Erasmus+

3D4ELDERLY

PROJECT NUMBER: 2020-1-LT01-KA204-077896

IO1A2 - Identification of 3D printing most suitable technologies to be used in Alzheimer and elderly context.

CONSORTIUM OF PARTNERS:

BETI Baltic Education Technology Institute

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

Alzheimer Bulgaria

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1. Introduction

3D4ELDERLY project aims, among others, to train caregivers and staff who work with people with Alzheimer and dementia about how to use a 3D printer, and what are the main types of technologies available on the market. For that purpose, to identify the most suitable and best technologies for them Is therefore fundamental and requires special attention.

There are many criteria to be taken into consideration. It is needed to understand how accurate a 3D printing technology really is, what are the costs related to this technology, the complexity of use, application areas, examples, etc. The result of this analysis is given in this report.

As a result of a previous internal study, there have been selected three 3D printing technologies, which are:

- Fused Deposition Modelling (FMD)

- Stereolithography (SLA)

- Selecting Laser Sintering (SLS)

Figure 1. Pieces obtained from FDM, SLA and SLS technologies. Source: https://elmundo3d.com/wp-content/uploads/elementor/thumbs/comparativa-fdm-sla-2--o92mz5e8wvraguk57d2rzf2ju3kjcghqk3824oyna4.jpeg

Here below, there are described deeply, regarding mainly the process itself, and the machines and materials available in the market, indicating also related costs.

2. Fused Deposition Modelling (FDM)

2.1. Process and overview

Fused Deposition Modelling (FDM), also known as Fused Filament Fabrication (FFF) is an additive manufacturing process in which an object is built by selectively depositing melted material in a pre-determined path layer-by-layer. The materials used are thermoplastic polymers and they come in the form of a filament.

It is the most widely used 3D printing technology. It is also often the first technology people are exposed to.

The process of FDM fabrication begins loading a spool of a thermoplastic filament into the printer. For that, the temperature of the nozzle has to be set at the required temperature for the material. The filament is fed to the extrusion head and in the nozzle, where it melts.

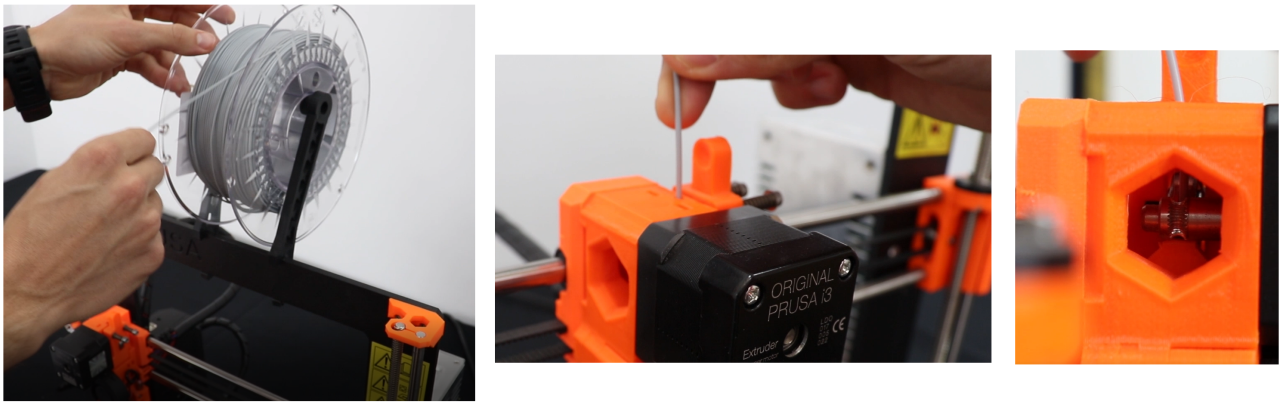

Figure 2. Loading a spool of material into the 3D printer. Source: CETEM.

In every FDM machine, the extrusion head is attached to a 3-axis system that allows it to move in the X, Y and Z directions. So the melted material is extruded and deposited layer-by-layer in the required locations, where it cools and solidifies.

So to fill an area, multiple passes of the extruder are required. When a layer is finished, the build platform moves down (or in other machines setups, the extrusion head moves up) the height of the layer and then a new layer begins to be deposited. This process is repeated over and over again until the piece is done.

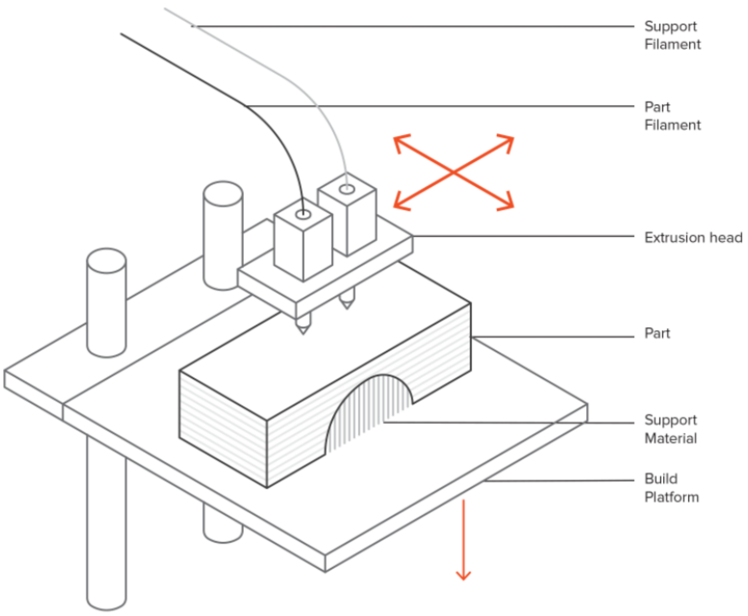

Figure 3. FMD scheme of work. Source: https://www.3dhubs.com/knowledge-base/introduction-fdm-3d-printing/

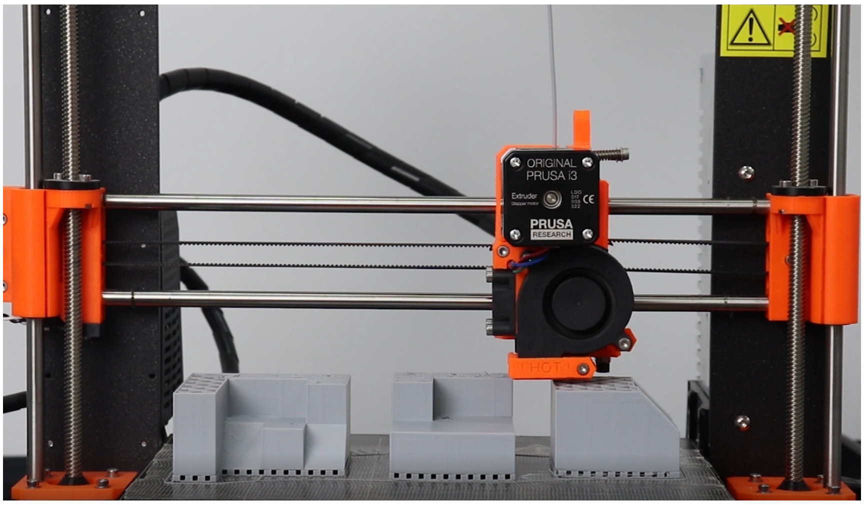

Figure 4. FDM printer working. Source: CETEM.

2.2. Machines and materials

Regarding FDM ***machines***, it is needed to distinguish between desktop 3D FDM printers and industrial 3D FMD printers. Differences between them are:

- **Standard accuracy**: ±0.15% in industrial printers, versus **±1% in desktop FDM printers.**
- **Typical layer thickness or layer height**: 0.18-0.5 mm in industrial FMD printers and 0.1-0.25 mm for desktop printers.

- **Maximum build envelope:** Up to 900x600x900 mm for industrial printers and up to 200x200x200 mm for desktop ones.
- **Materials:** Industrial printers can use more range of materials, due the range of temperatures that both extruder and bed surface can reach.
- **Costs:** There are important differences here. Industrial FDM printers price can vary between 10.000€ and >50.000€. Desktop machines are cheaper; you can found printers from 300€ to 5000€.

Figure 5. Desktop FMD printer (left) and industrial FDM 3D printer (right). Source: https://s3-eu-west-1.amazonaws.com/3dhubs-knowledgebase/industrial-vs-desktop-fdm/photo3.jpg Source: https://www.3dnatives.com/es/stratasys-v650-flex-sla-f120-010320192/

Regarding accuracy, Typically industrial FDM 3D printers produce parts of higher accuracy than desktop FDM machines, because of the closer control of the processing parameters during printing. Industrial machines run calibration algorithms before each print, include a heated chamber to minimize the effects of rapid cooling of the molten plastic. On the other hand, desktop FDM 3D printers are now catching up and there are machines that support these advanced features (i.e. calibration algorithms, heated chamber, higher printing temperatures and dual extrusion). A well calibrated basic desktop FDM machine can produce parts with fairly high dimensional accuracy (typically with tolerances of ± 0.5 mm) and with the same minimum feature size as industrial FDM machines (i.e. approx. 1 mm). This accuracy is sufficient for most applications.

Now, focusing on ***materials*** for FDM 3D printers, it is important to notice that One of the key strengths of FDM is the wide range of available materials. These can range from commodity thermoplastics (such as PLA and ABS) to engineering materials (such as PA, TPU, and PETG) and high-performance thermoplastics (such as PEEK and PEI).

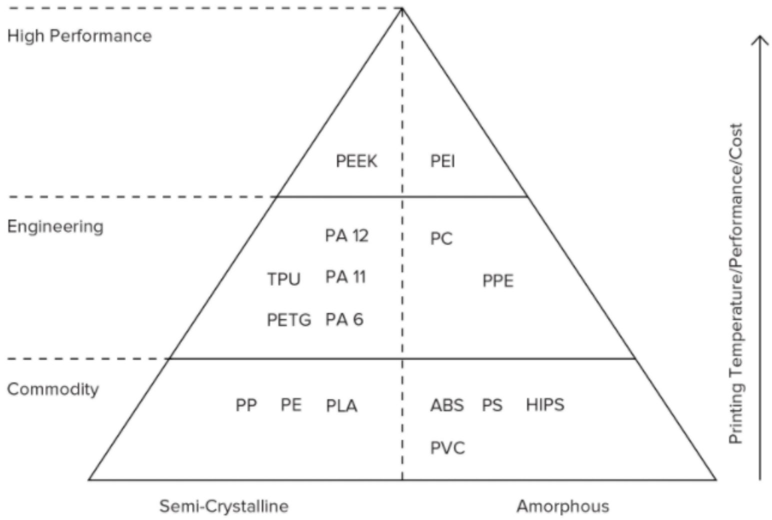

Figure 6. Thermoplastic materials in FDM. Source: https://www.3dhubs.com/knowledge-base/introduction-fdm-3d-printing/

The material most commonly used on desktop FDM 3D printers is PLA. PLA is easy to print with and can produce parts with finer details. Then, when higher strength, ductility and thermal stability is needed, ABS is commonly used. ABS is more prone to warping (due to shrinkage) and the geometry of the printed part can prohibit its use, especially in machines that do not have a heated chamber.

Industrial FDM 3D printers use mainly engineering plastics (ABS, polycarbonate (PC) or Ultem). These materials are usually loaded with certain additives that alter their properties and make them particularly useful for a certain industrial need (e.g. high impact strength, thermal stability, chemical resistance and biocompatibility).

Figure 7. FDM different rolls of material. Source: https://cdn2.sculpteo.com/wp-content/uploads/2019/06/Filaments2.jpg

Regarding the cost of all these materials, they are sold in the form of rolls of filaments (although some 3D printers can print parts from plastic pellets). For example, 1 kg of PLA is about 20€. Also basic ABS is near the 20€ per kg. For other engineering plastics, prices can be higher: 1 kg of PC (Policarbonate) is about 60€.

3. Stereolithography (SLA)

3.1. Process and overview

Stereolithography (SLA) is an additive manufacturing process in which the object is created by selectively curing a polymer resin layer-by-layer using an ultraviolet (UV) laser beam. The materials used in this technology are photosensitive thermoset polymers that come in a liquid form.
Other similar technologies, such as DLP (Digital Light Processing) are very similar, the only difference is that DLP uses a digital light screen, instead of a UV laser beam, for curing the resin. For simplicity, the two technologies can be treated as equals.

If parts of very high accuracy or smooth surface finish are required, SLA is the most cost-effective 3D printing technology available.
The process is the following in SLA technology. First of all, the build platform is positioned in the tank full of liquid photopolymer, at a distance of one layer for the surface of the liquid. Then a UV laser creates the layer by selective curing and solidifying the photopolymer resin. The laser beam is focused in the predetermined path using different ways depending on the machine. It can be done using mirrors, for example.
There are 2 kind of SLA machines: top-down SLA printers and bottom-up SLA printers. In top-down machines, the part is built facing upside down. The tank has a transparent bottom with a silicone coating that allows the light of the laser to pass through but stops the cured resin from sticking to it. After every layer, the cured resin is detached from the bottom of the tank, as the build platform moves upwards. This is called the peeling step.
The bottom-up orientation is mainly used in desktop printers, while the top-down is generally used in industrial SLA systems. Bottom-up SLA printers are easier to manufacture and operate, but their build size is limited, as the forces applied to the part during the peeling step might cause the print to fail. On the other hand, top-down printers can scale up to very large build sizes without a big loss in accuracy. The advanced capabilities of these systems come at higher costs.

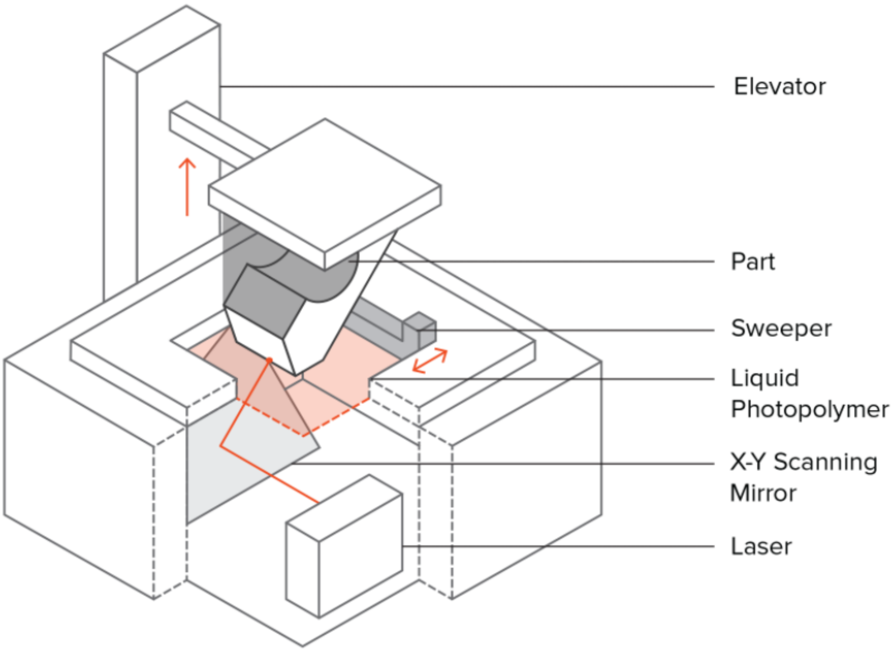

Figure 8. Scheme of a top-down SLA printer. Source: https://www.3dhubs.com/knowledge-base/introduction-sla-3d-printing/

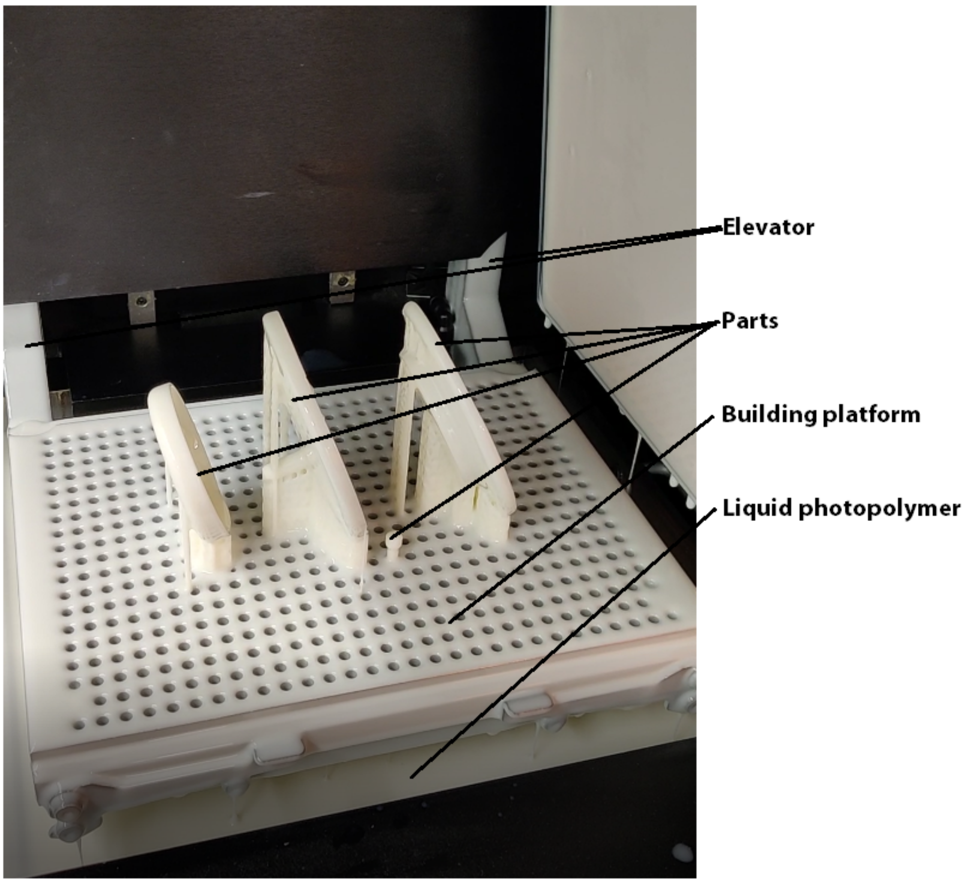

Figure 9. DLP (similar to SLA) 3D printing machine, with fresh printed parts. Source: CETEM.

3.2. Machines and materials

As in FDM technology, in regards of SLA 3D printers, it is important to distinguish between SLA desktop and industrial ***machines***. The main differences between them are the following:

- **Build size:** Desktop SLA machines build size is about up to 145x145x175 mm, while build size for industrial SLA printers is up to 1500x750x500 mm.
- **Typical layer height:** For both desktop and industrial SLA printers: 25 to 100 microns (0.025 - 0.1 mm).
- **Accuracy:** Dimensional accuracy for desktop SLA machines is about ±0.5%, but for industrial printers is about ±0.15%.
- **Costs:** There are important differences here. While a desktop SLA machine can range between 2.000€ up to 6.000€, industrial SLA printers can go up to 500.000€.

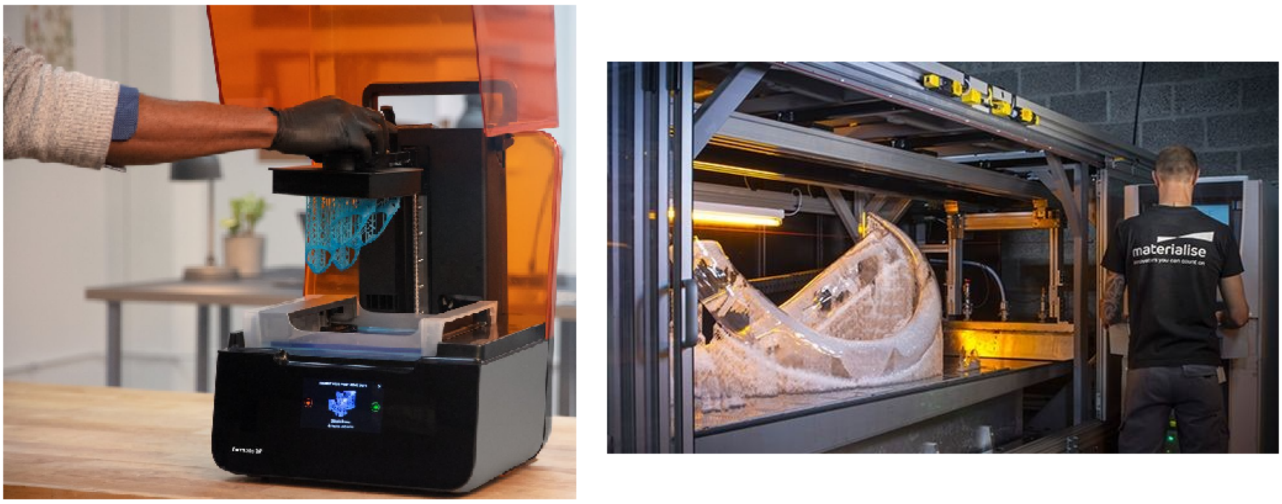

Figure 10. SLA desktop printer (left) versus SLA industrial printer (right). Source: https://formlabs-media.formlabs.com/filer_public_thumbnails/filer_public/be/50/be501495-9972-4536-9d27-57c0375b16a7/03062019_daguerre_1_565.jpg__1354x0_q85_subsampling-2.jpg Source: https://www.materialise.com/sites/default/files/styles/case_teaser/public/image-uploads/pages/Manufacturing/Technologies/3d-printing-technology_stereolithography.jpg?itok=DMgnH71i

Regarding ***materials*** for SLA technology, one of the biggest advantages of industrial SLA over desktop machines is the range of materials that industrial printers are able to print with. While desktop printers may offer a flexible resin, industrial machines offer a large range of

flexible resins each with varying mechanical properties (Shore Hardness, high temperature etc.).
SLA materials come in the form of a liquid resin. The price per liter of the resin varies greatly, from about $50 for the standard material, upwards to $400 for the specialty materials, such as the castable or dental resin. Industrial systems offer a wider range of materials than desktop SLA printers, that give the designer a closer control over the mechanical properties of the printed part.
SLA materials (thermosets) are more brittle than the materials produced with FDM or SLS (thermoplastics) and for this reason, SLA parts are not usually used for functional prototypes that will undertake significant loading. Advances in materials may change this in the near future.

Figure 11. SLA materials. Source: https://manufactur3dmag.com/wp-content/uploads/2018/05/Formlabs-Clear-Resin-300x214.jpg Source: https://5.imimg.com/data5/YL/QO/MY-11147533/dlp-sla-3d-printer-resin-500x500.jpeg

Most common materials are: standard resin (smooth surface finish but relatively brittle), clear resin (transparent, but requires post-processing for that), castable resin (used for created mold patterns), dental resin (biocompatible but with a higher cost), tough or durable resin (ABS-like or PP-like mechanical properties), etc.

4. Selective Laser Sintering (SLS)

4.1. Process and overview

Selective Laser Sintering (SLS) is an additive manufacturing process in which a laser selectively sinters the particles of a polymer powder, fusing them together and building a part layer-by-layer. The materials used in this technology comes in granular form and they are thermoplastic polymers.

This technology is used for prototyping but also for functional polymer components and small production runs, as it offers a very high design freedom, high accuracy and produces parts with good and consistent mechanical properties, unlike FDM or SLA.

The SLS fabrication process is here explained: First of all, the powder bin and the build area are heated just below the melting point temperature of the polymer. Then, a recoating blade spreads a thin layer of powder over the build platform (just of the layer height). Then, a CO2 laser selectively sinters (fuses) the particles of the powder, creating a rigid layer of the object. When a layer is complete, the build platform moves downwards and the blade recoats the surface with more powder. This process is repeated once again until the piece is complete.

So, at the end of the process, the part or parts are fully immersed into the powder. Once the powder bin has cool down, the piece can be unpacked and cleaned with compressed air. One big advantage is that unsintered powder is collected and it can be reused again.

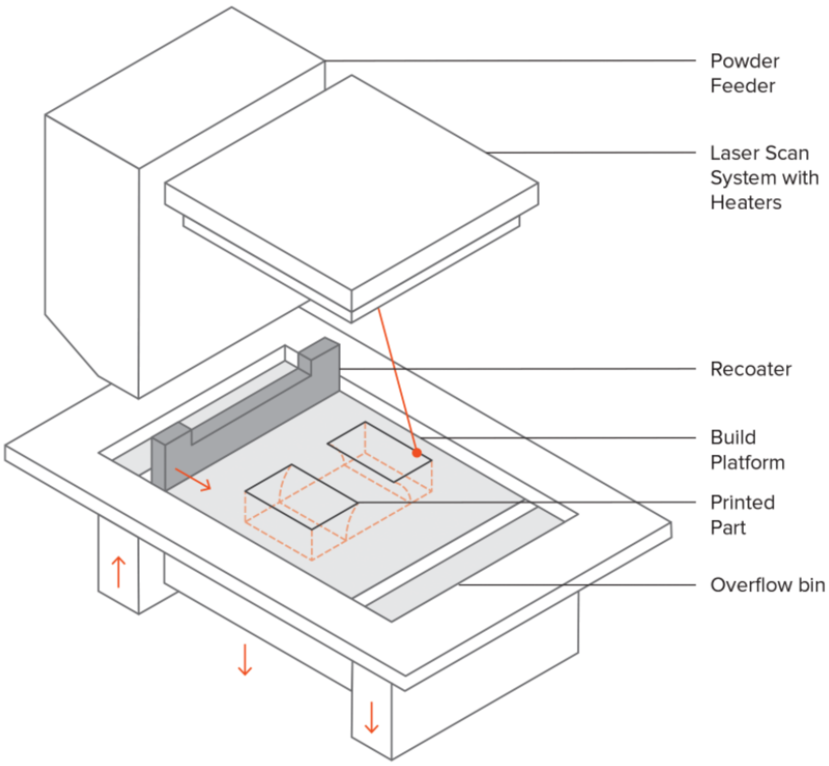

Figure 12. Scheme of SLS 3D printer technology. Source: https://www.3dhubs.com/knowledge-base/introduction-sls-3d-printing/

Figure 13. Extracting and cleaning pieces from a SLS 3D printer machine. Source: https://i.all3dp.com/cdn-cgi/image/fit=cover,w=1284,h=722,gravity=0.5x0.5,format=auto/wp-content/uploads/2018/11/05175257/cleaning-the-powder-off-a-batch-of-items-printed-with-mjf-hp-youtube-181105.jpg

4.1. Machines and materials

Once again, as well as in FDM and SLA, in the regards of SLS ***machines***, we can also talk about desktop or industrial SLS 3D printers.

In SLS almost all process parameters are preset by the machine manufacturer. The default layer height used is 100-120 microns.

In the regard of dimensional accuracy, most printers are about ±0.3%.

Desktop SLS machines building size is up to 180x180x300 mm. Contrarily, industrial SLS printers can range up to 600x600x500 mm. Taking advantage of the whole build volume is very important when printing with SLS, especially for small batch productions. A bin of a given height will take about the same time to print, independent of the number of parts it contains. This is because the re-coating step determines the total processing time (laser scanning occurs very rapidly) and the machine will have to cycle through the same number of layers. Bin packing may affect lead times of small orders, as operators usually wait until a bin is filled before starting a print.

A key advantage of SLS is that it needs no support structures. The unsintered powder provides the part with all the necessary support. For this reason, SLS can be used to create freeform geometries that are impossible to manufacture with any other method.

One important thing to take into account is that Porosity gives SLS parts their characteristic grainy surface finish. It also means that SLS parts can absorb water, so they can be easily dyed in a hot bath to a large range of colours but also that they require special post-processing if they are to be used in a humid environment.

Regarding the cost of the machines, the cheapest of the machines is about 12.000€ and the more expensive one is as expensive as SLA is, for example.

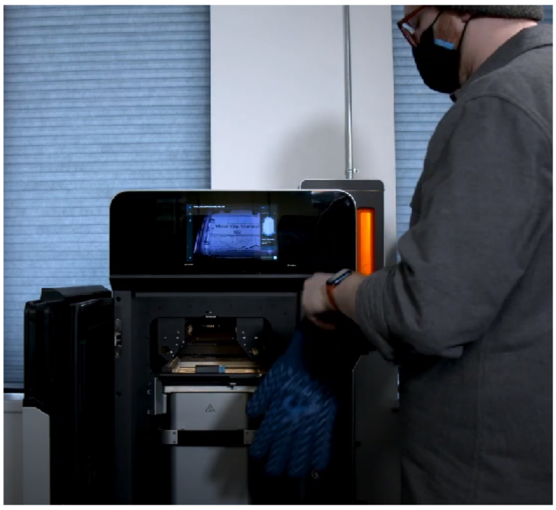

Figure 14. Desktop (left) and industrial (right) SLS 3D printing machine. Source: https://www.youtube.com/watch?v=oiEL4BGXQss Source: https://i.ytimg.com/vi/Y7Nj5NmTdEo/maxresdefault.jpg

The most widely used SLS ***material*** is Polyamide 12 (PA 12), also known as Nylon 12. The price per kilogram of PA 12 powder is approximately $50 - $60. Other engineering thermoplastics, such as PA 11 and PEEK, are also available but are not as widely used.

Polyamide powder can be filled with various additives (such as carbon fibres, glass fibres or aluminium) to improve the mechanical and thermal behaviour of the produced SLS part. Materials filled with additives are usually more brittle and can have highly anisotropic behaviour.

5. Why FDM?

Here in this chapter, we are going to talk about the benefits of Fused Deposition Modelling (FDM), and why this technology should be identified as the most suitable one for 3D4ELDERLY project purposes.
So, the main reasons and also advantages of FDM technology are the following:

- ✓ FDM is the most cost-effective way of producing custom thermoplastic parts and prototypes.
- ✓ The lead times of FDM are short (as fast as next-day-delivery), due to the availability of the technology.
- ✓ It is a cheap and accessible 3D printing technology. This makes it perfect for beginners to 3D printing. It's also the most commonly used rapid prototyping technology due to its ease of access.
- ✓ A wide range of thermoplastic materials is available, also in colours, suitable for both prototyping and functional applications.
- ✓ FDM printers are often user-friendly.
- ✓ Great build size of mostly desktop FDM 3D printers. The typical size of an FDM desktop machine is about 20x20x20cm, which is a good size for most of the parts to be printed.
- ✓ Safe to use. Comparing to SLS or SLA, FDM is a safe technology, because it causes not harm. SLS involves great temperature and can be dangerous, and some SLA materials can produce allergies in your skin.

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