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MIND COURSE SUPPORT

LECTURE 6
IMPLEMENTATION OF NEW MANUFACTURING TECHNOLOGIES AND SYSTEMS FOR INDUSTRY 4.0.

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1. *Objectives of the lecture*

This course aims to develop the general and specific skills of the students within the MIND project consortium. This course is one divided into two types of objectives, theoretical objectives as well as practical objectives. The theoretical objectives are those of producing, as well as of improving the understanding related to the concept of rapid prototyping. These theoretical objectives are related to the definition, identification of benefits and how they are used in different fields of education, such as mechatronics engineering.

Since the beginning of fourth industrial revolution (2010-2015) 3D printing is identified as one of biggest trends in industry. This means that there is a need for new competences and knowledge that new engineers need to have for challenges of fourth industrial revolution.
Theoretical aspects focus on improving the learning experience of students and teachers by using rapid prototyping that is based on new manufacturing technologies and systems.

General objectives:

- Formation of notions related to the concept of rapid prototyping,
- Formation of ideas on the advantages of new manufacturing technologies and systems,
- Understanding the relatively complex topics about learning and prototyping with the help of rapid prototyping.

Specific objectives:

- To know and understand main 3D printing technologies,
- Knowledge of the steps required for rapid prototyping,
- To prepare CAD model for specific 3D printing technology,
- To know how it works,
- To identify the causes of a possible problem.

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2. Introduction. New manufacturing technologies in education

Rapid prototyping means technologies that make it possible to create a physical representation of a three-dimensional (3D) model directly from a digital representation of a CAD model, and a fully functional and relatively complex working prototype. Alongside robotics and intelligent systems, additive manufacturing, or 3D printing, is a key technology driving Industry 4.0. Within the context of Industry 4.0, 3D printing is emerging as a valuable digital manufacturing technology. Once solely a rapid prototyping technology, today AM offers a huge scope of possibilities for manufacturing from tooling to mass customization across virtually all industries.

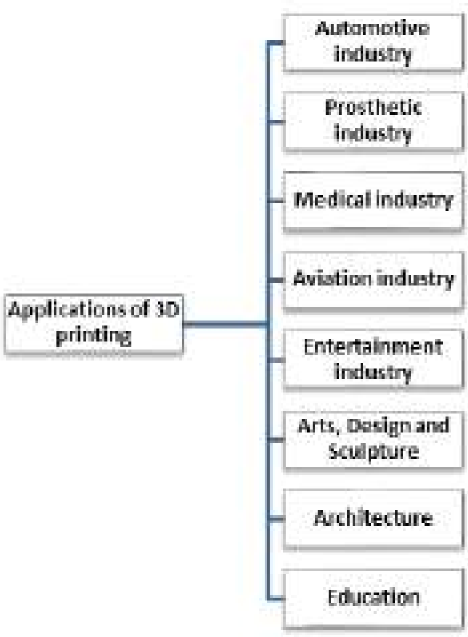

Figure 1. Applications of 3D printing

Rapid Prototyping devices build a model, unlike CAM technologies that realize geometry by removing materials. The construction of the model is based on digitally cut layers of the model, which are glued layer by layer in the final shape in the physical space. The advantage of building in layers is the creation of complex shapes that are almost impossible to create with classical methods. It is possible to build complicated structures inside the model and thin

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walls. All RP technologies (additive methods) build the model by applying layer by layer of material in the form of cross sections of the model in the x-y plane along the z axis.

First concept of 3D printing made in 1974 David E. H. Jones in the journal New Scientist. Early additive manufacturing equipment and materials were developed in the 1980s. In 1981, Hideo Kodama of Nagoya Municipal Industrial Research Institute invented two additive methods for fabricating three-dimensional plastic models with photo-hardening thermoset polymer, where the UV exposure area is controlled by a mask pattern or a scanning fiber transmitter.

On July 2, 1984, American entrepreneur Bill Masters filed a patent for his Computer Automated Manufacturing Process and System (US 4665492). This filing is on record at the USPTO as the first 3D printing patent in history; it was the first of three patents belonging to Masters that laid the foundation for the 3D printing systems used today.

The technology used by most 3D printers to date—especially hobbyist and consumer-oriented models—is fused deposition modeling, a special application of plastic extrusion, developed in 1988 by S. Scott Crump and commercialized by his company Stratasys, which marketed its first FDM machine in 1992.

All reports that are dealing with 3D printing and manufacturing trends are forecasting significant growth of investment and market share. For example: The Wohlers Report 2019 forecasts for 2020 is $15.8 billion for all AM products and services worldwide. The company expects that revenue forecast to climb to $23.9 billion in 2022, and $35.6 billion in 2024. [WOH1]

Advantages of 3D printing technologies:

- Reducing product development time and reducing costs;
- Shortening the time of arrival of products on the market;
- Enabled good communication between the functions of marketing, engineering, production and sales;
- Application of physical prototypes for analysis of critical structural elements;
- Testing of functional prototypes before making product making tools;

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- Precise definition of the necessary tools for making

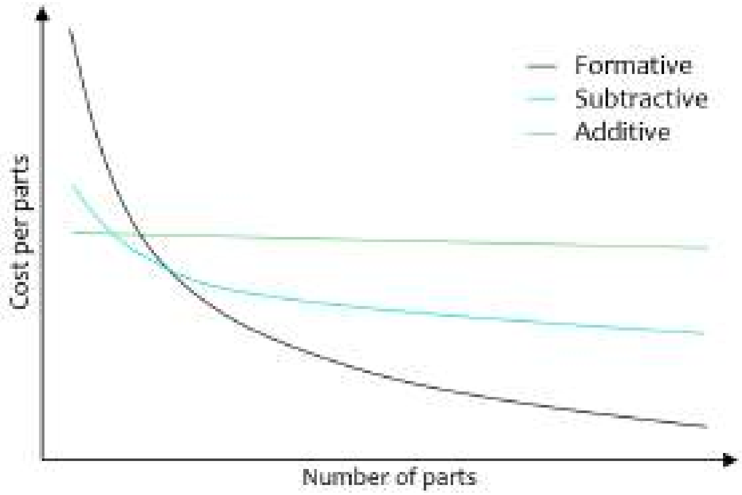

Figure 2. Economic comparison of costs per parts made by different technologies

Disadvantages of 3D printing technologies:

- Limited choice of materials;
- Surface quality;
- Uneconomical for large production series;
- Limited model dimensions;
- Lack of design complexity that would make 3D printing more competitive

The advantages of 3D printing in education

3D printing means existence of a digital model in a 3D CAD (Computer Aided Design) file and then creation of a physical three-dimensional object. For 3D printing's use in education, it's a matter of bringing objects out of the computer screen and into the real, physical world - and the into the hands of students for inspection, analysis, and other processes that benefit from physical manipulation.

Generally, 3D printing technologies are bridging the gap between the physical and the digital worlds and then print it into existence. 3D printing is a tool that gives students

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possibility to conceptualize and visualize their designs as they develop their work from the development stages of a sketch to the final product.

From the perspective of growth and development, future designers, engineers, and artists all will have been students who have been impacted by 3D printing.

Benefit that 3D printing brings to education:

- Creates Excitement
- Complements the Curriculum
- Gives Access to Knowledge Previously Unavailable
- Opens New Possibilities for Learning
- Promotes problem-solving skills

Feeding students' creativity skills can help develop a passion for original thinking and creativity that can later be applied in business. 3D printing promotes students achievements and also prepares them for a college education. As students explore and grow their imaginations, it cultivates innovation where the student creates their own unique 3D projects that can help train others as well as solve problems.

3. *Additive manufacturing*

Most important 3D printing technologies are given in Table 1.

Table 1. List of 3D technologies and used materials

Technology	Used material
Stereolithography (SLA) **Polyjet**	Photopolymers
Fused Deposition Modelling (FDM)	Thermoplastics
Selective laser melting (SLM) **Direct Metal Laser Sintering (DMLS)** **Direct Energy Deposition (DED)** **Electron Beam Melting (EBM)**	Metal materials
Material Jetting (MJ)	Powder materials

Binder Jetting (BJ)	Powder materials
Selective laser sintering (SLS)	Powder materials

The most-commonly used 3D printing process (46% as of 2018) is a material extrusion technique called fused deposition modeling or FDM. While FDM technology was invented after the other two most popular technologies, stereolithography (SLA) and selective laser sintering (SLS), FDM is typically the cheapest technology, which lends to the popularity of the process. Normally, every firm that have need to use rapid prototyping should have first FDM printer, after which they should choose some of other printing technology like SLA or SLS depending from the company needs.

Figure 3. represent rapid prototyping cycle that occur from the design of CAD model to 3D printing. The STL file has become the de facto standard format for data transmission used by RP devices. The STL format was designed in 1989 by 3D Systems. It is a representation of the geometry of three-dimensional surfaces in the shape of a triangle. The surface of the model is logically divided into a series of small triangles, so-called faces that have their own direction and orientation and are described by three points in space.

A file in this form is used to cut the model into layers of horizontal cross-sections. The preparation of the STL file, ie the display of the model in the network form must be optimal for the creation of the model, ie. the mesh constructed from the face must be so dense as to satisfy the required surface quality and display of details. Almost all CAD systems have the ability to export a STL file. The export itself is simple and varies in steps from system to system.

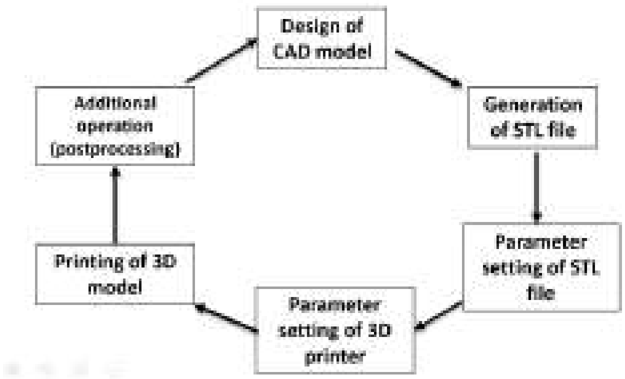

Figure 3. Rapid prototyping cycle

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3.1 Support structure

The main disadvantage of additive processes is the existence of support structure for most of AM technologies (Fig. 4).

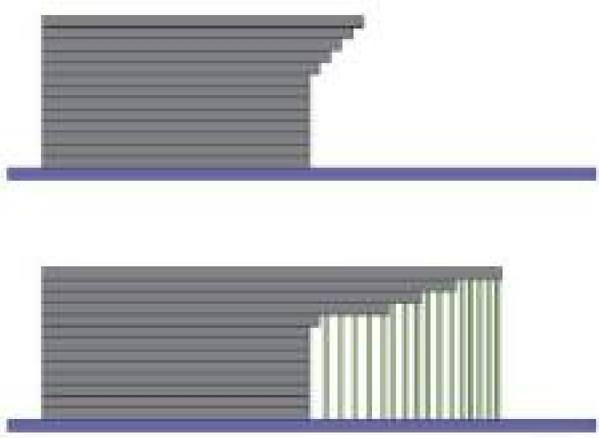

Figure 4. Support structure

Used with almost all 3D printing technologies, support structures help to ensure the printability of a part during the 3D printing process. Supports can help to prevent part deformation, secure a part to the printing bed and ensure that parts are attached to the main body of the printed part. Only SLS and Binder Jetting technology do not need support structures.

Parts with complex design features like overhangs, holes and bridges are more challenging to print. Since these features are likely to collapse if not supported, support structures can aid in preventing collapse during the printing process.

Supports can also work as heat dissipaters in processes where high temperatures are involved, as is the case with metal 3D printing. With metal AM technologies, support structures help to draw heat away from the part preventing residual stresses that occur due to high temperatures experienced during the printing process.

On the example of a scaffold made by SLA technology (Fig. 5), the functional surfaces are marked with a star (fixation for bones). If the supports are generated on the upper structure of the scaffold, the fibers will break during their removal.

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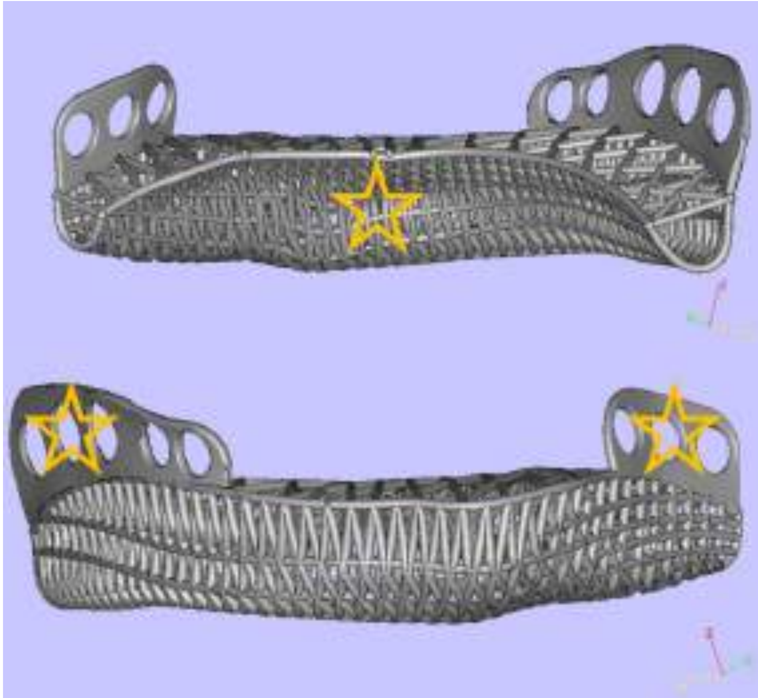

Figure. 5 Position of support structure

Also, if the supports were placed on functional surfaces, their quality would be significantly degraded and the installation of scaffolding would be prevented. Generation of support structure on the thin-walled structure could be very problematic while the walls will break during their removal of support structure.

3.2 Slicer

The slicer or slicing software is a software used in the majority of 3D printing processes for the conversion of a 3D object model to specific instructions for the printer. In particular, the conversion from a model in STL format to printer commands in g-code format in fused filament fabrication and other similar processes.

The slicer first divides the object as a stack of flat layers, followed by describing these layers as linear movements of the 3D printer extruder, fixation laser or equivalent. All these movements, together with some specific printer commands like the ones to control the

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extruder temperature or bed temperature, are finally written in the g-code file, that can after be transferred to the printer.

There are many slicer software, some of them are: Ultimaker Cura, PrusaSlicer, Slic3r, Eiger, Simplify3D, FlashPrint, KISSlicer, ideaMaker, REALvision, Voxelizer, Kiri:Moto etc.

3.3 Fused Deposition Modeling (FDM)

FDM technology is most common and is also known as Fused Deposition Modeling. This is a technology that has been patented by Stratasys and it is a technology that enables the creation of prototypes in a very short timeframe. This technology is also known as Fused Filament Fabrication or FFF 3D printing.

FDM 3D printing is a technology that works both horizontally and vertically, where an extrusion nozzle moves over a build platform. The process involves the use of thermoplastic material that reaches melting point and is then forced out, to create a 3D object layer by layer. As the design takes shape, it is clear to the see each layer as a horizontal cross section. Following the completion of one layer, the nozzle of the printer is lowered in order for the next layer of plastic to be added to the design. Once the object has been created, the materials that are used to support the object can then be removed [TRA17].

Many businesses use FDM 3D printing technology as it allows the creation of detailed and intricate objects. Therefore, engineers are using it to allow them to test parts for fit and form. It is a technology that is now assisting the creation of small parts and specialized tools that would once take a lot longer to produce.

The technology that drives FDM forward was invented in the 1980's which was down to the evolution of technology that became commercially available. [Str19].

How does FDM works?

In the same way as other forms of 3D printing, FDM uses a digital design that is uploaded to the 3D printer. There are a lot of different polymers used, such as ABS, PETG, PEI and PEEK. These take the shape of plastic threads that are fed from a coil and through a nozzle. The filaments are melted and fed onto the base, known as a build platform or table with the base

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and the nozzle, both of which are controlled by a computer. The computer works by translating the object and its dimension into co-ordinates that make it possible for the nozzle and base to follow (fig. 6) [Bai15]

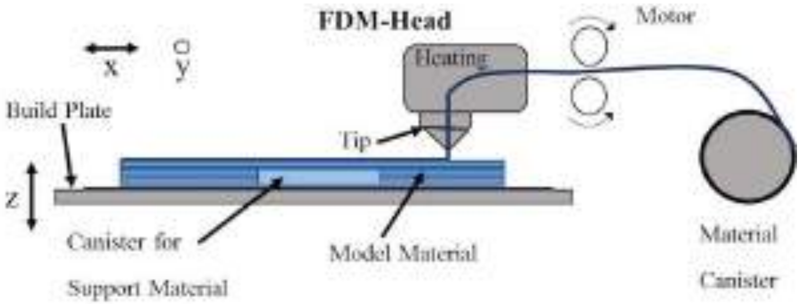

Figure 6. FDM process

As the nozzle moves across the base, the plastic cools and becomes solid, forming a hard bond with the previous layer. At this point the printhead goes up in order for the next layer of plastic to be laid. As always, 3D printing is efficient and fast but the time it takes to create an object does depend on its size. Smaller objects that are around several cubic inches can be created quickly but larger, more complex object will take longer [Str19].

Many different industries choose to use FDM 3D printing. Industries including automotive and a wide range of consumer goods manufacturers. They use FDM because it helps to aid their product development, their prototyping and their manufacturing process. Manufacturers of certain products use FDM 3D printing because of the thermoplastic that is used during development is perfect for anything ranging from Children's toys or even sports equipment.

Prototyping

Prior to a product being taken to the mass market, it is important that objects are tested vigorously. Therefore, the use of thermoplastics is ideal for creating prototypes because they can endure heat, chemicals and mechanical stress. Along with this, as FDM printing has the

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ability to create extremely detailed objects, it makes it the ideal choice for those industries that use need to create parts that need to be tested for fit and form.

However, it is not just about prototyping because FDM is also used to create end-use parts, especially small parts that have a lot of details. In fact, it is common for thermoplastics to be used for food packaging and drug packaging and so, it is a popular technology in the medical industry.

What are the advantages of FDM 3D printing?

- **Easy handling**

The 3D printing industry is constantly evolving. There is no doubt that it will become the main way to create parts and objects in the future. It simplifies the manufacturing process and enables manufacturers to test, alter and finally produce a final product in timeframe that is faster than traditional methods. Easy handling is one of the great benefits of FDM or FFF 3D printing.

- **Cost efficient**

For any business, cost is everything because it eats into the bottom line and affects profits and so, keeping costs low is vital. Therefore, FDM 3D printing, provides a viable solution that is designed to help keep manufacturing costs low. Of course, there is the prototype development costs to keep down, the testing costs and the final production costs. Through a comparison with other types of 3D printing techniques, FDM 3D printing is also cheaper than other methods. The materials used are cheaper than the ones used in SLS and SLA 3D printing.

- **Flexibility in material choice**

Often, many businesses are governed by the materials they use during the manufacturing process. However, when it comes to FDM or FFF 3D printing, there is a broad range of materials available and all are accessible and economical. It is also possible for a selection of materials to be used at the same time which helps to create complex objects while it is also possible to print using a wide range of colors offering versatility and flexibility.

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- **Less post-processing**

Time is money but FDM 3D printing is an option that optimizes production times and that saves money. As there is less post-processing required, it means that there is no need to think about how you use expensive liquids used in other methods, it simply creates a product that is ready to use.

Accessibility is vital for businesses if they are to take advantage of FDM 3D printing. Whether a business is looking for a 3D printing solution for the first time or simply looking for a feasible printing option that is readily-available, FDM 3D printing is a great option. The technique is efficient, easy to understand and the best FDM 3D printers deliver readily-available results with very little fuss.

Printable materials

There are many different print materials (filaments) available for FDM 3D printers. Each material has its pros and cons. What kind of material do you want to print? Be aware that not every FDM printer can handle all types of materials. For example high performance materials like PEEK need a higher extruder temperature, which the majority of FDM 3D printers do not offer (fig. 7). [3DHub19] - Thermoplastic materials pyramid available in FDM. As a rule of thumb, the higher a material is the better its mechanical properties.

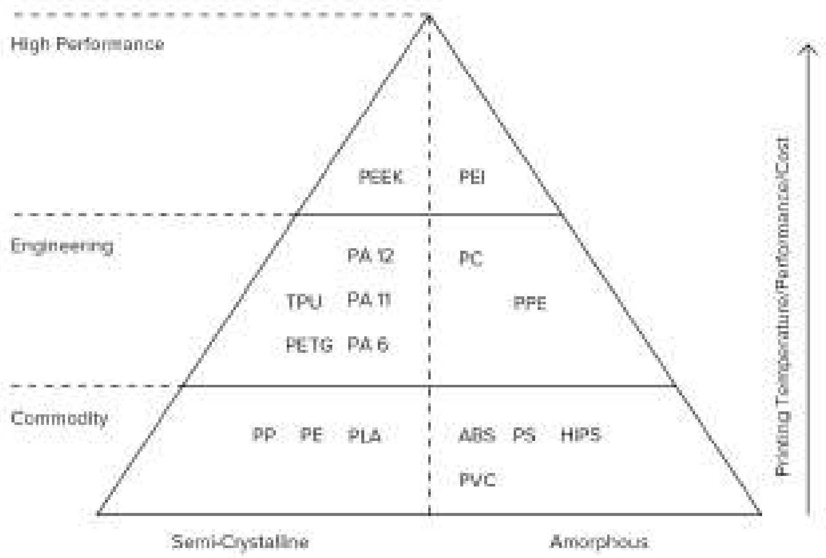

Figure 7. Materials for FDM

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Certain manufacturers have a closed filament system, meaning that it can only use the printing materials from a particular brand (often their own brand). On the other hand, there are also manufacturers with an open filament system, offering you freedom of choice. In that case you are free to choose your preferred filament brand, which is almost always less expensive.

Technical specifications

Finding the best FDM 3D printer also means looking into the, sometimes complicated, technical specifications of the machines. We already discussed the importance of the size of the print area (1. Build volume). Other important specifications are:

Extruder(s): Each 3D printing material has a different melting point, that is why the extruder (or nozzle) temperature of the FDM 3D printer is vital. Make sure that the extruder can handle the material you want to print.

Resolution: The thickness of the layers affect the quality of the output. A higher resolution means thinner layers, which are less visible. This is often measured in microns, a resolution of 10 microns is a layer thickness of 0,01 millimeters. Make sure its the best FDM 3D printer for the quality you need, check if the minimum and maximum resolution meet your requirements.
Speeds: There are two different speeds to consider, travel speed and printing speed. Printing speed is the actual speed each layer is 3D printed and travel speed is the speed at which the FDM printer moves from one point to the other while its not printing. Be aware that speed settings can also influence the quality of the output.

Other features which improve the 3D printing process are a automatic build plate calibration, out of filament detection and a closed chamber.

The 3D printer that we have in Mechatronics Department of Timisoara is Symme 3D – fig. 8.

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Figure 8. The Symme 3D printer

In case of material extrusion as shown in Fig. 6, there are several process parameters that influence the final part strength, quality, cost and production time including (but not limited to):

(1) Material and support selection, (2) Part design, (3) Layer thickness, (4) Print design (wall thickness, infill pattern), (5) Print conditions (uniformity of extruder and/or build-bed temperature).

The steps for obtaining a part are:

1. PRE-PROCESSING ("slicing" or sectioning CAD design into layers). The FDM process begins in one of build-preparation programs, Idea Maker. In operation, the first step is to import a design file, pick options, and create slices (layers). The preprocessing software calculates sections and "slices" the part design into many layers. Using the sectioning data, the software then generates "tool paths" or building instructions which will drive the extrusion head. Next send the job to the 3D printer.

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2. PRODUCTION (the layering process) Press “print” to start the building process.

3. POST-PROCESSING (removing disposable support material)

1. PRE-PROCESSING

CAD design of the part

The 3D model of the part can be made in any 3d software, we use proEnginner – Creo 5. The part is exported in .stl format (streolitography format). It is very important that the exported model to be made with Customized option to obtain a model with facets for better printed part fig. 9.

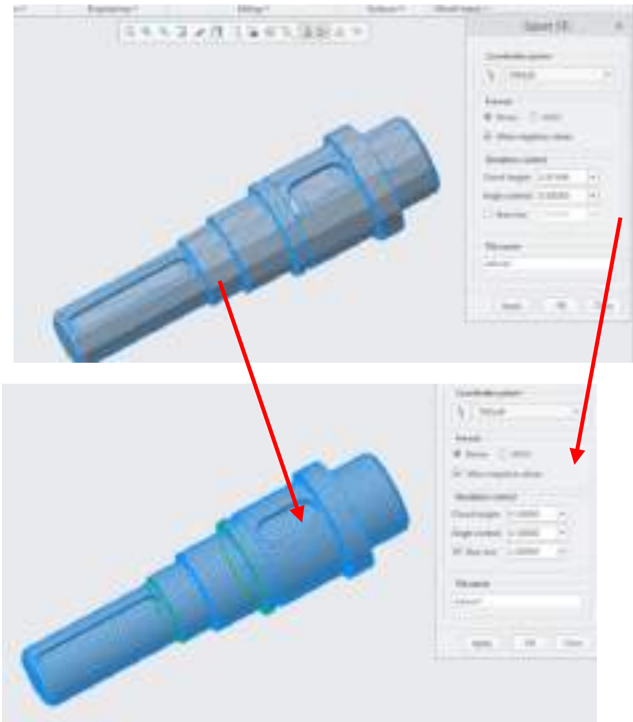

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Figure 9. The .stl part

The used program for slicing the 3D model was **IdeaMaker**, that is compatible with 3D printer.

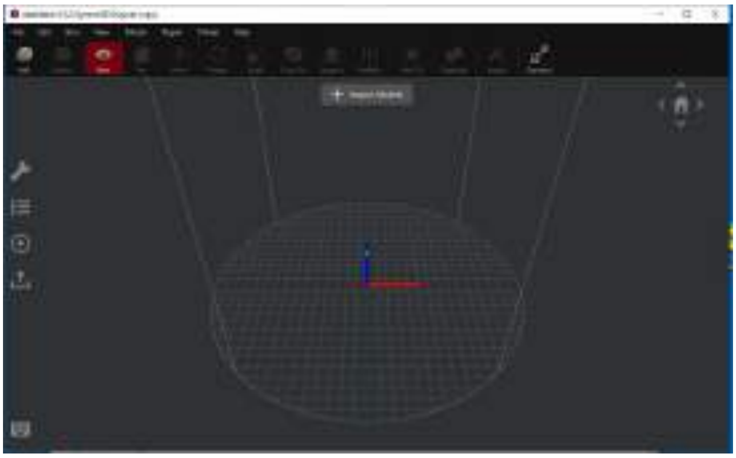

Figure 10. IdeaMaker – slicer programm

a. Import the model an prepare for printing (fig. 8).

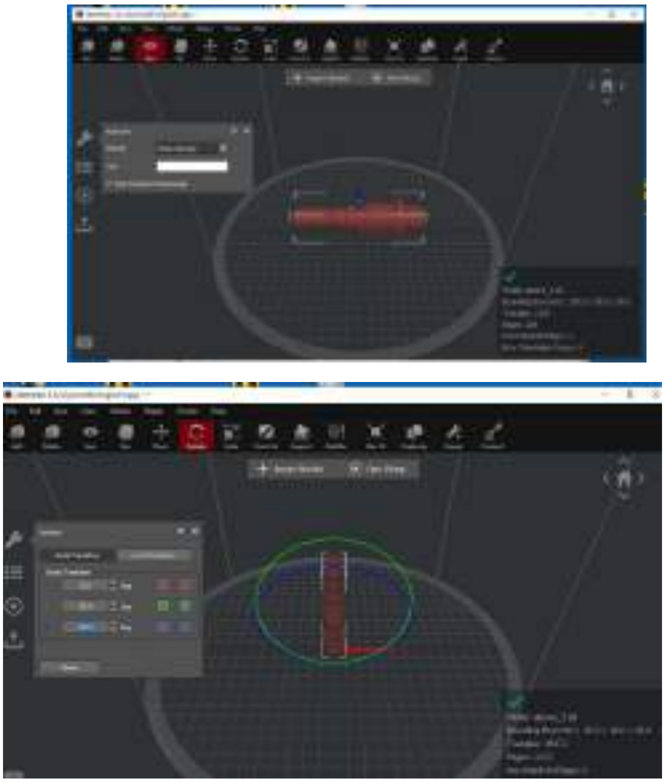

Figure 11. Preparing the part for slicing

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b. making the slicing – using predefined model (it can be created some templates for the slicing) – fig. 11.

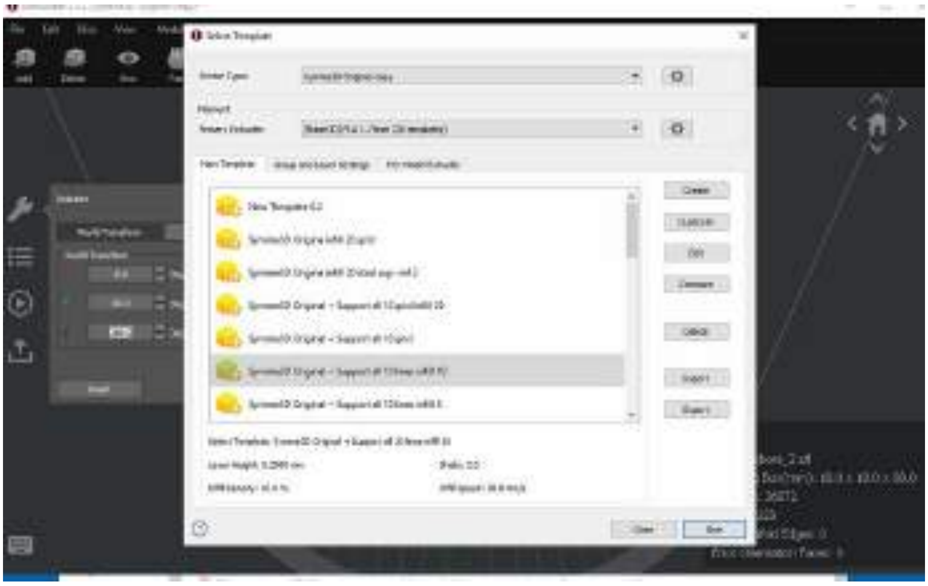

Fig. 12. Templates for slicing

c. the interface with the parameters that can be changed for obtaining a better slice for the part

- the layers - the height – fig. 12.

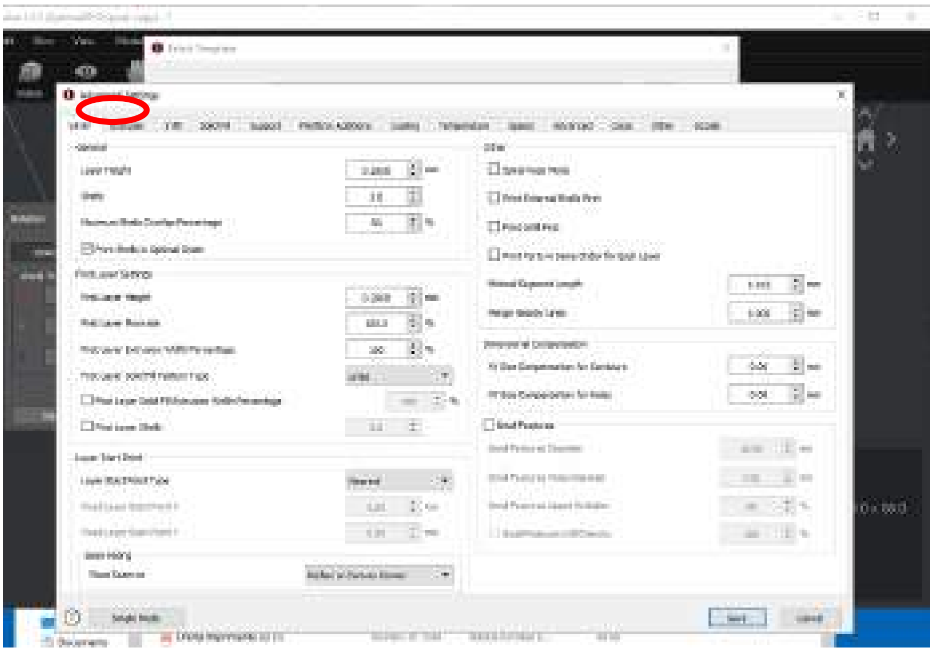

Figure 13. The interface for layers for the part

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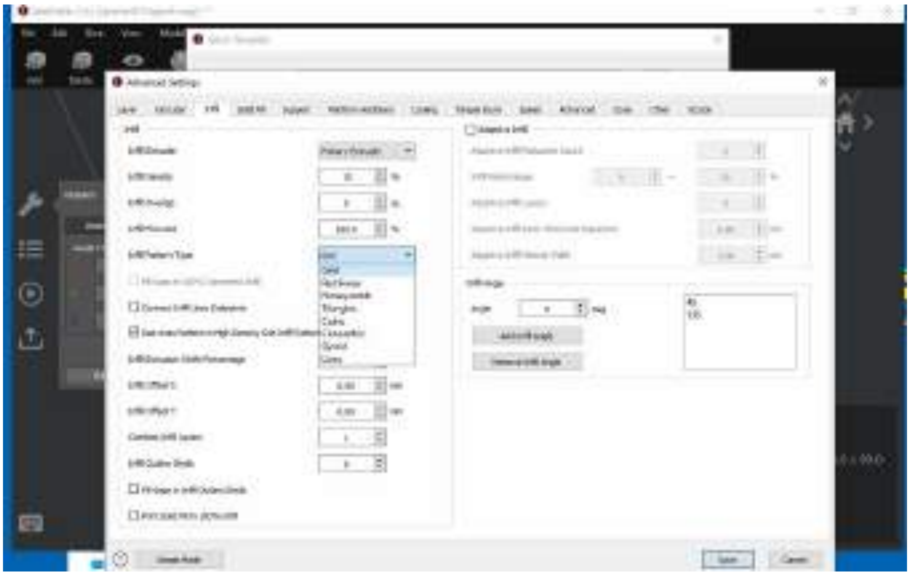
- the infill for the part – different types and densities – fig. 13.



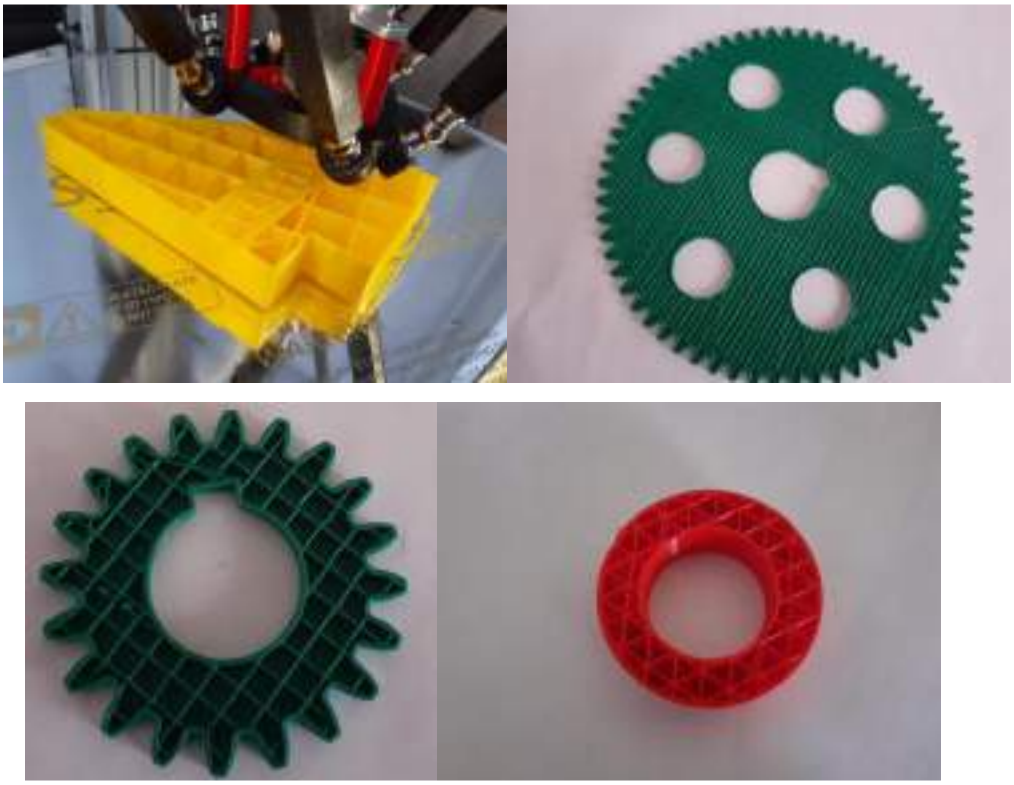


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Figure 14. The infill shape and density

- solid fill for the bottom and top layers – fig. 14.

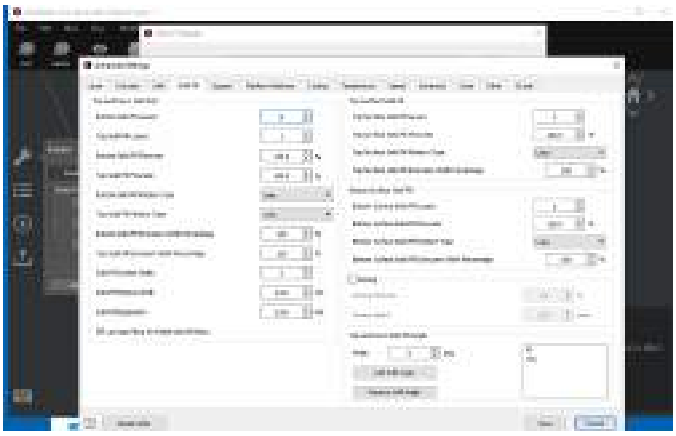
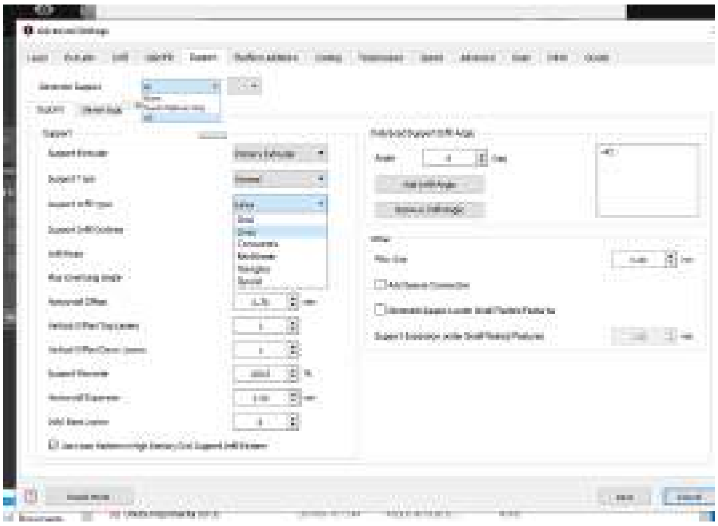


Figure 15. The interface for the top and bottom layer

- the support for the part – fig. 15.



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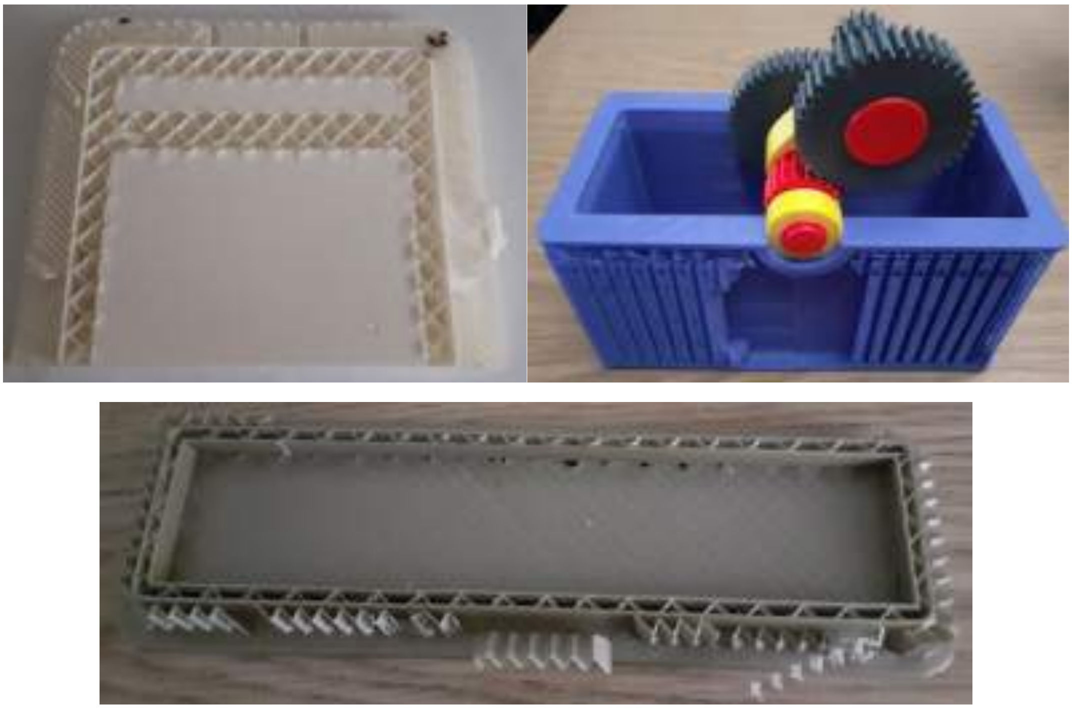

Fig. 16. Different types for supports

The interface for the sliced model, the previw for the layers – fig. 17.

Figure 17. The sliced model

2. PRODUCTION

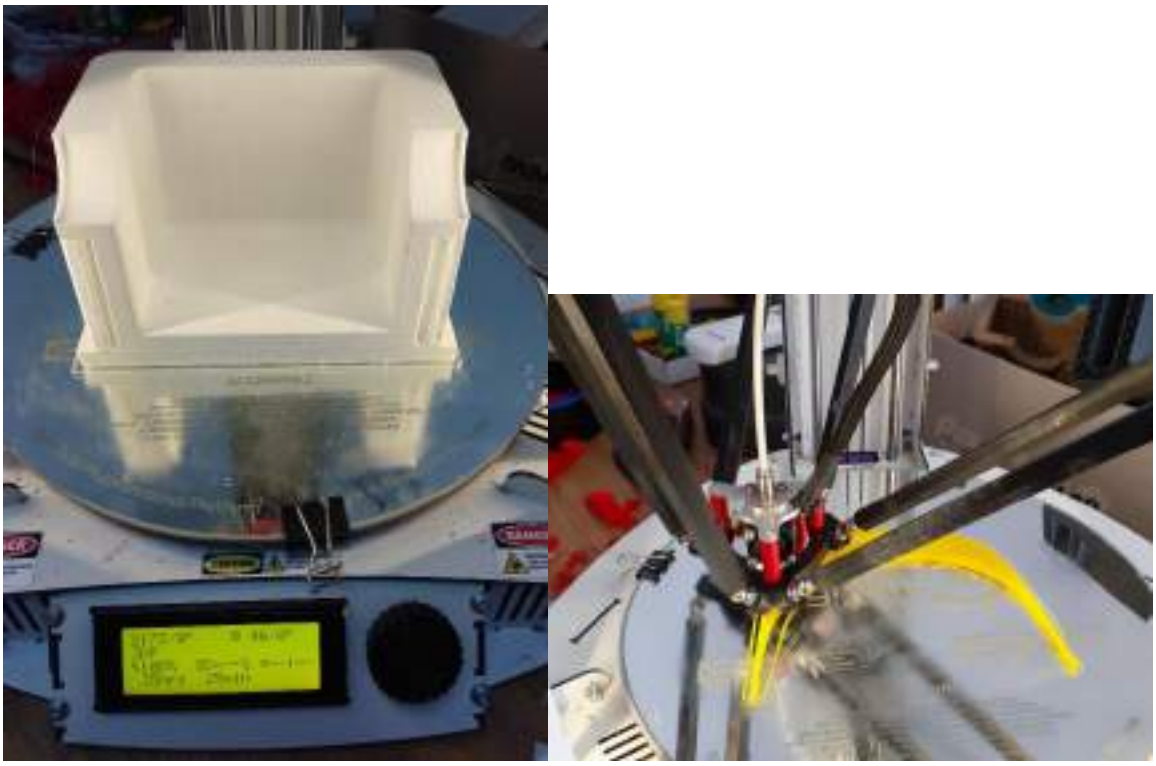

Fig. 18. Printing parts

3. POST-PROCESSING – cleaning the supports – fig. 19.

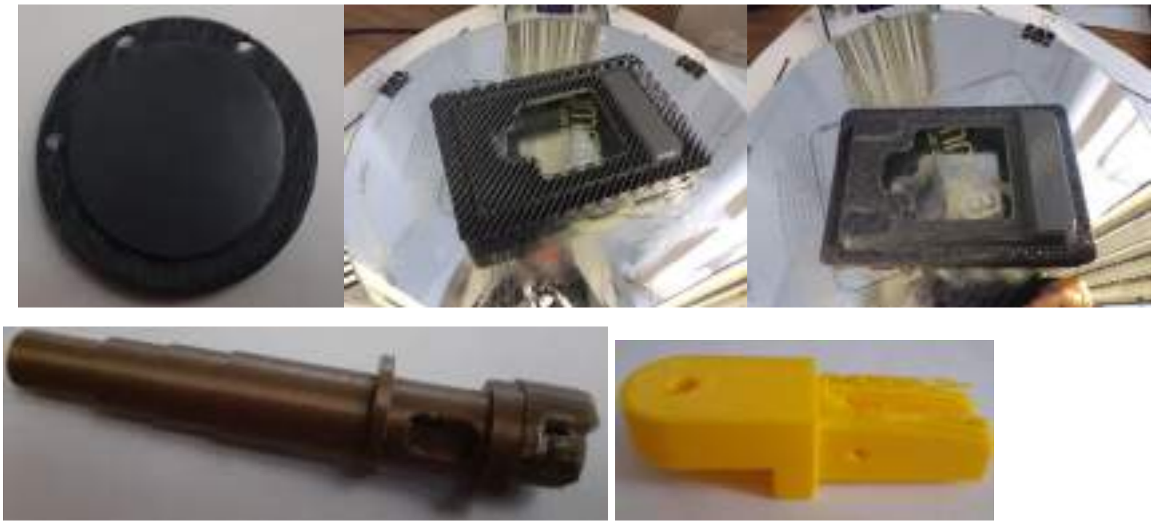

Fig. 20. The cleaning parts, problems with thw support

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Problems, when the density of the support is not corelated with the dimension of the part and the part has no upport – fig. 20.

Some assemblies obtained with 3D printer Symme 3D – fig. 21.

3.4 Stereolithography (SLA)

Stereolithography (SLA; also known as stereolithography apparatus, optical fabrication, photo-solidification, or resin printing) is a form of 3D printing technology used for creating models, prototypes, patterns, and production parts in a layer by layer fashion using photochemical processes by which light causes chemical monomers and oligomers to cross-

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link together to form polymers. Liquid photopolymer is used to build the model, and laser beam or DLP projection is used to solidify the photopolymer. SLA technology has become the gold standard for rapid prototyping, where precision in assembly is required.

The basic concept of the procedure is based on the use of a laser or a new technique of designing a voxel plane (UV image with micro thickness) using a DLP projector. As with most systems, you need to import an STL file to adjust the device parameters.

3D Systems uses the principle of fixing a liquid photopolymer with a laser. The type of laser used is crystal based (Nd: YVO4 - yttrium vanadate). The laser beam is guided by rotating mirrors in the x-y plane.

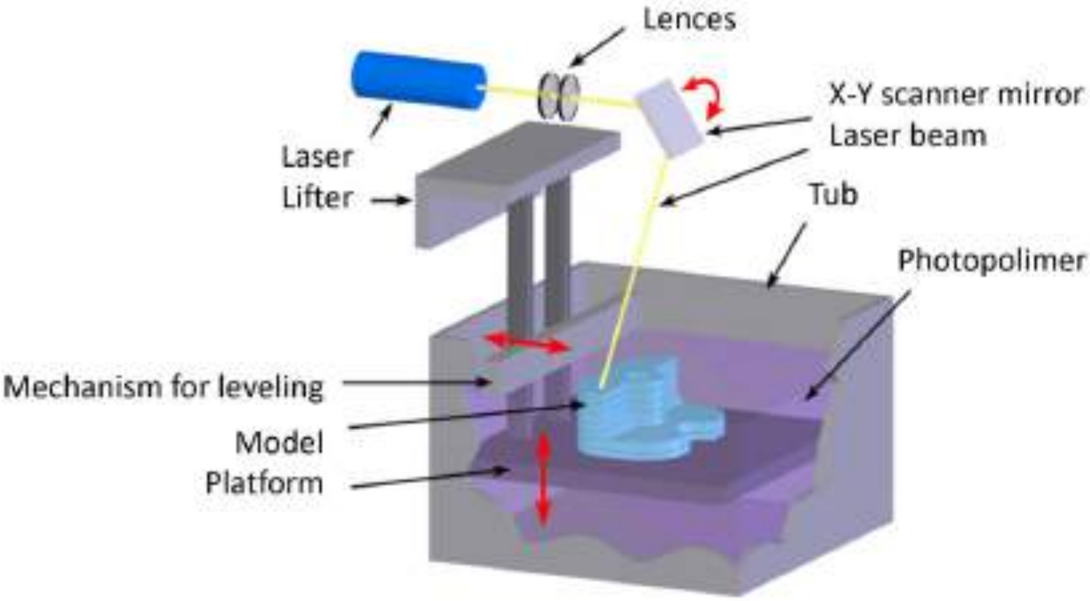

Figure 21. Princip of SLA technology

Air falls on the surface of the photopolymer and a chemical polymerization reaction occurs. After that, the tub in which the photopolymer is lowered along the z axis. Before building a new layer, a blade passes through the chamber, which aligns the previously built layer. Figure 22 shows the parts made by SLA technology with Envisiontec Ultra 3SP at Faculty of Mechanical Engineering University of Niš.

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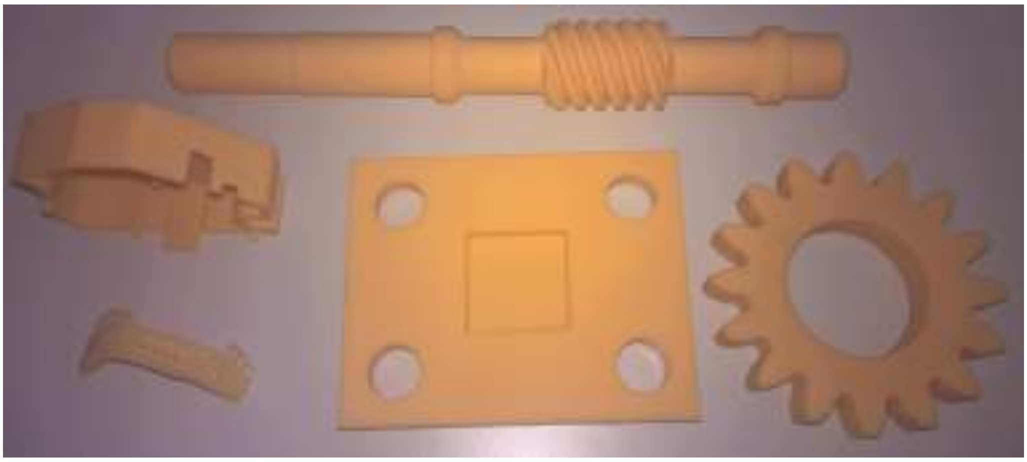

Figure 22. Parts made by SLA technology

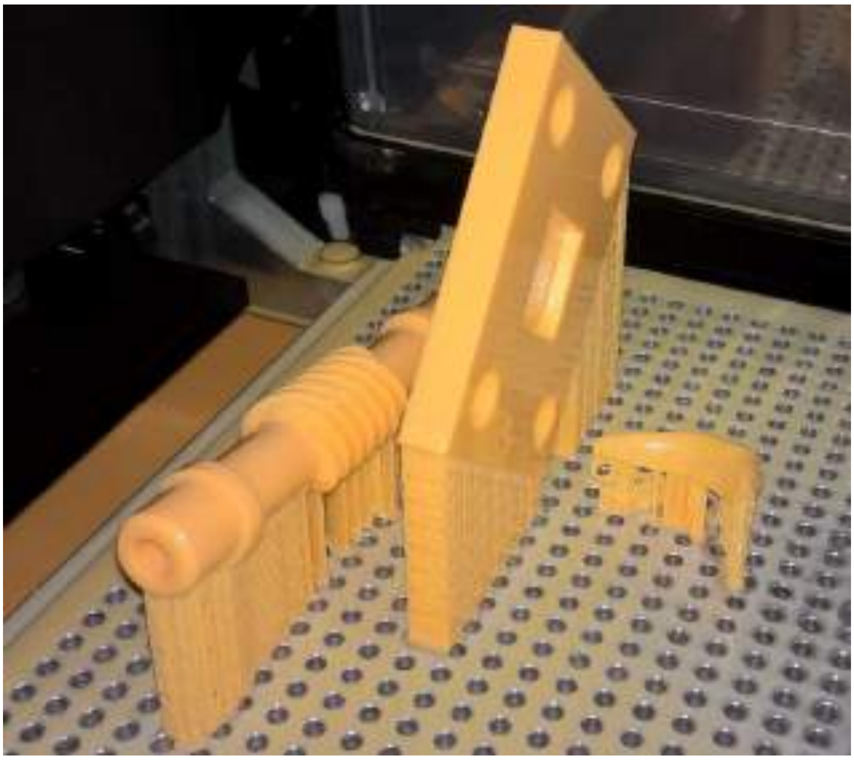

Figure 23. Parts made by SLA technology directly after finishing printing

Figures 23 and 24 shows the parts directly after finishing of 3D printing. Orientation of parts during 3D printing is on some angle. This increase the strength of printed parts.

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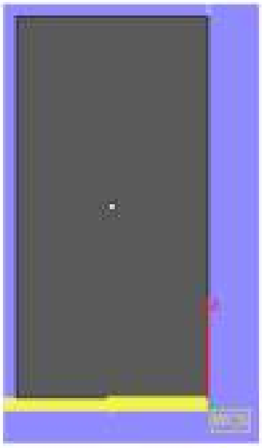
Figure 24. Parts made by SLA technology directly after finishing printing



Slow speed fast speed

Figure 25. Importance of positioning of part on the bed

Printing speed of the part depends from the positioning of the part on the bed (Figure 25). All manufacturing processes have the highest manufacturing precision in the z direction. For example, 3D printer Envisiontec Ultra 3SP has better resolution in the z direction 0.025 mm and in the x and y directions 0.1 mm. If the most important dimension is the length of the tile (30 mm), the tile should be oriented in the z direction.

During the laying of levels in all processes, the “effect of steps” on the surfaces that grow in the z direction appears. If the quality of these surfaces is important, the printed part is oriented so that their design is in the x-y plane. (Figure 26.)

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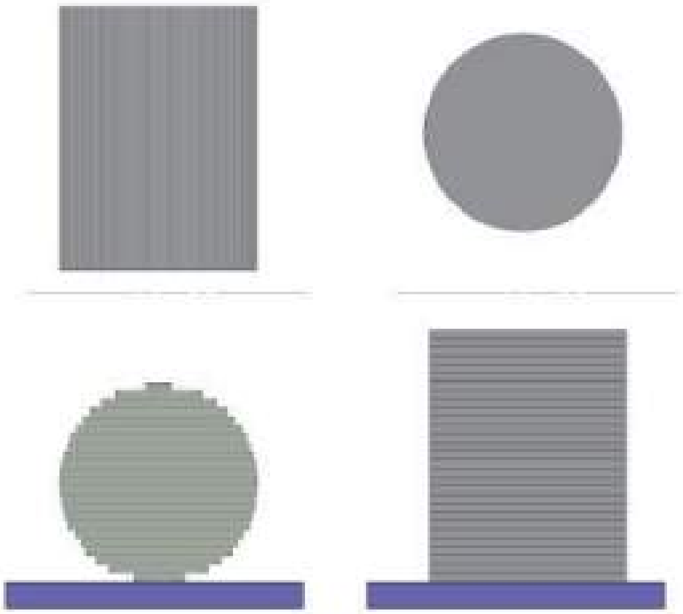

Figure 26. Importance of positioning of part on the bed

The strength of the object depends on the orientation of the object on the platform in relation to the directions of stress. The object has the lowest strength of the layers (z direction).

3.5 Selective laser sintering (SLS)

Selective laser sintering (SLS) is a manufacturing process for making 3D models using a laser as the power source to sinter powdered material. There is currently a wide range of different powder materials that can be used within the same device, which is one of the main advantages of this method.

The working principle is as follows: the beam of a strong carbon dioxide (CO_2) laser is directed to a preheated material in the form of a powder, which coalesces under the influence of high temperature.

The high temperature between the particles increases the adhesion so that the powder is grouped into a larger solid of a precisely defined shape, which was previously defined by a solid model in digital form (3D CAD). After joining the first layer of the cross-

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section of the model, the platform on which the powder is placed is lowered from 0.05 to 0.12 mm along the z axis.

Using a rotating roller, a new layer of powder is applied to the modeling chamber and the process of splicing the cross section of the model is repeated. In this way, the final shape of the 3D model is formed by additive layering.

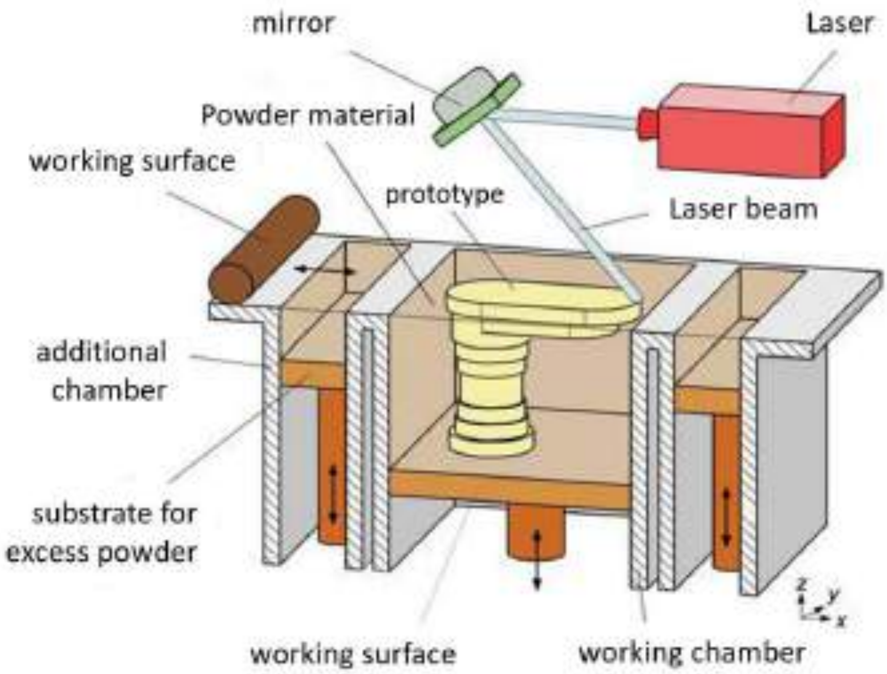

Figure 27. Princip of SLS technology

3.6 Binder Jetting (BJ)

Binder jetting (BJ) uses particles of a fine-grained powder, which are fused together using a binder, to form a three-dimensional object and it is licensed by MIT (Massachusetts Institute of Technology). The process is based on inkjet nozzles, by means of which a liquid binder is applied to the powdered polymeric material to which it binds. The process is a fast and precise way of making a model, used to verify the concept or build a mold and casting core.

The 3D printing cycle begins with heating the chamber, after which it is filled with a layer of 3.18 mm of polymer powder, on which the model is built and later easier to remove.

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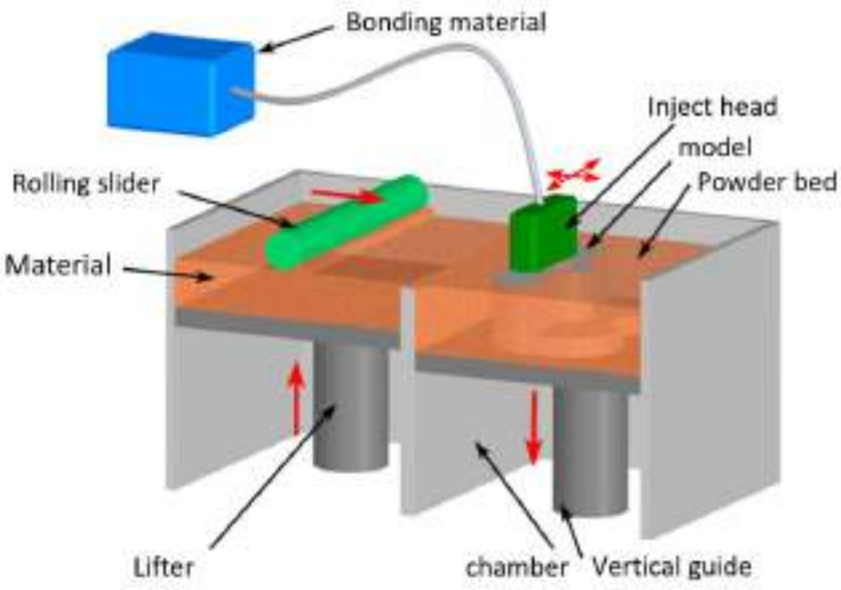

Figure 28. Princip of BJ technology

This completes the preparation. Using a slider, a new layer 0.1 mm thick is applied along the chamber. After that, the head passes through the chamber and applies the binder (and color if the printer is in color). The slider with the head moves in the x-y plane while the work table is lowered by the height of the layer along the z axis.

3.7 Photopolymer Jetting – PolyJet

3D Printing-Photopolymer Jetting (PolyJet) is similar to the process of stereolithography. The material is a liquid photopolymer that is polymerized using a UV lamp. The photopolymer is applied using inkjet nozzles. An STL file is used, using which the model is digitally cut into thin layers (layer thickness 0.015 mm) in the horizontal plane.

Model construction is based on the inkjet method. The liquid photopolymer is applied to the work surface layer by layer, using two heads containing several hundred (up to 1536) nozzles, which in one step simultaneously disperse the support material and the material for building the model.

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In the same step, polymerization with a UV lamp takes place. The work surface is lowered along the z axis for the thickness of the layer and a new layer is applied.

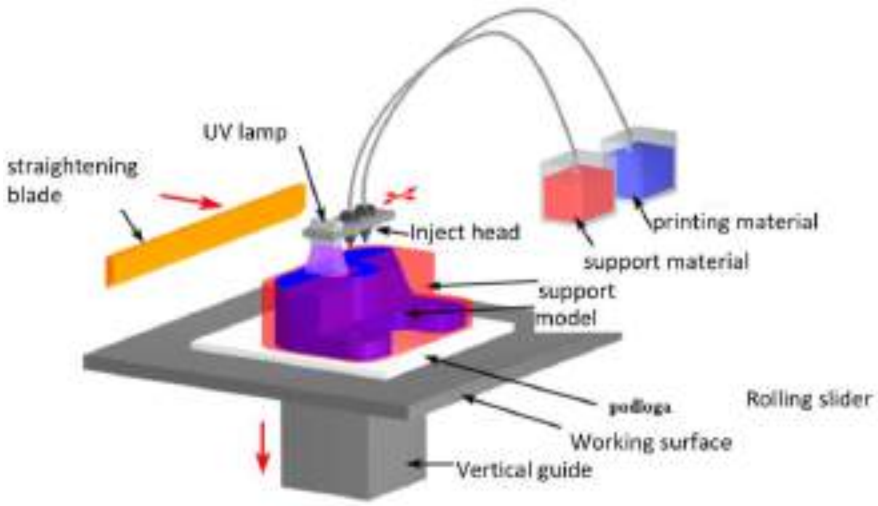

Figure 29. Princip of Polyjet technology

4. Conclusion

Rapid prototyping technology has been evolving for the past 25 years and is still relatively unknown.

Although it enables a fast, economical and high-quality prototyping process, tools and products, technology is slowly making inroads in the industry for several reasons: lack of information and standardization, investment costs, limited workload dimensions and limited number of materials offered.

In the near future, these shortcomings are likely to be partially or completely eliminated, making the technology ready to meet all the requirements set by the industry in various branches of production.

By using faster computers, improving control systems, and introducing new materials, AM technology should become faster, more accurate, and more economical.

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