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INTRODUCTION TO 3D PRINTING: TECHNIQUES, MATERIALS AND AGRICULTURAL APPLICATIONS

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Abstract: The Production of complex products is easily possible with the help of additive manufacturing. By using additive manufacturing products may be mass-produced. Compared to traditional subtractive manufacturing, Additive manufacturing is advantageous in short design cycles, suitable for manufacturing complex structures, and high material utilization. Polymers and composites are frequently used in AM technologies, which have evolved into a variety of industrial and emerging applications. Among the many materials currently used in 3D printing are ceramics, metals, polymers, and concrete. ABS and PLA thermoplastics are the most often used materials for agricultural 3D printing since they are easy to print and relatively cheap. This article provides an overview of 3D printing technologies, materials, and applications in agriculture.

Keywords: additive manufacturing, technologies, materials, agricultural, 3D printing techniques

1. Introduction

Three-dimensional printing is a buzzword in the material manufacturing world of materials manufacturing, and it has lately been the focus of the investigation by materials scientists. This technology has grown rapidly in recent years and is expected to revolutionize manufacturing sectors by enabling the development of next-generation high-performance materials. Additive manufacturing (AM) could be defined as "the process of joining materials to produce parts from 3D model data" Often layer upon layer, as opposed to formative and subtractive manufacturing methods. The AM process fuses, cools, and solidifies to create 3D geometries without adopting complex molds [1].

Additive manufacturing has been advantageous at short design cycles, suitable for manufacturing complex structures, and high material utilization compared to traditional subtractive manufacturing. Therefore, additive manufacturing has been widely used in manufacturing parts and devices for aerospace [2], aviation [3], automobiles [4], medical devices [5], construction [6], clothing [7], and so on. This technology creates objects by adding materials to reduce waste while reaching satisfactory geometric accuracy [8]. It is begun with a meshed 3D computer model that could be created by acquired image data or structures built in Solidworks or computer-aided design (CAD) software. An STL (Surface Tessellation Language) file is commonly created, Figure 1. the process of 3d printed product. These three technologies combined together made possible the printing of three-dimensional objects sent to the 3D printing machine[9, 10]. Speed, direct data translation, management of complicated geometry, high precision, environmental benefits, and cost-effectiveness are just a few of its features.

The main methods of AM: additive manufacturing of powders by selective laser sintering (SLS) [12], liquid binding in three-dimensional printing (3DP) [13], as well as inkjet printing, contour crafting, stereolithography [14], laminated object manufacturing (LOM) [15] and the most common method of 3D printing that mainly uses polymer filaments is known as modeling (FDM)[16].

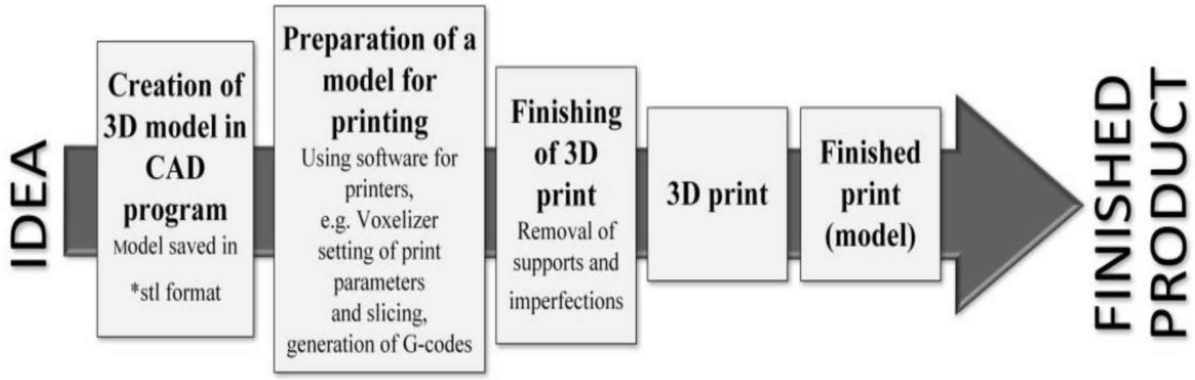

Figure 1. The process of 3d printed product [11]

Additive manufacturing become more prevalent in industrial applications that require high performance, like rapid prototyping, rapid manufacturing, rapid tooling [17–21], advanced electronics [22], water filtration, and desalination [21, 23], medical applications [24], and others. In agriculture, 3D printing is mainly useful for manufacturing agricultural equipment [25] and spare parts [26] without greatly affecting their quality. There are various materials and printing technologies for 3D printing. One of the most popular 3D printing technologies used in agriculture is Fused Deposition Modeling (FDM) because it offers consumer-grade materials/filaments like polylactic acid (PLA) thermoplastic and acrylonitrile butadiene styrene (ABS) [17]. The reason why 3D printers are very common in all kinds of industries is obvious because this technology offers distinct advantages Figures 2. shows the percentages of disciplines ranging from motor vehicles to medicine, from academic work to many others.

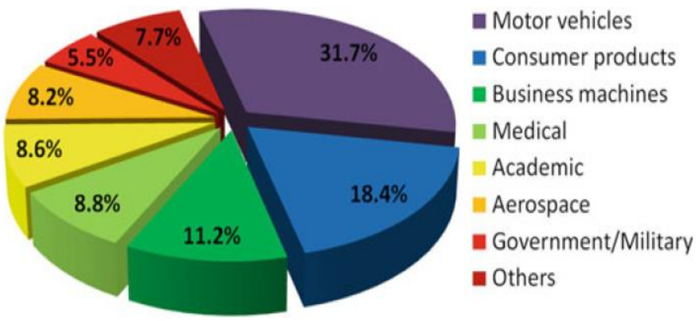

Figure 2. The range of 3D printing used by discipline [27].

2. Methods of 3D printing technologies

Additive manufacturing (AM) methods were developed to meet the demand for printing complex structures at high resolution, Figure 3. Rapid prototyping, the ability to print large structures, the reduction of printing defects, and the improvement of mechanical properties are one of the key factors that have been driven the development of AM technologies [28].

2.1 Selective Laser Sintering

Selective laser Sintering (SLS) is a method that employs a laser as the source for layer-by-layer sintering of powder into a single object [1]. The processes of sintering and melting (SLS/SLM) are identical. The configuration of SLS employing a CO2 laser is shown in Figure 4. Because the laser is the source of the binding, light rays are not permitted inside the chamber during printing [30]. The powder fills in the vat for layer spreading. The platform then moves in the z axis, spreading the powder across the next layer for sintering. The procedure is repeated till the item is finished. Metal powders are utilized in this process to make a component that may be used as a finished product [1, 30]. Electron Beam Melting (EBM) uses an electron beam source as energy to melt layers of material utilizing a vacuum chamber and a heated platform, similar to the electron beam. For better surface hardness and strength, use cyanoacrylate or epoxy resin in Figure 5.

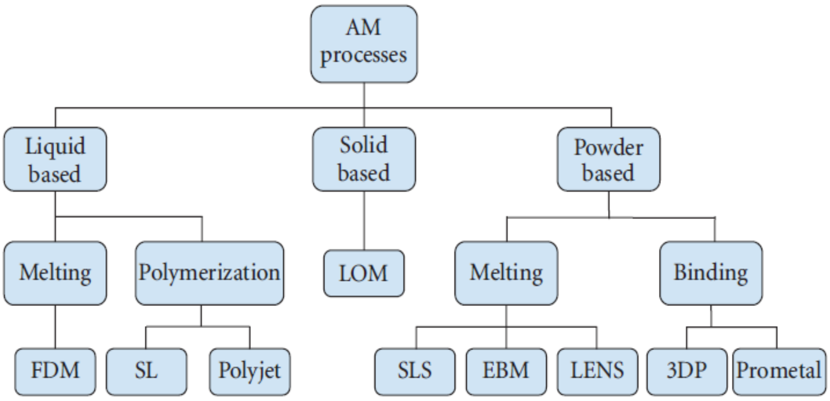

Figure 3. Three Dimension printing processes.

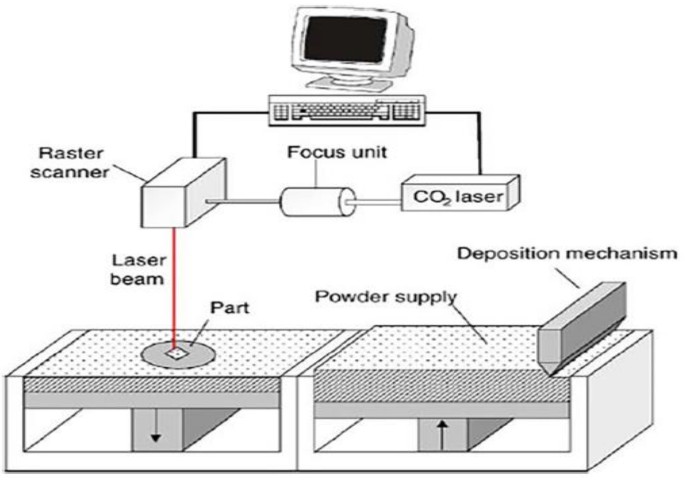

Figure 4. Selective Laser Sintering (SLS) layout

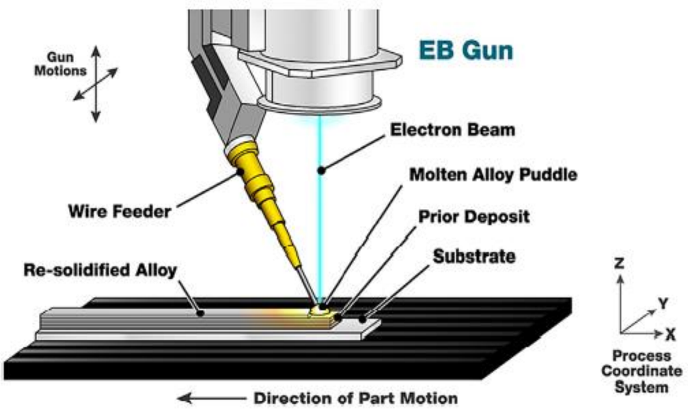

Figure 5. The nozzle of Electron Beam Melting (EBM)

2.2 Stereolithography (SLA)

A stereolithography Apparatus is built layers on resin layers by using light projectors or scanning lasers [31]. The resins which are used here are photopolymers cured by light [32]. Every layer is created by drawing light or laser on the resin surface on the construction platform (Figure 6.). Once the layer is built, the platform moves immersion into the resin and a coating is used to align the resin layer with the layer thickness in the input parameters [33]. The major limitation in this process is the size of the objects created. The process is performed in a light-proof room because the resin is light sensitive. If the support area is increased, the deposition of the resin layer might create an uneven layer. This process is used in dental applications and smaller parts such as molding gold ornaments, etc.[34] Casting resin could also be used for the production of dental parts. Direct end-use components for dental purposes can also be manufactured using the SLS technique.

2.3 Laminated Object Manufacturing

Laminated Object Manufacturing (LOM) is a process which is combines additive and subtractive techniques to build up a part layer by layer shown in Figure 7. In this process, the materials are in the form of sheets. The layers have been bonded together using pressure and heat, as well as a thermal adhesive coating. A laser of carbon dioxide cuts the material into the shape of the individual layers using the information from the 3D model which is created by the CAD and STL files. The advantages of this process are the low cost, no need for post-processing or supporting structures, no deformation or phase changes during the process, and the ability to produce large parts. The disadvantages are the low surface sharpness, the directionality of the materials in terms of machinability and mechanical properties, and the difficulty of building complex internal cavities. This method can be used for models made of paper, metal, and composite [9, 35].

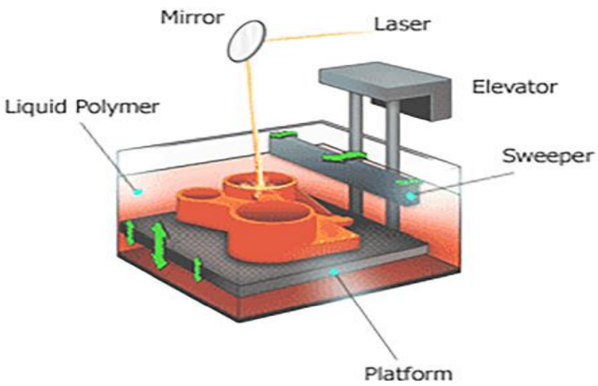

Figure 6. Stereolithography

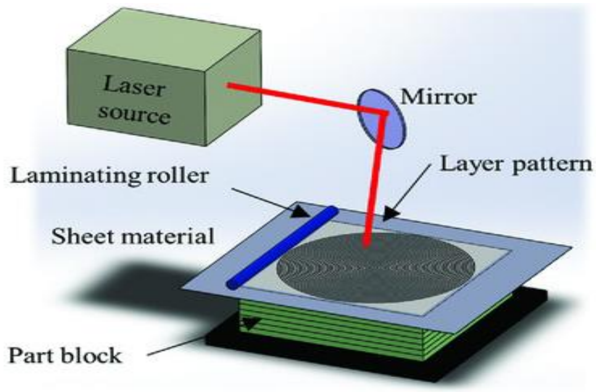

Figure 7. Laminated Object Manufacturing (LOM)

2.4 Inkjet printing and contour crafting (IJP)

The liquid resin is passed through a micro nozzle to create a thin layer on the platform. The extruder head's movement occurs in the contour created by the shape of the part during cutting. Curing of the resin is done in the air for some resins, but mostly often the resin printed objects are held in UV curing for better cure and stiffness [36].

2.5 Binder jetting

It is a process and technology that uses powder-based binders and materials. A liquid binder (adhesive) is placed in a thin layer of powder particles like ceramics, metal, composites, or sand to build the parts. An object is made layer by layer while the binder is placed in a powder bed to form a solid object [36]. The binder is responsible for holding the powder layer together [36]. Materials used in binder jetting include, silica, metal, ceramics, sand, and polymers in the granular form [37].

2.6 Directed energy deposition

Directed energy deposition is the most complex printing process often used to add additional material to or repair existing components [38]. Directed energy deposition allows the grain structure to be highly controlled and the good quality of the object to be achieved. This process is similar in principle to materials extrusion but here the nozzle is not fixed to a specific axis and may move in multiple directions. In addition, this process could be used for ceramics and polymers but is usually used for metals and metal-based hybrids in the form of wire or powder. An example of this technology is laser engineered net shaping (LENS) and laser deposition [38]. Laser deposition is an emerging technology and may be used to fabricate or repair parts that are in millimetres to meter range. Laser deposition technology is gaining traction in the transportation, aerospace, tooling, and oil and gas industries because it offers scalability and multiple capabilities in a single system [36]. Meanwhile, the laser LENS can use thermal energy for melting during casting and the parts are subsequently finished [39].

2.7 Fused Deposition Modeling (FDM)

Fused filament fabrication (FFF) or Fusion deposition modelling (FDM) is an old method for manufacturing parts in the AM process (Figure 8.). In this process, the source material is filaments made of various thermoset plastics [40]. Some materials are biodegradable polymers (PLA), which are used as key elements in scaffold structures [41, 42]. Extruder nozzles of various diameters are used to melt the filament in a semi-solid condition and make it flow on the platform [43]. Most often, the extruder moves in the x and y directions reading the g-code which is created by the slicing software. On some machines, the extruder moves in the z-direction, on others the platform does. For some materials, the platform must be heated to improve the adhesion and prevent warping [43]. Filaments with higher melting points are difficult in part production. When complex structures are created the support structure is formed. These support materials can be made of the same material or different materials. For some designs, the support materials can be easily removed, but when it comes to complex structures, removing the support materials presents some difficulties. Ultimaker has developed a water-soluble support material that leaves no trace in the supporting parts and creates a clear part. Dynamic structures may be easily created with this type of support material. The accuracy of the part that had been created depends on the movement of the extruder, the temperature, the speed, and the flow rate of the material during the nozzle. The FDM is widely used for creating anatomical models in dentistry and surgical exercises [44]. Table 1. Summary of materials, application, advantages, and drawbacks of the main additive manufacturing methods.

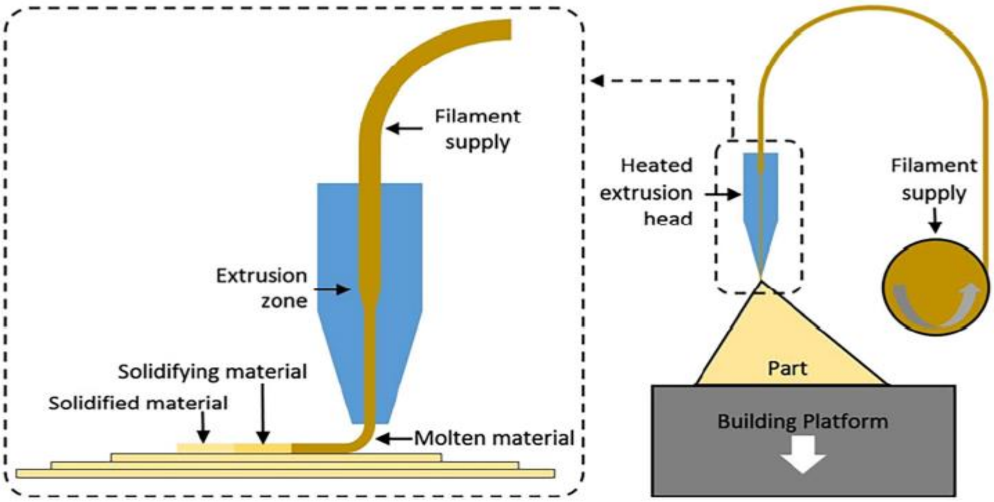

Figure 8. Fusion Deposition Modelling (FDM).

Table 1. Summary of materials, application, advantages, and drawbacks of the main additive manufacturing methods [45, 46].

Method	Description	Materials	Applications	Benefits	Drawbacks	Resolution range (µm)
Inkjet Binder Jetting (IBJ)	Drop-on-demand Binder	Ceramic, Powder of metals, concrete Sand, and soil	Structures Buildings Biomedical Large	Quick printing Ability to print large structures	Lack of adhesion between layers Layer-by-layer finish. Maintaining workability Coarse-resolution	Inkjet: 5–200 µm Contour crafting: 25–40mm [32]
Laminated object manufacture	Builds parts by Cutting sheets of material and assembling them together in layers	Ceramics Polymer composites Metal rolls Paper Metal-filled tapes	Electronics Paper manufacturing Foundry industries Smart structures	Low cost Reduced manufacturing and tooling time A vast range of materials Very good for manufacturing of larger structures	Limitation in manufacturing of complex shapes Inferior surface dimensional accuracy And quality	Depends on the thickness of laminates
Stereolithography	UV induced curing Laser scanning and	A resin with photo-active monomers	Biomedical Prototyping	High-quality Fine resolution	Slow printing Very limited materials Expensive	10 µm [13]
Selective Laser Sintering (SLS)	Heat and Laser scanning induced sintering	ceramics Plastic; metals;	Aerospace Biomedical Lightweight Electronics structures (lattices)	High-quality Fine resolution	Expensive Slow printing	80-250 µm [13]
Direct energy deposition	Builds parts By directing thermal energy to fuse materials when applied to a substrate.	Metals and alloys in the form of powder or wire Ceramics and polymers	Aerospace Retrofitting Repair Cladding Biomedical	Excellent for repair and retrofitting Reduced mechanical properties are Controlled microstructure Accurate composition control manufacturing time and cost Excellent	Low surface Need for a dense Low accuracy quality Limitation in printing complex shapes with fine details support structure	250 µm [23]
Fused deposition modeling	Creates objects by Extrusion material through a nozzle to build layers	Polymer; composites; cement; aggregates	3D curve printing, Aggregate, Rapid prototyping advanced composite parts	High speed Simplicity Low cost	Limited materials (only thermoplastics) Weak mechanical properties Layer-by-layer finish	50-200 µm [13]

3. Materials that are used in 3D printing

While engineers have focused on improving equipment function and AM methods, applications of various 3D printing technologies evolved on developing the best 3D printing materials through scientific research. For 3D printing of polymers, thermomechanical properties, reactivity (or stability), stimulability, and hybrid materials are important factors. Practical considerations emphasized durability, price, strength, frequency, and safety to animals, humans, and the environment. To date, various polymeric materials such as thermoplastic materials including acrylonitrile butadiene styrene (ABS), polylactic acid (PLA), polyethylene terephthalate glycol (PETG), and polyether ether ketone (PEEK), have been widely used. Thermosets and elastomeric materials for 3D printing are usually made from better-formulated starting materials such as acrylates. These materials can be used in different forms, such as liquid resins, filaments, powders, etc. The following discussions focus on the common and widely known polymer materials used for agricultural 3D printing and do not claim to be exhaustive.

3.1 Polylactic Acid

PLA (Polylactic acid) [45, 46] is a biodegradable thermoplastic polymer compound. It's a non-toxic, ecologically friendly aliphatic polyester made from lactic acid (derived from animals and plants) that's used to make films, textiles, and bottles. PLA has excellent mechanical qualities and, because of its biodegradability, can be used to replace petroleum-based polymers [47]. PLA has quite a high melting and boiling point than nylons and ABS, which is one of its greatest benefits in 3D printing [48]. PLA is very useful in medical technologies due to its compatibility. Also, it is a good material for disposable food packaging because of its biodegradability [49]. Previous works [17, 49, 50] have detailed in detail the significant physical features including thermal and mechanical of PLA material. PLA has low heat resistance and brittleness, properties that limit its potential applications compared to ABS [51]. However, its biodegradable property is an important reason why it can be used in numerous biomedical applications such as drug delivery microspheres, tissue engineering, and bone fixation [52]. The chemical structure of PLA can be found elsewhere [53].

3.2 Acrylonitrile Butadiene Styrene (ABS)

ABS is a commonly used thermoplastic substance in 3D printing, especially for FDM. Acrylonitrile, which offers chemical resistance and impact resistance, Butadiene, which provides toughness and impact resistance, and Styrene, which provides rigidity and ease of manufacturing, are the three components of ABS [54]. It is a material that is amorphous, rigid, hard, and abrasion-resistant [55]. ABS, like other polymer materials, melts when heated and solidifies when cooled. Because it can be reshaped or remodelled at a certain temperature, it is an excellent polymer for FDM [56]. In previous works[17, 54, 57], several research groups described the material ABS's other physical features (mechanical, thermal, and so on). When ABS is used, hazardous fumes are released during printing, a well-ventilated area, and requiring proper handling [57]. Some examples of 3D printing applications of the material ABS are wheel covers, dashboards, and car body parts. It could also be used for the body of devices such as vacuum cleaners, telephone sets, and cameras. It can also be used for medical equipment [58].

3.3 Nylon or Polyamide

Polyamide (PA), sometimes known as nylon, has grown in importance in 3D printing. Although the printed material has extraordinary elasticity, high tensile strength, and excellent tribological properties, it is moisture sensitive[59]. This material is available in powdered or filament form and is based on 3D printing processes such as multi-jet fusion (MJF), FDM, and SLS.

PA can be further classified depending on their chemical composition, particularly the number of carbon atoms (n). PA6, PA11, and PA12 are the most prevalent PA (n) on the market, and they're used in FDM. PA6 is the most widely available chemical. It has a lot of elasticity and can withstand a lot of wear and tear. Nylon, on the other hand, must be printed on a heated plate (about 80°C) to minimize adhesion problems and moisture absorption in the environment, which might compromise print quality. The extrusion temperature should be between 220-250°C [60] depending on the kind of nylon. Other advantages of using PA in the medical field include biocompatibility with human tissue, robust mechanical properties, chemical stability, high toughness, excellent wear, and sliding properties. These are the reasons why PA is used not only in engineering and OEM manufacturing but also in biomedical applications [61].

3.4 Recycled 3d Filaments

Plastic recycling technologies are not new to research, but the raw materials for 3d printing are not yet made from recycled plastic. There is research in the field of Development of 3D Printing Raw Materials from Plastic Waste. More research is being done on the recycling of plastics to make new raw materials suitable for 3D printing from waste [68, 69, 70]. [68], [69], [70].

The PET is recycled quite frequently and has the number "1" as its recycling symbol, and after drying PET prepared for extrusion, then material is shredded and dried, its ready to be extruded. The ‘Next filament extruder’ was used for the extrusion of PET (shredded format), with 3 different diameters of shredded material and constant range of temperature heater and speed of fan speed, the measurement can be ready after 3 or maximum 5 tests. Recent research points the way towards chemical recycling methods with lower energy requirements, compatibilization of mixed plastic wastes to avoid the need for sorting, and expanding recycling technologies to traditionally non-recyclable polymers. They mentioned the recycling technologies from which they concluded that mechanical recycling is the only widely adopted technology for large-scale treatment of plastic solid waste. The main steps were the removal of organic residue through washing, followed by shredding, melting, and remoulding of the polymer, which is often blended with virgin plastic of the same type to produce a material with suitable properties for manufacturing.

4. 3D Printing applications in agriculture

4.1 Printing technology and materials

FDM is the most widely utilized printing method for producing different agricultural implements and equipment. Agricultural equipment such as sprinklers and hose manifolds for irrigation [62], spare parts for machinery such as corn augers [63] and gears [64], and seed application equipment are all made from thermoplastics, particularly PLA and ABS. [65]. Farmers can also make customized tools from PLA, such as a fruit picker and shovel, because the material is biodegradable and recyclable [62]. Although these thermoplastics differ slightly in properties such as heat resistance and stiffness, their (low) cost and ease of use in 3D printing make them the most commonly used filaments. Table 1 highlights the application, material, and 3D printing method which is used in the field of agriculture.

4.2 Urban farming

While there are many numerous innovations for optimizing bulk harvesting, 3D printing can provide a simple mechanism for picking up high-hanging fruit without the use of ladders. The 3D-printed parts of the tool may be assembled with conventionally manufactured components such as the wooden handle, screws, and spring to create the three claw fruit picker and 3D printed corn shellers are shown in Figure 9,10 [62]. PLA (Polylactic acid) proves useful in the material composition of parts produced by fused deposition modelling because it is biodegradable and recyclable. This eliminates unnecessary waste generated by conventional manufacturing and thus promotes sustainability.

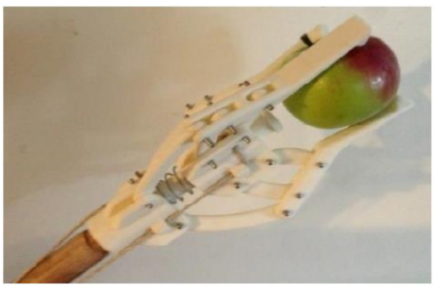

Figure 9. 3D printed fruit picker [63]

Figure 10. 3D printed corn-shellers [63]

4.3 Irrigation and water management

The adapter/garden hose manifold shown in Figure 11. [62] is an example of water management and irrigation equipment that may be created using 3D printing. This add-on device's design might be altered to allow water to flow in several directions from a garden hose. The most popular material for 3D printing items and components is thermoplastic, which may be highly beneficial in agricultural water distribution systems since it can replace pricey, original parts. PLA thermoplastic is used as a printing medium in this application due to fused deposition modelling.

The 3D-printed spigot shown in Figure 12. was made specifically for a 5-gallon bucket [62]. It is made from the thermoplastic PLA using FDM technology. Additive Manufacturing, can be used to customize the size and dimensions of such a tool with a unique design and attachments like a contour that fits the specific water container. The technology enables efficient production and cost-effectiveness and of these parts.

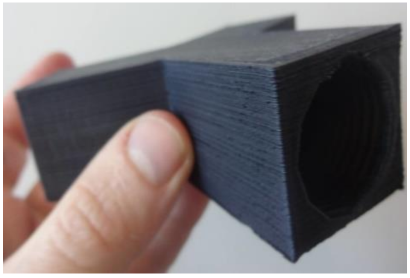

Figure 11. 3D printed garden hose splitter [66]

Figure 12. 3D printed spigot [66]

Table 2. 3D printing techniques, materials, and application used for 3D printing in agriculture [62].

3D Printed Part	*3D Printing Technique*	*Material/Filament*	*Application*	*Reference*
Shovel and handle	FDM	PLA	Urban Farming	[62]
Fruit picker	FDM	PLA	Urban Farming	[62]
Sprinkler	FDM	ABS	Irrigation	[66]
Hose splitter	FDM	PLA	Irrigation	[62]
Corn Auger	FDM	PLA	Spare Part	[63]
Gear	FDM	Polymeric material	Spare Part	[64]
Spigot	FDM	PLA	Water Management	[62]
Packer bottom	FDM	ABS	Testing Equipment	[65]

5. Conclusion

3D printing is now used in many different fields. From manual labour to making machines that help us fabricating the products we consume and the parts which have practical applications. Additive manufacturing allows us to take our thoughts from the digital to the tangible also this technology allows us to save time and capital that we would have to spend on conventional manufacturing methods, which often involve lengthy and complicated processes. 3D printing can foster entrepreneurship among young people by allowing them to design and print their own models and potentially use of the technology as a business. Such businesses can also lead to collaboration between professional designers, entrepreneurs, and especially farmers, who are the main beneficiaries of additive manufacturing in agriculture. Research and development could be conducted to further increase the efficiency and quality of manufacturing and to find new materials that could be used as alternatives to common 3D printing materials such as thermoplastics [67].

With the advent of large-format 3D printers, large parts of at least 1 cubic meter, can now be produced, further expanding the applications of 3D printing. This paper showed some use cases of 3D printing in agriculture. Specifically, the different materials used in 3D printing parts and the different printing technologies were discussed.

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