INTERCONNECTION OF MATERIALS SCIENCE, 3D PRINTING AND MATHEMATIC IN INTERDISCIPLINARY EDUCATION

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ABSTRACT

The substantial advantage of 3D printing is the ability to fabricate complex shapes objects from liquid molecules or powder grains which joins or solidifies using computer design files (CAD) to produce a three-dimensional object with material being added together layer by layer. This process is considered as an industrial technology. The most-commonly used 3D printing procedure is a material extrusion technique called fused deposition modelling. The producers of 3D printers have already developed prototypes for education purposes. The importance of the incorporation this printing method in schools is the fact. The learning experience for digital media is becoming a priority in school education. The practical application of this technique can be incorporated into a wide variety of school subjects to simplify the sophisticated theoretical concepts. 3D printing is the example of cooperation within material science and mathematics but this platform is very often not supported by the high school curriculum, but latest trends propose different approaches and make education close to the science achievements and contemporary life. Building lessons plans and project could help students to learn more contemporary achievement in this field. It is new trend to support enthusiastic teachers who want to implement this method of additive manufacturing in education. This paper provides an overview of 3D printing methods and highlights the possibility of their implementation in educational techniques.

Keywords: education, mathematics, polymers, additive manufacturing, materials.

INTRODUCTION

The whole process begins by virtually designing of object that should be printed. Virtual designing is performed in a CAD (Computer - Aided Design) file using a 3D program for modeling (to create a brand new object) or using a 3D scanner (to copying an existing object). The 3D scanner performs three-dimensional digital copying object. These scanners use different technologies to generate the desired model. To prepare the object for printing, 3D software virtually cuts the final model into a large number of horizontal layers. Object proposed by software is created in succession applying layers of material until the final shape is obtained (Freedman et al., 2012). Typical layer thickness is 0.1 mm, although depending on the technology, it can range from a few microns to several centimeters. The first layer is applied to the substrate, then the desk is lowered (or the print head is raised) by the height of the layer, the next layer is applied and procedure is repeated until the entire item is printed. Printing time depends on the subject and technology. For smaller items, the crafting process will take several minutes, while for larger items the time will be measured in hours. Everything the mind can think of, at a simple and fast way, using 3D printing can be obtained, so there are no restrictions in terms of dimensions and shape of desired objects. Materials used in 3D printing can be in form of of powders, granules or fibers, divided into the following categories:

1. polymer materials – thermoplastic, thermosetting polymers polymer composites,
2. ceramic materials,
3. metals - aluminum, cobalt, gold, silver, tungsten, titanium, titanium beryllium and copper alloys, steel
4. wood, paper
5. food - ie. natural macromolecules such as carbohydrates (starch).

The selection of material type depends on the field of application and costumers' need. Use of polymers for consumer goods (bottles, toys, dishes, electronical components etc.) as well as for special applications (drug delivery, biomedical devices) makes those materials applicable for processing by 3D printing, which allows rapid manufacturing (Song et al., 2009, Wang et al. 2017). Plastic materials used in additive manufacturing can be divided into four categories: thermoplastic, thermosets and elastomers, polymer blends and polymer composites.

There are several different 3D printing technologies, depending on the printer working mode and material used to make the item, such as stereolithography, selective laser sintering (SLS), inkjet, Fused deposition method (FMD), production of laminated objects - LOM (Laminated object manufacturing). No matter which one applies, the entire process of manufacturing a 3D printing object can be divided into two stages:

1. designing an object in programs such as AutoCAD, Blender, Open- SCAD, etc., using a 3D modeling program,
2. printing the object.

Stereolithography is based on the use of UV light passing over a pool with a photosensitive polymer (Figure 1). During production, the model is formed in the pool layer by layer, until the final product is obtained. The advantages of this method are the rapid fabrication, detailed surface treatment, as well as the way of pulling objects out of the pool, after which there is no need to break excess structural parts (Song et al., 2009).

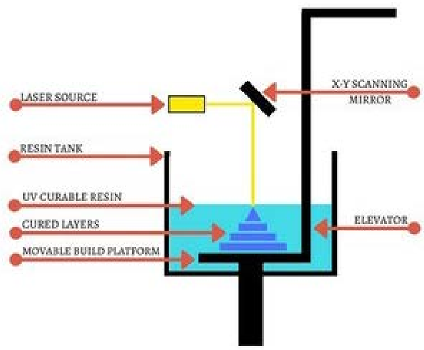

Figure 1. SLA method (https://all3dp.com/2/stereolithography-3d-printing-simply-explained/).

Selective laser sintering (SLS) (Figure 2) is very similar to stereolithography. It works on the principle of material exposure to laser beams. The polymer is in the form of a compact powder. The main advantage of this method is that ceramic, plastic and metal products can be obtained. The resulting objects generally have very good strength, but the disadvantage of the SLS method is that the surface of the object often has imperfections (Decard et al., 1989).

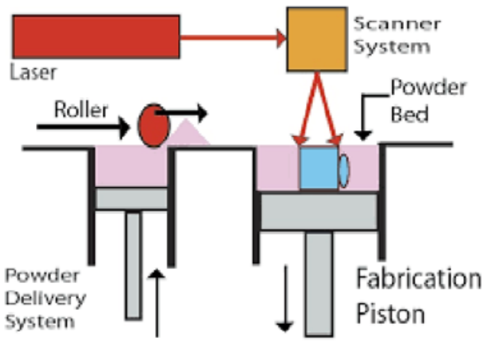

Figure 3. SLS method (Raja et al., 2006).

The inkjet method (Figure 4) is actually an upgrade to classic Inkjet printing. The model is made layer by layer, usually of plaster or resin, and the device disperses the binder to obtain the desired shape of the object. The advantage of this method is that a single object can be made of multiple types of material (Song et al., 2009). Fused deposition method (FDM) (Figure 5) is the most widely used 3D printing method. It works on the principle of material extrusion with an extruder, and the nozzle opening is adapted to extrude the used material. Thermoplastic polymers are used as material for this 3D printing method. Layers are obtained by extruding a thin nozzle of thermoplastic material onto a printing pad. They are formed crosswise, ie. each layer is extruded at an angle of 90° from the previous one. Today, in addition to the base material, water-soluble and easily removable material is often used as temporary support for certain parts of the item (Konta et al., 2017).

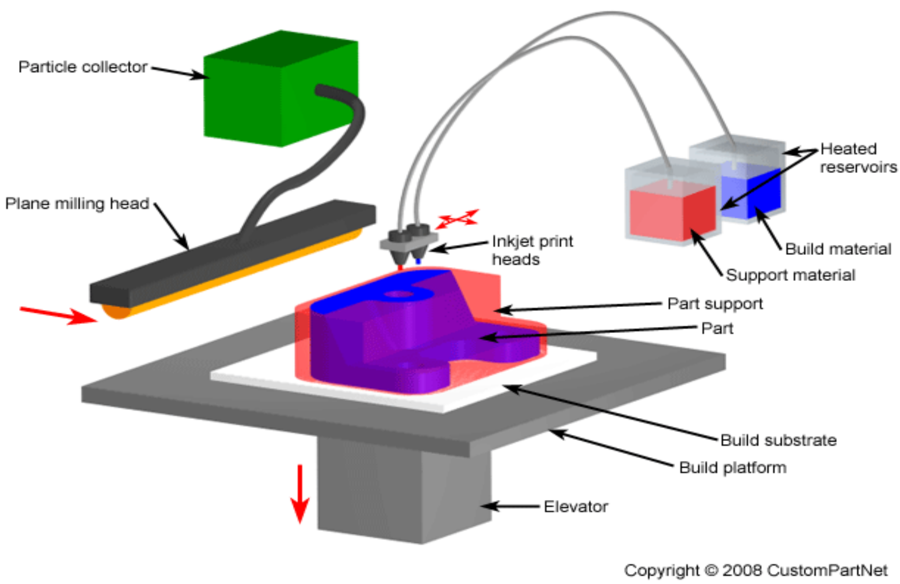

Figure 4. Inkjet method (https://www.custompartnet.com/wu/ink-jet-printing).

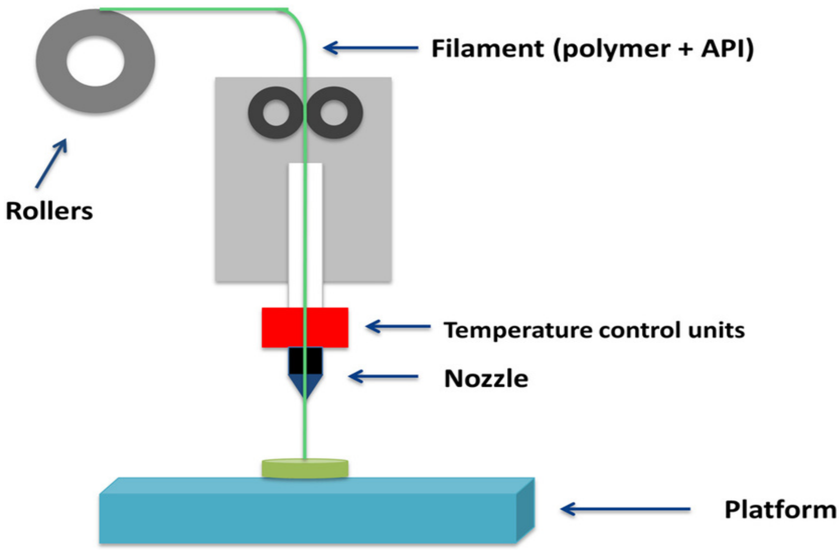

Figure 5. FDM method (Konta et al., 2017).

Laminated object manufacturing (LOM) method can use paper as a material, which is a great advantage because of the much lower cost of production and final price of the product. In tis method, layers of material that are laser-cut to specific dimensions are used and then bonded together (Figure 6). Today, A4 paper is often used as a water-based material and adhesive, which significantly decreases the cost and has no adverse effects on humans and the environment.

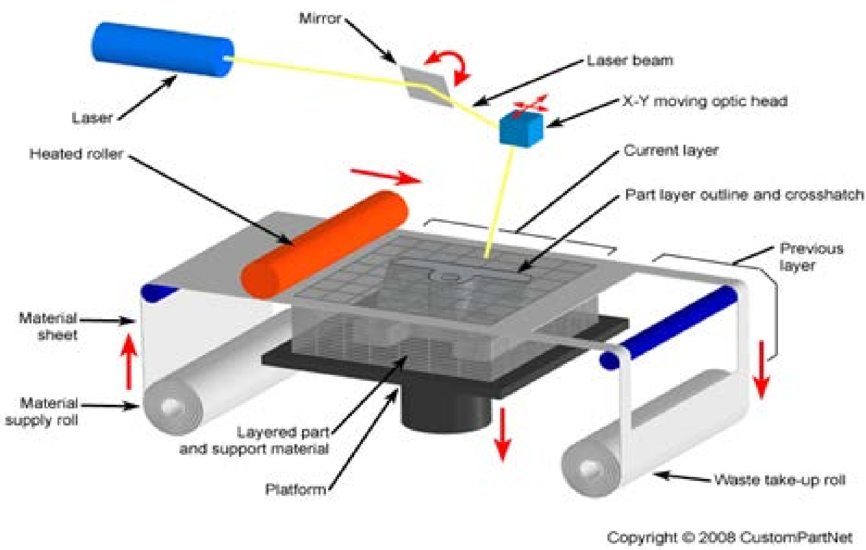

Figure 6. LOM method (https://www.makepartsfast.com/laminate-object-manufacturing-lom/).

POLIMER MATERIALS 3D PRINTING

There are several main materials used in 3D printing such as polymer, polymer composites, wood, metals, paper, ceramics, sandstone, wax. The selection of material type depends on the field of application and costumers' need. Use of polymers for consumer goods (bottles, toys, dishes, electronical components etc.) as well as for special applications (drug delivery, biomedical devices) makes those materials applicable for processing by 3D printing, which allows rapid manufacturing (Wang et al., 2016, Šafka et al., 2016). Plastic materials used in additive manufacturing can be divided into four categories: thermoplastic, thermosets, elastomers and polymer composites.

Thermoplastic polymers

Thermoplastic polymers have the great significant from te point of 3D technology, because of their widespread use and recyclability. Thermoplastic polymers used in 3D technology can be biodegradable and non-bioderadable. They are printed using mostly FDM method. Amorphous polymers are preferred over semicrystalline ones. The reason lies in the fact that printing temperature or amorphous polymers should be simply greater than glass transition temperature and for semicristaline polymers has to exceed melting point (Šafka et al., 2016). The most commonly used non-biodegradable thermoplastic polymers in 3D processing are acrylonitrile butadiene styrene (ABS), polypropylene (PP), polyethylene terephthalate (PET), polycarbonate (PC), polyamide (PA), acrylonitrile styrene acrylate (ASA), which are non-biodegradable. Biodegradable polymer with importance in 3D printing is on the first place polylactide (PLA). Besides PLA, the use of other biodegradable polyesters such as poly-(hydroxyalkanoates) (PHA) and poly-(ε-caprolactone) (PCL) are intensively considered Vaidya et al., 2019).

ABS is the most commonly used polymer in 3D printing. ABS is amorphous copolymer based on three monomers: acrylonitrile, butadiene and styrene. Different components for cars, cell phones, as well as toys can be produced by processing ABS using the additive technology. The good properties of this polymer result from the combination of three monomers, where the presence of acrylonitrile contributes to good resistance to aging, temperature and chemicals; the gloss and stiffness come from the presence of styrene, and also the strength and elasticity due to butadiene. During the processing of ABS using the 3D technology, ABS is heated to between 230 ºC and 260 ºC. It is tough, reusable material with high strength, which degrades from humidity in the surrounding air, so ABS filaments should be stored in containers and vacuum bags before processing. ABS is mainly used in fused deposition modeling technologies, the most affordable and accessible 3D printing technology. There is however also a liquid form of ABS which is sometimes used in stereolithography and PolyJet processes. Figure 7 shows the ABS printing filament with product of 3D processing (Ngo et al., 2018).

Figure 7. ABS printing filament and 3D printed toy.

PP is semicrystaline polymer widely used in automotive, packaging industry and in manufacturing of different everyday objects (Figure 8). Good properties of PP is resistance to abrasion, many chemicals, toughness, flexibility and ability to absorb shocks. PP is also cost-effective and suitable for food packaging. Drawbacks of PP include low temperature stability and UV sensitivity. Printing temperature of PP is 230-260 °C. PP filaments come in black, white and yellow colours and they are used in Fused Deposition Modeling (FDM) (Safka et al., 2016).

Figure 8. PP 3D printed objects.

PET is semicrystaline polymer useful for food and beverage packaging. It is rigid material, with good chemical resistance, 100% recyclable. Printing temperature for PET is between 75-90 ºC (Figure 9).

Figure 9. PET printed bottle.

Mixing PET with glycol gives PET-G filaments, more practical and useful for 3D printing. PET-G filaments exibit good temperature, chemical and stretch resistance, as well as good electrical properties. Optimal temperature for 3D printing of PET-G filament is 230-250 °C. PET-G printed objects are used in many fields, such as cases for electronic devices, containers etc. (Figure 10).

Figure 10. 3D printed cases for electronic devices based on PET-G.

Polycarbonate (PC) is durable, tough amorphous polymer with high strength and good temperature resistant. PC is resistant to any physical deformation until around 150 °C, but has tendency to absorb moisture from the air, which can affect its printing performance. The main fields of application of PC are engineering, electronics, any other fields where transparency and durability are required (Figure 11). Printing temperature is very high, between 290 and 300 °C (Safka et al., 2016).

Figure 11. PC 3D printed object.

PA are semicrystalline polymers, tough, flexibile with good shock resistance, which provides many applications of theses polymers in automotive industry, robotics, aerospace market, manufacture of gears etc. (Figure 12). Polyamides usually comes in form of powder, therefore 3D printing is carried out by SLS method. However, nylon is also available in filaments, so the FDM is used for its processing. Printing temperature for polyamides is between 220 and 250 °C (Safka et al., 2016).

Figure 12. PA 3D printed object.

ASA is amorphous polymer that combines good mechanical strength, dimensional stability, UV and chemical resistance, making it suitable for outdoor applications and automotive industry (Figure 13). ASA comes in filaments and being printed at about 250 °C.

Figure 13. ASA 3D printed object.

PLA is fully biodegradable thermoplastic polymer. It is one of the easiest materials to print, with good strength; it is simple to use and comes in different coloured fillaments, suitable for FDM printing method (Figure 14). PLA is renewable, low cost, but with low heat resistant, which makes it inconvenient for outdoor applications. During the 3D printing, PLA is heated to between 190 ºC to 230 ºC and it is suitable for architectural mock-ups and complex educational models. High hardness and very low shrinkage make PLA suitable for 3D printing high-quality parts and consumer goods. PLA is suitable for fabrication of 3D prototypes and educational tools, because of low cost and printability (Gkartzou et al., 2017).

Figure 14. PLA 3D printed object.

Thermosets and elastomers

For processing of thermoset polymer materials via 3D printing method the most suitable method is the digital light processing (DLP) according to stereolitography. DLP method is modificated stereolithography metod, because they are both based on applying of photopolymerization principles (Melchels et al., 2010). DLP method uses a conventional DLP projector as a light source, which projects a two-dimensional (2D) image into a light-curable resin in a vat, in te first step. Epoxy and acrylate resins are the most used thermoset materials in 3D printing. Elastomer materials used in 3D technology are usually being processed by PolyJet printers. This 3D technology made parts by pouring out photopolymer droplets onto a build platform and solidifying them by UV light. This technique allows creation of complex parts using elastomer materials such as liquid silicone rubber.

Polymer composites

Different types of polymer matrix can be used for tailoring of composite materials. Micro and nano sized particles as well as fibers (natural and synthetic ones) are used as filler component in polymer composites. The composite materials based on iron particles and thermoplastic polymers such as nylon (Masood et al., 2004) and ABS (Sa'ude et al., 2004) were investigated.

ABS is also used as polymer matrix in composite materials with copper, carbon black, strontium titanate and alumina (Torrado et al., 2015). Senatov et al. prepared scaffold based on PLA and hydroxyapatite using FDM printing method which can be used as self-fitting implant for small bone replacement (2016). Group of authors have demonstrated the possibility of the use of jute fibers as reinforcement for thermoplastic composite filaments which can be processed by FDM printing method. As polymer matrix they have used well researched polymers in 3D printing technology such as ABS, PLA (Matsuzaki et al., 2016). Synthetic fibers which are investigated in combination with ABS, nylon and PLA are carbon, glass and Kevlar fibers (Tekinalp et al., 2014, Chen et al., 2017). Modeled on balsa wood, scientists from Harvard have created a new composite material based on epoxy resin containing nano clay particles, silicon carbide fillers and carbon fibers. The material is printed to looks like a honeycomb – small density and high mechanical strength due to epoxyde matrix.

3D PRINTING IN EDUCATION

Due to the accessibility and affordability on the market, 3D printers with its technological potential became available in the classrooms and in the process of improvement of teaching and learning. Whole 3D printing process from an idea to modeling and producing a model is helpful in conceptualization and visualization. Usage of 3D printers in the classroom combines science, technology, engineering, math but also has aesthetic and artistic aspect which makes 3D printer excellent tool for supporting STEAM concept which combines Science, Technology, Engineering, Art and Mathematics to empower students in the developing competences such as inquiry or critical thinking. 3D printing is certainly a tool that could be helpful in developing 21st century skills of students (Becker et al., 2018). Activities during 3D printing are close to the reality, usually based on solving real-world problems which solution requires compliance of various disciplines (Cross, 2001). Together with 3D printers in the classrooms, education needs development of 3D printing teaching strategies, planning lessons that fit into the curriculum and meaningful integration that connects science, mathematics and technology in creative and constructive way in order to achieve educational goals (Novak et al., 2016). There are limited resources that provide instructions for 3D printing integration into the classroom which is for now an obstacle of effective use of 3D printers in the classroom (Kolodner et al., 2003). One of the research of 3D printing in classroom summarizes several benefits, but also challenges about this new technology. One of the obstacle in usage of 3D printing technology was that teachers need to have additional knowledge in advanced technology, while the second observed problem was that even though students possess knowledge in technology, the engagement with new technologies was not that easy as expected (Thibaut et al., 2018). As a potentially benefits, 3D printing in the classroom supports different teaching and learning styles, encourage students to be active and to explore, even though they have not been previously interested in such activities. Design experience improves their ability to solve problems, to learn from mistakes and find solutions (Kostakis et al., 2017). Also this kind of activities and projects help to the conceptual understanding of different things and to self-guided inquiry (Vones at al., 2018). In Figure 15. it can be seen students (age 13) in the process of printing models of Lego brick in Petro Kuzmjak school in Serbia in October 2019. In this activities students had to apply their knowledge related to the proportions and make a model of prism that would resemble to the Lego brick. In this process students by their initiative explored more information about Lego bricks, from the interesting playful facts to the mathematical facts and proportions. Collaborating together, students got 3D printed models of Lego bricks as it is showed in Figure 16.

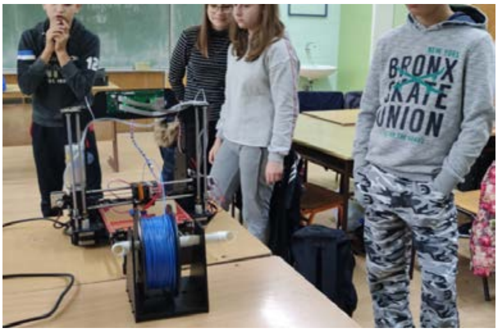

Figure 15. Students learn how to use 3D printer.

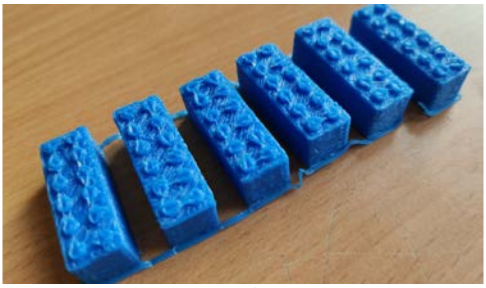

Figure 16. Final model of 3D printer Lego brick modeled by students.

CONCLUSION

From the previous it can could be concluded that the future of the 3D printing is positive in many aspects. It is evident that 3D printers are improving quality of life, making many things more assessable. Practical application of 3D printing and its technological advance impacts different fields from everyday life, from medicine, education to space research. Quick replication of objects has a possibility to change lives in the future for the better.

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