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TEHNOLOGIJE I SOFTVER U 3D ŠTAMPI SA PRIMEROM PRIMENE U PČELARSTVU

TECHNOLOGIES AND SOFTWARE IN 3D PRINTING WITH EXAMPLE OF USAGE IN APICULTURE

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Field – ELECTRICAL ENGINEERING AND COMPUTING

Abstract – *Main contribution of this paper is comparison of 3D printing technologies with detailed description of their work processes, usage of technologies in different applications and their advantages and disadvantages. This paper also describes software that are most commonly used in 3D printing world, and example of usage of 3D printing in Apiculture for creating system of rollers for making beeswax foundations.*

Keywords: *3D printing, 3D modeling, 3D software, CAD*

Kratak sadržaj – *MGlavni doprinos ovog rada jeste poređenje 3D tehnologija štampe, sa detaljnim opisom radnog postupk, primnen, prednosti i nedostataka. Rad opisuje najčešće korišćen softver u oblasti 3D štampe, kao i primere primene 3D štampe u pčelarstvu, za iyradu sistema valjaka za izradu osnova košnica.*

Ključne reči: *3D štampa, 3D modelovanje, 3D softver, CAD*

1. INTRODUCTION

3D printing is a category of additive manufacturing in which from digital 3D model real 3D object is created by the method of joining thin layers of materials that represent horizontal cross-sections of the model being printed.

Additive manufacturing is a transformative approach to industrial production that enables the creation of lighter, more powerful parts and systems. It represents another technological advancement that is made possible by switching from analogue to digital processes [1].

Technology was created in the 80s of the 20th century and was used primarily for the production of prototypes. Since then, 3D printing has begun to be used as a technique for creating products in almost all industries. Lately, 3D printers and their ability to quickly make complicated prototypes find their place in many areas - in science, technology, medicine, or entertainment.

There are printers that can print from materials such as sugar, plastic, metal, nylon, and even human cells. As technology progresses, 3D printers cease to be expensive exotic technology and move into everyday life of average consumers [2].

NOTE:
This paper came from a MSc thesis under supervision of Dr. Dragan Dinu, assistant professor.

2. 3D PRINTING TECHNOLOGIES

American scientist Chuck Hal printed the first three-dimensional object in 1986. It was a plastic cup made with a stereolithography technique, curing a liquid plastic resin under UV light. Hal patented this technique and founded 3D Systems, which is still one of the leading companies in the field.

The company also developed the first file format for 3D printing, STL (from the term stereolithography). On the other hand, in the late eighties, Scott Kramp set the basis for modeling by joining coatings or FDM (Fused Deposition Modeling).

Kramp patented this technique and founded Stratasys, dedicated to the development and use of this 3D printing technique. It turned out to be one of the most important techniques for the expansion of 3D printing in the general public.

Since 2010, the American Society for Testing and Materials, the group "ASTM F42 - Additive Production", has developed a set of standards that classify the additive production processes in several categories according to the standard terminology for additive production technologies, which are: SLA/DLP , FDM, SLS, Material Jetting/DOD, Binder Jetting, DMLS/SLM/EBM [2].

2.1. SLA

Stereolithography (SLA) is an additive manufacturing process that belongs to the Vat Photopolymerization family. In SLA, an object is created by selectively curing a polymer resin layer-by-layer using an ultraviolet (UV) laser beam. The materials used in SLA are photosensitive thermoset polymers that come in a liquid form.

SLA is famous for being the first 3D Printing technology: its inventor patented the technology back in 1986. If parts of very high accuracy or smooth surface finish are needed, SLA is the most cost-effective 3D printing technology available.

Work process:

The build platform is first positioned in the tank of liquid photopolymer, at a distance of one layer height for the surface of the liquid. Then a UV laser creates the next layer by selectively curing and solidifying the photopolymer resin. The laser beam is focused in the predetermined path using a set of mirrors, called galvos. The whole cross sectional area of the model is scanned, so the produced part is fully solid. When a layer is finished, the platform moves at a safe distance and the sweeper blade re-coats the surface.

The process then repeats until the part is complete. After printing, the part is in a green, no-fully-cured state and requires further post processing under UV light if very high mechanical and thermal properties are required.
The liquid resin is solidified through a process called photopolymerization: during solidification, the monomer carbon chains that compose the liquid resin are activated by the light of the UV laser and become solid, creating strong unbreakable bonds between each other.
The photopolymerization process is irreversible and there is no way to convert the SLA parts back to their liquid form: when heated, they will burn instead of melting. This is because the materials that are produced with SLA are made of thermoset polymers, as opposed to the thermoplastics that FDM uses [3].

2.2. SLS

Selective Laser Sintering (SLS) is an Additive Manufacturing process that belongs to the Powder Bed Fusion family. In SLS, a laser selectively sinters the particles of a polymer powder, fusing them together and building a part layer-by-layer.
The materials used in SLS are thermoplastic polymers that come in a granular form.
SLS 3D Printing is used for both prototyping of functional polymer components and for small production runs, as it offers a very high design freedom, high accuracy and produces parts with good and consistent mechanical properties, unlike FDM or SLA.
Work process:
The powder bin and the build area are first heated just below the melting temperature of the polymer and a recoating blade spreads a thin layer of powder over the build platform. $CO2$ laser then scans the contour of the next layer and selectively sinters (fuses together) the particles of the polymer powder. The entire cross section of the component is scanned, so the part is built solid. When the layer is complete, the build platform moves downwards and the blade re-coats the surface.
The process then repeats until the whole part is complete. After printing, the parts are fully encapsulated in the unsintered powder and the powder bin has to cool down before the parts can be unpacked.
This can take a considerable amount of time (up to 12 hours). The parts are then cleaned with compressed air or other blasting media and are ready to use or further post process [3].

2.3. MJ

Material Jetting (MJ) is an additive manufacturing process that operates in a similar fashion to 2D printers. In material jetting, a printhead (similar to the printheads used for standard inkjet printing) dispenses droplets of a photosensitive material that solidifies under ultraviolet (UV) light, building a part layer-by-layer. The materials used in MJ are thermoset photopolymers (acrylics) that come in a liquid form.
MJ 3D Printing creates parts of high dimensional accuracy with a very smooth surface finish. Multi-material printing and a wide range of materials (such as ABS-like, rubber-like and fully transparent materials) are available in Material Jetting.
These characteristics make MJ a very attractive option for both visual prototypes and tooling manufacturing.A variation of the MJ process uses Drop-On-Demand (DOD) printheads to dispense viscous liquids and create wax-like parts.
Work process:
First, the liquid resin is heated to 30-60°C to achieve optimal viscosity for printing. Then the printhead travels over the build platform and hundreds of tiny droplets of photopolymer are jetted/deposited to the desired locations. UV light source that is attached to the printhead cures the deposited material, solidifying it and creating the first layer of the part. After the layer is complete, the build platform moves downwards one layer height and the process repeats until the whole part is complete [3].

2.4. BJ

In Binder Jetting (BJ) a binder is selectively deposited onto the powder bed, bonding these areas together to form a solid part one layer at a time. The materials commonly used in Binder Jetting are metals, sand, and ceramics that come in a granular form. Binder Jetting is used in various applications, including the fabrication of full-color prototypes , the production of large sand casting cores and molds and the manufacture of low-cost 3D printed metal parts.
Work process:
First, a recoating blade spreads a thin layer of powder over the build platform. Then, a carriage with inkjet nozzles (which are similar to the nozzles used in desktop 2D printers) passes over the bed, selectively depositing droplets of a binding agent (glue) that bond the powder particles together. In full-color Binder Jetting, the colored ink is also deposited during this step. The size of each drop is approximately 80 µm in diameter, so good resolution can be achieved.
When the layer is complete, the build platform moves downwards and the blade re-coats the surface. The process then repeats until the whole part is complete. After printing, the part is encapsulated in the powder and is left to cure and gain strength. Then the part is removed from the powder bin and the unbound, excess powder is cleaned via pressurized air [3].

2.5. SLM/DMLS

Selective Laser Melting (SLM) and Direct Metal Laser Sintering (DMLS) are two metal additive manufacturing processes that belong to the powder bed fusion 3D printing family. The two technologies have a lot of similarities: both use a laser to scan and selectively fuse (or melt) the metal powder particles, bonding them together and building a part layer-by-layer. Also, the materials used in both processes are metals that come in a granular form.
The differences between SLM and DMLS come down to the fundamentals of the particle bonding process (and also patents): SLM uses metal powders with a single melting temperature and fully melts the particles, while in DMLS the powder is composed of materials with variable melting points that fuse on a molecular level at elevated temperatures.

Work process:
The build chamber is first filled with inert gas (e.g. argon) to minimize the oxidation of the metal powder and then it is heated to the optimal build temperature. A thin layer of metal powder is spread over the build platform and a high power laser scans the cross-section of the component, melting (or fusing) the metal particles together and creating the next layer. The entire area of the model is scanned, so the part is built fully solid. When the scanning process is complete, the build platform moves downwards by one layer thickness and the recoater spreads another thin layer of metal powder. The process is repeated until the whole part is complete [3].

2.6. FDM

Fused Deposition Modeling (FDM), or Fused Filament Fabrication (FFF), is an additive manufacturing process that belongs to the material extrusion family. In FDM, an object is built by selectively depositing melted material in a pre-determined path layer-by-layer. The materials used are thermoplastic polymers and come in a filament form.
FDM is the most widely used 3D Printing technology: it represents the largest installed base of 3D printers globally and is often the first technology people are exposed to. In this article, the basic principles and the key aspects of the technology are presented.
Work process:
A spool of thermoplastic filament is first loaded into the printer. Once the nozzle has reached the desired temperature, the filament is fed to the extrusion head and in the nozzle where it melts. The extrusion head is attached to a 3-axis system that allows it to move in the X, Y and Z directions. The melted material is extruded in thin strands and is deposited layer-by-layer in predetermined locations, where it cools and solidifies. Sometimes the cooling of the material is accelerated through the use of cooling fans attached on the extrusion head. To fill an area, multiple passes are required (similar to coloring a rectangle with a marker). When a layer is finished, the build platform moves down (or in other machine setups, the extrusion head moves up) and a new layer is deposited. This process is repeated until the part is complete [3].

3. SOFTWARE

In the world of 3D printing, CAD software are used mostly for creating 3D printing models such as OpenScad, Fusion 360, Simplify 3D, and software that generate 3D-readable G-code from 3D models, of which the most popular is Ultimaker Cura [6]. Cura prepares a 3D model for printing. It is possible to print according to the recommended mode or customized mode in which more than 300 settings for maximum control can be configured. It has support in the form of CAD software add-ons and optimized material profiles. Every model that is designed for printing must be translated into the G code, or in the instructions that the 3D printer understands. Cura does this by dividing the model vertically into thin layers and creating a ready-to-print file [4]. Prior to the printing process, the Cura offers an animation option for the 3D model to look after printing and the ability to view the models in layers of printing. Image 1 represents a overview of the 3D model by layers in Cura.

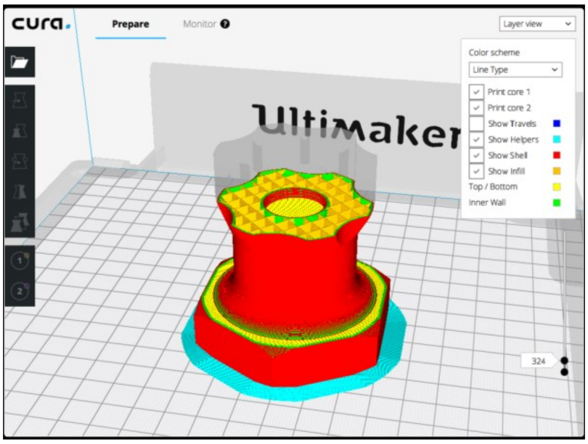

Image 1. *3D model view by layers in Cura*

4. EXAMPLE OF USAGE IN APICULTURE

Traditional manufacturing of system of rollers for making beeswax foundations requires usage of expensive machines such as CNC machine. This process requires a lot of precision and time to build, and the amount of waste after CNC milling can be high. 3D printing can do this process with much less time to build, nearly the same precision and without any waste. Image 2 shows rollers for making beeswax foundations printed on FDM 3D printer.

Image 2. *Printed rollers on FDM 3D printer*

5. COMPARISON OF TECHNOLOGIES

3D printers use different techniques for printing 3D models. While some use a thermoplastic filament, others use a conventional light source or a laser source to harden the molecules of the material to print the model. Some technologies use materials based on plastic polymer for printing while other technologies use metals and alloys of metals. Comparison of 3D printing technology of plastic materials is given in table 1.

Table 1. *Comparison of 3D printing technology of plastic materials*

	SLA	SLS	MJ	FDM
Usage	*Ideal for full 3D printing. Best waterproof waterproofing models. Use in the production of jewelry making patterns, use in dentistry [3,5].*	*Production of functional mechanical models with complex details. Production of temperature and chemically resistant models [5].*	*The most common use in 3D prototype prints, which requires the use of multiple colors and multiple different materials.*	*Production of prototypes and making decorative objects, molds and templates for casting concrete or silicone.*
Advantages	*The technology that first appeared in 3D printing. Smooth finishing surface.*	*Does not require a support structure, the ability to print more robust functional models with excellent mechanical properties. A wide range of colors [3].*	*Multiple color printing, very detailed print of small parts of the model. Homogeneous mechanical and thermal properties of materials [3].*	*Good finishing surface, wide range of colors and the ability to print one model from several different materials. Recycling and reuse of filaments. the minimum amount of waste after printing [3].*
Disadvantages	*Prints are fragile, not intended for the production of mechanical parts. It is impossible to recycle material after printing [3].*	*The porous, granular finish of the model, printing is more expensive compared to the other technologies [3]*	*MJ prints have poor mechanical properties, are easily fragile, materials are photosensitive, degrade over time [3].*	*ABS and PLA presses are fragile. Very strong filaments such as Nylon or Ultem material [3].*

6. CONCLUSION

SLA is the most popular 3D printing technology. Today it is widely used because it provides accuracy along with excellent finishing surface.

It also allows printing of objects using various materials. However, it can be quite expensive and is mainly used in the prototype manufacturing industry.

DLP is very similar to SLA. The main difference between these two technologies is the type of light source they use.

SLS is a good choice for building objects with complex shapes and geometries. No additional structural support is required as for other 3D printing technologies, and no further processing is required. The final object may not be very precise and the finish surface is not quite smooth.

MJ offers a wide range of possibilities in terms of 3D printing, which consists of different colors and materials, which is a key advantage of this technology compared to others. It also supports two different 3D printing settings regarding the final surface of the printed model, matte and shine, which can be useful in emphasizing the aesthetic details of the model.

FDM is the cheapest process compared to all other 3D printing methods. This makes it suitable for home use. The level of accuracy and finishing of the surface is good. Materials used by FDM are limited mainly to thermoplastics [5].

7. REFERENCES

[1] Additive Manufacturing Technologies, Rapid Prototyping to Direct Digital Manufacturing, Ian Gibson, David W. Rosen, Brent Stucker, Springer, 2014

[2] Svet kompjutera, Dragan Kosovac, 3D štampači, https://www.sk.rs/2013/05/skpr01.html, (last time accessed 03.05.2019.)

[3] 3D Hubs, Alkaios Bournias Varotsis, Knowledge Base, Manufacturing Processes Explained https://www.3dhubs.com/knowledge-base/, (last time accessed 03.05.2019.)

[4] Ultimaker, Ultimaker Cura software, https://ultimaker.com/en/products/ultimaker-cura-software (last time accessed 03.05.2019.)

[5] Comparison of Different Types of 3D Printing Technologies, Shiwpursad Jasveer, Xue Jianbin International Journal of Scientific and Research Publications, Volume 8, Issue 4, 2018

[6] MatterHackers, Anatomy of a 3D Printer: How Does a 3D Printer Work?, https://www.matterhackers. com/, (last time accessed 03.05.2019.)

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