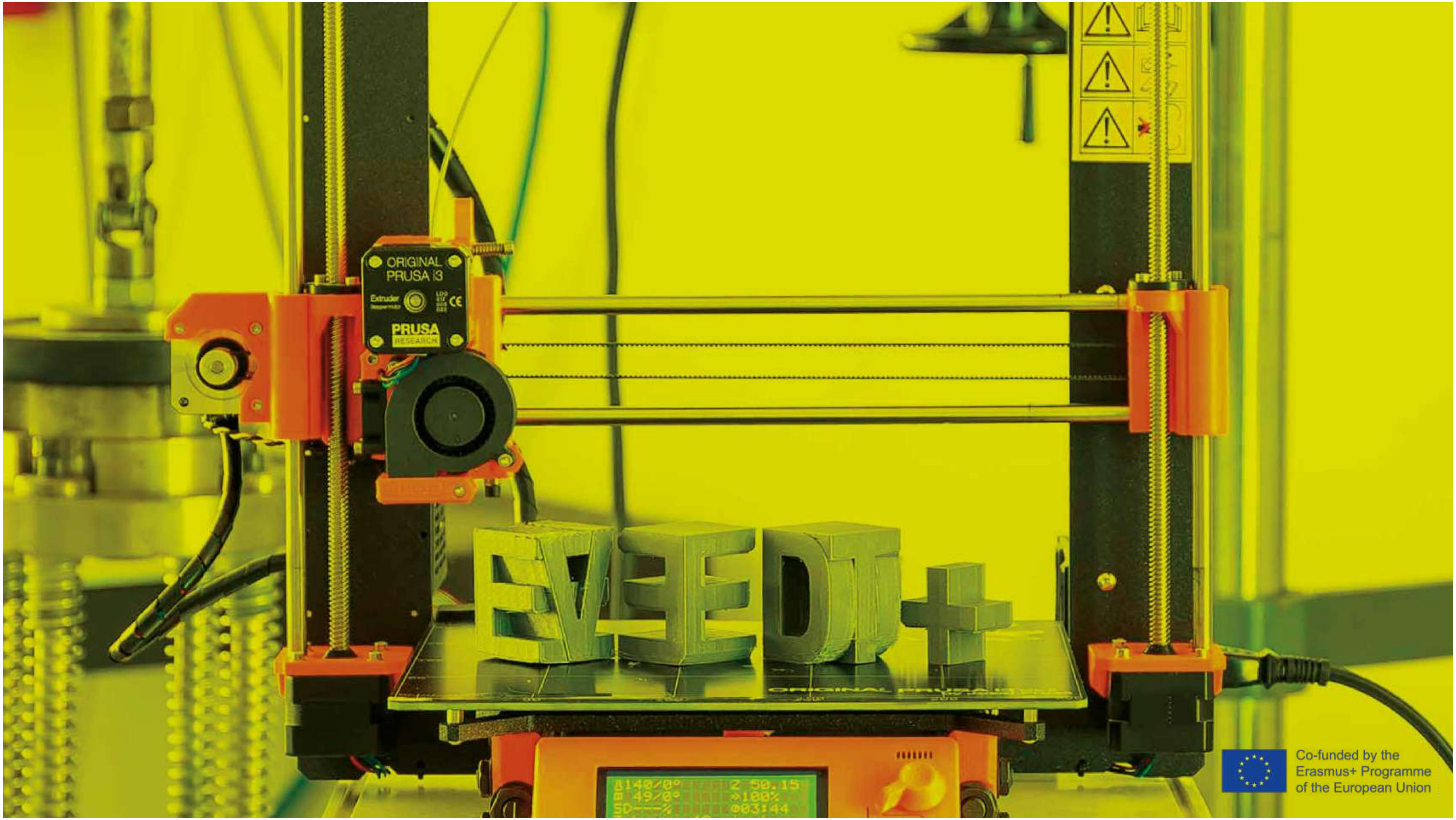

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O4-A1 – Training materials suitable for workshops

Information about selected 3D Printing Technologies

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Erasmus+ for the immersion in 3D Printing of VET centres

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Technical Research Centre of Furniture and Wood of the Region of Murcia
CETEM

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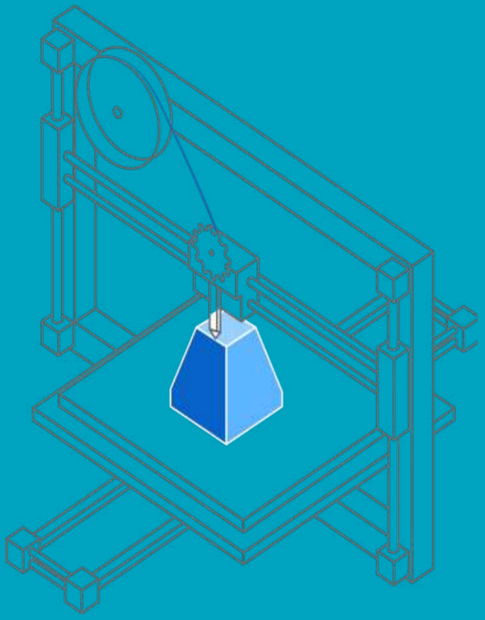
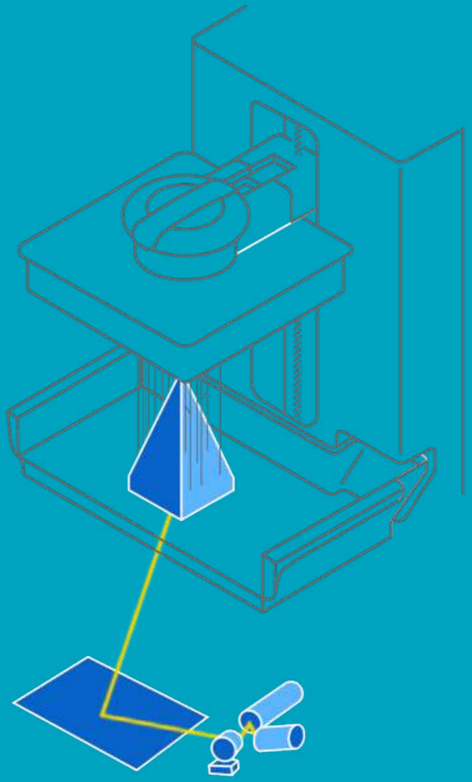
Introduction

Top 3 Technologies:

- Fused Deposition Modeling **(FDM)**
- Selective Laser Sintering **(SLS)**
- Stereolithography **(SLA)**



FDM 3D printers extrude and deposit molten thermoplastics on a build platform to produce parts layer by layer.



SLA 3D printers use a precision laser to cure resin and produce parts with high accuracy.

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Fused Deposition Modelling (FDM)

FDM is the most widely used 3D printing technology at the consumer level. It works by extruding a thermoplastic polymer that is fed through a heated nozzle which gets deposited, layer by layer, on a platform, creating a 3D printed object.

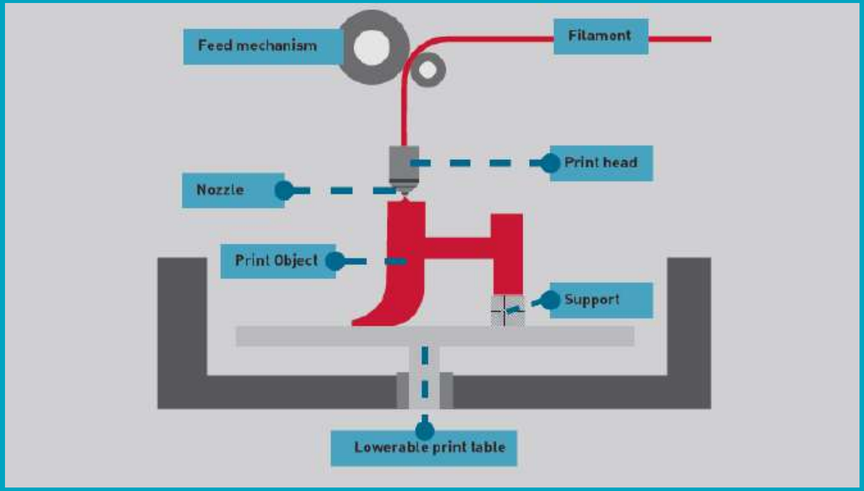

Figure 1: FDM printing process. [1]

The printer continuously moves the nozzle around, laying down the melted material at a precise location, where it instantly cools down and solidifies. Once a layer is finished, it rises the nozzle to the next one, until the part is finished.

The 3D model needs to be “sliced” into layers before it can be printed.

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Which materials can be used with FDM?

- **ABS** (Acrylonitrile Butadiene Styrene),
- **PLA** (Polyactic Acid) and
- **PETG** (Polyethylene terephthalate glycol-modified)
- **TPU** (Thermoplastic Polyurethane)
- **PA** or Nylon (Polyamide)
- **PEEK** (polyether ether ketone)
- **PEI** (polyetherimide)

Figure 2: FDM filaments. [2]

The technology behind this filaments is often referred to as “Fused Filament Fabrication” (FFF).

The most used materials are ABS and PLA. New special types of filament have been developed as well. Glow in the dark, metallic, wood or flexible filaments are just some examples.

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Fused Deposition Modelling (FDM)

STRENGTHS	WEAKNESSES
FDM printing machines are among the cheapest.	The 3D prints do not reach the same level of accuracy and quality of other items which are instead produced through the use of Stereolithography.
FDM is considered to be a very clean technology, usually simple-to-use and office-friendly.	Contrary to SLA, FDM presents also an increased complexity.
FDM can also produce complex geometries and cavities	FDM is that it presents a generally slower compared to both Stereolithography and Selective Laser Sintering

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Selective Laser Sintering (SLS)

SLS is a technique that uses laser as power source to form solid 3D objects. A chamber is filled with powdered material, and every layer the laser fuses creating a shape defined by the 3D model.

Unlike SLA and FDM, Selective Laser Sintering does not require the use of support structures, as the powder itself serves as support. Once the print is finished, the extra powder is removed.

The main difference with SLA is that SLS uses powdered material in the build area instead of liquid resin.

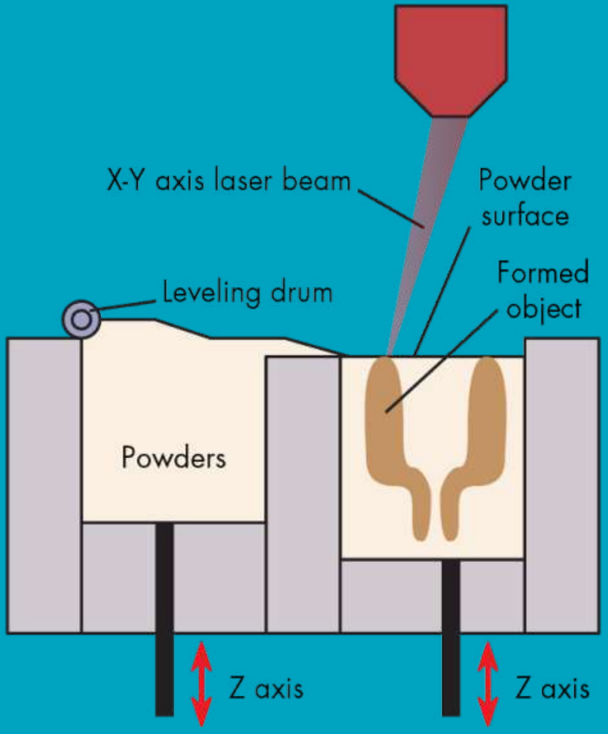

Figure 3: SLS technology. [3]

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SLS Process

1. The interior of the printer is heated up to just below the melting point of the powder used.
2. The printer then spreads out an incredibly fine layer of this powder.
3. A laser beam heats up the areas that need to be sintered together just above the melting point. The parts that were touched by the laser are now fused together while the rest continues to remain loose powder.
4. The Z axis lowers, and repeats from (2) until the part is finished.

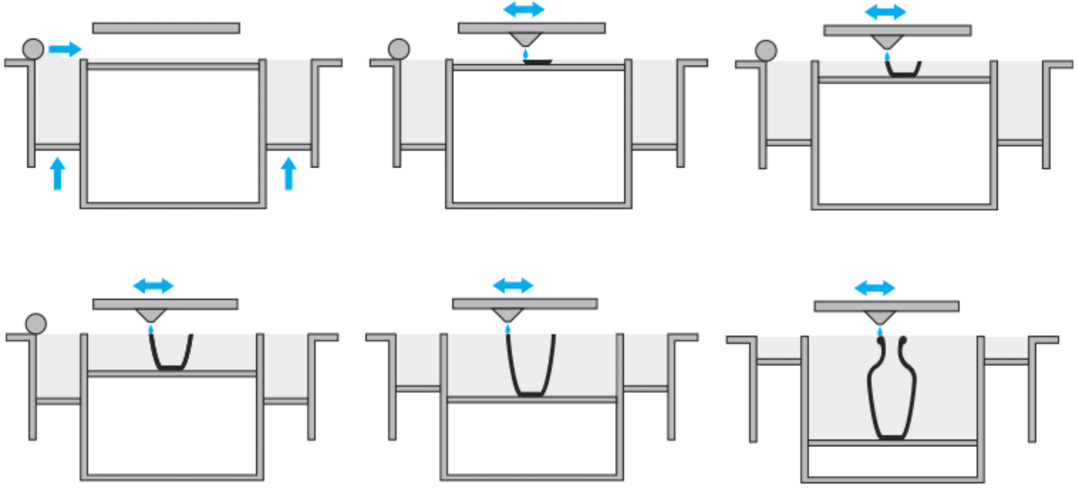

Figure 4: SLS process [4]

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Which materials can be used with SLS?

- **Plastic:** Polyamides (PA), Polystyrenes (PS), Thermoplastic Elastometers (TPE), etc.
- **Metal**: Aluminium, Silver and Steel
- **Ceramic**
- **Glass**

Figure 5: Shoe silhouette created using SLS. [5]

Metal materials are not commonly used in SLS, since the development of Selective Laser Melting (SLM). The most used one is Nylon (polyamides).

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Selective Laser Sintering (SLS)

STRENGTHS	WEAKNESSES
No use of support structures.	SLS prints present a certain surface porosity hence, Post-processing is required.
Reduced costs of the materials.	
Can handle a high complexity of geometry and high accuracy.	
Fastest additive manufacturing process for printing functional, durable prototypes and end user parts.	

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Stereolithography (SLA)

Stereolithography (SLA) is a photopolymerization process that builds individual layers of a model with liquid polymer (resin).

There are two types of SLA printers:

- **Top-down SLA printers:** the laser is placed above the resin tank.
- **Bottom-up SLA printers:** the laser is placed under the tank.

SLA produces fully dense isotropic parts that are water and airtight, which is ideal for engineering and manufacturing applications where material properties matter.

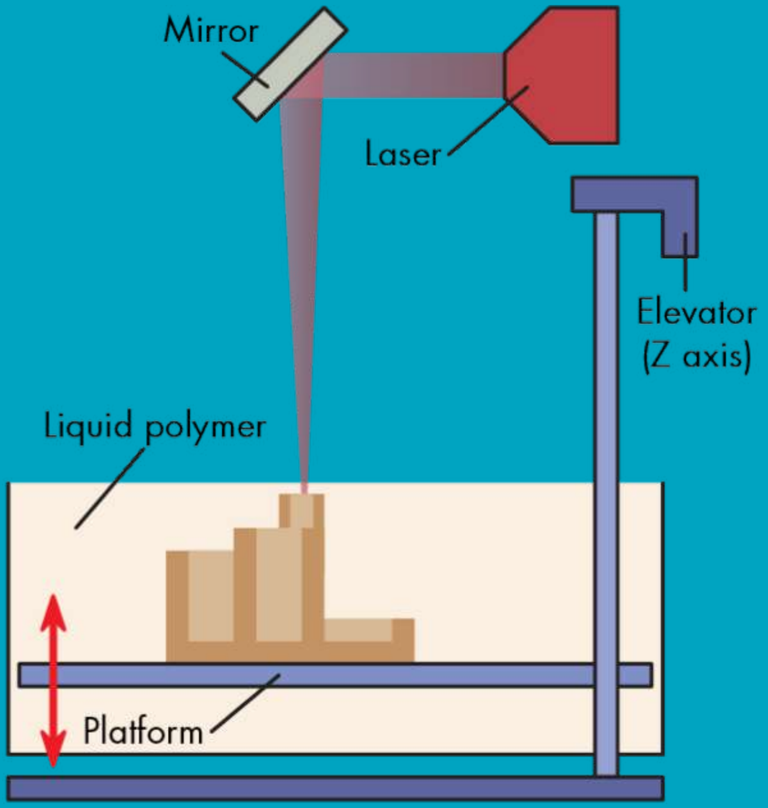

Figure 6: SLS technology. [3]

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SLA Process

1. The building platform is placed one layer away from the surface of the resin.
2. The UV laser creates a layer by selectively curing the shape defined by the 3D model.
3. When a layer if finished, the platform moves and the next layer is formed.
4. When the printing is complete, the part needs to be rinse in isopropyl alcohol (IPA) and some materials require a post-curing process.

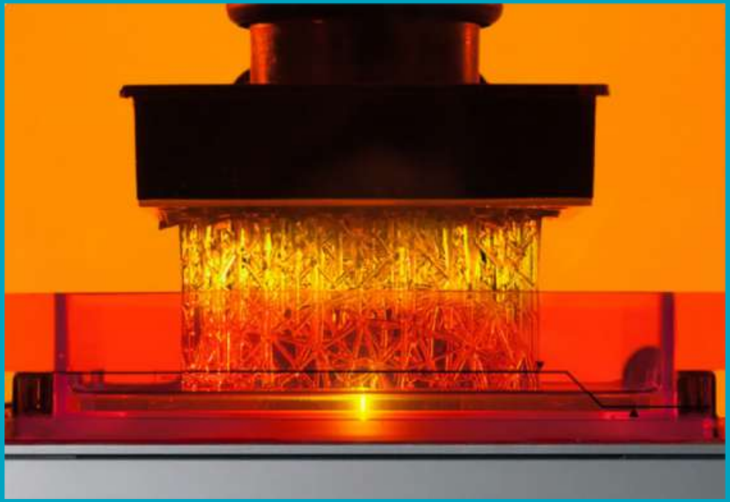

Figure 7: The curing process of SLA 3D printer [6]

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Which materials can be used with SLA?

There is a wide variety of SLA materiales that come as liquid resins:

- **Standard resin**
- **Clear resin:** transparent
- **Castable resin:** Used for molds
- **Gray resin (Prime Gray):** very smooth finsh
- **Dental resin:** for implants
- **High temperatura resin:** resistant up to 238 ºC

Figure 8: SLA 3D printers offer diverse materials for engineering and manufacturing applications. [2]

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Stereolithography (SLA)

STRENGTHS	WEAKNESSES
High resolution of the 3D prints	Photopolymer materials can be very expensive.
Allows to print objects with very complex geometries.	Liquid resins are generally irritating and toxic.
Reasonable period of time.	Prints usually require cleaning, Post-processing is generally needed.
	Requires support structures.

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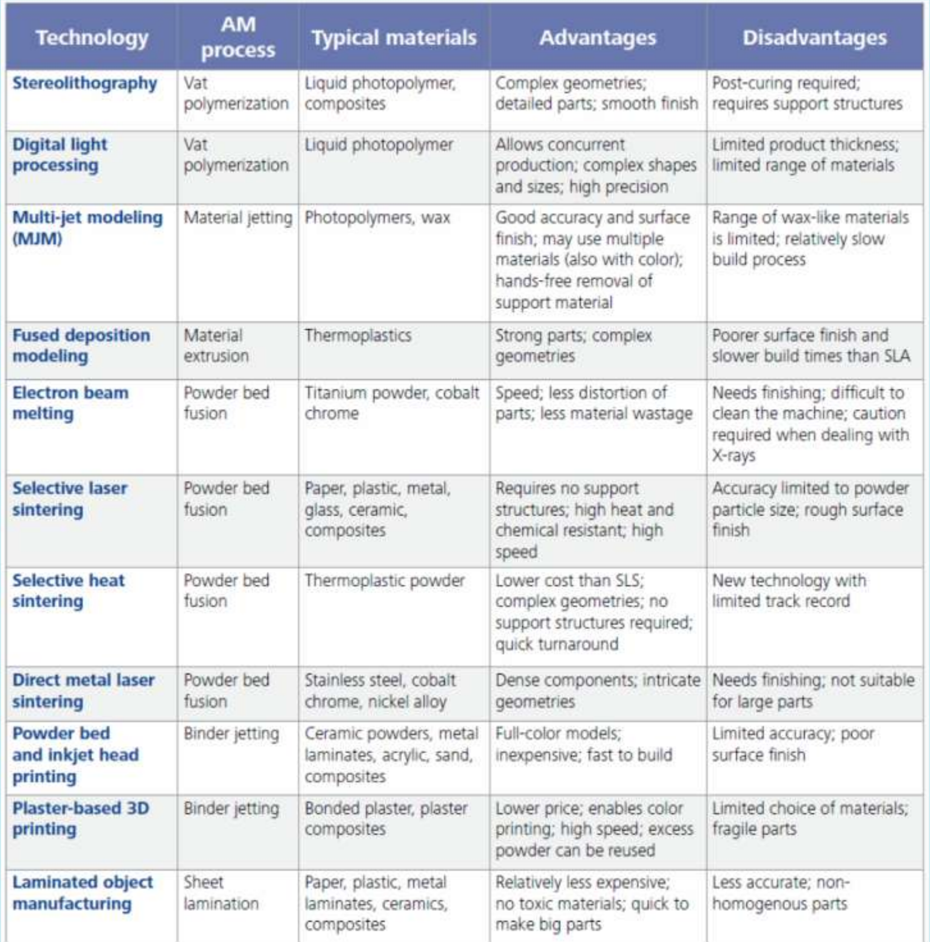
The workflow for SLA 3D printing consist of three steps:

1. **Designing:** It requires CAD software or 3D scan data to design a model, and export it in a 3D printable file format (STL or OBJ). 3D printers then require software to specify printing settings and slice the digital model into layers for printing.

2. **3D printing:** It can take from a few minutes up to days, depending on the size of the model, the technology used and the quality settings specified.

3. **Post-processing:** Depending on the technology used, there may or not be some post-processing work to do, like removing support structures, or painting the parts.

Typical materials of various 3D Technologies



Technology	AM process	Typical materials	Advantages	Disadvantages
Stereolithography	Vat polymerization	Liquid photopolymer, composites	Complex geometries; detailed parts; smooth finish	Post-curing required; requires support structures
Digital light processing	Vat polymerization	Liquid photopolymer	Allows concurrent production; complex shapes and sizes; high precision	Limited product thickness; limited range of materials
Multi-jet modeling (MJM)	Material jetting	Photopolymers, wax	Good accuracy and surface finish; may use multiple materials (also with color); hands-free removal of support material	Range of wax-like materials is limited; relatively slow build process
Fused deposition modeling	Material extrusion	Thermoplastics	Strong parts; complex geometries	Poorer surface finish and slower build times than SLA
Electron beam melting	Powder bed fusion	Titanium powder, cobalt chrome	Speed; less distortion of parts; less material wastage	Needs finishing; difficult to clean the machine; caution required when dealing with X-rays
Selective laser sintering	Powder bed fusion	Paper, plastic, metal, glass, ceramic, composites	Requires no support structures; high heat and chemical resistant; high speed	Accuracy limited to powder particle size; rough surface finish
Selective heat sintering	Powder bed fusion	Thermoplastic powder	Lower cost than SLS; complex geometries; no support structures required; quick turnaround	New technology with limited track record
Direct metal laser sintering	Powder bed fusion	Stainless steel, cobalt chrome, nickel alloy	Dense components; intricate geometries	Needs finishing; not suitable for large parts
Powder bed and inkjet head printing	Binder jetting	Ceramic powders, metal laminates, acrylic, sand, composites	Full-color models; inexpensive; fast to build	Limited accuracy; poor surface finish
Plaster-based 3D printing	Binder jetting	Bonded plaster, plaster composites	Lower price; enables color printing; high speed; excess powder can be reused	Limited choice of materials; fragile parts
Laminated object manufacturing	Sheet lamination	Paper, plastic, metal laminates, ceramics, composites	Relatively less expensive; no toxic materials; quick to make big parts	Less accurate; non-homogenous parts

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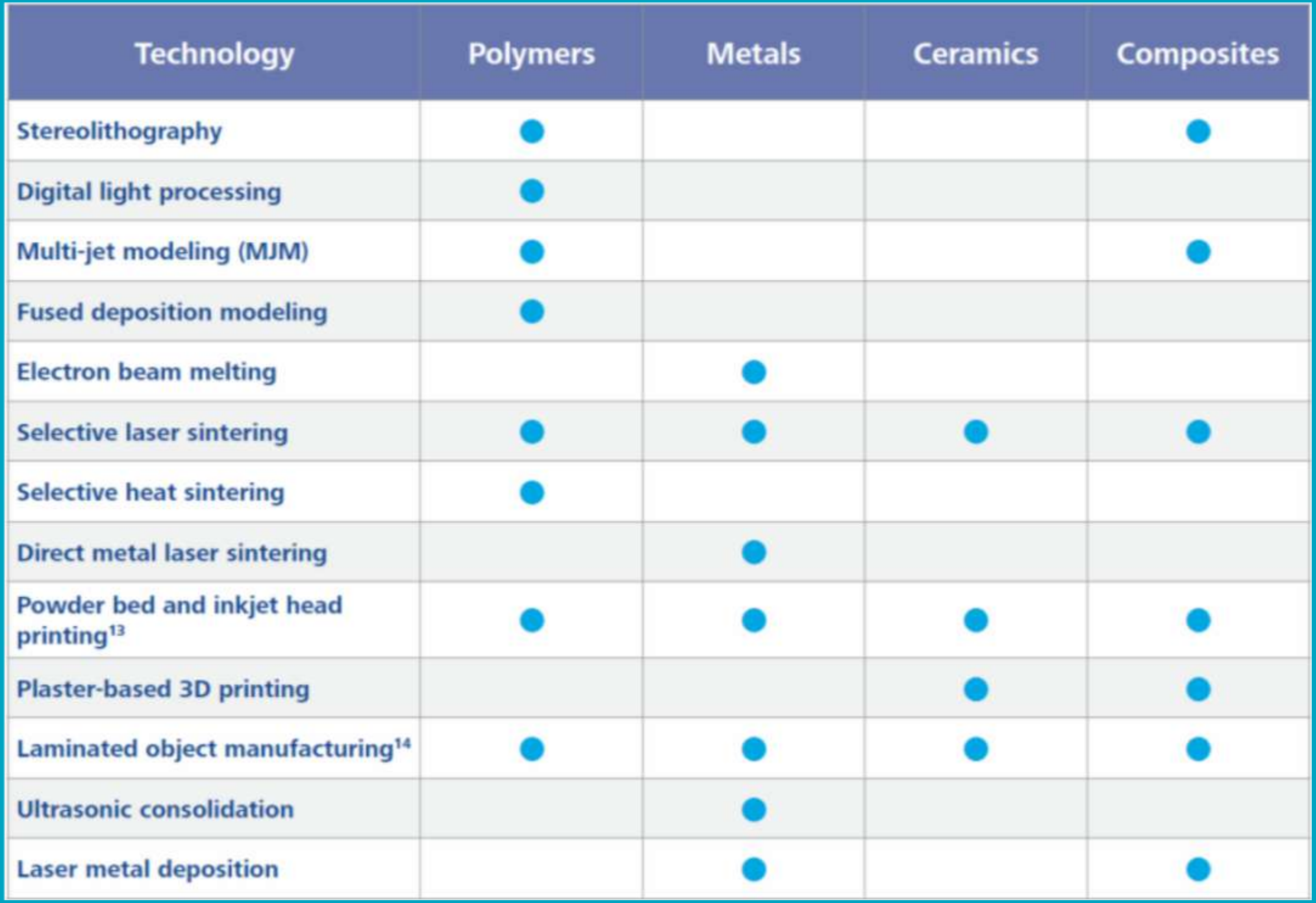
Technologies and materials matrix



Technology	Polymers	Metals	Ceramics	Composites
Stereolithography	●			●
Digital light processing	●			
Multi-jet modeling (MJM)	●			●
Fused deposition modeling	●			
Electron beam melting		●		
Selective laser sintering	●	●	●	●
Selective heat sintering	●			
Direct metal laser sintering		●		
Powder bed and inkjet head printing[13]	●	●	●	●
Plaster-based 3D printing			●	●
Laminated object manufacturing[14]	●	●	●	●
Ultrasonic consolidation		●		
Laser metal deposition		●		●

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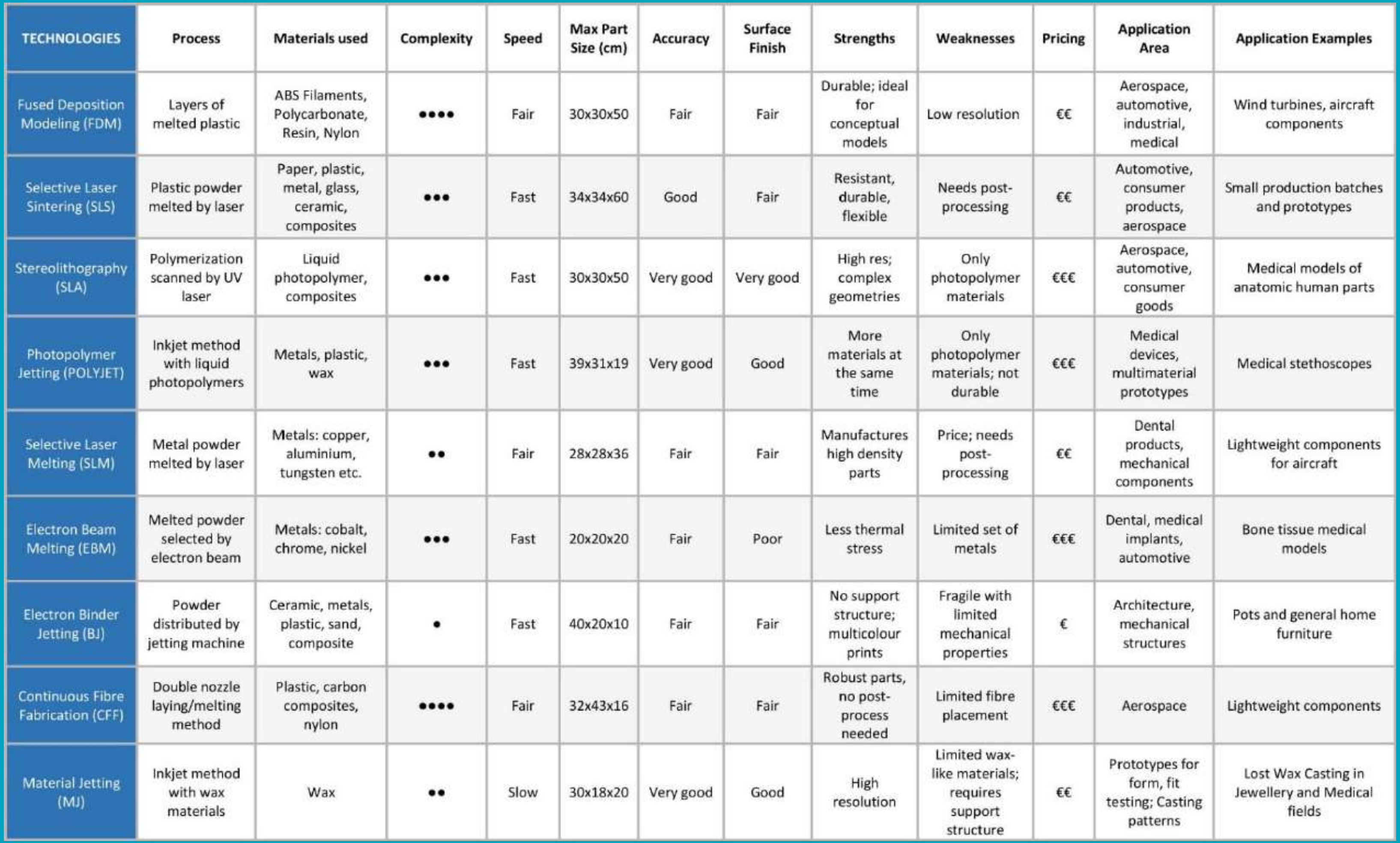
3DP Technologies Comparison



TECHNOLOGIES	Process	Materials used	Complexity	Speed	Max Part Size (cm)	Accuracy	Surface Finish	Strengths	Weaknesses	Pricing	Application Area	Application Examples
Fused Deposition Modeling (FDM)	Layers of melted plastic	ABS Filaments, Polycarbonate, Resin, Nylon	●●●●	Fair	30x30x50	Fair	Fair	Durable; ideal for conceptual models	Low resolution	€€	Aerospace, automotive, industrial, medical	Wind turbines, aircraft components
Selective Laser Sintering (SLS)	Plastic powder melted by laser	Paper, plastic, metal, glass, ceramic, composites	●●●	Fast	34x34x60	Good	Fair	Resistant, durable, flexible	Needs post-processing	€€	Automotive, consumer products, aerospace	Small production batches and prototypes
Stereolithography (SLA)	Polymerization scanned by UV laser	Liquid photopolymer, composites	●●●	Fast	30x30x50	Very good	Very good	High res; complex geometries	Only photopolymer materials	€€€	Aerospace, automotive, consumer goods	Medical models of anatomic human parts
Photopolymer Jetting (POLYJET)	Inkjet method with liquid photopolymers	Metals, plastic, wax	●●●	Fast	39x31x19	Very good	Good	More materials at the same time	Only photopolymer materials; not durable	€€€	Medical devices, multimaterial prototypes	Medical stethoscopes
Selective Laser Melting (SLM)	Metal powder melted by laser	Metals: copper, aluminium, tungsten etc.	●●	Fair	28x28x36	Fair	Fair	Manufactures high density parts	Price; needs post-processing	€€	Dental products, mechanical components	Lightweight components for aircraft
Electron Beam Melting (EBM)	Melted powder selected by electron beam	Metals: cobalt, chrome, nickel	●●●	Fast	20x20x20	Fair	Poor	Less thermal stress	Limited set of metals	€€€	Dental, medical implants, automotive	Bone tissue medical models
Electron Binder Jetting (BJ)	Powder distributed by jetting machine	Ceramic, metals, plastic, sand, composite	●	Fast	40x20x10	Fair	Fair	No support structure; multicolour prints	Fragile with limited mechanical properties	€	Architecture, mechanical structures	Pots and general home furniture
Continuous Fibre Fabrication (CFF)	Double nozzle laying/melting method	Plastic, carbon composites, nylon	●●●●	Fair	32x43x16	Fair	Fair	Robust parts, no post-process needed	Limited fibre placement	€€€	Aerospace	Lightweight components
Material Jetting (MJ)	Inkjet method with wax materials	Wax	●●	Slow	30x18x20	Very good	Good	High resolution	Limited wax-like materials; requires support structure	€€	Prototypes for form, fit testing; Casting patterns	Lost Wax Casting in Jewellery and Medical fields

Resources

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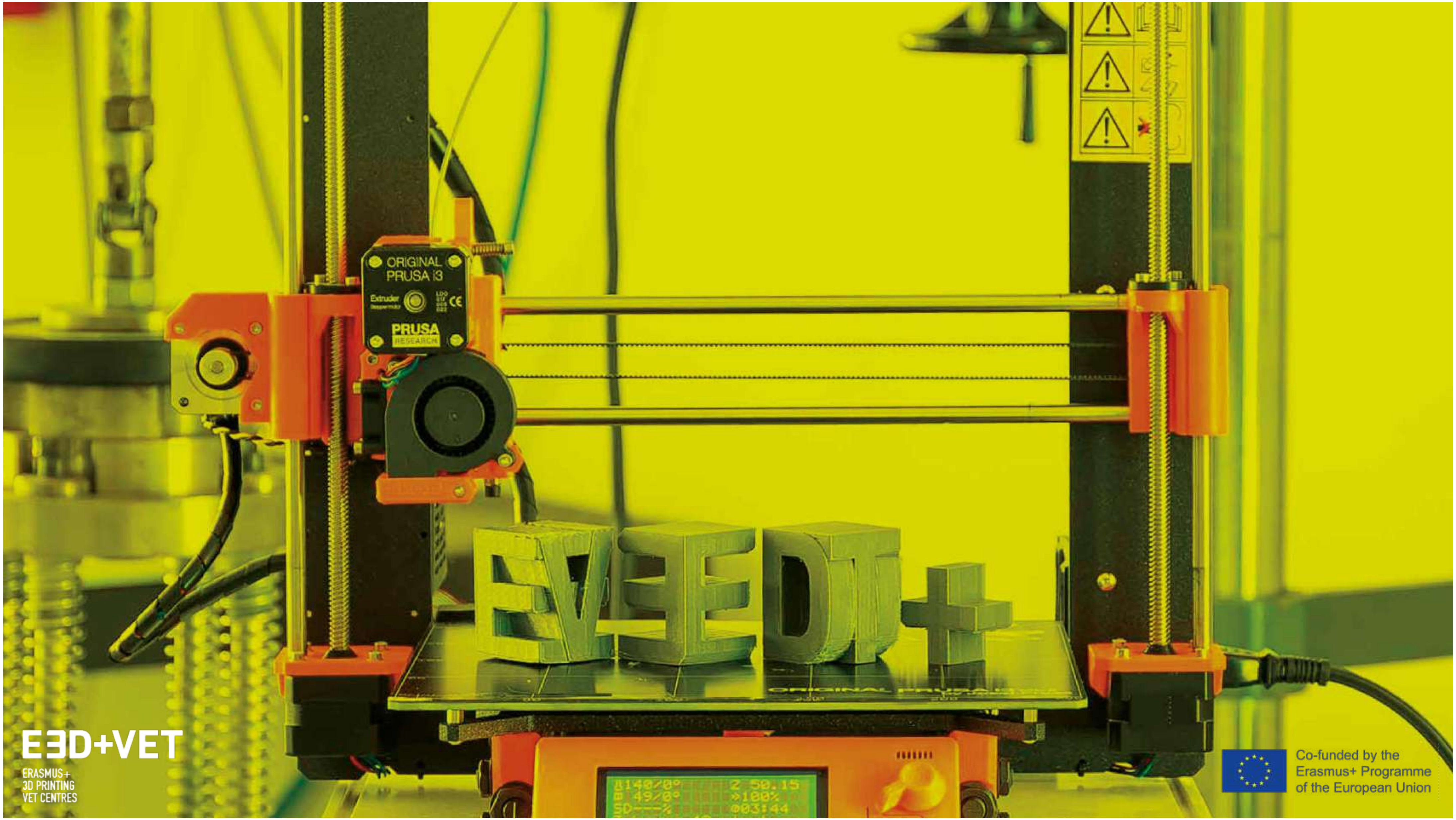
[5] 3.5 Rapid prototyping – Selective laser sintering (SLS). 2015. Source: http://ibdesigntech.com/3-5-rapid-prototyping-selective-laser-sintering-sls-5/

[6] Formlabs White Paper: 3D Printing with Desktop Sterelithography. 2015.



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