A review on current trends of additive manufacturing technologies

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Keywords

Additive manufacturing, ultrasound, polymeric materials, 3D printing, Ultrasonic Fused Deposition Modelling (UFDM)

1. Introduction

The **3D printing** process builds a three-dimensional object from a computer-aided design (CAD) model, usually by successively adding material layer by layer, which is why it is also called **additive manufacturing**, unlike conventional machining, casting and forging processes, where material is removed from a stock item (subtractive manufacturing) or poured into a mold and shaped by means of dies, presses and hammers. [1,2] Additive manufacturing techniques - 3D printing are a relatively new side of prototyping that has undergone important changes and evolution in recent years. Until recently, it seemed impossible for any object, conceived and designed, by the consumer to be made using specialized equipment and software, but with the evolution of technology it has become increasingly easy to achieve. Increased interest in the field of 3D printing is visible both among technology enthusiasts as well as the average consumer. As a result of this interest and the growing market

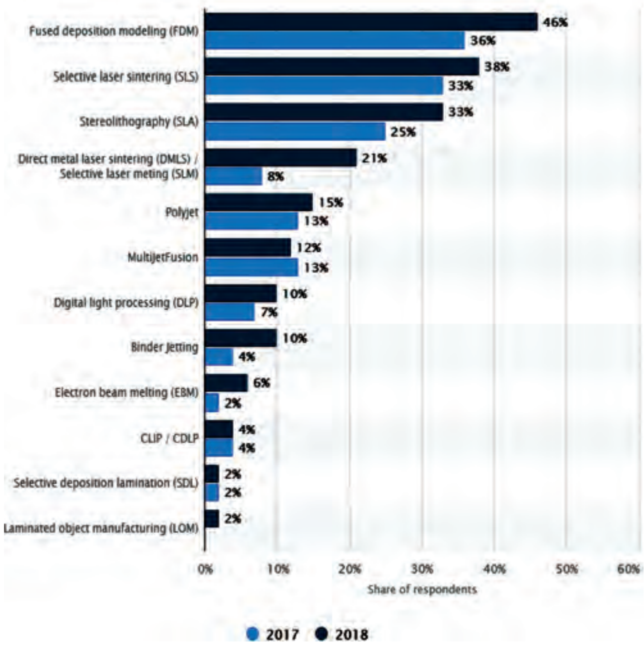


Figure 1. Most used additive manufacturing technologies worldwide, in 2017-2018 [5]

demand, it has become increasingly easy to create a low-cost 3D printed model [3]. Additive manufacturing is increasingly proving itself useful in a wide array of segments, including the automotive industry, the medical sector, the military industry and even in food manufacturing. The United States is the most important market for additive manufacturing, both in terms of production and consumption [4].

Globally, the most used additive manufacturing technologies, between 2017-2018 are presented in the figure 1.

2. Worldwide state of the art in additive manufacturing

Prototyping (55%), production (43%) and Proof of Concept models (41%) are the three most popular 3D printing applications in 2018 with R&D departments being the most active adopters. Prototyping is experiencing rapid growth in 2018, as evidenced by the 21% increase in adoption between 2017 and this year. Adoption of 3D printing in production environments is soaring, increasing 21% between 2017 and 2018. Proof of Concept has increased 18% in one year. The following graphic compares adoption rate of 3D printing applications and 3d printing users by [6]:

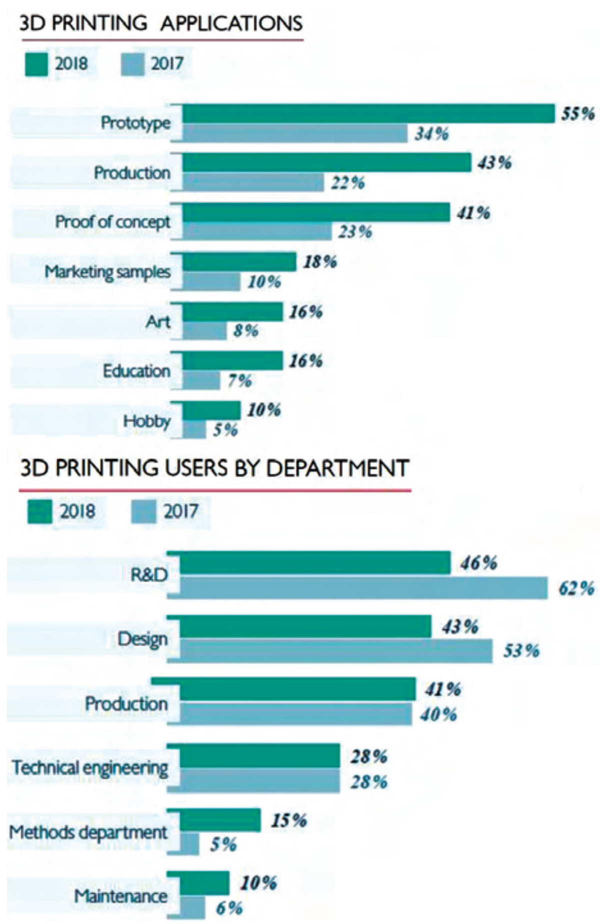


Figure 2. The most used 3D printing applications and departments worldwide [6]

36% of companies are using metal materials for 3D printing this year, up from 28% in 2017 signalling greater adoption for production operations. 46% are using 3D printing devices based on Fused Deposition Modelling (FDM), an increase of 12% from last year. Polishing (48%), painting (27%) and machining (23%) are the top three finishers used on 3D printed objects. The study found that nearly all companies using 3D printing today are relying on polishing and painting as part of their development process.

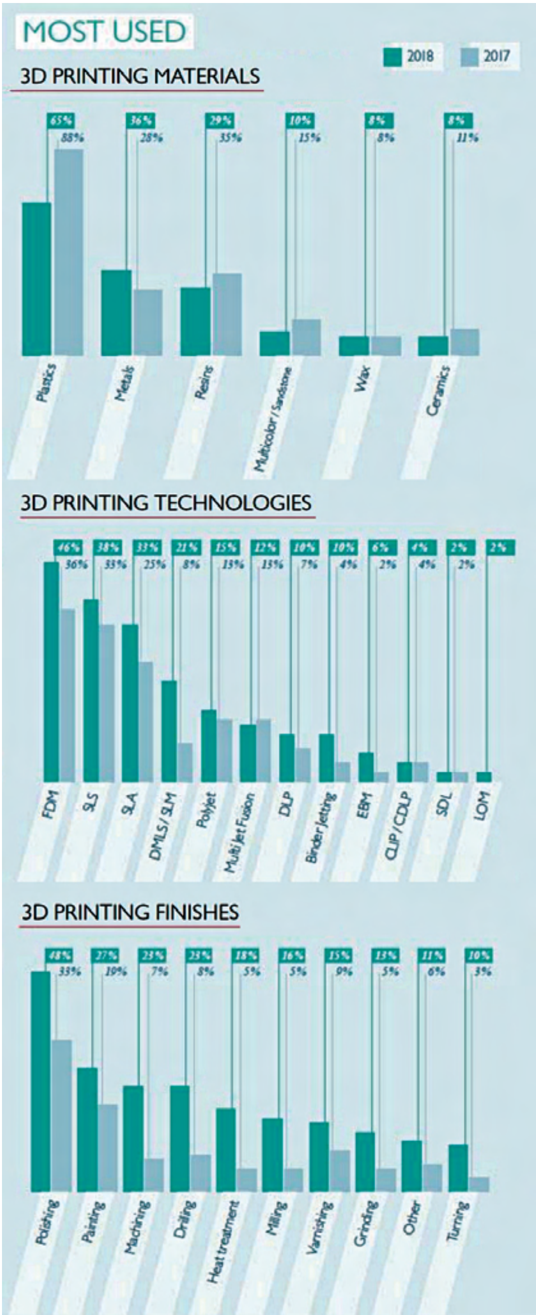


Figure 3. Most used materials, technologies and finishing's in additive manufacturing [7]

3D printing applications are steadily increasing. Spare parts and prototypes have given way to commercial production, where a substantial number of printed parts are made for various industries. The industrial goods market is estimated to be the largest application of the 3D printing in 2018. The aeronautics and aerospace segment is expected to have a significant growing trend over the coming years [8].

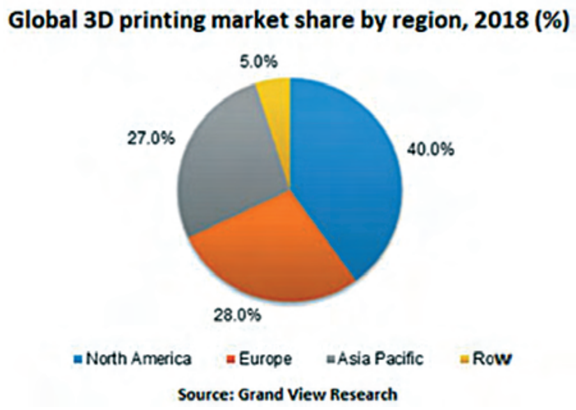


Figure 4. Global additive manufacturing market [8]

Worldwide projected spending, in 2019, for the additive manufacturing industry are presented below:

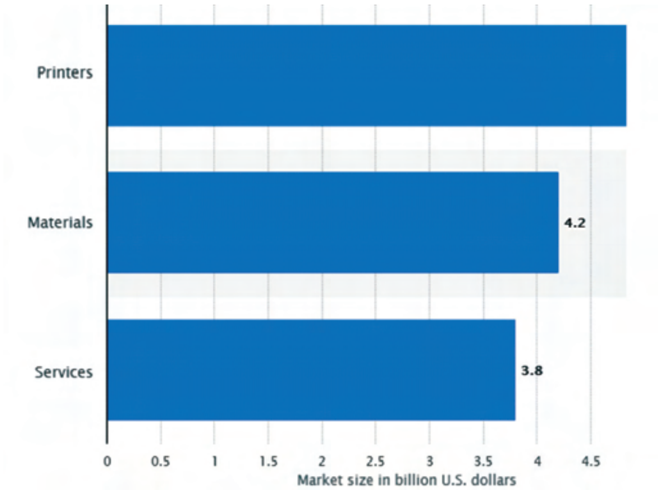


Figure 5. Projected spending on 3D printing worldwide in 2019 (in billion U.S. dollars) [5]

The present review intends to enhance the knowledge of ISIM – PN 19.36.02.01 researchers in the additive manufacturing present state of the art, concept development, as well as equipments and materials used by the industry [9].

3. 3D printers and software

Equipment used for 3D manufacturing allows designers to produce prototypes in a very short time, thus the prototypes can be tested and quickly remodeled / repaired. Additive production of parts by classical methods can take up to several weeks, but the use of these new printing technologies reduces this time interval significantly; thus, the time gained offers the possibility of testing several variants of components in order to develop the required solution as quickly as possible [10].

Globally there are several additive manufacturing techniques:

- FDM – Fused Deposition Modeling;
- SLA – Stereolithography;
- DLP – Digital Light Processing;
- SLS – Selective Laser Sintering;
- SLM – Selective Laser Melting / Direct Metal Laser Sintering;
- 3DP – Three-dimensional inkjet printing;
- LOM – Laminated Object Manufacturing;
- PJP – PolyJet Printing [10].

The most common additive manufacturing technology, for polymeric and composite materials, is FDM, which imposes low equipment and consumables costs, it uses as base materials PLA/ABS filament.

Specialized literature highlighted studies like Joris Peels Jun's [12] that shows how to choose industrial 3D printers, which are used in manufacturing processes and are reliable, durable and offer repeatability. Printer availability and production capacity are key considerations when purchasing a 3D printer. Industrial 3D printers have a wide range of application areas and make many different types of parts. Many 3D printers are manufactured by niches and are optimized for a particular application, a particular client, respectively a certain type of material. Given the multitude of specific applications in different top areas, it can be stated that there is no 3D printer that is the best. There are examples of specific 3D printing systems for dental offices, others for dental center and others where dental production can be done in a manufacturing-like environment. Similarly, there are systems that are intended for factory use and others that are less industrial, but both are used for manufacturing. Depending on its capacity, or even the material or geometry of the print component, a particular printer might be better suited to a particular application [13]. Another study by A. Aimar, A. Palermo and B. Innocenti specify that 3D printing refers to a series of manufacturing technologies that generate a physical model from digital information [14]. Diana Popescu researches several software applications for additive manufacturing. Several free software products containing tools designed to support the designer's activity have been analyzed and which allow the design process to be adapted to take into account the specific limitations of AM [15]. Furthermore, in the second article in Additive Manufacturing (AM) software application series, Diana Popescu intends to present the new Spark platform recently launched by Autodesk. Unfortunately, despite the many emails requesting beta testing of the platform, it has not (yet) received the desired access. Therefore, this article will continue with the presentation of three other free software applications that allow the pre-print verification of the STL model. These include: Netfabb, Willit 3D Print and 3D Printing Toolbox Blender [12].

Figure 6. 3D printers [11]

4. Polymeric materials and composited used in the additive manufacturing industry

The basic constituents of plastics are organic polymers; these are pure chemicals resulting from polymerization. Polymers consist of a large number of fundamental units, monomers, which are organic molecules made up of carbon atoms, or silicon, in the case of silicone polymers. Starting from monomers, polymers are formed by addition polymerization or condensation polymerization, and depending on their behaviour under the action of heat and pressure, they are divided into thermoplastic or thermosetting materials [16].

Filaments frequently used in the additive manufacturing industry [17]:

- PLA Filament – density 1.24 g/cm^3, recommended printing temperature 190-220 °C;
- PET Filament - density 1.2 g/cm^3, recommended printing temperature 220-240°C;
- TPU/TPE Filament - density 1.15 g/cm^3, recommended printing temperature 190-240°C;
- ABS Filament - density 1.03 g/cm^3, recommended printing temperature 220-245°C;
- HIPS Filament - density 1.04 g/cm^3, recommended printing temperature 220-270°C;
- ASA Filament - density 1.75 g/cm^3, recommended printing temperature 235-255°C;
- PA Filament – nylon, recommended printing temperature 230-260°C;
- PC Filament - density 1.19-1.20 g/cm^3, recommended printing temperature 250-270°C;
- PP Filament - density 0.9 g/cm^3, recommended printing temperature 220-240°C;
- Ligmin Filament – biodegradable polymer - density 1.23 g/cm^3, recommended printing temperature 140-180°C.

Figure 7. Common filaments used in additive manufacturing [18]

Globally, the most used materials in the additive manufacturing industry, in 2017 (blue) and 2018 (black), are polymeric materials (88% in 2017, respectively 65% in 2018), according to the statistics presented in the figure 8 [19].

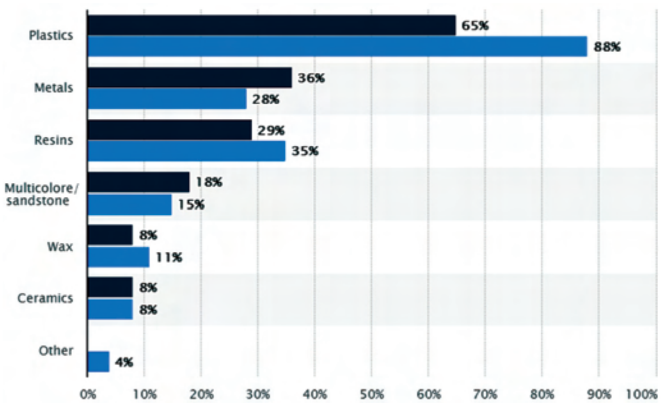


Figure 8. The most used materials in the additive manufacturing industry, in 2017 (blue) and 2018 (black) [19]

Studies and experimental research carried out on 3D printing with polymeric materials in the specialized literature are increasingly numerous and diversified by points of interest such that:

Louis Columbus, made a study by Sculpteo; The methodology of the study was based on interviews with 1,000 respondents distributed globally, with 60% in Europe, 25% in America, 9% in Asia and Oceania and 1% in Africa, respondents from a large database of ten industries, including aeronautics and aerospace, automobiles, consumer goods, education, including students, electronics and electrical industry, healthcare, state-of-the-art, industrial products, mechanics, metalworking and services [7].

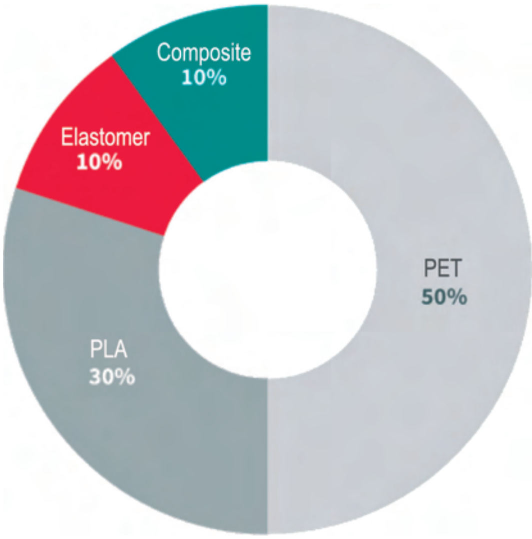
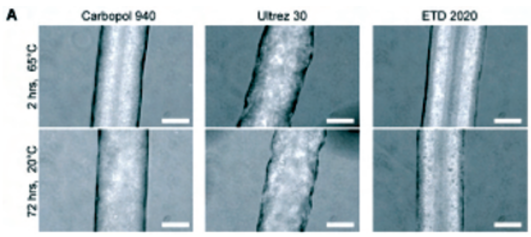


Figure 9. Additive manufacturing industry most uses materials: Co-polyester (PET family) , PLA, Specials (Metal Wood), Composites [20]

Due to limited mechanical properties of materials used in the additive manufacturing industry, there is a general need to improve and create new materials with advanced properties. In this sense, at the global level, different studies are being carried out in order to improve and / or develop new materials:

Fuda Ning and co. [21] study possible methods of adding reinforced materials (such as carbon fibers) into plastic materials to form thermoplastic matrix carbon fiber reinforced plastic (CFRP) composites that could be directly used in actual application areas, such as aerospace, automotive, and wind energy. CFRP composite filaments were firstly prepared from carbon fiber and ABS by extrusion processes. Experimental investigations on if adding carbon fiber (different content and length) into ABS plastic can improve the mechanical properties of FDM-fabricated parts have been conducted. Effects on tensile properties (including tensile strength, Young's modulus, toughness, yield strength, and ductility) and flexural properties (including flexural stress, flexural modulus, flexural toughness, and flexural yield strength) of specimens were investigated. Fracture interface of CFRP composite specimens after tensile testing and flexural testing was observed and analyzed using SEM micrograph. Carbon fiber reinforced ABS composites fabricated by both compress moulding and FDM. Tensile testing was conducted in this work and tensile strength and Young's modulus were measured for the comparisons, but no other tensile properties were investigated for details. [21].

Among reported literatures, there are limited numbers of studies on developing new materials especially the fibre reinforced thermoplastic composites using FDM process. Zhong et al. [23] conducted experiments to investigate the process ability of glass fibres reinforced ABS matrix composites with three different glass fibre contents used as feedstock filaments in FDM. The results showed that glass fibres could significantly improve the tensile strength and surface rigidity of the ABS filament. Gray et al. [23,24] presented thermo tropic liquid crystalline polymer (TLCP) fibre reinforced polypropylene (pp) composites filament for FDM. Compared with chopped fibre, using longer TLCP fibres (length/ diameter ratio > 100) in composites, led to larger tensile strength and better functionality

<table>
<tr><td>(A) Representative phase-contrast images of PDMS filaments extruded into Carbopol 940, ETD 2020 and Ultrez 30 and cured at 65 °C for 2 h or 20 °C for 72 h showed small morphological differences due to the type of Carbopol, but not due to cure temperature (scale bar is 200 μm).</td><td>
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<tr><td>(B) Quantification of PDMS filament diameter for target extrusion diameters of 140, 280, and 400 μm (green lines) showed the ability to generally achieve diameters within 10%. The cure temperatures of 65 °C for 2 h (red) and 20 °C for 72 h (blue) did not have a statistically significant effect on diameter (as determined by t tests between cure temperatures for each target diameter and Carbopol type, P < 0.05).</td><td>
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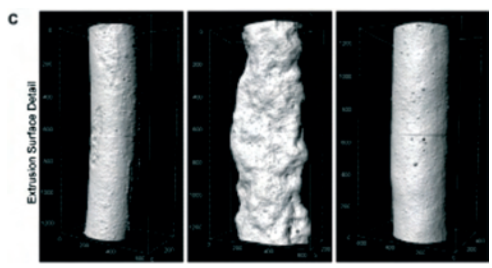
<tr><td>(C) Surface and cross-sectional renderings of PDMS filaments imaged using laser scanning confocal microscopy verified the smooth surface and circular cross-section of PDMS extruded in Carbopol 940 ETD 2020 and the rough surface of PDMS extruded in Ultrez 30 (units in 3D rendering are in micrometers, scale bar is 100 μm).</td><td>
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Figure 10. PDMS pre-polymer filaments extruder and cured at different temperatures and in different Carbopols are dimensionally stable [27]

of the fabricated prototypes. The tensile strength of TLCP fibre reinforced pp composites was much larger than that of most of other FDM fabricated materials. Shofner et al. [25] developed nano-fibre reinforced ABS matrix composites using FDM. Feedstock filaments consisted of single-walled carbon nano-tubes and ABS plastics. Compared with unfilled ABS specimens, nearly 40% and 60% increase in tensile strength and tensile modulus were obtained at nano-fibre loading of 10 wt%, respectively. Tekinalp et al [26].

Thomas J. Hinton and co. [27] demonstrate the 3D printing of hydrophobic PDMS prepolymer resins within a hydrophilic Carbopol gel support via freeform reversible embedding (FRE). In the FRE printing process, the Carbopol support acts as a Bingham plastic that yields and fluidizes when the syringe tip of the 3D printer moves through it, but acts as a solid for the PDMS extruded within it. This, in combination with the immiscibility of hydrophobic PDMS in the hydrophilic Carbopol, confines the PDMS pre-polymer within the support for curing times up to 72 h while maintaining dimensional stability. After printing and curing, the Carbopol support gel releases the embedded PDMS prints by using phosphate buffered saline solution to reduce the Carbopol yield stress. As proof-of-concept, we used Sylgard 184 PDMS to 3D print linear and helical filaments via continuous extrusion and cylindrical and helical tubes via layer-by-layer fabrication. Importantly, we show that the 3D printed tubes were manifold and perfusable. The results demonstrate that hydrophobic polymers with low viscosity and long cure times can be 3D printed using a hydrophilic support, expanding the range of biomaterials that can be used in additive manufacturing [27].

Halil L. Tekinalp and co. [28] investigated short fibre (0.2–0.4 mm) reinforced acrylonitrile–butadiene–styrene composites as a feedstock for 3D-printing in terms of their processing ability, microstructure and mechanical performance. The additive components are also compared with traditional compression moulded composites. The tensile strength and modulus of 3D-printed samples increased 115% and 700%, respectively. 3D-printing yielded samples with very high fibre orientation in the printing direction (up to 91.5%), whereas, compression moulding process yielded samples with significantly lower fibre orientation. Microstructure–mechanical property relationships revealed that although a relatively high porosity is observed in 3D-printed composites as compared to those produced by the conventional compression moulding technique, they both exhibited comparable tensile strength and modulus [28].

5. 3D printing technologies [10, 29, 30]

3-D printing employs an additive manufacturing process whereby products are built on a layer-by layer basis, through a series of cross-sectional slices. While 3-D printers work in a manner similar to traditional laser or inkjet printers, rather than using multi-colour inks, the 3-D printer uses powder that is slowly built into an image on a layer-by-layer basis. All 3-D printers also use 3-D CAD software that measures thousands of cross-sections of each product to determine exactly how each layer is to be constructed. The 3-D machine dispenses a thin layer of liquid resin and uses a computer-controlled ultraviolet laser to harden each layer in the specified cross-section pattern. At the end of the process, excess soft resin is cleaned away through use of a chemical bath. 3-D printers can produce simple objects, such as a gear, in less than 1 hour. The advantages of 3-D printing include the ability to economically build custom products in limited production runs, the ability to share designs and outsource manufacturing, as well as reduced design time and ease of designing and modifying products. These characteristics lend themselves to small and medium production run applications such as mass-customized products, prototypes, replacement parts, medical/dental applications, and bridge manufacturing. Advantages, applications and limitations of the additive manufacturing industry are presented in figure 11 [29].

Advantages of 3-D Printing in Comparison to Other Technologies

- Can economically build custom products in small quantities as if mass production were used.
  Sources of cost effectiveness include:
  - No need for costly tools, molds, or punches
  - No scrap, milling, or sanding requirements
  - Automated manufacturing
  - Use of readily available supplies
  - Ability to recycle waste material
  - Minimal inventory risk as there is no unsold finished goods inventory
  - Improved working capital management as goods are paid for before being manufactured
- Ability to easily share designs and outsource manufacturing
- Speed and ease of designing and modifying products

Important 3-D Printing Applications

Small Production Run Applications of 3-D Printing
- Mass-customized products
- Prototypes
- Replacement parts
- Medical/Dental applications

Medium Production Run Applications of 3-D Printing
- Bridge manufacturing

Current Limitations of 3-D Printing

- Higher costs for large production runs relative to injection molding and other technologies
- Reduced choice for materials, colors, and surface finishes
- Lower precision relative to other technologies
- Limited strength, resistance to heat and moisture, and color stability

Figure 11. Characteristics of 3-D manufacturing [29]

The ingenuity of 3-D additive manufacturing is based on custom products, such as dental and medical devices, spare parts; these goods are usually ordered in unique configurations and in very small series. [29] Given the industrial need for products developed using equipment that builds additive parts, globally various additive manufacturing technologies are used.

The FDM technique was invented in the 1980s by researcher Scott Crump, the founder of Stratasys, a company that ranks among the top companies in the 3D printing industry. FDM is a term derived from Fused Filament Modelling, and FFF stands for Fused Filament Fabrication. In the case of the FFF technique, an entire tube, relative to a nozzle, is used in the material feeding process. Using the FDM method, in 3D printing, a filament from a molten thermoplastic material is extruded through the nozzle at the end of the filament removal system, onto the surface for coating in layers to achieve the projected objects. Each new layer will be deposited on top of the layer already deposited and attached to it because the extruded material heals very quickly, immediately after being removed through the nozzle. Usually, FDM printers use ABS plastic, PLA, biodegradable polymers, and some more "eccentric" ones even use concrete, chocolate, sugar or other unusual foods. In the printing process with the FDM / FFF technique, the layers are overlapped one by one by removing the molten material through the extruder tip. The ABS filament is introduced by a mechanism that comprises the toothed rollers and is melted while it is in the extrusion system, more precisely in the thermal cavity [30].

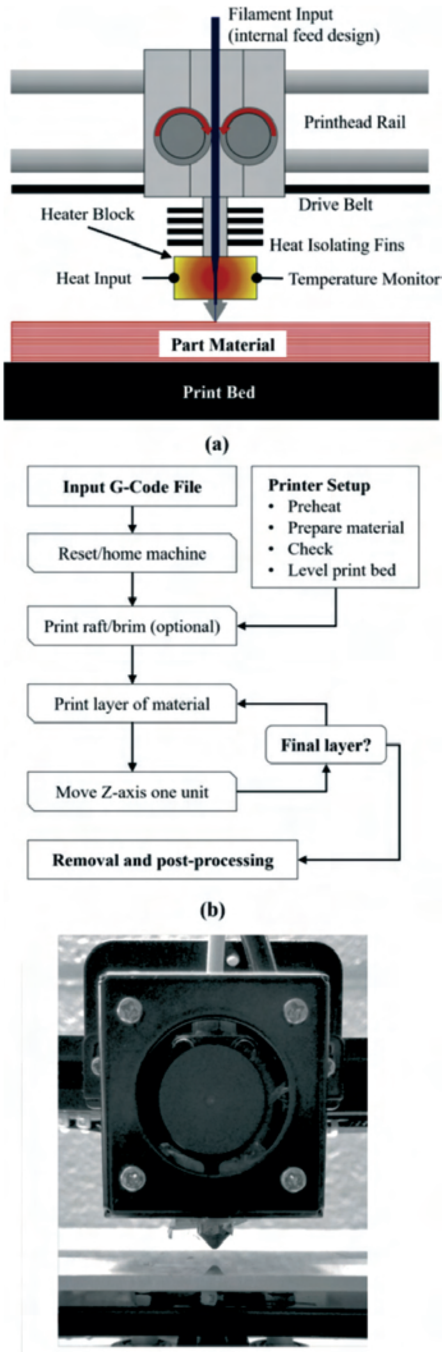

Figure 12. FDM/FFF equipment concept – a) process, b) process flow, c) extruder [30]

Stereolithography (SLA or SL) is a rapid prototyping technology widely used in the industrial environment for making moulds, models and even functional components. Also known as photo-solidification or optical fabrication, stereolithography involves the use of a laser beam with ultraviolet light to solidify a liquid photopolymer resin in the printer's construction tank. Under the action of ultraviolet laser light this treated resin (sensitive to ultraviolet light) solidifies in successive layers thus obtaining the solid 3D model [10].

DLP (Digital Light Processing) printing technology is an additive manufacturing process based on the use of UV light to solidify liquid polymer resins. Developed by Texas Instruments, DLP technology has as its core element the DMD (Digital Micro-mirror Device) - a matrix of micro-mirrors used for fast spatial light modulation [10].

SLS (Selective Laser Sintering) is a rapid prototyping technology, was patented in the late 1980s and is close to SLA. Besides the SLS name it is widely used and the generic name LS (Laser Sintering), or Laser Sintering [10].

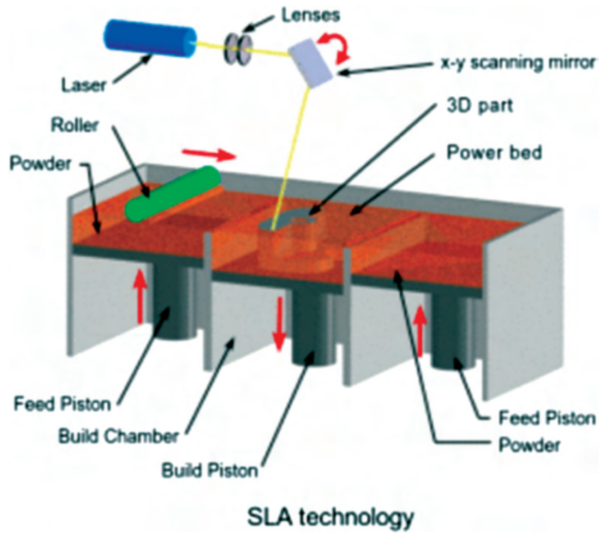

Figure 13. SLA equipment concept [10]

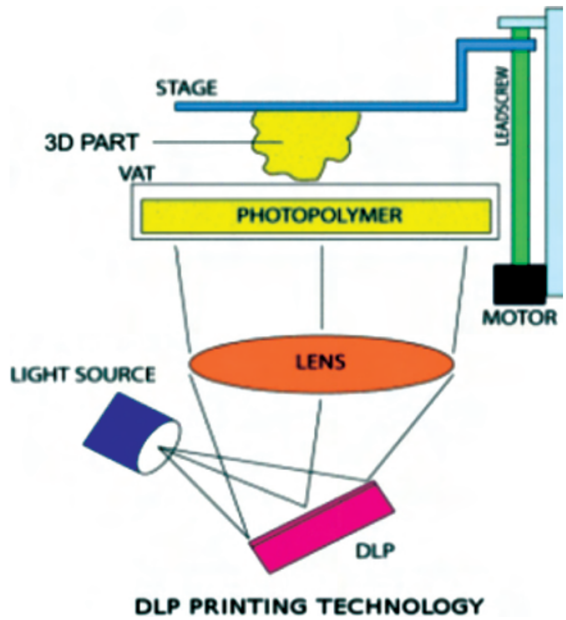

Figure 14. DLP equipment concept [10]

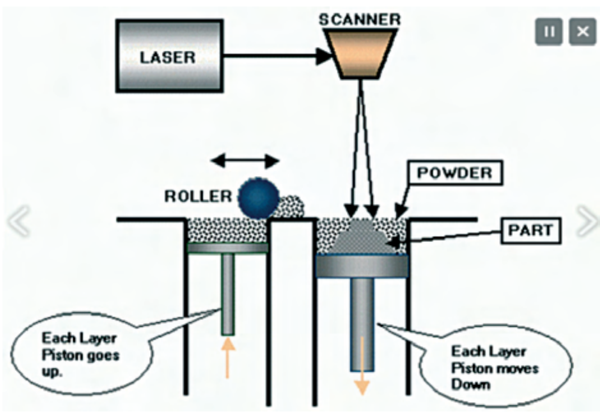

Figure 15. SLS equipment concept [10]

SLM (Selective Laser Melting) or Laser (melting) Sintering is a sub-branch of SLS technology with a similar additive manufacturing process. The technology is also called DMLS (Direct Metal Laser Sintering) or Laser Cusing [10].

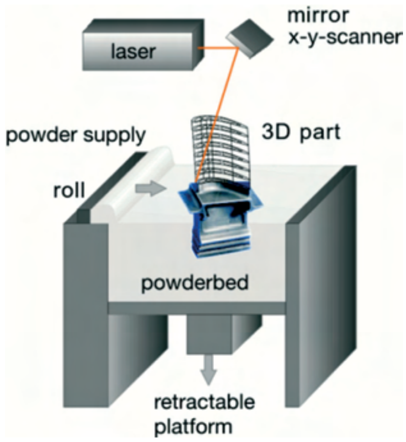

Figure 16. SLM equipment concept [10]

3 DP (Three-Dimensional Printing) technologies are also called 3D inkjet printing or Plaster-based 3D printing (PP). Three-dimensional printing was among the first 3D technologies introduced in Romania and is still the favourite technology in fields such as architecture and design. Until the advent of LOM technology, with paper, 3DP was the only technology that allowed 3D colour printing [10].

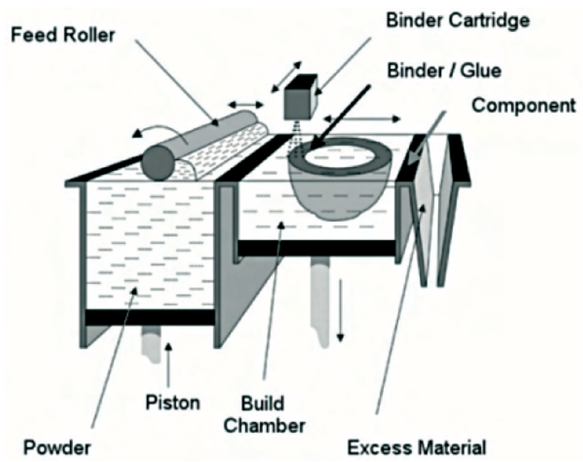

Figure 17. 3DP equipment concept [10]

Laminated Object Manufacturing or **LOM** is a lesser known technology, although the first LOM manufacturing system was developed since 1991 by Helisys Inc.LOM technology allows the layered fabrication of the 3D object from layers of paper or plastic that are glued together, one after the other, and cut using a knife or laser. The printing material used can be supplied both in roll (plastic) and in sheets or sheets (paper) [10].

3D PJP (PolyJet Printing), also known as Jetted Photopolymer, or as MultiJet Printing (MJP) is another additive manufacturing technology, somewhat similar to stereolithography (SLA) because it utilizes all-photo-solidification of a liquid photopolymer. PolyJet technology is similar to the usual inkjet printing technology. Unlike office printers that spray ink, 3D PolyJet printers emit a jet of liquid photopolymers that are then cured in UV light [10].

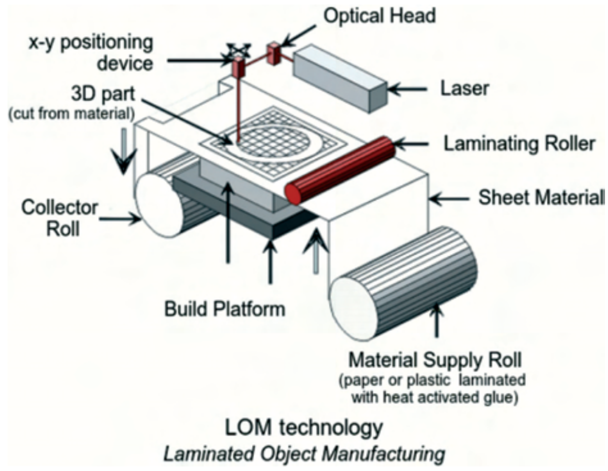

Figure 18. LOM equipment concept [10]

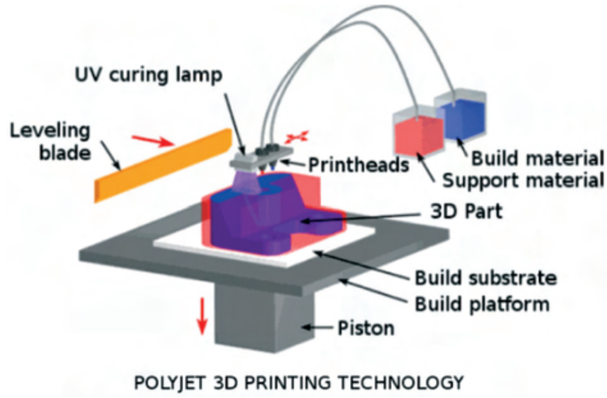

Figure 19. 3D PJP equipment concept [10]

6. Active ultrasound applications implemented into the additive manufacturing industry

Specialized literature highlighted interest in ultrasound assisted active applications used in the additive manufacturing industry, presented as follows [31]:

An existing open source 3D printer (Prusa i3) was used to demonstrate the ease of incorporating ultrasonic assembly into an existing fused filament fabrication printer, by replacing the thermoplastic extrusion system. As shown in figure 1, a 405 nm laser diode module was mounted on the print head to cure the resin, with an emitting power of 50 mW.

In Figure 20 (a) Switchable laser module is attached to the print head carriage, and traces out the shape of the printed part. The laser can be deliberately defocused to cure large regions slowly by increasing the height of the laser module [31].

In Figure 20 (b) Focused laser beam cures resin within the cavity of the ultrasonic manipulation device. P = PMMA, W = Water, PZT = lead zirconate titanate transducers, R = spot-a low Viscosity photocurable resin. Cross sections of the bundles of fibres lying within traps are shown, and are separated by half a wavelength [31].

Heterogeneous materials used in biomedical, structural and electronics applications contain a high fraction of solids (>60 vol.%) and exhibit extremely high viscosities (μ > 1000 Pa·s), which hinders their 3D printing using existing technologies. This study shows that inducing high-amplitude ultrasonic vibrations within a nozzle imparts sufficient inertial forces to these materials to drastically reduce effective wall friction and flow stresses, enabling their 3D printing with moderate back pressures (<1 MPa) at high rates and with precise flow control. This effect is utilized to demonstrate the printing of a commercial polymer clay, an aluminium-polymer composite and a stiffened fondant with viscosities up to 14,000 Pa·s with minimal residual porosity at rates comparable to thermoplastic extrusion. This new method can significantly extend the type of materials that can be printed to produce functional parts without relying on special shear/thermal thinning formulations or solvents to lower viscosity of the plasticizing component [32].

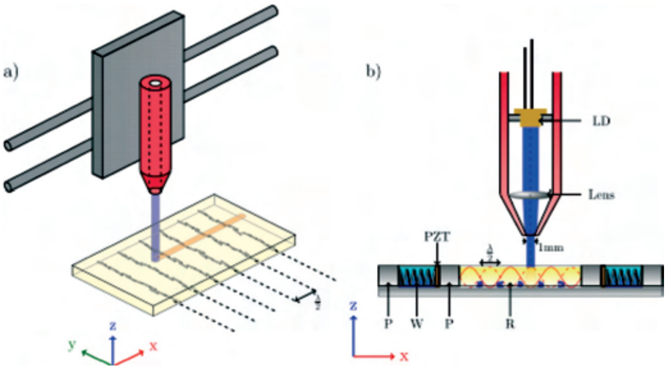

Figure 20. Schematic representation of printer and ultrasonic manipulation rig [31]:
(a) Switchable laser module is attached to the print head carriage, and traces out the shape of the printed part;
(b) Focused laser beam cures resin within the cavity of the ultrasonic manipulation device

Swank M.L and co. [32] developed a machine that provides a mobile FDM unit that does not require a special build chamber or build surface. Therefore a build can be performed on virtually any surface in any location. Unlike standard FDM machines which have a moveable z build stage; this machine has been modified so that the nozzle head is controlled directly by the z stage. This allows the x-y build surface. In order to create a support structure for a UC part, a mirror image of the supported regions must be created by the FDM machine. The flexible fused deposition modelling system can also have other applications within the UC machine besides a support materials delivery system. Essentially the two machines have been combined to create a combined metal and plastic AM process. This integration could also be used to automatically create insulated surfaces for electronics embedding, insulated direct write build surfaces, and other complex multi-material structures. [32].

S. Maidin and co. [33] conducted an analysis on US frequency on FDM nozzle, results of the analysis, enfolded that the FDM extrusion nozzle could potentially withstand frequencies up to 40 kHz. The lowest FoS obtained was 18.8975. The findings prove that the nozzle is structurally and mechanically strong enough to withstand the high frequencies transmitted from the ultrasonic system. Conducted research aims to investigate the application of using ultrasound technology for a desktop FDM system. The idea is to transmit high vibration from the ultrasonic transducer to the FDM system's nozzle, and the objective is to examine whether the nozzle is able to withstand the high vibration being transmitted. Computer-aided design (CAD) software used to develop the 3D model of the extrusion nozzle component and a computer-aided engineering (CAE) software was used to perform static and vibration analysis. A frequency range of 20 to 30kHz and 30 to 40kHz was applied to the nozzle and it was found that the nozzle was able to withstand frequencies up to 40 kHz of vibration. In addition, the lowest Factor of Safety (FoS) obtained was 18.8975, concluding that the nozzle of FDM can withstand the high vibration transmitted from the ultrasonic transducer [33].

Wenzheng Wu and co. [34] studied the input of ultrasonic vibration energy into 3D printed samples under pressure, and investigated the effects of ultrasonic vibration on the bending and dynamic mechanical properties of FDM 3D printed ABS samples. It was found that ultrasonic strengthening increased the bending strength of ABS samples by 10.8%, increased the bending modulus by 12.5%, and improved the dynamic mechanical properties. The combination of ultrasonic strengthening technology and FDM 3D printing technology can improve the flexural and dynamic mechanical properties of existing FDM 3D printed samples, and is important in broadening the application of 3D printed parts [34].

7. Conclusions

Developing the present scientific review on the state of knowledge in the field of additive manufacturing, technologies, materials and active ultrasound implemented into the 3D printing process, it aims to update researchers from CEX-US department, ISIM Timisoara, on new and innovative materials,

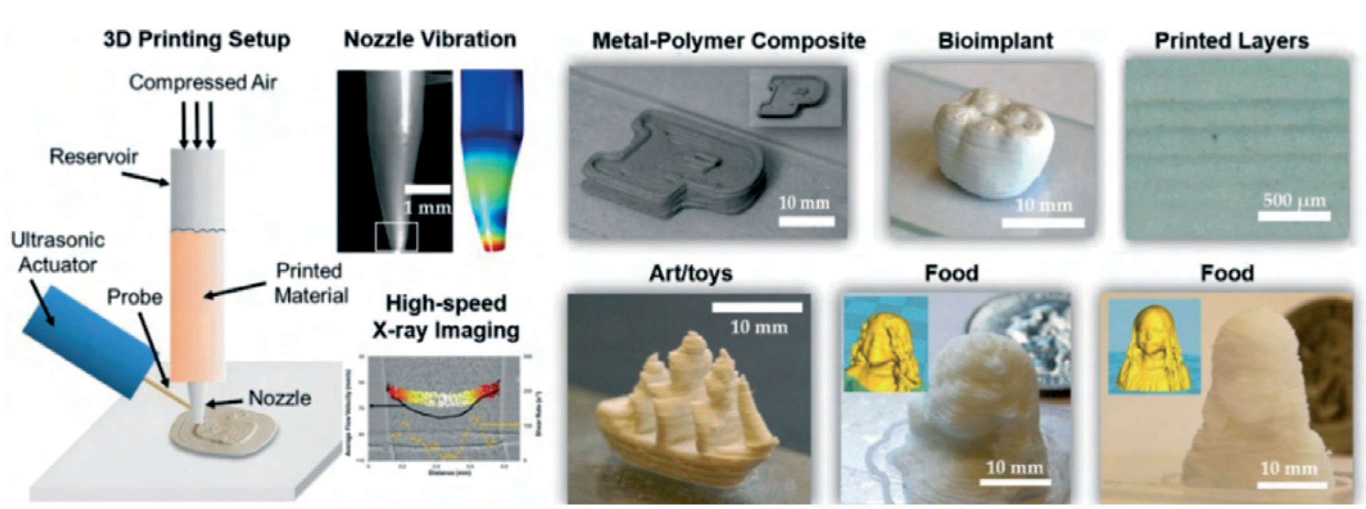

Figure 21. Applications with heterogeneous materials [32]

technologies and equipments that are of interest on the global 3D market. Following the knowledge accumulation, the purpose is to develop a new innovative concept of additive manufacturing, namely U-FDM (Ultrasonic Fused Deposition Modelling) modelling by ultrasonic thermoplastic extrusion, by combining the technique of 3D additive manufacturing - modelling by thermoplastic extrusion (FDM - Fused Deposition Modelling) - with the ultrasonic activation technique.

Researchers from CEX-US department could conclude, after studying the scientific literature, that worldwide, 3D printed parts are not satisfactory in terms of mechanical characteristics. Scientific literature also highlights, that worldwide, there is a rising interest in applying certain ultrasonic pressures and vibrations on 3D printed samples in order to study the effect on the mechanical properties of 3D printed non-crystalline and semi-crystalline polymers. It has been noticed that the use of ultrasound can significantly improve mechanical properties of additive manufactured parts, without altering the developed 3D material or adjusting the parameters of the forming process.

Following this scientific review, it is necessary to continue to research and develop new materials, technologies and equipment that combine additive manufacturing with ultrasonic micro-vibrations in order to obtain improved materials, increasingly efficient equipment, as well as superior parts from the point of view of mechanical and qualitative characteristics.

The purpose of developing new technologies is to obtain superior performances of parts made of polymeric and / or composite materials, to ensure their reproducibility, to reduce and even eliminate scratches, pores or cracks, respectively to increase the speed of 3D manufacturing of parts that have complex geometries, eliminating defects that appear in the case of classic equipment.

Acknowledgements

This paper was elaborated on the basis of the results obtained within the project PN 19.36.02.01 entitled “*Cercetări privind dezvoltarea principiului de fabricație aditivă, printare 3D, prin realizarea de echipamente inovative de modelare prin extrudare termoplastică ultrasonică*”, financed by the Ministry of Research and Innovation, in the frame of ” *Program Nucleu*” of INCD ISIM Timisoara (contract no.: 35/25.02.2019)

References

[1]. Taufik, Mohammad; Jain, Prashant K. (12 January 2014). “Role of build orientation in layered manufacturing: a review”. International Journal of Manufacturing Technology and Management. 27 (1/2/3): 47–73.doi:10.1504/IJMTM.2013.058637;

[2]. Bin Hamzah, Hairul Hisham; Keattch, Oliver; Covill, Derek; Patel, Bhavik Anil (2018). “The effects of printing orientation on the electrochemical behaviour of 3D printed acrylonitrile butadiene styrene (ABS)/carbon black electrodes”.Scientific Reports. 8 (1): 9135. Bibcode:2018NatSR...8.9135B.doi:10.1038/s41598-018-27188-5. PMC 6002470. PMID 29904165;

[3]. Ghiniță Dana-Silvia, (2016), Imprimantă3D în sistem cartezian, UP București, pg. 13-15. http://speed.pub.ro/speed3/wp-content/uploads/2017/01/2016-Proiect-de-diploma-Dana-Ghinita.pdf;

[4]. https://www.statista.com/topics/1969/additive-manufacturing-and-3d-printing/;

[5]. Cele mai folosite tehnologii de manufacturare aditiva la nivel global 2017-2018 https://www.statista.com/statistics/560304/worldwide-survey-3d-printing-top-technologies/;

[6]. https://blogs-images.forbes.com/louiscolumbus/files/2018/05/3D-Printing-Applications-and-Departments.jpg;

[7]. Louis Columbus, (2018), The State of 3D Printing, 30.05.2018, https://www.forbes.com/sites/louiscolumbus/ 2018/05/30/the-state-of-3d-printing-2018/;

[8]. Piața globala de fabricare 3D https://knowledge.ulprospector.com/9434/pe-3d-printing-materials-the-new-age-manufacturing-solution/;

[9]. Chris Clare, (2018), Discovering the latest innovations at 3D Printing USA 2018, Posted on: August 21st 2018, https://www.3dprintingprogress.com/articles/15170/ discovering-the-latest-innovations-at-3d-printing-usa-2018;

[10]. https://www.zspotmedia.ro/blog/printare-3d/;

[11]. https://3dinsider.com/3d-printer-types/;

[12]. Diana Popescu, (2015), Aplicații software pentru fabricație aditivă Pot printa această piesă? (I), FABRICATIE ADITIVA; https://www.ttonline.ro/revista/fabricatie-aditiva/aplicatii-software-pentru-fabricatie-aditiva-pot-printa-aceasta-piesa-i;

[13]. Joris Peels Jun, (2018), Ghid achiziționare imprimante industriale 3D 2018, https://3dprint.com/ 216738/industrial-3d-printer-guide-2018/, 3DPRINT/COM, The Voice of 3D printing / Additive manufacturing;

[14]. http://www.livescience.com/39810-fused-deposition-modeling.html;

[15]. A. Aimar, A. Palermo and B. Innocenti, (2019), Rolul printării 3D în aplicații medicale -State of the Art, Journal of Healthcare Engineering, Volume 2019, Article ID 5340616, 10 pages, https://doi.org/10.1155/2019/5340616;

[16]. http://magnum.engineering.upm.ro/~gabriela.strnad/Tehnologia%20materialelor%20II%20-%20curs%20licenta%20an%20II/1%20CURS/capitolul%207.pdf;

[17]. https://www.eshop.formwerk.ro/cumpara/filament-polymaker-polysupport-1153;

[18]. https://www.allthat3d.com/3d-printer-filament/;

[19]. https://www.statista.com/statistics/560323/worldwide-survey-3d-printing-top-technologies/;

[20]. https://www.3dprintingmedia.network/3d-printing-filament/;

[21]. https://www.sciencedirect.com/science/article/abs/pii/S1359836815003777?via%3Dihub;

[22]. Zhong W, Li F, Zhang Z, Song L, Li Z. Short fiber reinforced composites for fused deposition modeling. Mat Sci Eng A Struct 2001;301(2):125e30;

[23]. Gray RW, Baird DG, Bohn JH. Effects of processing conditions on short TLCP fiber reinforced FDM parts. Rapid Prototyp J 1998;4(1):14e25;

[24]. Gray RW, Baird DG, Bohn JH. Thermoplastic composites reinforced with long fiber thermotropic liquid crystalline polymers for fused deposition modeling. Polym Compos 1998;19(4):383e94;

[25]. Shofner ML, Lozano K, Rodríguez-Macías FJ, Barrera EV. Nanofiber-reinforced polymers prepared by fused deposition modeling. J Appl Polym Sci 2003;89(11):3081e90;

[26]. Tekinalp HL, Kunc V, Velez-Garcia GM, Duty CE, Love LJ, Naskar AK, et al. Highly oriented carbon fiber-polymer

composites via additive manufacturing. Compos Sci Technol 2014;105(10):144e50;

[27]. Hinton, T. J., Hudson, A., Pusch, K., Lee, A., & Feinberg, A. W. (2016). 3D Printing PDMS Elastomer in a Hydrophilic Support Bath via Freeform Reversible Embedding. ACS Biomaterials Science & Engineering, 2(10), 1781–1786. doi:10.1021/acsbiomaterials.6b00170;

[28]. Tekinalp, H. L., Kunc, V., Velez-Garcia, G. M., Duty, C. E., Love, L. J., Naskar, A. K., … Ozcan, S. (2014). Highly oriented carbon fiber–polymer composites via additive manufacturing. Composites Science and Technology, 105, 144–150.doi:10.1016/j.compscitech.2014.10.009;

[29]. https://www.sciencedirect.com/science/article/pii/S0007681311001790;

[30]. https://www.mdpi.com/2504-4494/3/1/6;

[31]. https://iopscience.iop.org/article/10.1088/0964-1726/25/2/02LT01/pdf;

[32]. https://www.sciencedirect.com/science/article/pii/S2214860418301945;

[33]. Integrating UC and FDM to Create a Support Materials Deposition System Swank, M.L.a , Stucker, B.E.a , Medina, F.R.b , Wicker, R.B.b , aUtah State University, b The University of Texas at El Paso;

[34]. Maidin, S., Abdul Aziz, K. F., Muhamad, M. K., & Pei, E. (2015). Analysis of Applying Ultrasonic Frequency on a Desktop FDM Nozzle. Applied Mechanics and Materials, 761, 329–332. https://www.scientific.net/AMM.761.329.

Calendar of International and National Events

2019			
9 Dec.	17th International Symposium On Tubular Structures (Ists17)	Singapore	https://www.ists17-singapore.org/
5 - 7 Dec.	NDE 2019 - Conference and Exhibition on Non-Destructive Evaluation	Bangalore, India	https://since2019.org/
2020			
27 - 29 Jan.	International Conference of Welding, Joining and Additive Manufacturing - Organized by AEAI.	Tel-Aviv, Israel	https://www.aeai.org.il/welding2020
26 - 30 Apr.	SPIE Smart Structures + Nondestructive Evaluation 2020	Anaheim, USA	https://www.spie.org/
14 - 15 May	International Symposium on Structural Health Monitoring and Nondestructive Testing (SHM-NDT 2020)	Québec City, Canada	https://www.shm-ndt2020.gel.ulaval.ca/home/
19 - 22 May	Young Professional International Conference and WRTYS 2020	Kiev, Ukraine	https://ypic2020.com/
27 - 29 May	4th International Congress on Welding & Joining Technologies - 3rd IIW International Congress in the Western European Region	Sevilla, Spain	http://www.cesol.es/congress2020/index-EN.html
10 - 12 Jun.	ITSC 2020 - International Thermal Spray Conference and Exposition	Vienna, Austria	http://www.dvs-ev.de/itsc2020/
19 - 24 Jul.	THE 73rd IIW Annual Assembly and International Conference	Singapore	https://iiw2020.com/