3D printing in agriculture - review

3D nyomtatás a mezőgazdaságban - áttekintés

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Abstract: Additive Manufacturing techniques are more and more popular in the word. The most popular name of it is 3D printing. This solution is used in many different areas and applications. This work is a review that concentrate the applications of 3Dprinting in agriculture. The paper discusses the different tools and devices used in agricultural producing, sensors that can be used for process monitoring. In both fields There are many types of raw material that use in this technology, but the most popular at the PLA and the ABS. The popularity of these come from the low prise and the easy and many side usability. An interesting area of printable materials is the usage of agricultural wastes such as nut and crab shells, etc. An interesting usage of 3D printing when we are printing food. This should be helps for sick person who has swallowing problems or unique look at can be created with it for example for a restaurant.

Keywords*: 3D printing; agriculture; food processing*

Összefoglalás: A 3D nyomtatást - hivatalos nevén additív gyártás - számos különböző alkalmazásban használják már sikeresen a világon. Ez a cikk a 3D nyomtatás mezőgazdasági, élelmiszer-feldolgozási és felügyeleti felhasználási eseteinek áttekintését mutatja be. A munka bemutatja a mezőgazdasági termelésben használt különböző eszközöket és berendezéseket, valamint olyan érzékelőket, amelyeket ennek a technológiának a segítségével lettek hatékonyabbak/olcsóbbak/jobbak. Bár számos nyomtatási alapanyagot ismerünk a műanyagtól a fémig, mégis a PLA és az ABS hőre lágyuló műanyagok a legelterjedtebbek, mivel a többihez képest olcsóak és könnyen nyomtathatóak. Az alapanyagok közül érdekes terület a mezőgazdasági hulladékok, melyekre kiváló például a dió- és rákhéjak felhasználása. Egy másik fontos alkalmazás az élelmiszerek közvetlen extrudálása, amely segítséget tudnak nyújtani a nyelési nehézségekkel küzdő embereknek, hogy könnyebben és jobb minőségben tudjanak táplálkozni. További előnye ennek az eljárásnak, hogy speciális étrendek alakíthatóak ki, amely testre szabható és változatos étrendet eredményez. A 3D nyomtatás alkalmazási területei várhatóan bővülni fognak és egyre újabb és újabb területek fog megjelenni.

Kulcsszavak*: 3D nyomtatás; mezőgazdaság; élelmiszer feldolgozás*

1. Introduction

In various industries, there is a growing focus on 3D printing in the field of manufacturing. Due to its widespread adoption, it offers a sustainable and efficient method for creating various objects layer by layer (Dizon et al., 2018). This technology significantly reduces waste and production time compared to traditional manufacturing, which often involves subtractive processes, where a portion of the material is removed from a larger whole to create the desired product. An undeniable advantage of 3D printing over traditional manufacturing is its ability to create complex shapes, some of which may be unachievable with current technologies. The burden of high costs associated with traditional manufacturing is also greatly reduced through additive manufacturing (Dizon et al., 2020).

Additive manufacturing is widely used in various fields, including the construction industry, electronics, automotive manufacturing, personal protective equipment, space exploration, the study of various marine life forms, defence, and more (Carolo and Haines, 2020, Espera et al., 2019, Advincula et al., 2020, Al-Dulimi et al., 2021, Wong, 2016, J. Mohammed, 2016, Peels, 2017). Furthermore, 3D printing is becoming increasingly prevalent in industrial applications where time is a critical factor, such as rapid prototyping, rapid tooling, and fast production (Dizon et al., 2018, Diego et al., 2021, Dizon et al., 2021, Valino et al., 2019, Dizon et al., 2019, Dong et al., 2015). Additive manufacturing is also finding broader applications in the medical field (Advincula et al., 2020), water purification and desalination (Dong et al., 2015, Tijing et al., 2021). In agriculture, 3D printing is primarily used for the production of agricultural tools (Pearce, 2015) and components (Podchasov, 2021a). The food industry primarily uses 3D printing to accelerate personalized nutrition (Derossi et al., 2018) and to assist individuals with swallowing difficulties in increasing their food intake (Pant et al., 2021). Regarding environmental protection, relevant applications of additive manufacturing include the use of recycled filaments (M. I. Mohammed et al., 2019) and components for devices used in air quality monitoring (Salamone et al., 2015) and wastewater treatment facilities (Martín de Vidales et al., 2019).

There are numerous 3D printing technologies, each of which uses various materials. One of the most popular technologies is fused deposition modelling (FDM) because it offers consumer-grade materials (filaments) such as acrylonitrile butadiene styrene (ABS) and polylactic acid (PLA) (Dizon et al., 2018). Additionally, it can be used to directly 3D print food using the printer head. It can build food layer by layer or pour it into a mold (for example, 3D-printed puree (C. Liu et al., 2018)), which can also be created using 3D printing technology.

The application of 3D printing represents the future of manufacturing across various industries and sectors (Jan Lloyd at al., 2021). It is a revolutionary technology where efficiency and sustainability go hand in hand, offering significant improvements in the way we design and manufacture products. This overview article provides insights into the applications of 3D printing in agriculture, food production, and monitoring, as well as the applied technologies and materials used in these fields.

2. Overview of Additive Manufacturing

Manufacturing can be divided into groups according to many aspects. One such breakdown defines two broad groups. One is the additive - and the other is subtractive manufacturing. Subtractive manufacturing is the process of removing parts from a solid material to create the desired tool. One of the best known of these techniques is CNC machining. While additive production builds it layer by layer. Both technologies have advantages and disadvantages. We will make an overview only from the latter now. 3D printing usually goes through a 5-step

process. First, a 3D model is created using computer-aided design (CAD) software. Then this model is converted into a Standard Tessellation Language (.STL) file. The 3D printer can read the geometry of the surface with the help of STL file. The model is then sliced into several layers so that printing instructions can be sent to the 3D printer. The model is then materialised in the additive manufacturing system (3D printer) where the object is extruded layer by layer. Finally, post-processing takes place to improve the print quality of the 3D printed object (Dizon et al., 2018).

We know many different 3D printing technologies. In addition to fused deposition modelling (FDM) based on extrusion, stereolithography (SLA) is a common 3D printing technology, often using light-curing resin as a material. Digital light processing (DLP) uses a projected digital image instead of a laser, which allows the printing process to proceed much faster, compared to SLA. You can see schematic figure from the operating principles in the Figure 1. Another solution the selective laser sintering (SLS) that uses a laser as a heating source that selectively sinters a powdered polymer such as resin or metal to create a 3D printed model. Next to the previous techniques there are other 3D printing for example the electron beam melting (EBM), the multijet fusion (MJF), laminated object manufacturing (LOM) and direct metal laser sintering (DMLS).

PLA and ABS are widely used materials for 3D printing. Both of them are associated with consumer FDM printing technology. There are many kinds of colour variation of these filaments. These are very popular because of their strength, rigidity, printability, cost-effectiveness, and other favourable properties (Markforged, 2021). Resins belong to other materials include, which exhibit high-quality prints with transparent and smooth surfaces. Polyamide nylon-based powders are also popular because of highly detailed and flexible printed items (Company, 2017). Jewellery industry can use precious metals such as gold, silver and brass with this solution (i.materialise, 2021).

3. 3D printing in agriculture

Indeed, 3D printing can play a significant role in agriculture. This encompasses the creation of tools and equipment to support production, optimization of production conditions, and even the customization of end products. Additionally, it offers opportunities for recycling and reusing waste generated in the food industry.

3.1. Printing tools and devices

3D printing indeed enables the rapid and flexible production of custom agricultural tools and equipment. For instance, machine components (Garuda3D, 2023, Podchasov, 2021a), spray nozzles (ProximityDesigns, 2023), fertilizer spreaders, hose splitters for irrigation (Pearce, 2015), seed planting tools (Halterman, 2023), or even garden implements can be easily and cost-effectively produced using 3D printing. The most commonly employed technology for this purpose is Fused Deposition Modeling (FDM), while thermoplastic materials like PLA and ABS are frequently used for the printing process.

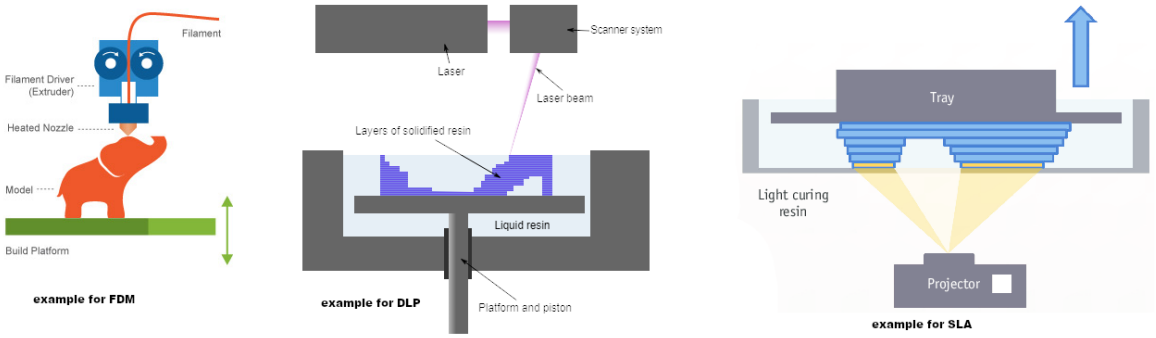

Figure 1. *Example for 3d printing technologies.*

The technology also offers significant potential for manufacturing personalized tools that cater to the unique needs of farmers and are often not commercially available. One example is the fruit tree picker and shovel, where 3D-printed parts of the tools can be combined with traditionally manufactured components like wooden handles, springs, and screws (Pearce, 2015). The advantage of the fruit picker shown in Figure 2 is that it allows for the retrieval of high-hanging fruits without the need for a ladder, making the work faster, safer, and less physically demanding.

It's important to note that while the PLA materials used here may vary slightly in their properties, such as rigidity and heat resistance, they are still the most commonly used thermoplastic filaments due to their low cost and ease of use in 3D printing. Another significant advantage is that the 3D printing process avoids the generation of unnecessary waste associated with traditional manufacturing. Additionally, since PLA is biodegradable and recyclable, its use promotes sustainability. Table 1 summarizes the applications of tools, materials, and 3D printing techniques used in agriculture (ProximityDesigns, 2023, Pearce, 2015, Halterman, 2023, Garuda3D, 2023).

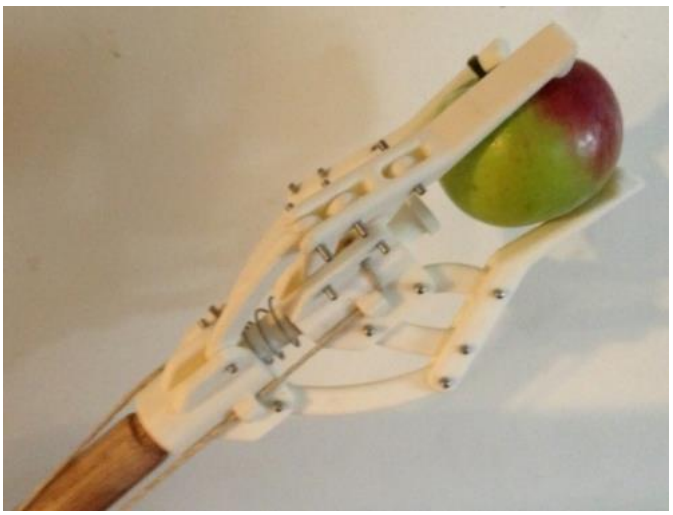

Figure 2. *Fruit picker from 3D printed material and wood.*

Table 1. Applications examples on 3D printing in agriculture (Jan Lloyd at al., 2021).

Printed part	Application	Printing technique	Material
Tube distributor	Irrigation	FDM	PLA
Sprinkler	Irrigation	FDM	ABS
Paddle and handle	Urban farming	FDM	PLA
Picker	Urban farming	FDM	PLA
Packing bottom	Testing equipment	FDM	ABS
Spigot	Water management	FDM	PLA
Corn auger	Spare part	FDM	PLA

3D printing opens up the possibility of creating various cultivation systems and accessories. This can include containers, supports, frames, or even plant containers needed for hydroponic or aeroponic systems (3Dponics, 2023). Another opportunity is the manufacture of irrigation and water treatment equipment through 3D printing. An example of this is the fruit picker that you can see in Figure 2. (Pearce, 2015), which demonstrates how you can modify an accessory to allow for multi-directional water flow from a garden hose. Thermoplastic materials are also used here to produce the components, which can greatly assist in replacing costly original parts in farm water distribution systems.

Figure 3 show an example for spigot that was printed with the help of 3D printing technique (Pearce, 2015), (Jan Lloyd at al., 2021). PLA was the raw material in this exact example and of course the applied technology was FDM (Fused Deposition Modelling). Unique size and scaling are needed many times in the practice. The Additive Manufacturing can give solution for this challenge in easy way. We can do personalisation our ideas with the help of 3d planning solutions. Today, this technology provides efficient and cost-effective solutions to the challenges mentioned above.

Figure 3. *A 3D printed spigot.*

3.2. Sensors and data logging

Absolutely, in modern agriculture, the use of various sensors and data collection solutions has become essential across many areas, whether it's crop cultivation or animal farming. Each field has its own unique characteristics and requirements. With 3D printing, it's possible to create customized tools and enclosures that, when combined with traditional sensors, can effectively

support agricultural applications. This allows for tailored solutions that can enhance efficiency and precision in farming practices.

Monitoring air quality can be crucial in many places. The "nEMos" is such a device produced with 3D technology (from PLA material), which, due to its ease of portability, can be applied in various contexts and even over large geographical areas. (Salamone et al., 2015). In the case of various wastewater treatment solutions, flexible materials that can be used to build specialized filters can be particularly useful. Nylon, as a 3D printing material, combined with sensors and alternative automated adjustable water pathways, can create an efficient water pre-filter (Podchasov, 2021b). The further treatment of this process can be aided by the application or combination of ceramic (Natives, 2019) and/or membrane-based (Tijing et al., 2020) 3D-printed water filters in the aforementioned solution.

It's essential to recognize that 3D printing opens up new possibilities for the location-specific deployment and application of traditional sensor solutions. In practice, this can involve housing or integrating sensors with specialized, otherwise difficult-to-assemble solutions that can enhance the efficiency of the intended application. Collecting and transmitting sensor data to a central database is a crucial part of this process, and there are several methods to achieve this.

In the simplest case, the deployed data collector (equipped with sensors and/or actuators) locally stores the data (e.g., on an SD card) and, from time to time, a person collects this data and inputs it into the central database. In more advanced scenarios, this process can be fully automated, with data flow occurring through a communication channel. It's important to prepare these systems for potential disruptions, such as intermittent server connectivity.

In this context, 3D printing plays a significant role in creating specialized enclosures and housings that are ideal for the specific operating environment. This can encompass everything from meeting specific attachment and spatial requirements to resistance against various environmental factors, including exposure to organic materials.

3.3. 3D Printing Applications in Food

At first glance, it may seem strange that 3D printing can be used in the food industry, but there are many useful applications. Of course, we work with completely different materials than classic 3D printing technology. In this sector again, extrusion-based 3D printing (FDM), is the most widely used printing technology. In this case, the raw material is mostly edible. In a significant number of cases, classic materials have to be reworked, made denser or softer, i.e. printable. In practice, this means mixing 3D-printed purees with a certain number of thickening additives. It should be for example include meat slices mixed with gelatin and the use of pectin in fruit-based snacks (Derossi et al., 2018), (C. Liu et al., 2018). Another example is Mashed potatoes are made from potato flakes containing gelatinised starch, which is known to be an ideal raw material for the production of finished products due to its low post-processing requirements (Z. Liu et al., 2018). Important to know there are many vegetables such as corn, carrots, peas and turnips that can also be 3D printed, as they are relatively easy to produce and inexpensive food colours.

Figure 4. *Example for 3D Printing Applications in Food.*

Next to the raw materials the usage is also important. There are many areas where this technology is more accurate, faster, more predictable and more standardizable than the traditional way. In the case of confectionery, for example, using a cake decorating robot, we can make the layer-by-layer production of a cake (Wolf, 2019). We can repeat this process again and again as often as we want. Other uses may include direct preparation of desserts, pasta and pizzas (Z. Liu et al., 2017).

In certain diseases and special cases, this technology can be particularly useful. One example is the people who live with dysphagia and the other is when a person needs special diet. Dysphagia is a disease where the patient has difficulty in swallowing and therefore unable to swallow solid food. In this case, only pulp food is an option. In the disease mentioned earlier, not only can you get pulp and free-formed food, but this technology also helps you to formulate a diet. This can be achieved by manipulating (even automating) the exact nutritional ingredients before printing. Vegetables are an important part of a balanced diet and, as we have read before, many vegetables can easily be used as a raw material. We can enhance the visual appeal of the dish by shaping and colouring the food so that the dining experience is not or only minimally compromised (Pant et al., 2021).

Of course, there are also disadvantages of the technology, which are important to mention, such as the large space requirements, the need for cleaning and maintenance of equipment. All in all, there have been useful developments in this area and there are also advances in the field of operation, so we can expect this technology to become widespread in the near future.

3.4. Printing from agricultural waste

Printing in 3D from agricultural waste is indeed an exciting and emerging area of research. While these materials are originally unsuitable for technical use due to their properties and perishability, food and agricultural products generate a significant amount of waste globally. Food wastage is a serious issue, and from a recycling and waste reduction perspective, agricultural waste represents a potential resource (Yu and Wong, 2023).

3D printing allows the transformation of these wastes into useful and recyclable products, such as agricultural tools, packaging materials, or even construction materials. This way, recycling food waste can contribute to sustainable development and environmental protection while creating economic value. Furthermore, such technologies can aid in more efficient resource utilization and waste reduction in agriculture.

Drying and grinding have provided a solution to the problem of poor condition and perishability. After mixing with known plastics such as PLA, these processes result in composites that can be used in 3D printing. Numerous experiments have been conducted using various plant waste materials. The most commonly used composite materials from plant sources include rice husks, coffee grounds, sugarcane bagasse, walnut shells, eggshells, and fruit peels.

Other intriguing experiments have involved PLA combined with buckwheat husks or even PLA reinforced with shrimp shells. In most cases, the aim is to enhance the static properties of traditional plastics. However, the combination of powdered banana peels and guar gum, for example, could be an excellent choice for packaging materials (Shepherd and McKay, 2021).

It's essential to examine how the finished composite is processed because it significantly impacts the strength of the final product. For instance, Fused Deposition Modelling (FDM) has been shown to create the strongest and most durable structures when working with these composites (Yu and Wong, 2023).

4. Conclusion

3D printing is now a widespread technology with many applications. This review article looks mainly at the agricultural applications of this technology. Due to the technological capabilities, a wide range of parts/devices with specific dimensions and solutions can be produced with this solution. As a result of it, time and money can be saved. In addition to the efficient application options, the sustainability options are also an important advantage of this technology. One example is the use of agricultural waste as raw material. Another advantage is that it improves the possibilities for maintenance, repair and further development. The article clearly shows that 3D printing is already being used successfully in a number of areas in the context of agriculture and is expected to become more widespread in the future.

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