics of the company. The logistics of the companies can manage the entire process, offer more comprehensive and start-to-finish services [10].

Nowadays, 3D printing is widely used in the world. 3D printing technology increasingly used for the mass customization, production of any types of open source designs in the field of agriculture, in healthcare, automotive industry, and aerospace industries [11].

At the same time, there are several disadvantages the adoption of 3D printing technology in manufacturing industry. For instance, the effect of the use of 3D printing technology is will reduce the use of manufacturing labour so automatically will greatly affect the economy of countries that rely on a large number of low skill jobs. Furthermore, by using 3D printing technology, users can print many different types of objects such as knives, guns and dangerous items. Therefore, the use of 3D printing should be limited to only certain people to prevent terrorists and criminals bring guns without detected. At the same time, the people who get a hold of a blueprint will be able to counterfeit products easily. This is because, the use of 3D printing technology is simple, just sketching, and set the data in the machine-printed so 3D objects can generate [12].

To sum up, 3D printing technology has emerged during recent years as a flexible and powerful technique in advance manufacturing industry. This technology has been widespread used in many countries, especially in the manufacturing industry. Therefore, this paper presents the overview of the types of 3D printing technologies, the application of 3D printing technology and lastly, the materials used for 3D printing technology in manufacturing industry.

2. Types of 3D Printing

Varieties of 3D printing technologies have been developed with the different function. According to ASTM Standard F2792 [13], ASTM catalogued 3D printing technologies into seven groups, including the binding jetting, directed energy deposition, material extrusion, material jetting, powder bed fusion, sheet lamination and vat photopolymerization. There are no debates about which machine or technology function better because each of them has its targeted applications. Nowadays, 3D printing technologies are no longer limited to prototyping usage but are increasingly also being used for making variety of products [14].

Binder jetting

Binder jetting is a rapid prototyping and 3D printing process in which a liquid binding agent is selectively deposited to join powder particles. The binder jetting technology uses jet chemical binder onto the spread powder to form the layer [9]. The application of the binder jetting is would be producing the casting patterns, raw sintered products or similar large-volume products from sand. Binder jetting can print a variety of materials including metals, sands, polymers, hybrid and ceramics. Some materials like sand not required additional processing. Moreover, the process of binder jetting is simple, fast and cheap as powder particles are glued together. Lastly, binder jetting also has the ability to print very large products.

Directed energy deposition

Directed energy deposition is a more complex printing process commonly used to repair or add additional material to existing components [8]. Directed energy deposition has the high degree control of grain structure and can produce the good quality of the object. The process of directed energy deposition is similar in principle to material extrusion, but the nozzle not fixed to a specific axis and can move in multiple directions. Furthermore, the process can be used with ceramics, polymers but is typically used with metals and metal-based hybrids, in the form of either wire or powder. The example of this technology is laser deposition and laser engineered net shaping (LENS) [8]. Laser deposition is the emerging technology and can be used to produce or repair parts measured in milimeter to meters. Laser deposition technology is gaining attraction in the tooling, transportation, aerospace, and oil and gas sectors because it can provide scalability and the diverse capabilities in the single system [15]. Meanwhile, laser LENS can exploit thermal energy for melting during the casting and parts are accomplished subsequently [16].

Materials extrusion

Material extrusion-based 3D printing technology can be used to print multi-materials and multi-colour printing of plastics, food or living cells [17]. This process has been widely used and the costs are very low. Moreover, this process can build fully functional parts of product [8]. Fused deposition modelling (FDM) is the first example of a material extrusion system. FDM was developed in early 1990 and this method uses polymer as the main material [18]. FDM builds parts layer-by-layer from the bottom to the top by heating and extruding thermoplastic filament. The operations of FDM are as follows:

I. Thermoplastic heated to a semi-liquid state and deposits it in ultra-fine beads along the extrusion path [19].
II. Where support or buffering needed, the 3D printer deposits a removable material that acts as scaffolding. For example, FDM uses hard plastic material during the process to produce 3D bone model [19].

Materials jetting

According to ASTM Standards, material jetting is a 3D printing process in which drop by drop of build material are selectively deposited. In material jetting, a printhead dispenses droplets of a photosensitive material that solidifies, building a part layer-by-layer under ultraviolet (UV) light [20]. At the same time, material jetting creates parts with a very smooth surface finish and high dimensional accuracy. Multi-material printing and a wide range of materials such as polymers, ceramics, composite, biologicals and hybrid are available in material jetting [8].

Powder bed fusion

The powder bed fusion process includes the electron beam melting (EBM), selective laser sintering (SLS) and selective heat sintering (SHS) printing technique. This method uses either an electron beam or laser to melt or fuse the material powder together. The example of the materials used in this process are metals, ceramics, polymers, composite and hybrid. Selective laser sintering (SLS) are the main example of powder based 3D printing technology. Carl Deckard developed SLS technology in 1987. SLS is 3D printing technology that's functionally in fast speed, has high accuracy, and varies surface finish [21]. Selective laser sintering can used to create metal, plastic, and ceramic objects [22]. SLS used a high power laser to sinter polymer powders to generate a 3D product. Meanwhile, SHS technology is another part of 3D Printing technology uses a head thermal print in the process to melt the thermoplastic powder to create 3D printed object. Lastly electron beam melting enhances an energy source to heat up the material [22].

Sheet lamination

According to ASTM definition, sheet lamination is the 3D printing process in which sheet of materials are bond together to produce a part of object [20]. The example of 3D printing technology that uses this process are laminated object manufacturing (LOM) and ultrasound additive manufacturing (UAM) [8]. The advantages of this process are sheet lamination can do full-colour prints, it relatively inexpensive, easy of material handling and excess material can be recycled. Laminated object manufacturing (LOM) is capable to manufacture complicated geometrical parts with lower cost of fabrication and less operational time [23]. Ultrasound additive manufacturing (UAM) is an innovative process technology that uses sound to merge layers of metal drawn from featureless foil stock.

Vat Photopolymerization

The main 3D printing technique that frequently used is photopolymerization, which in general refers to the curing of photo-reactive polymers by using a laser, light or ultraviolet (UV) [24]. The example of 3D printing technologies by using photopolymerization is stereolithography (SLA) and digital light processing (DLP). In the SLA, it was influenced by the photo initiator and the irradiate exposure particular conditions as well as any dyes, pigments, or other added UV absorbers [18]. Meanwhile, digital light processing is a similar process to Stereolithography that works with photopolymers. Light source is the major difference. Digital Light Process uses a more conventional light source, such as an arc lamp with a liquid crystal display panel. It can apply to the whole surface of the vat of photopolymer resin in a single pass, generally making it faster than Stereolithography [25]. The important parameters of Vat Photopolymerization are the time of exposure, wavelength, and the amount of power supply. The materials used initially are liquid and it will harden when the liquid exposed to ultraviolet light. Photopolymerization is suitable for making a premium product with the good details and a high quality of surface [17].

3. Materials Used for 3D Printing Technology in Manufacturing Industry

Like any manufacturing process, 3D printing needs high quality materials that meet consistent specifications to build consistent high-quality devices. To ensure this, procedures, requirements, and agreements of material controls are established between the suppliers, purchasers, and end-users of the material. 3D printing technology is capable to produce fully functional parts in a wide range of materials including ceramic, metallic, polymers and their combinations in form of hybrid, composites or functionally graded materials (FGMs) [8].

Metals

Metal 3D printing technology gain many attentions in aerospace, automobile, medical application and manufacturing industry because the advantages existing by this process [26]. The materials of metal have the excellent physical properties and this material can be used to complex manufacturer from printing human organs to aerospace parts. The examples of this materials are aluminium alloys [27], cobalt-based alloys [28], nickel-based alloys [29], stainless steels [30], and titanium alloys [31-32]. Cobalt-based alloy is suitable to use in the 3D printed dental application. This is because, it has high specific stiffness, resilience, high recovery capacity, elongation and heat-treated conditions [28]. Furthermore, 3D printing technology has capability to produce aerospace parts by using nickel base alloys [29]. 3D-printed object produces using nickel base alloys can be used in dangerous environments. This is because, it has high corrosion resistance and the heat temperature can resistant up to 1200 °C [26]. Lastly, 3D printing technology also can print out the object by using titanium alloys. Titanium alloy with have very exclusive properties, such as ductility, good corrosion, oxidation resistance and low density. It is used in high stresses and high operating temperatures and high stresses, for example in aerospace components [31] and biomedical industry [32].

Polymers

3D printing technologies are widely used for the production of polymer components from prototypes to functional structures with difficult geometries [33]. By using fused deposition modelling (FDM), it can form a 3D printed through the deposition of successive layers of extruded thermoplastic filament, such as polylactic acid (PLA), acrylonitrile butadiene styrene (ABS), polypropylene (PP) or polyethylene (PE) [33]. Lately, thermoplastics filaments with higher melting temperatures such as PEEK and PMMA can already be used as materials for 3D printing technology [34]. 3D printing polymer materials in liquid state or with low melting point are widely used in 3D printing industry due to their low cost, low weight and processing flexibility [35]. Mostly, the materials of polymers played important role in biomaterials and medical device products often as inert materials, by contributing to the efficient functioning of the devices as well as providing mechanical support in many orthopaedic implants [28].

Ceramics

Nowadays, 3D printing technology can produce 3D printed object by using ceramics and concrete without large pores or any cracks through optimization of the parameters and setup the good mechanical properties [37]. Ceramic is strong, durable and fire resistant. Due to its fluid state before setting, ceramics can be applied in practically any geometry and shape and very suitable on the creation of future construction and building [37]. According to [38], they said ceramics materials is useful in the dental and aerospace application. The examples of this materials are alumina [39], bioactive glasses [40] and zirconia [41]. Alumina powder for instance has the potential to be processes by 3D Printing technology. Alumina is an excellent ceramic oxide with a very wide range of applications, including catalyst, adsorbents, microelectronics, chemicals, aerospace industry and another high-technology industry [42]. Alumina has great curing complexity [38]. By using 3D printing technology, complex-shaped alumina parts with has a high density after sintering and also has high green density can be printed [39]. Furthermore, in successive experiment, Stereolithographic (SLA) machine was used to process glass-ceramic and bioactive glass into dance part. It significantly improving the bending strength of this materials. The increasing of the mechanical strength will open up the potential for apply bioactive glass in relevant clinical structure such as scaffolds and bone. By using Stereolithographic Ceramic Manufacturing (SLCM), it is probable to produce solid bulk ceramics with high densities, very homogeneous microstructure, high compression strength and bending [40]. Meanwhile, zirconia are the main construction materials in nuclear power sectors, using for element tubing. Hafnium-free zirconium is very suitable for this application because it has low susceptibility to radiation and also has low thermal neutron absorption [41].

Composites

Composite materials with the exceptional versatility, low weight, and tailorable properties have been revolutionizing high-performance industries. The examples of composite materials are carbon fibers reinforced polymer composites [43] and glass fibers reinforced polymer composite [44]. Carbon fiber reinforced polymers composite structures are widely used in aerospace industry because of their high specific stiffness, strength, good corrosion resistance and good fatigue performance [43]. At the same time, glass fibers reinforced polymer composites are widely used for various applications in 3D printing application [44] and has great potential applications due to the cost effectiveness and high-performance [45]. Fiberglass have a high thermal conductivity and relatively low coefficient of thermal expansion. Furthermore, fiberglass cannot burn, and it not affected by curing temperatures used in manufacturing processes, therefore, it is very suitable for use in the 3D printing applicant [45].

Smart materials

Smart materials are defined as this material have the potential to alter the geometry and shape of object, influence by external condition such as heat and water [46]. The example of 3D printed object produces by using smart materials are self-evolving structure and soft robotics system. Smart materials also can be classified as 4D printing materials. The examples of group smart materials are shape memory alloys [47] and shape memory polymers [48]. Some shape-memory alloys like nickel-titanium [47] can be used in biomedical implants to micro-electromechanical devices application [37]. In the production of 3D printed products by using nickel-titanium, transformation temperatures, reproducibility of microstructure and density is the important issue. Meanwhile, Shape memory polymer (SMP) is a kind of functional material that responds to a stimulus like light, electricity heat, some types of chemical and so on [48]. By using 3D printing technology, the complicated shape of shape memory polymer could be easily and conveniently to produce. The quality evaluation of this material is performed based on the dimensional accuracy, surface roughness and part density [48].

Specials materials

The examples of special materials are:

- Food

  3D printing technology can process and produce the desired shape and geometry by using food materials like the chocolate, meat, candy, pizza, spaghetti, sauce and so on [49]. 3D-food printing can produce healthy food because this process allows customers to adjust the ingredients of materials without reducing the nutrients and taste of the ingredients [50].

- Lumar dust

  3D printing process has the capability to directly produce multi-layered parts out of lunar dust, which has potential applicability to future moon colonization [51].

- Textile

  With 3D printing technology, jewellery and clothing industry will be shine with the development on 3D-textile printing. Some advantage of 3D printing technology in fashion industry are short processing time to make the product, reduced costs related with the packaging and reduce supply chain cost [16].

4. The Applications of 3D Printing in Manufacturing Technology

Aerospace industry

3D printing technology provides unparallel freedom design in component and production. In aerospace industry, 3D printing technology has potential to make lightweight parts, improved and complex geometries, which can reduce energy requirement and resources [52]. At the same time, by using 3D printing technology, it can lead to fuel savings because it can reduce the material used to produce aerospace's parts. Furthermore, 3D printing technology has been widely applied to produce the spare parts of some aerospace components such as engines. The engine's part is easily damaged, which require regular replacement. Therefore, 3D printing technology is a good solution to the procurement of such spare parts [53]. In aerospace industry, nickel-based alloys is more preferred due to the tensile properties, oxidation/corrosion resistance and damage tolerance [54].

Automotive industry

Nowadays, 3D printing technology have rapidly changed our industry to design, develop and manufacture new things. In the automotive industry, 3D Printing technique have made phenomena to bring new shines, allowing for lighter and more complex structures in the fast time. For instance, Local Motor had printed the first 3D-printed electric car in 2014. Not only cars, Local Motors also extended the wide range application of 3D printing technology by manufacturer a 3D-printed bus called OLLI. OLLI is a driverless, electric, recyclable and extremely smart 3D printed bus. Furthermore, Ford is the leader in the use of 3D printing technology also apply 3D printing technology to produce prototype and engine parts [55]. In addition, BMW uses 3D printing technology to produce hand-tools for automotive testing and assembly. Meanwhile, in 2017, AUDI was collaborated with SLM Solution Group AG to produce spare parts and prototypes [56].

Consequently, by using 3D printing technology in automotive industry enable company to try various alternatives and emphasize right in the improvement stages, prompting ideal and effective automotive design. At the same time, 3D printing technology can reduce the wastage and consumption of the materials. Moreover, 3D printing technology can reduce costs and time, therefore, it allows to test new designs in a very fast time [57].

Food industry

3D printing technology open the doors not only for aerospace industry, but also for food industry. At present, there is a growing demand for the development of customized food for specialized dietary needs, such as athletes, children, pregnant woman, patient and so on which requires a different amount of nutrients by reducing the amount of unnecessary ingredients and enhancing the presence of healthy ingredients [58]. However, the development of customized foods must be conducted in a very detailed and inventive way, which is where the adoption of 3D-food printing appears. Food layer manufacture also known as 3D-food printing fabricated through the deposition of successive layers by layer derived directly from computer-aided design data [49]. By using 3D printing technology, specific materials can be mixed and processes into various complicated structures and shape [59]. Sugar, chocolate, pureed food and flat food such as pasta, pizza and crackers can be used to create new food items with complex and interesting designs and shape.

3D printing technology is a high-energy efficiency technology for food production with environmentally friendly, good quality control and low cost. 3D-food printing can be healthy and give benefit for human because it creates new process for food customization and can adjust with individual preferences and needs. By allowing food preparation and ingredients to be automatically adjusted to the consumer's information, it would be possible to have diets which enforce themselves without need to exercise [49].

Healthcare and medical industry

3D printing technology can used to print 3D skin [60], drug and pharmaceutical research [61], bone and cartilage [62], replacement tissues [63], organ [22], printing for cancer research [64] and lastly models for visualization, education, and communication. There are several advantages of 3D Printing technology for biomedical products which are:

- 3D printing technology can replicate the natural structure of the skin with the lower cost. 3D printed skin can be used to test pharmaceutical, cosmetics, and chemical products. Therefore, it is unnecessary to use the animal skin to test the products. Consequently, it will help the researcher to get accurate result by using replicate the skin [65].
- By using 3D printing technology to print drug can increase efficiency, accurate control of dropped size and dose, high reproducibility and able to produce dosage form with complex drug-release profiles [22].
- 3D printing technology is able to print cartilage and bone to replace bony voids in the cartilage or bone that caused by trauma or disease [66]. This treatment is different options from using auto-grafts and allografts because this treatment focuses on to generate bone, maintain, or improve its function by using in vivo.
- 3D printing technology also can be used to replace, restore, maintain, or improve the tissues function. The replacement tissues produced by 3D printing technology have the interconnected pore network, biocompatible, appropriate surface chemistry and has good mechanical properties [63].
- 3D printing technology also can be used to print out similar organ failure caused by critical problems such

as disease, accidents, and birth defects.

- 3D printing technologies are able to form highly controllable cancer tissues model and shows great potential to accelerate cancer research. By using 3D printing technology, the patients can get more reliable and accurate data.
- 3D printout models can use in the learning process to help neurosurgeons practicing surgical techniques. By using 3D model, it can improve accuracy, can take the short time to the trainer when performing clinical procedure, and provides opportunities for training surgeons hands-on, as the 3D model is a simulation of a real patient's pathological condition.

Architecture, building, and construction industry

3D printing technology can be considered as environmentally friendly derivative and it give unlimited possibilities for geometric complexity realization. In the construction industry, 3D printing technology can be used to print entire building or can create construction components. The emergence of the Building Information Modelling (BIM) will facilitate better use of 3D printing technology. Building Information Modelling is a digital representation of functional and physical characteristics, can share an information and knowledge about 3D building. It can form a reliable source for decision during its life cycle, from initial conception to demolition for construct or design the building [67]. This innovative and collaborative technology will support more efficient method to designing, creating and maintaining the built environment.

With 3D printing technology, companies can design and create the visual of the building in the fast time and inexpensively as well as avoid delays and help pinpoint problem areas. At the same time, with 3D printing technology, construction-engineer and their clients can communicate more efficiently and clearly. Much of a customer's expectations come from an idea, and 3D printing makes it simple to appear that idea beyond the dated method of paper and pencil [68]. The examples of 3D printed building are Apis Cor Printed House in Russia [67] and Canal House in Amsterdam [68].

Fabric and Fashion Industry

When 3D printing technology enters the retail industry, 3D printed shoes, jewellery [4], consumer goods and clothing [69] are emergence into the market. The combination of fashion and 3D printing may not seem like the most natural fit, but it is starting to become an everyday reality all over the world. For instance, big companies like Nike, New Balance and Adidas are striving to development the mass production of 3D printed shoes. Nowadays, 3D printed shoes are produced for athlete's shoes, custom-made shoes and sneakers [70].

Besides, 3D printing technology can spread creative possibilities for fashion design. Indeed, it makes it possible to makes shapes without moulds. In fashion industry, by using 3D printing technology, it can design and produce garments by using mesh system and also can print ornaments for traditional textile. Moreover, the application of 3D printing technology not limited to the fashion industry, but also can print leather goods and accessories. For instances, jewellery, watchmaking, accessories and so on [71].

The retailers and designers believe the purpose of creating fashion products by using 3D printing technology is not to duplicate current products, but to improve product design by offering personalised and unique products to customers [72]. The advantages of the product development by using 3D printing technology are the product is on-demand custom fit and styling. At the meantime, by using 3D printing technology, it can reduce the supply chain cost. Lastly, 3D printing technology can create and deliver products in small quantities in the fast time [73].

Electric and Electronic Industry

As 3D printing becomes more and more accessible to sciences, technology and manufacturing fields, the manufacturers are starting to see its potential realized in all sorts of interesting ways. Nowadays, various 3D printing technologies have already been used broadly for structural electronic devices like active electronic materials, electrode and devices with mass customization and adaptive design through embedding the conductors into 3D printed devices [74].

The production process for the 3D electrode by utilizing the Fused Deposition Modelling of 3D printing technique provides low-cost and a time efficient approach to mass producing electrode materials. Compared to commercial electrodes such as aluminium, copper and carbon electrodes, the design and surface area of the 3D electrode can be easily customized to suit a particular application. Furthermore, 3D printing process for the 3D electrode is fully automated, with a high degree of precision, made it possible to complete the printing process for eight 8 electrodes in just 30 minutes [75].

In addition, active electronic components are any electronic devices or components capable of amplifying and controlling the flow charges of electric. Besides, active devices also include those that can generate power. Examples of active electronic components include silicon-controlled rectifiers, transistors, diodes, operational amplifiers, light-emitting diodes (LEDs), batteries and so on. These components normally require highly elaborate fabrication processes compared to those used for passive components due to their complex functionalities [76]. 3D printing technology provides advantages for processing of product along with its electronics. With multi-material printing technology, the efficiency of electronic system may possibly be adopted in Industry Revolution 4.0, enabling more innovative designs created in just one process [37]. The development of a green electronic device with low-manufacturing cost, good safety, high reliability and rapid production, is urgently in demand to address environment pollutions in today's society [75].

5. Summary

This evaluation covers a wide range of 3D printing applications in the manufacturing sector. Currently, 3D printing technology is starting to be used in the production sectors; it has many advantages for individuals, businesses, and the government. Thus, research into strategies to accelerate the adoption of 3D printing technology must continue. The corporation and the government will be able to enhance and develop the infrastructure of 3D printing technology with the aid of additional information about the technology. In order to provide a general overview of the various 3D printing technologies, the materials utilised in the manufacturing sector, and finally the applications of 3D printing technology. In the future, researchers can do some study on the type of 3D printing machines and the suitable materials to be used by every type of machine.

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