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3D FOR VET
STRATEGIC PARTNERSHIP FOR THE DEVELOPMENT OF 3D COMPETENCES

3D PRINTING BASIC

AURORA
REGIONALNI KOORDINATOR ISTRE
COORDINATORE REGIONALE DELL' ISTRIA

METRIS

TEHNIČKA ŠKOLA PULA

Všį Panevėžio profesinio rengimo CENTRAS

MAŁOPOLSKA

CARINTHIA UNIVERSITY OF APPLIED SCIENCES
FACHHOCHSCHULE KÄRNTEN

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Contribution

Task group

Carinthia University of Applied Sciences, Austria

Coordination

Region of Istria, Regional Coordinator for European Programmes and Funds of the Region of Istria

Project Partners

- Regional Coordinator for European Programmes and Funds of the Region of Istria, Croatia
- Carinthia University of Applied Sciences, Austria
- Pula Technical School, Croatia
- METRIS Research Centre, Croatia
- Malopolska Voivodship, Poland
- Public Institution Panevežys Vocational Education and Training Centre, Lithuania
- Jan Pawel II's School Miechow, Poland

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Content

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1. Introduction to 3D printing

Manufacturing technologies can be classified into three categories. These three categoriesare formative manufacturing, subtractive manufacturing and additive manufacturing.

Formative manufacturing (casting, injection molding, forging, stamping and bending) forms material with heat and pressure into the desired shape. The raw material can be melted and cast into the mold or extruded with pressure into the mold.
Furthermore the material can be pressed or pulled into the desired shape. The usable materials covers a wide range from metals and plastics. This manufacturing process is suited for a high production volume of the same part.
The initials investment in tooling for the process are high but the production of parts are fast and at a low price unit.

Subtractive manufacturing (milling, turning and drilling) removes materials from a solid block until the desired shape is created. Milling cutters, lathe tool and drill bits are tools to remove the material.

The cutting tool must be able to reach the areas where material is removed. During the manufacturing a large amount of material is removed to produce the final part.

Additive manufacturing which is also known as 3D printing forms a shape by building up one layer at a time. There are different 3D printing technologies available, which have their own benefits and limitations and is able to print with different materials. An advantage of 3D printing is the design freedom of the parts and the individualization.
The general printing process can be divided into five steps, which are constant for the different printing technologies. These five steps are:

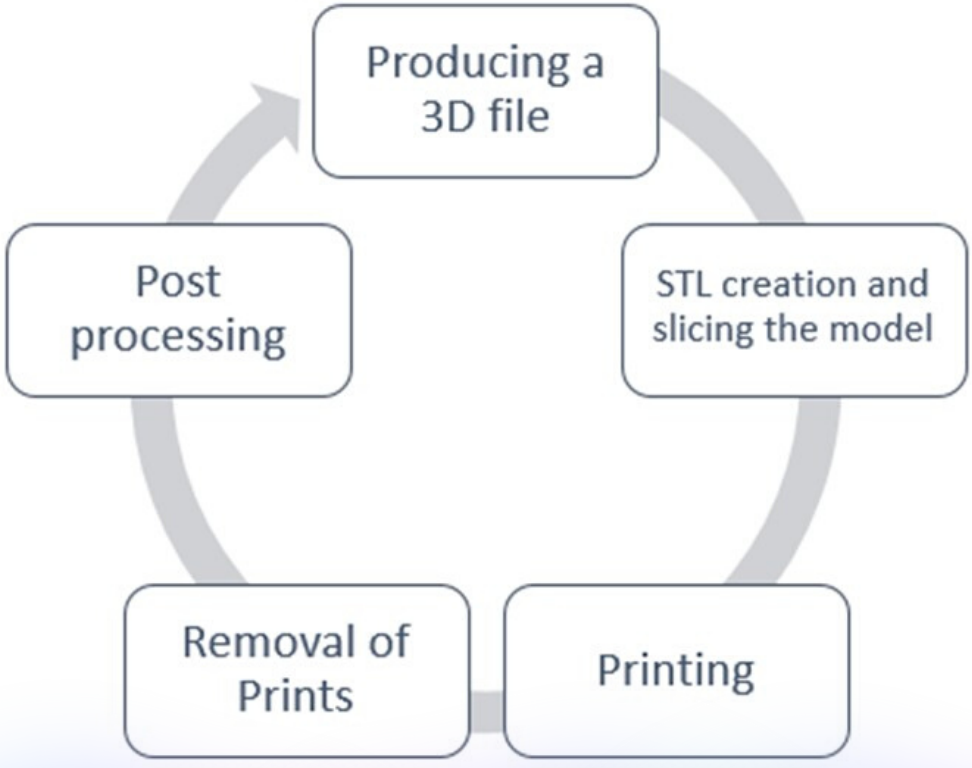


Figure 1 Procedure of a 3D Printing process

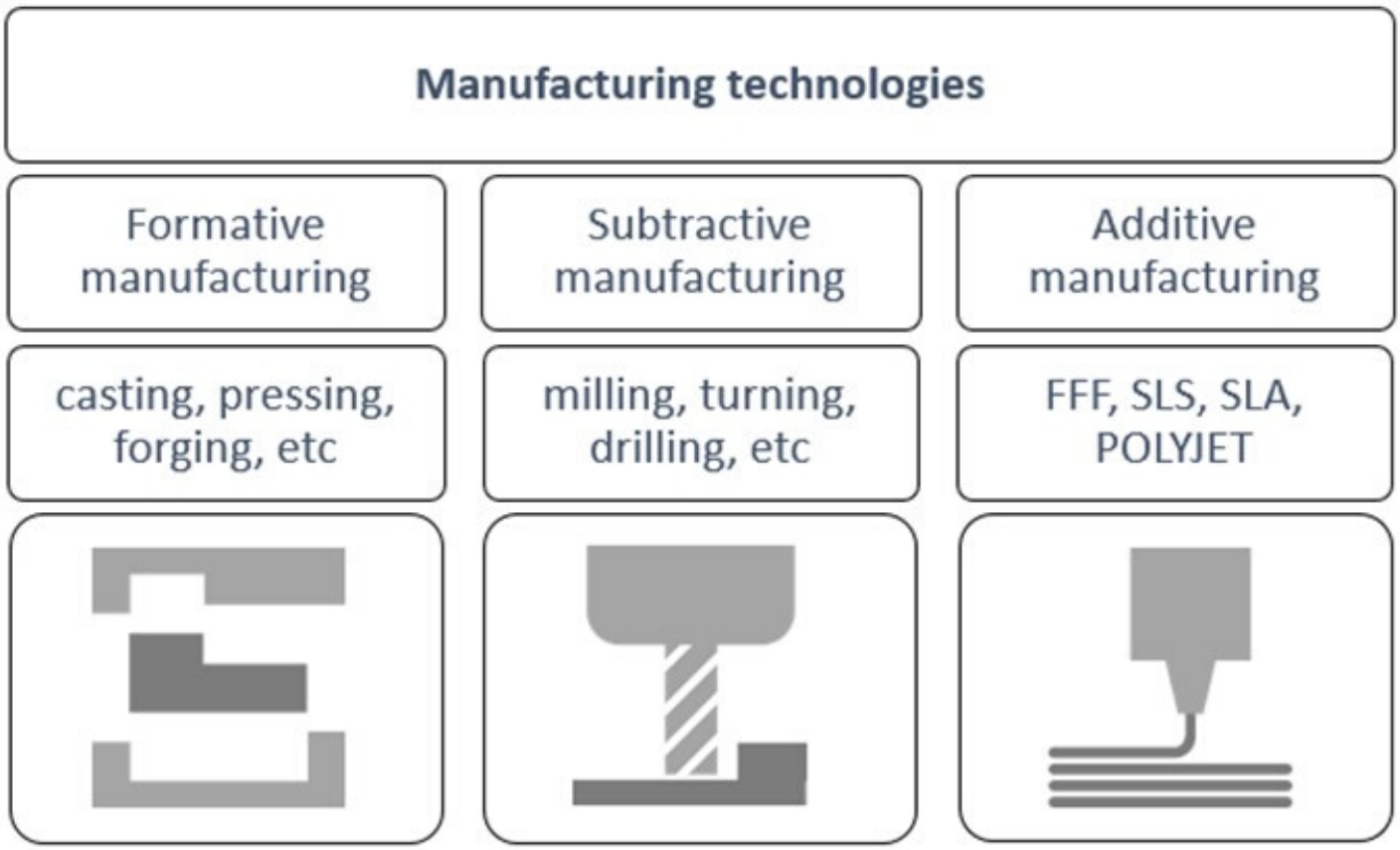


Figure 2 Different Manufacturing technologies

A decisive factor for choosing the manufacturing technologies are the costs. A comparison of the three mentioned manufacturing technologies are shown in the following picture. There you can see how the costs per part changes with the number of parts that are manufactured.

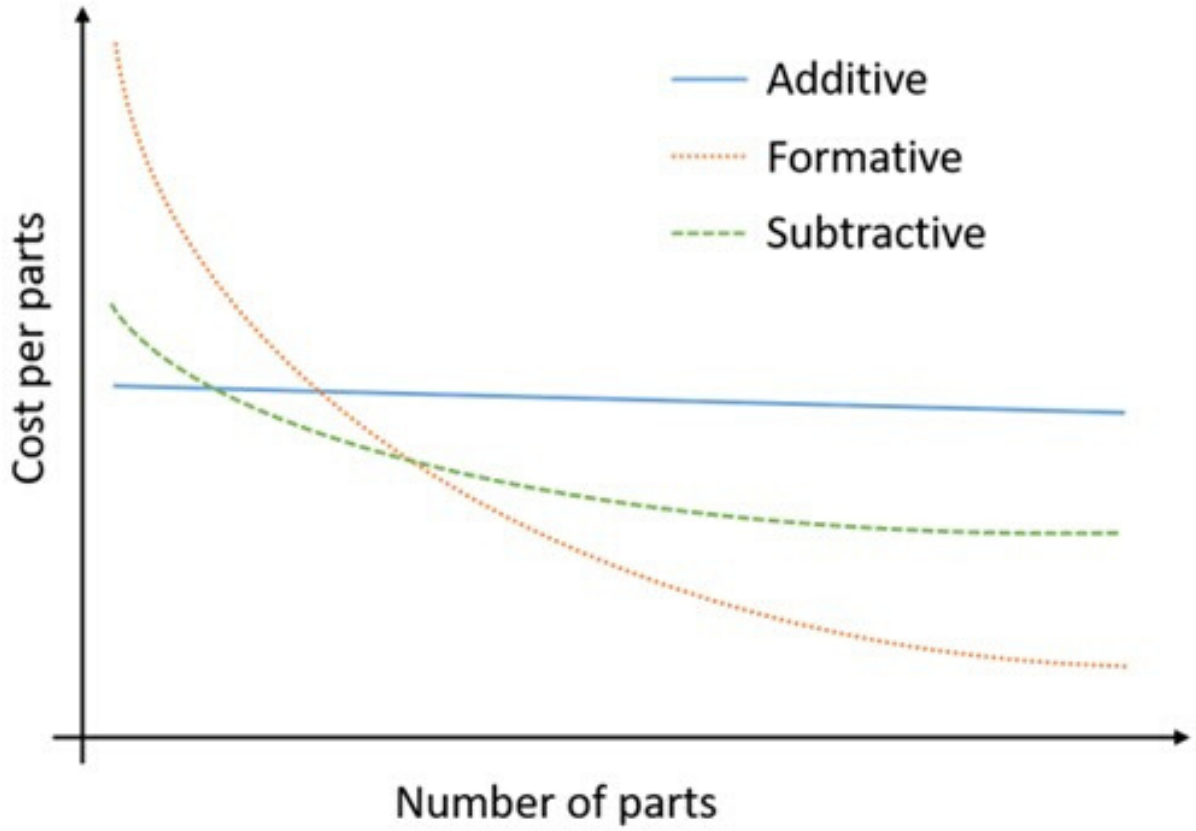


Figure 3 Production and costs of different manufacturing technologies compared to each other

2. Classification of 3D Printing technologies

The 3D printing process is grouped in different process categories. These where described in the following table.

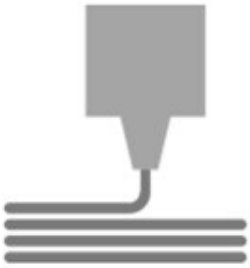
Classification of 3D Printing technologies		
Technologies	Process	Description
Material Extrusion - Fused Filament Fabrication (FFF) or Fused Filament Modeling (FDM)		3D Printing process in which melted thermoplastics is selectively dispensed through a nozzle.
Vat Polymerization - Stereolithography (SLA) and Direct Light Processing (DLP)		3D Printing process in which a liquid photopolymer in a container is selectively cured by a light activated polymerization.
Powder Bed Fusion - Selective Laser Sintering (SLS), Selective Laser Melting (SLM) and Direct Metal Laser Sintering (DMLS)		3D Printing process in which thermal energy selectively fuses regions of a powder bed. The granular powder consist of a plastic, metal or ceramic.

Figure 4 Classification of 3D Printing technologies

3. Materials for 3D Printing

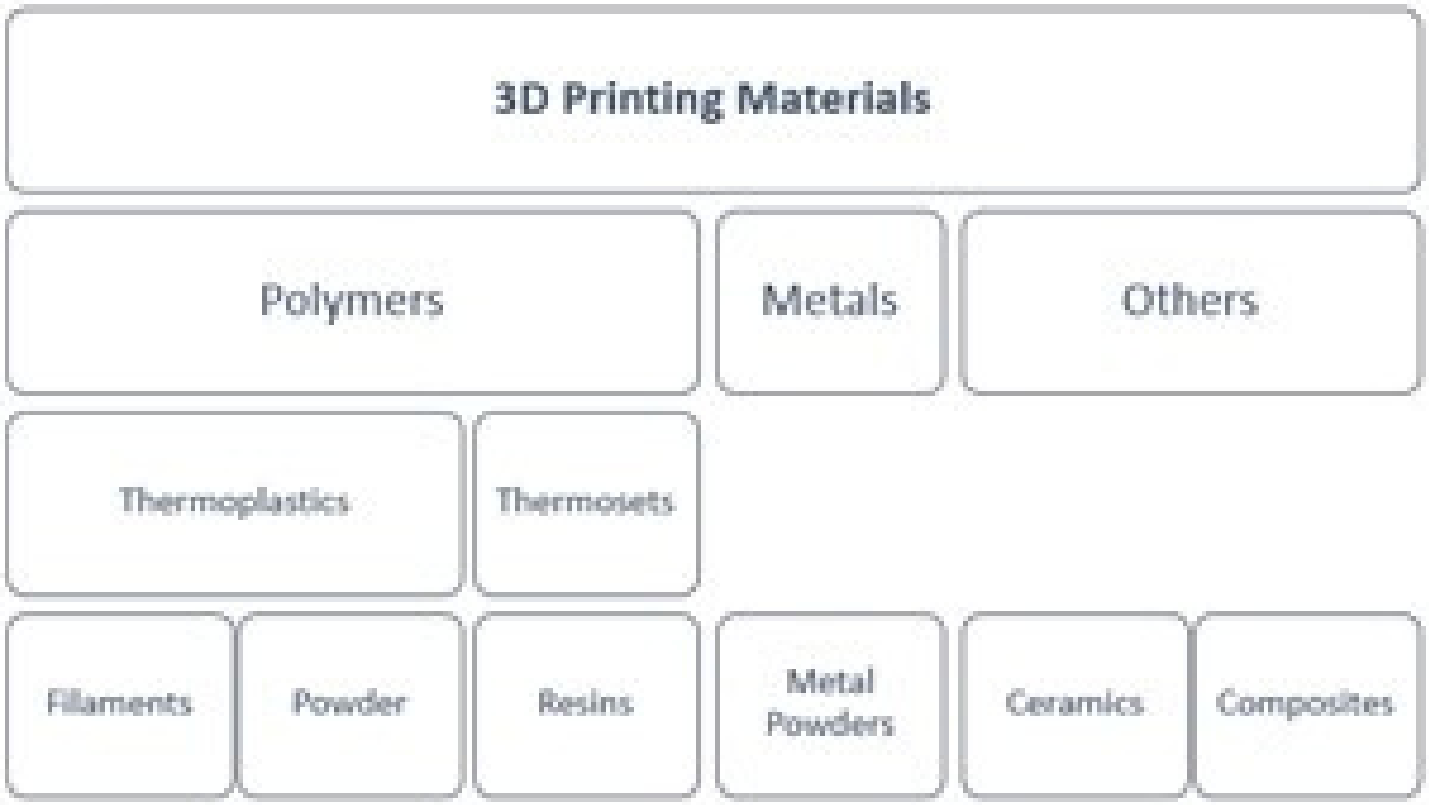


Figure 5 Classification of 3D Printing materials

3.1. Polymers

The 3D printing materials can be separated into three main groups: polymers, metals and other materials. polymers came in many different forms and offers a wide range of applications. The polymers that are used in 3D printing came in three different forms: filament, powder and resin. These are separated into two categories: thermoplastics and thermosets.

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Thermoplastics can be melted with heat and become solid again. They are used for a traditional injection molding process and for a Fused Filament Fabrication (FFF) printing process.
Compared to Thermoplastics the Thermosets can not be melted. Thermosets get cured under heat or light and get solid.

PLA (polylactic acid)	Easy to print with Low cost material Unsuiatable for high temperaturs
ABS (Acrylonitrile butadiene styrene)	Better mechanical and thermal properties then PLA Wear and corrosion resistance Susceptible to warping
Nylon	Excelent mechanical properties High chemical and abrasion resistance For functional applications
ASA (cetylsalicylic acid)	Similar to ABS With better UV stability and better chemical resistance
TPU (thermoplastic elastomers out of urethane)	Themoplastic elastomer Can be flexed and compressed
Resin	Thermoset polymer High accuracy and detailed parts Smooth surface finish

3.2. Metals

In comparison to polymers, the 3D metal printers almost uses a powder material. The printed parts obtain a high-quality and with the according strength. There are different metals powder available to work with.

Aluminium	Good strenght to weight ratio High thermal and electrical conductivity Low density Weather resistance
Stainless Steel	Metall alloy High ductility Wear and corrosion resistance
Titanium	Excellent strength-to-weight ratio Low thermal expasion High corrosion resistance Sterilizable for medical applications Biocompatible

3.3. Others

Other materials that can be used for a 3D printing process are ceramics and composites. For the ceramic materials are material extrusion printer used and for the finish the parts needed a firing. The composites are a reinforcement for the printed part and consist of chopped carbon fiber that is embedded in a nylon filament. Another possibility is to use an endless composite fiber.

Composites	Hight strenght related to weight Highimpact strenght Durable
Ceramics	Resistance to wear, heat and pressure Extreme hardness Excellent electrical insulation

4. Printing Technology – Material extrusion

The most common and easiest printing technology is the Fused Filament Fabrication process (FFF). Another name for this process is Fused Deposition Modeling (FDM) which is a term trademarked by Stratasys.
To start the printing process, a spool of filament is fed into the extrusion head. In the extrusion head, the filament melts and get pressed through a nozzle and the printer lays down the melted plastic at a precise location.
The thermoplastic material solidifie after it cool down. If a layer is completed the building platform moves down and the machine prints the next layer.

This process repeats until the part is build up layer by layer. For FFF Printers are a wide ranges of materials available. These are PLA, ABS, Nylon and PC.

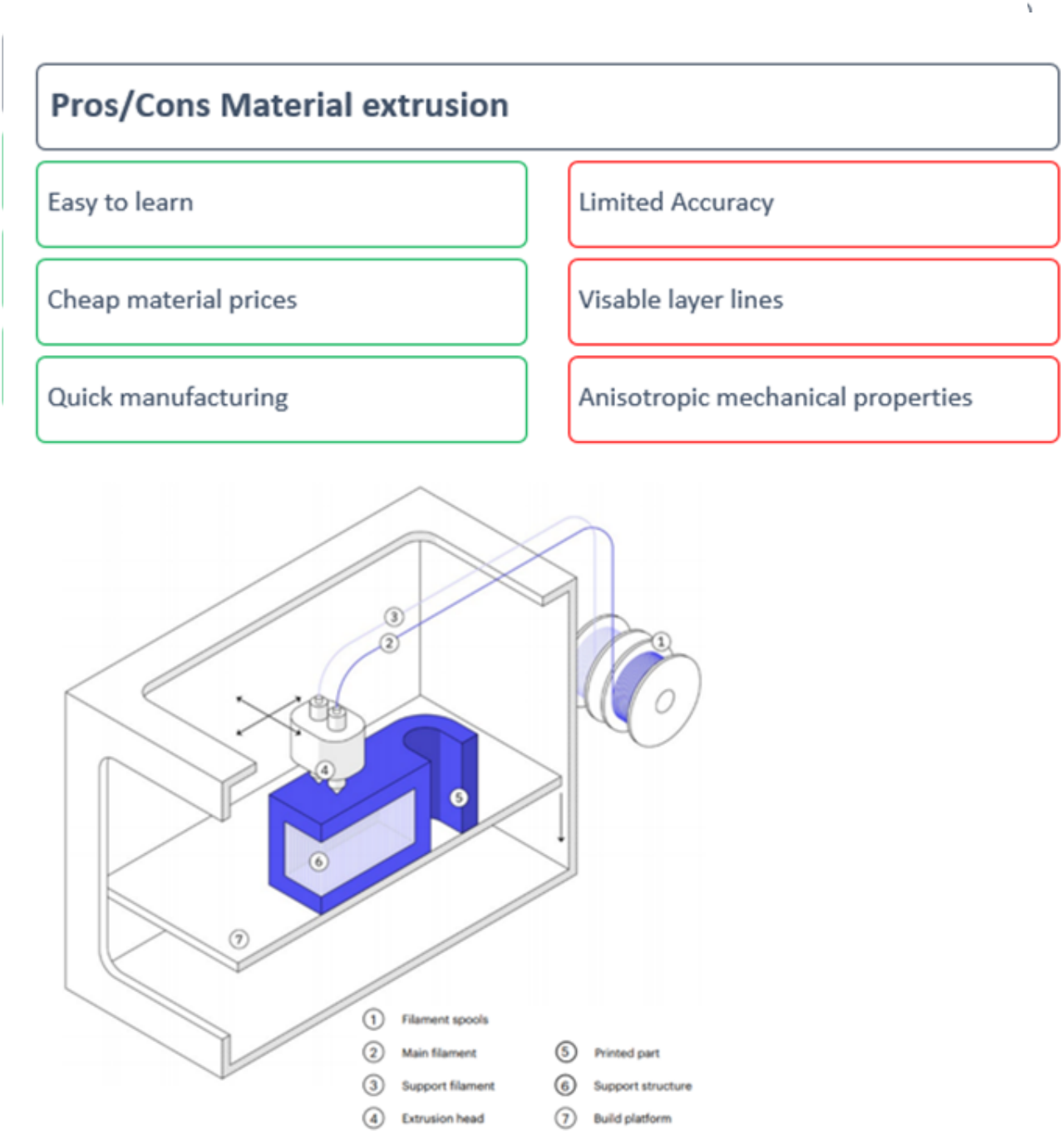

Figure 6 Schematic of a material extrusion printer

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5. Printing Technology – Vat polymerization

In this process a vat of liquid resin is cured by a UV light. The model is constructed layer by layer by solidify the resin. A Stereolithography printer (SLA) uses a single laser beam to cure the resin, while a Direct Light Processing printer (DLP) flash a single image of each layer all at once. After the print is finished, the model need to be cleaned from the remained resin.
To improve the strength and get the optimum material properties the part is cured with temperature under a UV light.

SLA printers deliver a smooth finish and a high level of details. Therefore, the most suitable use are visual applications. Some popular printable materials are: standard, though, durable, clear, flexible and castable.

Pros/Cons Vat polymerization	
High accuracy	Produces brittle parts
Smooth surface	Degrade with exposure to sunlight
Large range of specialty materials	Support marks

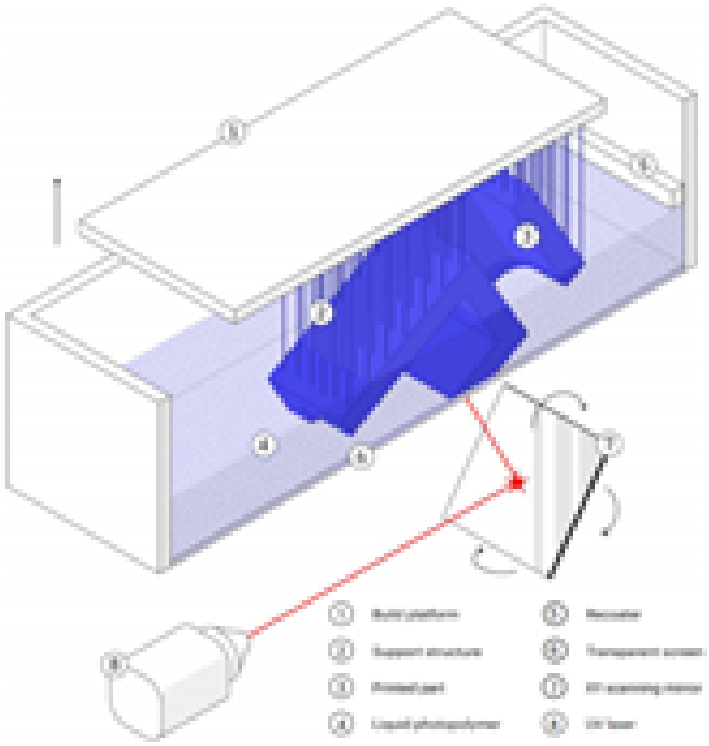

Figure 7 Schematic of a vat polymerization printer

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6. Printing Technology – Powder Bed Fusion

During the Selective Laser Sintering process (SLS), a bin of polymer powder is heated up just below the melting point of the material. A laser sinters the particles and binding them together. After the layer is finished, the build platform moves down one layer and a recoater deposits a new layer of powder onto the build platform. The layer height is typically 0,1 mm thick. Some popular printable materials are: Polyamide PA 11 (trade name: Nylon) and TPU

Pros/Cons Powder Bed Fusion for SLS	
Ideal for functional prototypes	Higher cost than FDM or SLA
No support is needed	Slower turn-around due to batch production
Small batch production capabilities	Grainy surface & internal porosity

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The direct Metal Laser Sintering (DMLS) and Selective Laser Melting (SLM) process are similar to the SLS process except the difference that these processes uses a metal powder. The usable materials are Stainless steel, Aluminum and Titanium. The DMLS process heats the metal particles and they fuse together on a molecular level, while the SLM process melted the powder particles. For both printing processes is a support structure recived which need to get removed.

Pros/Cons Powder Bed Fusion for DMLS and SLM	
Complex and topology optimized parts	The most expensive 3D printing process
Parts with exvellent material properties	Mechanical properties degrade over timeProcuce
Ideal for high- end engineering applications	Produce relatively brittle parts

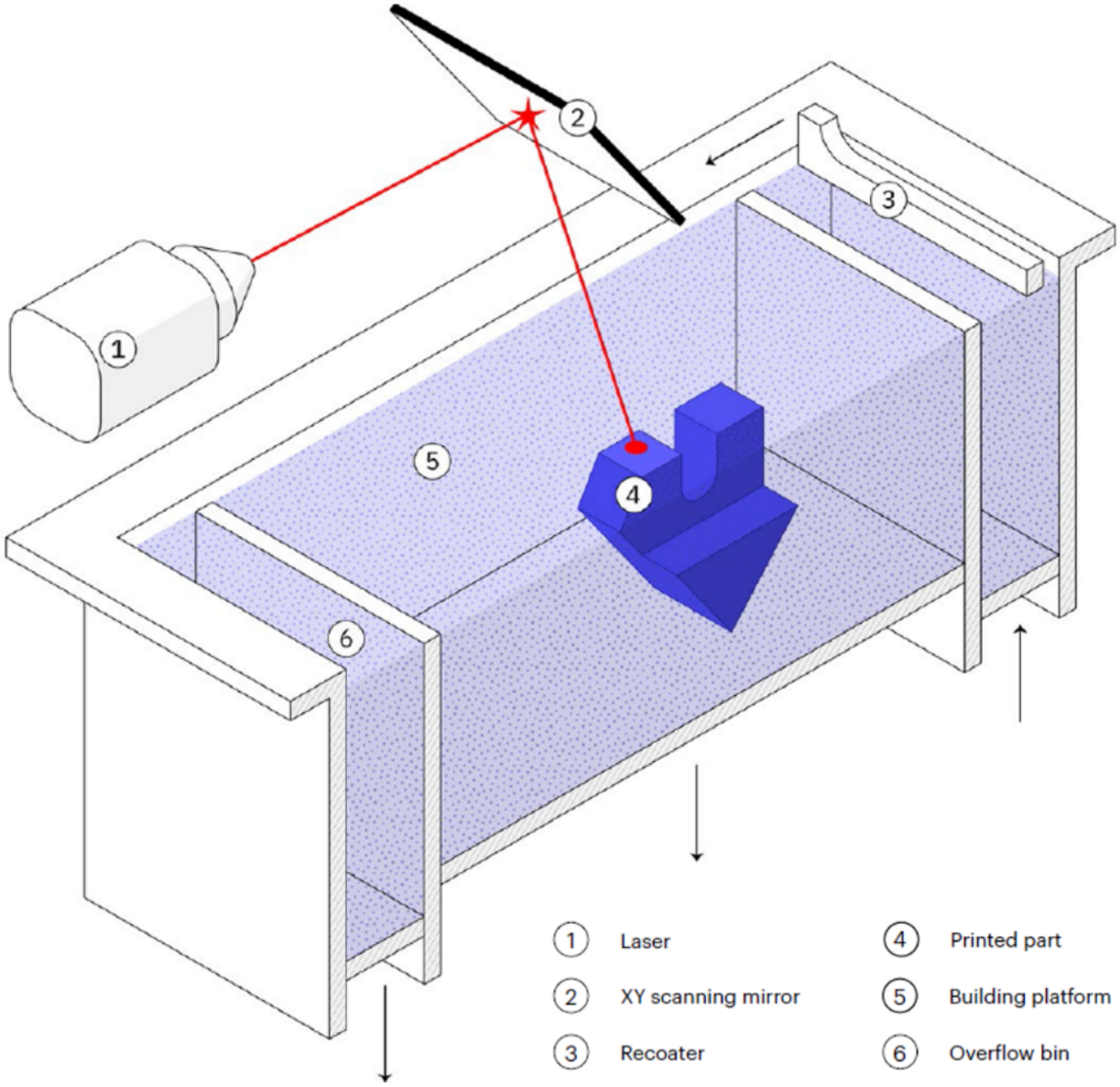

Figure 8 Schematic of a powder bed fusion printer

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7. 3D printing process

The general printing process can be divided into five steps, these are:

Producing a 3D file

To start a 3D printing process, a Modell of your object that you want to print is needed. For that you can design a 3D printable model by yourself. You can do that with a computer-aided design (CAD) software. As an alternative to create an own model you can find modals on online platforms. Some popular websites are: Thingiverse and GrabCAD

STL creation and slicing the model

The STL (Stereolithography) file format is used in the industry for Computer-aided manufacturing (CAM) and Additive manufacturing. The STL format described the outer and the inner surface of an object with triangles. The process of converting the STL file into machine language (G-Code) is the slicing process

Printing

The printing process of producing a part

Removal of Prints

The removing of the printed part is addicted to its printing technologies. For some technologies, it’s a simple separation of removing the printed part from the build platform

Post processing

Some 3D printing technologies that utilize a support material for overhanging structures that need to be removed. Or the support material is different from the main material and can be washed out. Some technologies required a curing process under an ultraviolet light to get the final strength. To increase the surface finish of the prints of parts that are printed with FFF can be sanded, holes can be filled with epoxy resin and the parts can painted.

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8. Printing Settings

Most 3D Printers came with their own Software program to overwatch and start the printing process. Depending on the different Printer brands and the chosen printing technologies the settings and the design of the software changes. For the FFF printing process are some commend adjustment possibilities:

Layer Hight	Defines the layer in which the Part is printed Smaller layers give a smoother surface finish particular by spherical shapes Larger layers reduced the printing time Commend value is 0,2 mm
Infill and the Infill pattern	Defines volume of the inner part that is filled Printing time vs Toughness Depends on the application
Shells of the model	The number of printed shells around the infill Commend value are three Depends on the application (strenght v.s printing time)
▪Raft	Creates a sublayer on that the main part is printed Increased the contact force between the Bed and the model Reduced Warping

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▪**Brim**	Increased the size of first layer on the printing bed Increased the contact force between the Bed and the model Reduced Warping
▪**Skirt**	A printed boarder around the Model which isn't attached to the model To check if the print bed is set on the right height Cleans the nozzle from old filament
▪**Nozzle and bed temperature**	Set the temperatures of the Nozzle and the bed for printing Mostly the default vales are good to start

List of sources

- What is 3D printing? The definitive guide - https://www.3dhubs.com/guides/3d-printing/

- MAKERBOT EDUCATORS GUIDEBOOK https://www.makerbot.com/stories/education/educators-guidebook-full-version-free-download/