Trainers for Visually Impaired Students Introduce 3D Printing

Tutorial Module 1

Introduction to 3D printing and potential applications in the education of visually impaired people

Tutorial for the T4VIS-In3D trainer course

Published by the
T4VIS-In3D project consortium

The project “T4VIS-In3D” was co-financed by the “ERASMUS+” Programme of the European Commission

This Tutorial is published by the T4VIS-IN3D project consortium.

Licensing

Printed:

April 2021 by Berufsförderungswerk Düren gGmbH

The T4VIS-In3D Project Consortium:

Berufsförderungswerk Düren gGmbH (Project co-ordination)
Karl-Arnold-Str. 132-134, D52349 Düren, Germany, http://www.bfw-dueren.de

Fundacion Aspaym Castilla Y Leon
C/ Severo Ochoa 33, Las Piedras 000, 47130, Simancas Valladolid, Spain, https://www.aspaymcyl.org/

Hilfsgemeinschaft der Blinden und Sehschwachen Osterreichs
Jagerstrasse 36, 1200 Wien, Austria, https://www.hilfsgemeinschaft.at/

Instituttet for Blinde og Svagsynede, IBOS
Rymarksvej 1, 2900 Hellerup, Denmark, https://www.ibos.dk

Istituto Regionale Rittmeyer per i ciechi di Trieste
Viale Miramare 119, 34136 Trieste, Italy, http://www.istitutorittmeyer.it/

NRCB
24 Landos Str., Plovdiv, 4006, P. Box 11, Bulgaria, http://www.rehcenter.org

Content

1 History of 3D printing

Since the beginning of the millennium, 3D printing has become more and more popular. This technology is becoming increasingly widespread in the industry and also in economic sectors that were not originally involved in production.

The machines are becoming more and more powerful, user-friendly and cost-effective.

Although the media attention suggests that 3D printing is a recent development, the developments date back to the 1980s. The reason for the growing importance of 3D printing is that the patents from the 1980s expired at the turn of the millennium. Further developments in the hardware and software area could thus be continued without licence fees or legal restrictions.

1.1 Development of 3D fabrication processes

Dr. Hideo Kodama of the Nagoya Municipal Industrial Research Institute in Japan was one of the first to explore the principle of curing by the use of a laser beam.

As early as 1980, he filed a patent (JPS56144478A) and described his system as follows: "A vat of photopolymer material is exposed to UV light. This light hardens the material in the vat, creating a model layer by layer."

The **Stereolithography (abbrev. SLA)** process also works exactly according to this principle. Unfortunately, due to problems with funding, he was unable to register his patent in full within the one-year deadline after submission, which denied him a place on the podium of 3D printing history.

Figure 1 Early SLA printer SLA 1 (Reference: ResearchGate)

In the early 1980s, **Charles Hull** worked for a small company that used UV light to give tables a robust plastic surface and to repair tablecloths, floor coverings and the like. The effect that UV light has on photosensitive surfaces fascinated Hull.

In 1984, he found the optimal connection between UV light and photopolymers and applied for a patent together with other colleagues.Patent(US4575330)

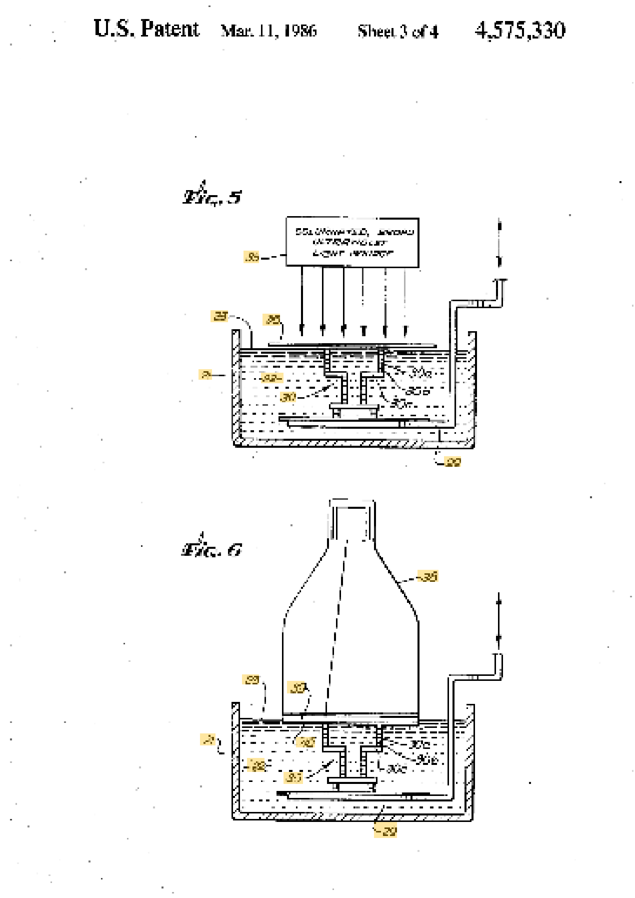

Figure 2 Graphic of Charles Hull's patent application

In 1989, **Carl Deckard** filed another patent application for the 3D printing process of laser sintering. In this process, a plastic powder is fused with a laser. Patent (US4863538). This corresponds to **powder bed-based** processes such as selective **laser sintering (SLS**) or **selective laser melting (SLM).**

In 1989, Scott Crump applied for a patent (US5121329) for the **fused deposit modelling process** (**FDM),** which is very widespread today. In this process, plastic is melted and then applied in layers. Today, the FDM process is widely used and has a high flexibility in the availability of materials. In the meantime, there are also FDM printers available for the production of metal components.

Based on the fact that in 3D printing the component is always created in successive layers, the technical term "additive manufacturing" arose as a synonym for 3D printing.

1.2 Differences between traditional and additive manufacturing processes

The traditional processes are ablative and casting processes. In ablative processes, tools are used to create the component from a block of material. This requires machines with appropriate tools and possibly also coolants.

In casting processes, liquid material is poured into a casting mould. The material usually hardens by cooling. The mould must then be removed and the hardened material in the casting channels must be removed.

The shape of the workpiece is not determined exclusively by its function. Designers must also take the different areas the tools can reach into account. This "machine-compatible design method" partially restricts the freedom of shape.

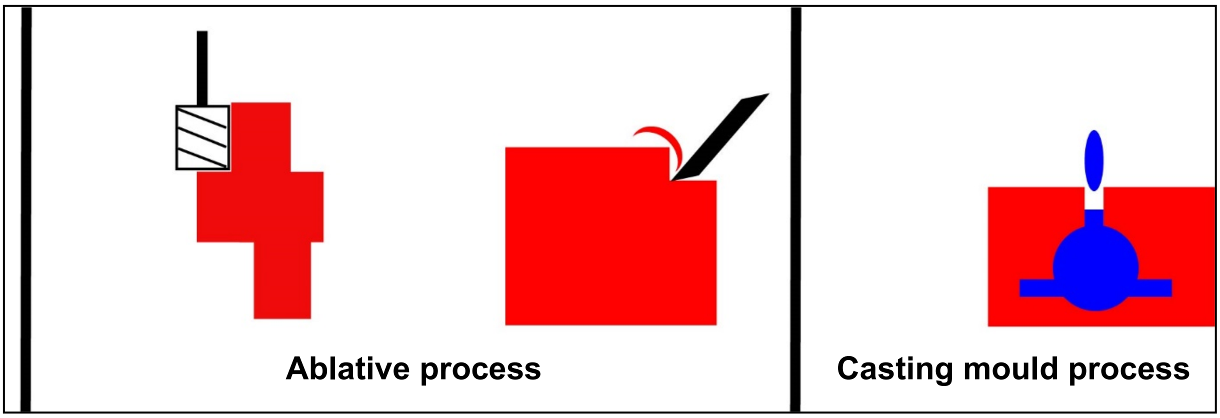

Figure 3 Traditional processes

These processes require more material than the actual component needs. The ablated or cast residues can be recycled but require higher material costs in procurement.

In additive manufacturing processes, the components are created layer by layer. Apart from the 3D printer, no other tools are needed for the production. The material is only applied or solidified in the shape of the component. Material waste, as in the case of ablative processes, is either produced only to a very small extent or not at all.

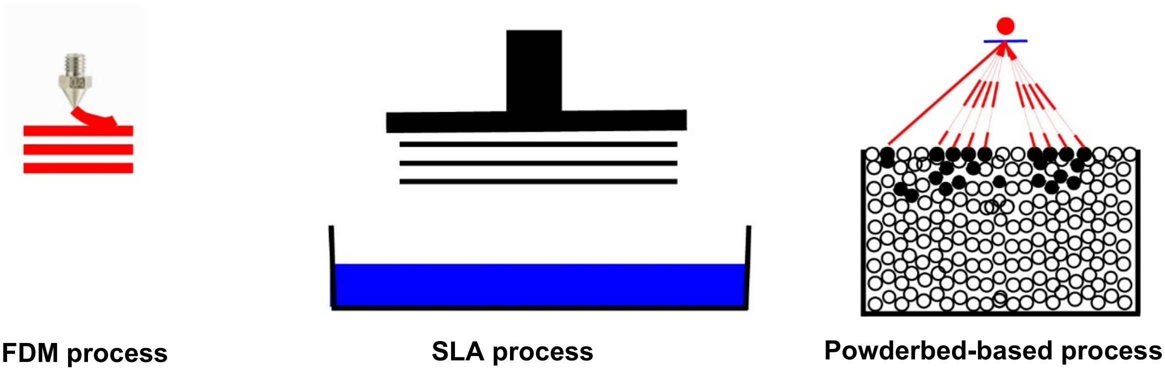

Figure 4 Additive processes

This process offers the possibility to produce the design with a higher degree of freedom of shape.

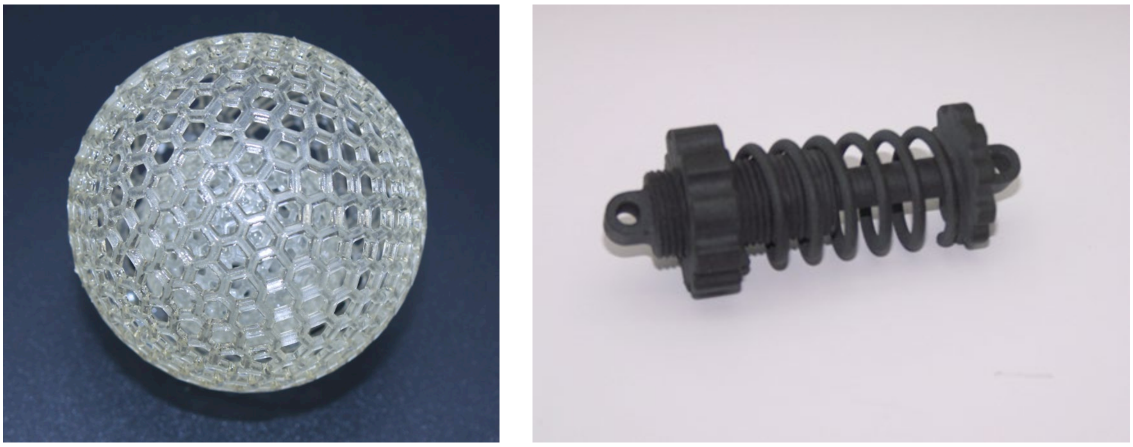

Figure 5 Freedom of shape. Both models were printed in one process

This saves raw material and reduces the assembly effort and weight of the component.
Another advantage of 3D printing is the cost-effective production of prototypes and small quantities.
However, additive manufacturing processes currently also offer certain disadvantages. These are:

1. comparatively slow process
2. limited component size
3. post-processing of the components is sometimes necessary

For the foreseeable future, additive manufacturing is an additional manufacturing process that complements conventional processes but will not replace them.
Concerning the production of tactile teaching materials, 3D printing represents a significant improvement in terms of the quality, variety and cost-effectiveness of the materials to be produced.

2 Appropriate 3D printing technology to produce tactile teaching materials

2.1 Previous methods

In comparison to the previous methods for the production of tactile teaching materials, 3D printing offers significant advantages. The previous processes are primarily:

1. the use of swell paper
2. thermoforming with plastic film

In the swell paper process, a medium of backing paper and thermoplastic material is heated. The blackened areas on this medium are thickened (or "swelled") by heating with a "fuser".
This thickening depends on the blackening and is normally no greater than 1.5 mm. Greyscales cannot be represented and neither is it possible to realise more complex three-dimensional images.

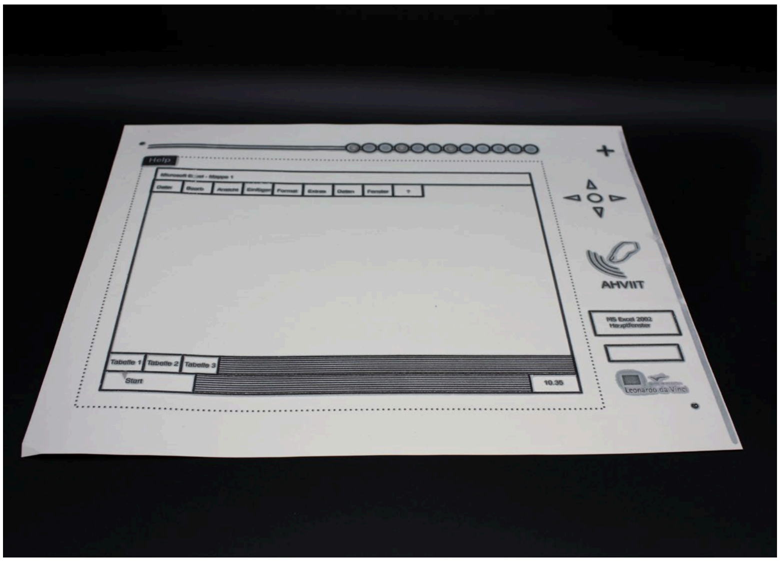

Figure 6 Representation of a computer window with swell paper

The blackening of the material can be done with any fibre pen or inkjet printer. Any simple graphics programme can be used to create simple graphics. With frequent use, the representations wear out quickly and need to be replaced.

In the thermoforming process, a plastic film is passed over a three-dimensional matrix, heated, drawn onto the matrix by a vacuum and formed. The film is therefore an imprint of the matrix. This process allows the realisation of larger elevations and a large number of copies. However, the richness of detail depends on the scale, as the forming process does not allow for fine embossments.

Figure 7 Model of a keyboard made with thermoforming

Up to now, matrixes were created in time-consuming manual work. Changes to the model were thus very time-consuming or even required a complete redesign of the matrix.

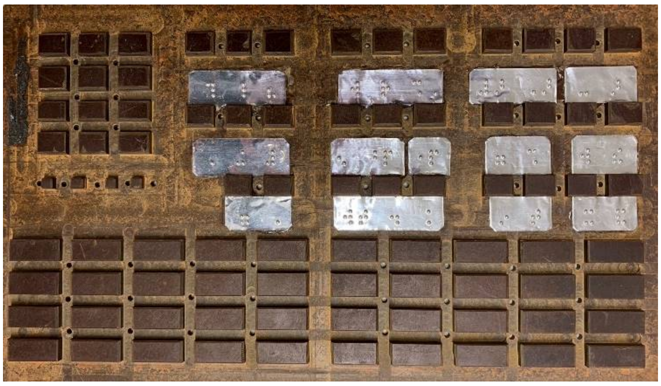

Figure 8 Matrix of the keyboard from previous figure

If you are equipped with a thermoforming machine and a 3D printer, it is much easier to produce the required moulds with a CAD programme and the 3D printer.

2.2 Advantages of 3D printing

Compared to the methods described above, 3D printing offers considerable advantages for the production of tactile teaching materials that are very detailed and relatively inexpensive. Essentially, all that is needed for production is the 3D printer and its materials, as well as CDA software. The production of matrices does not require a variety of tools and materials.

Compared to teaching materials made of thermoforming foils or swell paper, tactile models from a 3D printer allow significantly enlarged and detailed elevations, bodies and textures of the surface. Elevations, bodies as well as textures can be digitally adapted and changed very easily to the requirements.

In addition, it is possible to produce models in different scales from the same file.

Figure 9 Tactile map in 3D print

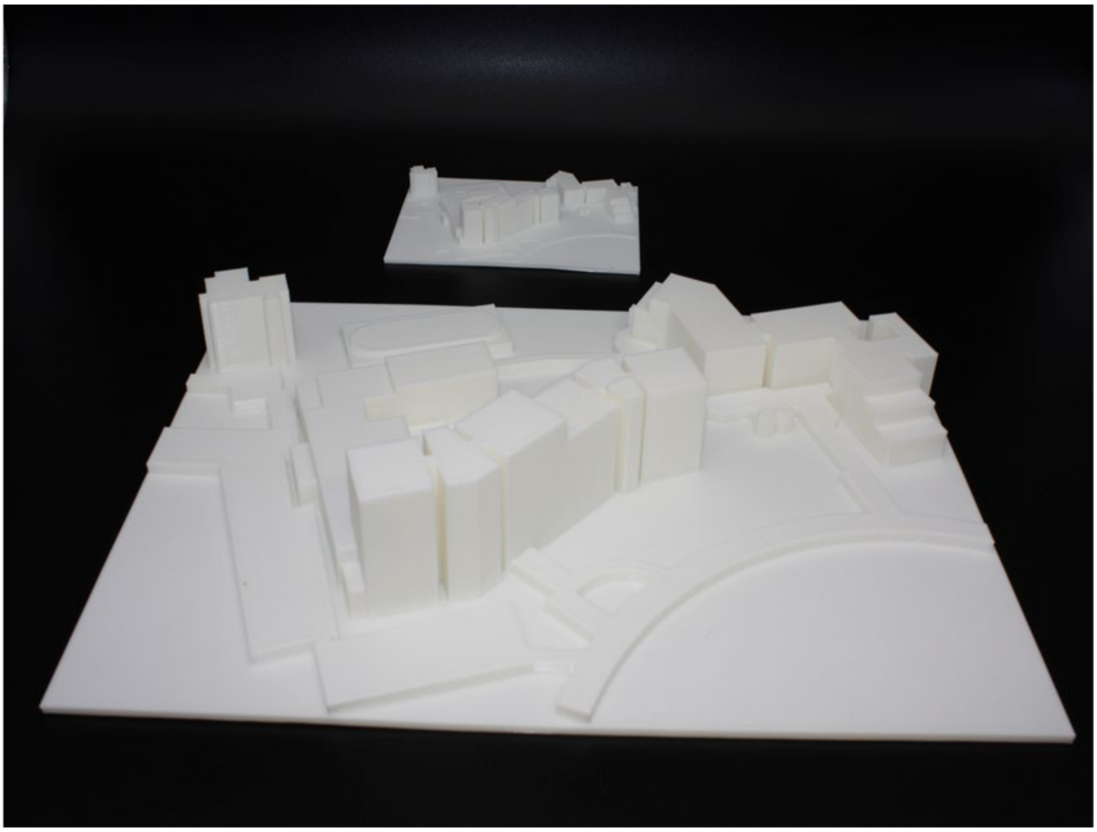

Figure 10 3D model from the same floor plan of the previous figure

Another advantage of 3D printing is that it allows for the production of models from different materials. Flexible and hard materials can be combined on one model to obtain differentiated tactile impressions. This can be advantageous for medical models. It is also possible to produce models in different contrasting colours. This is particularly beneficial for people with severe visual impairments who have some remaining vision.

Tactile site plans for orientation can also be created very easily and inexpensively from digital maps such as OpenStreetmap or available apps.

Figure 11 Tactile models of cell structures

In this way, tactile details can be represented even in smaller models, which are not achievable for the other production methods.

The comparatively simple possibility of creating 3D models also facilitates the creation of individual solutions with tactile elements. Due to the small number of units, this could not be realised cost-effectively by commercial manufacturers.

Figure 12 Examples door signs with Braille

In the context of tactile teaching media for blind people, individual solutions for training Braille were often found. In many cases, these developments had to be produced by hand from materials such as wood or cardboard. These materials are difficult to work with and sometimes impossible to clean. With 3D printing, there are hardly any limits to the design and the choice of plastic materials.

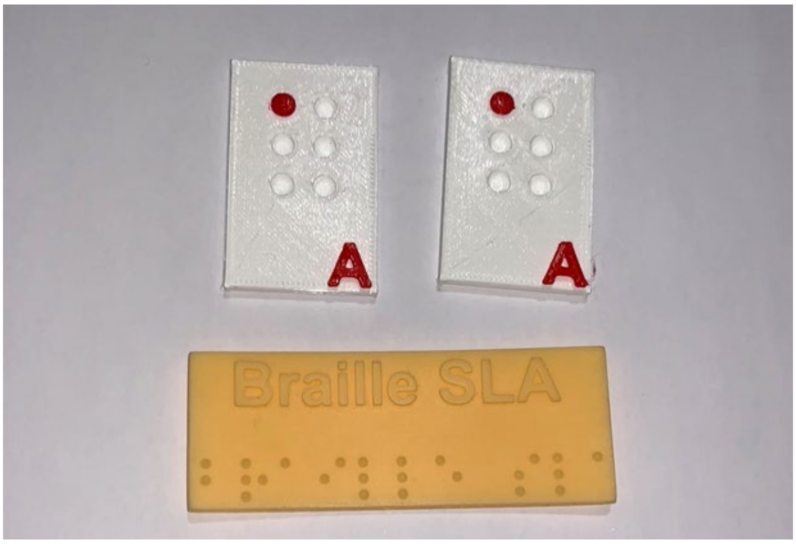

Figure 13 Example Braille teaching tabs

2.3 Required ressources

For the production of tactile teaching materials, at least one suitable 3D printer is needed. Fused deposit modelling (FDM) printers and stereolithography printers (SLA) are already suitable for the production of tactile teaching materials.

These machines can be purchased for as little as €650 in order to produce components of a usable size and quality. In general, the larger the installation space, the more expensive the printer.

The corresponding printer technology will be explained in chapter 3.

Although the printer hardware ultimately produces the models, the required software is just as important.

The starting point for 3D printing is a file that conforms to the STL interface. STL stands for Stereo Lithography or Standard Triangulation/Tesselation Language. The STL format describes the surface of 3D bodies with the help of triangular facets and is thus mathematically structured.

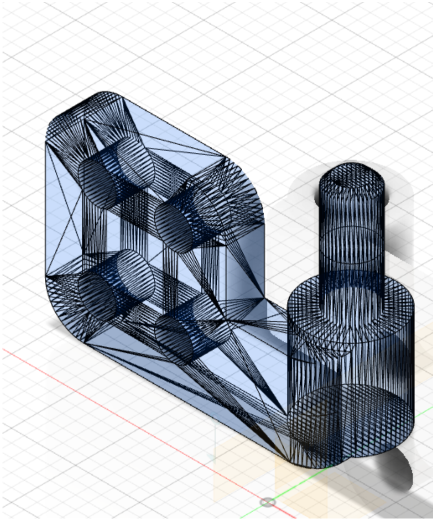

Figure 14 Triangular facets of an STL file

Such an STL file can be obtained in various ways:

1. Getting the file from an available database, also called a repository. Well-known repositories are e.g. Thingiverse, MyMiniFactory, Cults,
2. Constructing the model with a CAD software and exporting the construction as an STL file.
3. Capturing a body with a 3D scanner.

This STL file is used to generate a file that can be read by the 3D printer. This file contains device-specific parameters that allow the model to be built up layer by layer. This is done with programmes that are usually supplied with the devices and are known as "slicers". Well-known products are e.g.: Cura, Simplify3D or Repetier Host.

Given the very specific task of producing tactile teaching materials, it is inevitable that many models will have to be constructed by ourselves using a suitable CAD software.

A well-known open source application is FreeCad. This software is very comprehensive and powerful. However, it is not focused on additive manufacturing.

The browser-based application Thinkercad from Autodesk constitues a simple solution. However, it is not suitable for more complex designs.

For our project we use the software Autodesk Fusion360. This software offers special features for additive manufacturing and is available for educational institutions and students with a free licence.

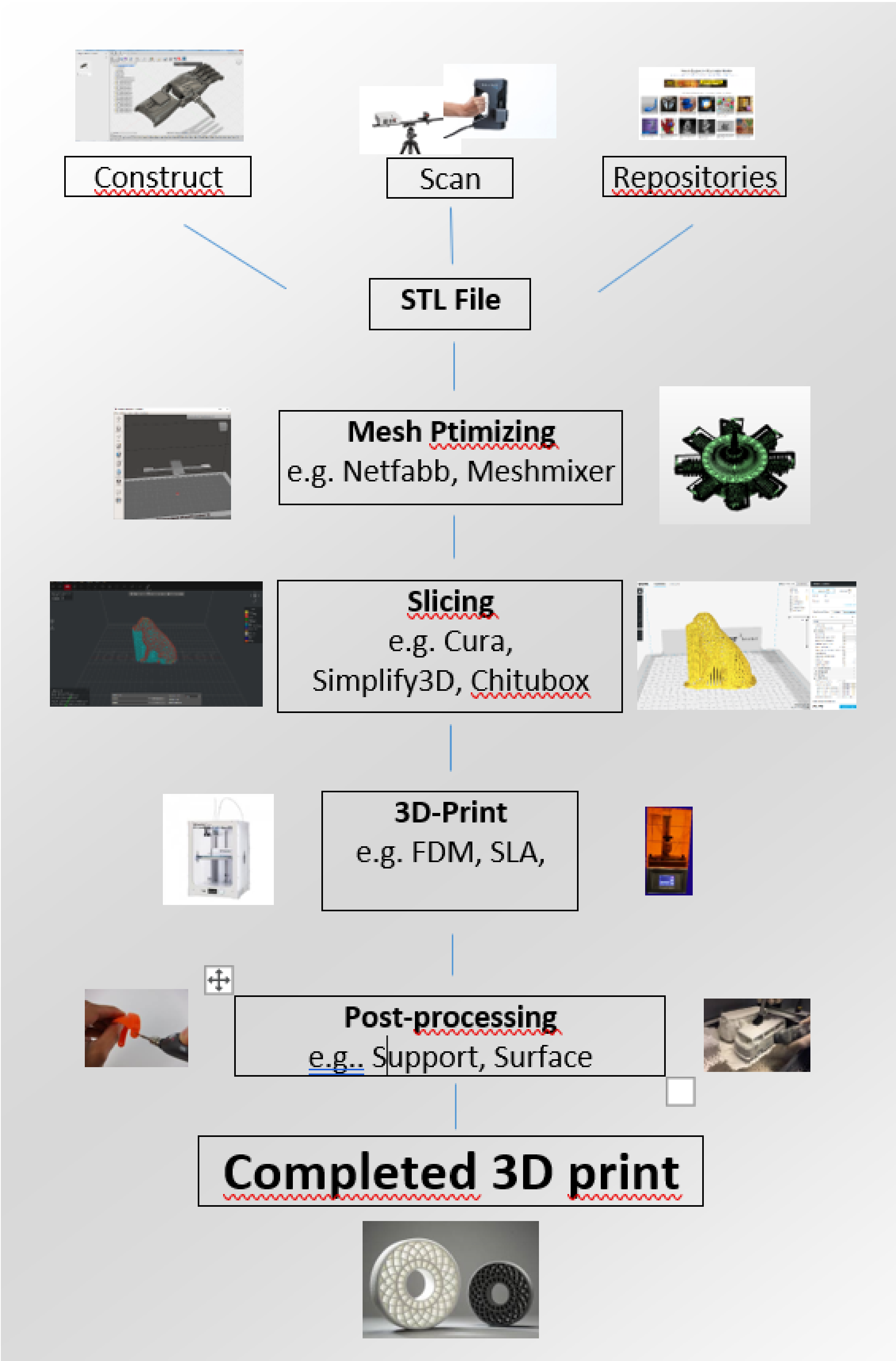

Figure 15 The path to a 3D print

2.4 Advantages and disadvantages of the different methods to obtain design files

2.4.1 Files from repositories

The easiest way is, of course, to obtain finished and suitable design files from repositories. These only need to be converted for the 3D printer and then produced.

In fact, there are already many files for the target group and these may also meet the requirements. However, it is almost always problematic if Braille is part of the design. Since many of these files, which are stored in repositories, originate from the English-speaking world, they cannot be used without restrictions.

In addition, the finished design files, which are usually saved as STL files, can only be edited to a limited extent.

2.4.2 With CAD programs self-designed files

The construction of own models is certainly the most time-consuming solution, as not only the time for the construction, but also various tests of the optimum print have to be taken into account. Own designs require a certain amount of user knowledge. However, experience teaches that only this approach offers individual and optimal solutions.

2.4.3 Re-design with 3D scanner

Another method of obtaining usable STL files is the use of 3D scanners. However, the prerequisite is the existence of a suitable three-dimensional template and a 3D scanner, or a digital camera and suitable photogrammetry software. Meanwhile, suitable apps for smartphones and tablets are also available.

Yet, it is deceptive to believe that a 3D scan can be used directly without post-processing. In almost all cases, errors in the scanned model must be corrected with correction programmes such as Autodesk Meshmixer.

Furthermore, it should be noted that even simple 3D scanners or suitable smartphones or tablets can exceed the price of a 3D printer.

3 Introduction to FDM and SLA 3D printing technology

3D printers that use fused deposit modelling (FDM), stereolithography (SLA) or digital light processing (DLP) are suitable for the production of tactile teaching materials. Efficient devices that can achieve good results are available for under €1000.

Due to the short innovation cycles, specific manufacturers and model types are not considered here. This chapter essentially describes the standardised assemblies, operating elements and materials. The basic and model-independent operating steps are also explained.

The exact operation of the 3D printers must be taken from the enclosed operating instructions and the corresponding safety instructions.

3.1 Construction and functionality of FDM printers

In simple terms, the FDM process works like a hot glue gun, which is used to join several layers of adhesive strands together.

The FDM process uses strands of plastic with a diameter of 2.85 or 1.75mm. The generic term for these plastics is "filament" and is independent of the plastic or diameter used.

The filament is fed into an assembly called "extruder" by a stepper motor. There are different types of extruders. However, they all have a heating element in which the filament is brought to temperature. The correct temperature is controlled by a thermal sensor (Thermistor). The filament is pressed through the nozzle thanks to the continuous transport by means of a stepper motor. As a standard, nozzles with a 0.4 mm diameter bore are used. However, the filament thickness is considerably less and can be as thin as 0.05mm. The extruder is movable and applies the melted filament layer by layer to the build plate.

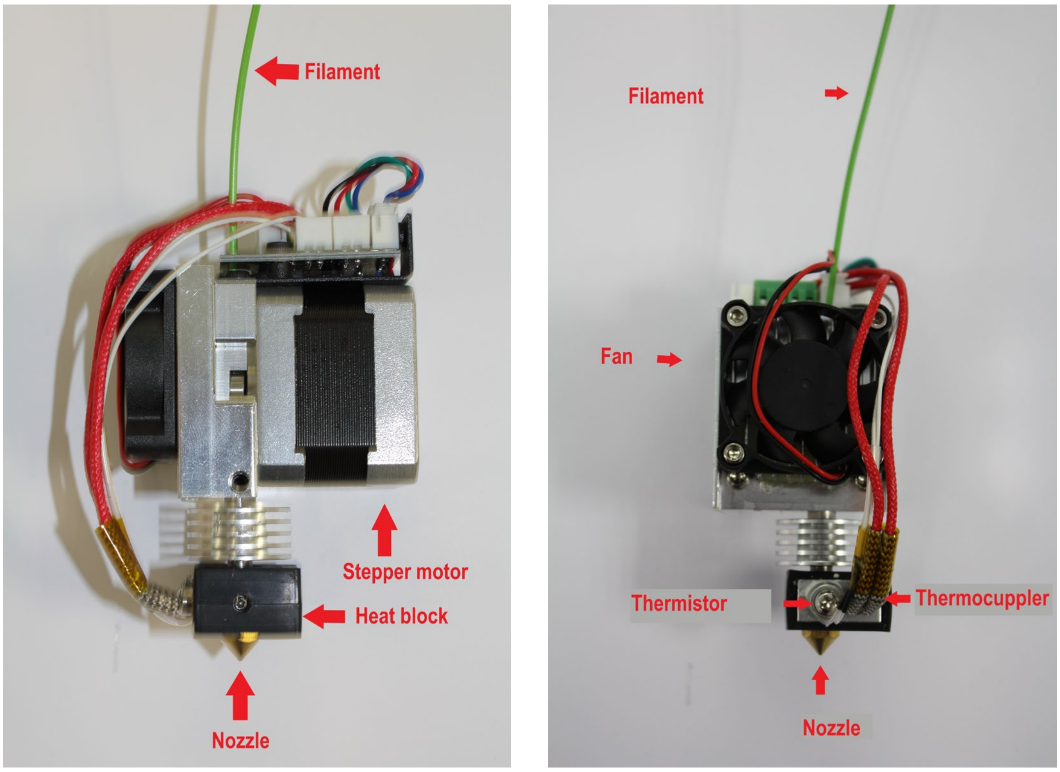

Figure 16 Structure of an extruder left: side view, right: front view

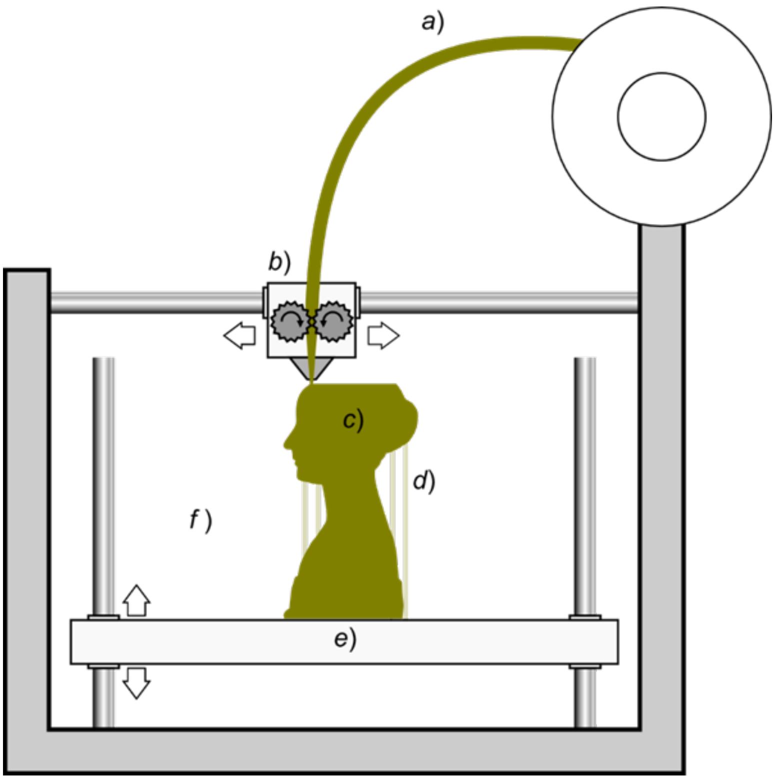

Figure 17 Functionality of an FDM printer ([Scopigno R.,et.al]., 2017)

Schematic representation of estrusion deposition; a filament **a)** of plastic material is fed through a heated moving head **b)** that melts and extrudes it depositing it, layer after layer, in the desired shape **c)**. A moving platform **e)** lowers after each layer is deposited. For this kind of technology additional vertical support structures **d)** are needed to sustain overhanging parts. (*Wikipedia 2021)*

3D printers have their own control electronics. For many devices, this is based on the single-board architecture Arduino. The operating system is mainly the open source Marlin operating system. The open hardware and software structure allow all manufacturers to adapt the systems to their printers without having to pay licence fees. Of course, this also has a very positive effect on the price of the printers.

USB sticks and/or SD memory cards are used as storage media. Increasingly, inexpensive devices are also being equipped with a LAN or WLAN interface for transferring print files directly from the PC to the 3D printer. These interfaces also make it possible to control the 3D printer via the Internet. Popular controller applications are, for example, OctoPrint or AstroPrint.

3.1.1 Filaments

If the FDM printer does not have a heated build plate, the only choice of material is usually polyactide (PLA) and other filaments based on this basic material. PLA is, however, quite sufficient for the production of tactile teaching materials. It has many advantages, but also some disadvantages.

Advantages

+ Easy to handle
+ Wide range of colours
+ UV resistant
+ High stability
+ Biomaterial-based raw material
+ Easy to clean with water or alcohol
+ No odour during processing
+ Non-toxic surface

Disadvantages

- Temperature resistant only up to 55°C
- Lower shock resistance

If the 3D printer has a heated print bed, other filaments such as ABS or PETG can also be processed, which compensates the disadvantages of PLA. However, processing these materials is somewhat more difficult and requires some experience from the operator. In addition, these materials are printed at higher temperatures, which the extruder can generate permanently.

3.1.2 Required tools

The most important tools for making the first components are:

1. tweezers to remove filament residues from the nozzle
2. side cutters to separate the filament
3. spatula to loosen the component from the building plate

Figure 18 Most important tools

Other tools may be useful for finishing the components. These are:

1. tinker's knife for removing support material and material overhangs
2. deburrer
3. plastic glue
4. acrylic paint and primer

3.1.3 Required safety equipment

Although working with FDM printers is relatively unproblematic, the following personal protective equipment (PPE) is required:

1. FFP2 mask when working close to the printer (e.g.: loading the filament, checking the pressure) to avoid inhaling emissions from the heated filament,
2. safety goggles when reworking the component or cleaning the nozzle,
3. cut-resistant gloves for reworking the components with cutters.

3.2 Construction and functionality of SLA printers

The design of SLA printers is much simpler than that of FDM printers in terms of the number of moving assemblies.

Essentially, the printer consists of a system unit that contains the necessary electronics, exposure unit and operating elements. Above this system unit there is a threaded spindle that holds the build platform in the Z-axis. Directly on top of the system unit is the tank or VAT, which holds the liquid photopolymer (also called resin). These containers have a transparent bottom through which the exposure and curing is carried out by UV light or laser.

To protect the resin from light during operation, the upper unit is closed with a UV light filtering cover.

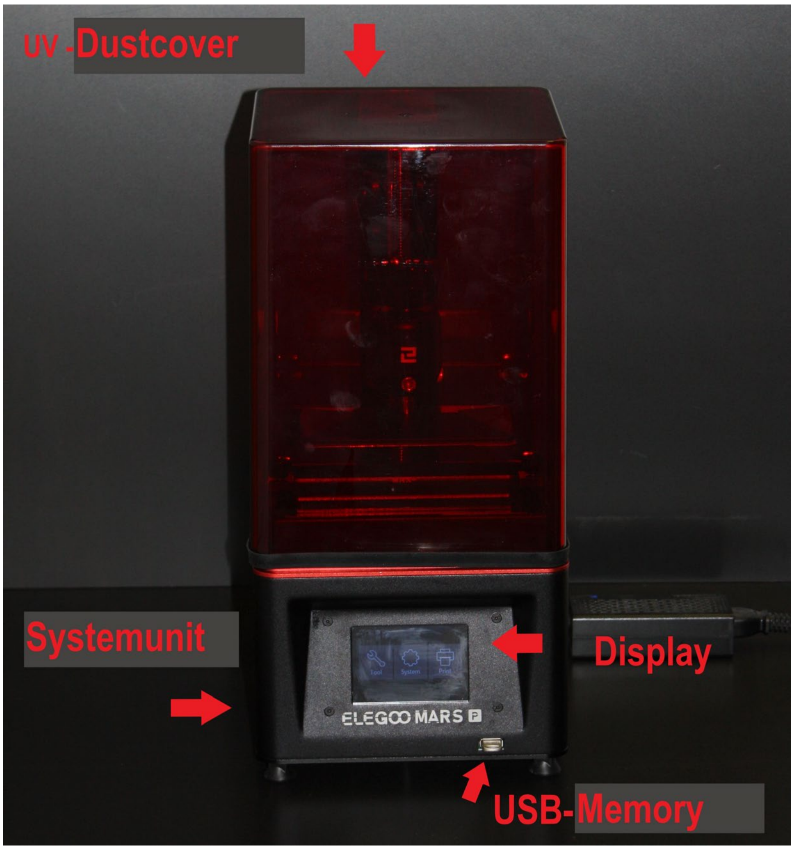

Figure 19 SLA printer assembly with cover

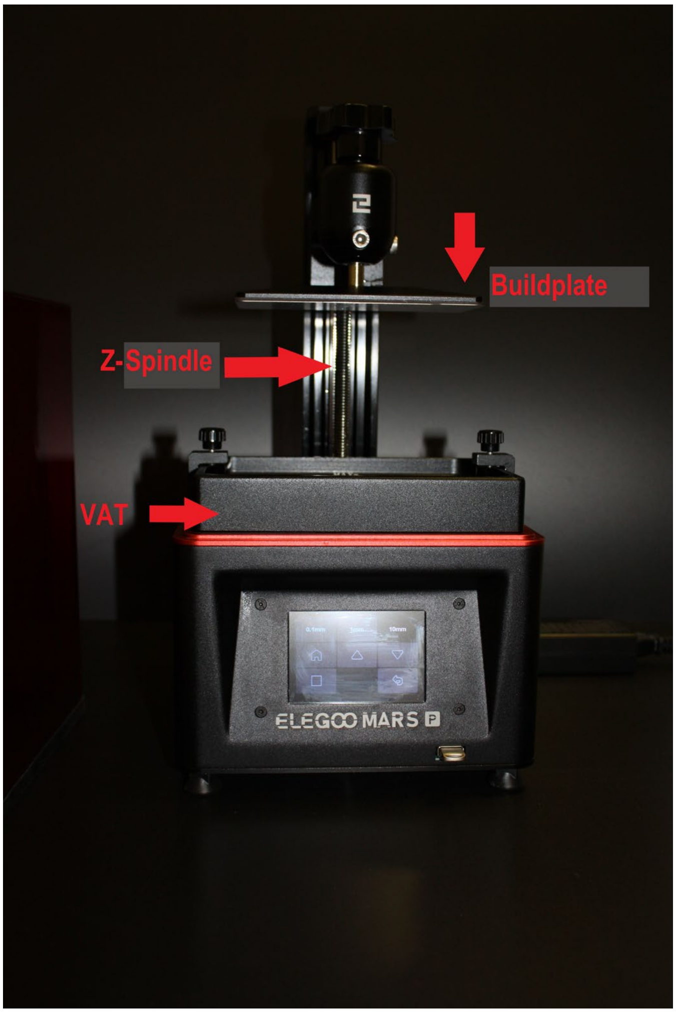

Figure 20 SLA printer without cover

The layer thickness of SLA printers can range from 0.01 to 0.05 mm. After curing, these layers are usually not visible to the naked eye. The surface is smooth and therefore very suitable for braille.

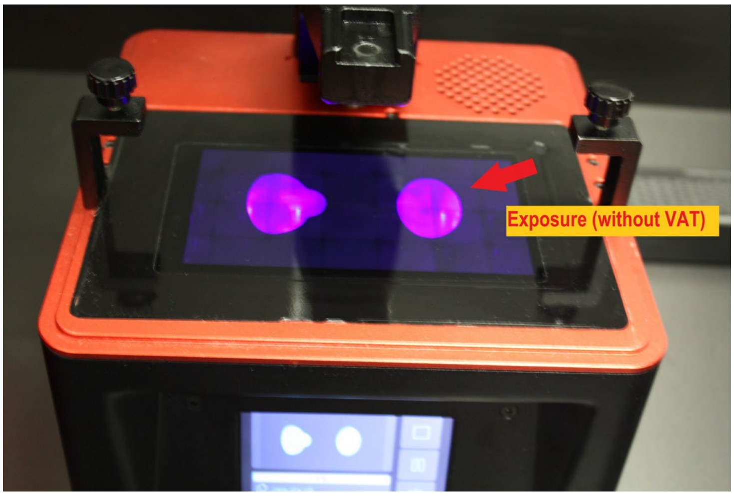

Figure 21 Exposure phase in SLA printing. VAT was taken off for better visualisation

The printing process is easy to describe: The build plate is submerged in the tank for each layer. Then, it is exposed to light and the resin layer is hardened and adheres to the previously generated layer. The distance between the transparent base must be adjusted with precision, otherwise there will be insufficient adhesion to the build plate.

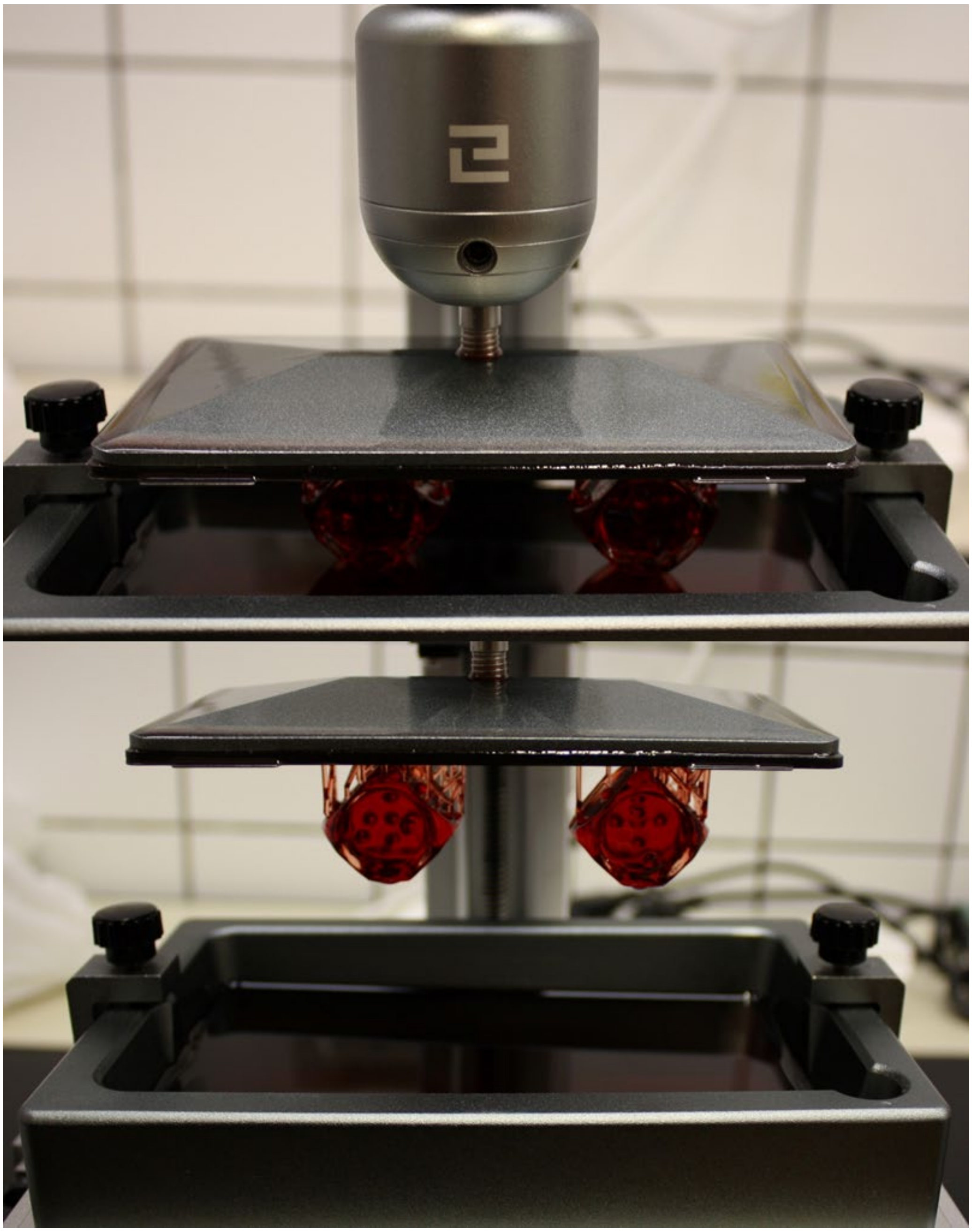

Figure 22 SLA print process

SLA printers also have memory interfaces. USB sticks are often used and some low-cost SLA printers also have LAN and/or WLAN interfaces.

In contrast to FDM printing, the SLA process requires significantly more materials and tools for post-processing.

The components adhering to the building board must first be cleaned in an isopropanol bath (recommended 99%). After this cleaning process, the model must dry.

After cleaning the workpiece, the unused resin must be filled back into the bottle via a varnish filter if no prints are made for a longer period of time.
The VAT must then also be thoroughly cleaned with isopropanol.

Since the material is not fully cured yet, the component must be cured in a UV curing chamber. Finally, the component should be sealed with a varnish with UV protection. This prevents the component from yellowing when exposed to light.

It becomes quite apparent that this manufacturing process requires much more labour, material and space than the FDM process. In addition, the emissions from the isopropanol and the resin require a well-ventilated workspace, or even better, an exhaust air system.

Figure 23 SLA cleaning station with three cleaning baths

Figure 24 UV curing chamber of the XYZprinting company

3.2.1 Resins

All printer manufacturers offer suitable resins for their devices. These are specified for a defined wavelength range that the printer must perform. The standard resins are available in different colours as well as in transparent versions. Different resins may require different exposure times per layer. This data can be found in the corresponding data sheets of the various manufacturers.

There are also third-party manufacturers who produce special resins that compensate for the disadvantages mentioned in chapter 3.3. In addition, these resins meet special requirements from the medical and dental sector. Fortunately, these special resins are now also available for low-cost SLA printers. While these were previously only available for devices from €3000, the range of products offered by the manufacturers proves that the lower-priced devices are becoming more and more important in professional applications.

However, it should not be forgotten that these special resins often cost 8-10 times more than the standard resins.

3.2.2 Required tools

To remove the components from the build plate and clean the build plate as well as the resin tanks/VAT, you need the following tools and materials:

- Plastic spatula
- Isopropanol 99% in bottle and spray bottle
- Paper towels
- At least one plastic tub that can hold the build plate used and is filled with isopropanol to clean the component.
-

For removing the support material and finishing the component:
- Pointed tweezers
- Tinker's knife or scalpel
- Side cutters
- 500 grit sandpaper

3.2.3 Required safety equipment

In general, the required protective equipment can be found in the safety data sheets for the printer and the used resins.

However, the following personal protective equipment (PPE) is generally recommended when handling SLA printers:

- FFP2 mask (or even better FFP3 masks) to be protected from the emissions of the resin and isopropanol,
- Disposable gloves
- Safety goggles
- Work or lab coat
- Cut-resistant gloves

3.3 Comparison of SLA and FDM printing methods for creating tactile teaching materials

When comparing SLA to FDM printing in terms of tactile teaching materials, there are two aspects to consider first:

1. The surface of objects printed with an SLA printer is much smoother than when using an FDM printer.
2. The material is more brittle and can only be used to a limited extent for functional models with mechanical loads.
3. More filigree and smaller details can be printed with SLA printers.
4. The cured material is not food-safe and therefore **not suitable** as learning material **for children**.

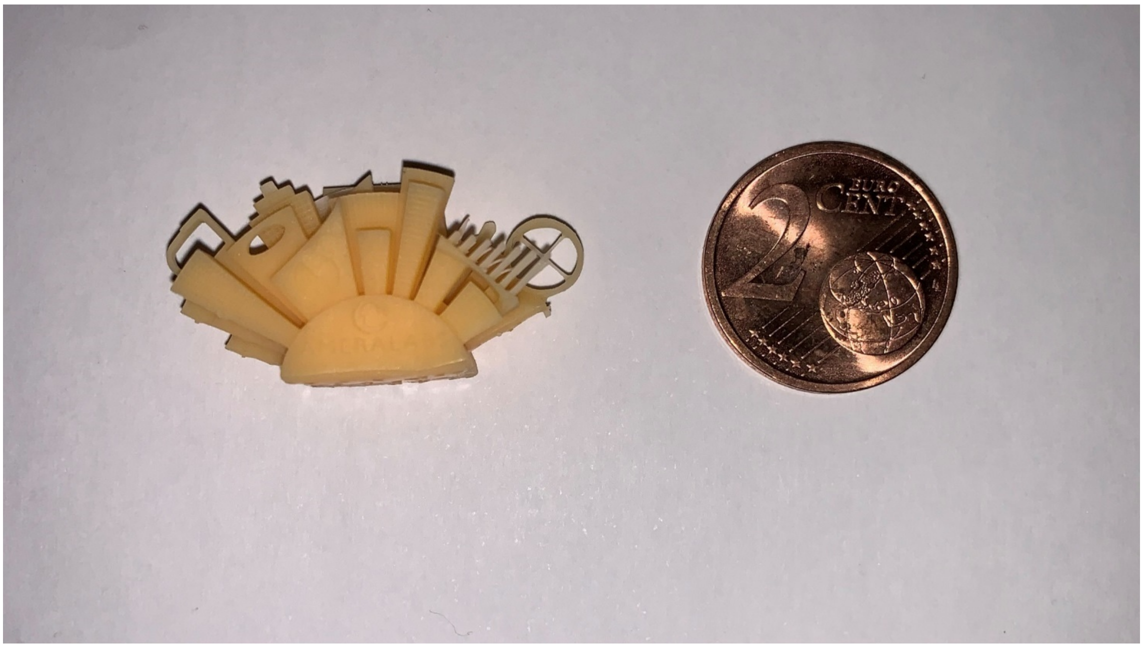

Figure 25 Detail representation with SLA printing

4 Re-Design with 3D scanner

4.1 Example of an affordable 3D scan solution

The production of 3D scans is becoming increasingly attractive with mobile devices, as the technology used here is becoming more and more technically sophisticated and better.

One example of a low-cost smartphone and tablet app is QLONE (www.qlone.pro). The price at the time of release is around €45. The app is available for iOS and Android. The solution delivers good and easy-to-use results.

QLONE is intended for models up to 15 cm³. It requires a grid that can be downloaded from the manufacturer's homepage. This grid can be printed on different paper sizes.

The model to be scanned must then be positioned centred on this grid.

Figure 26 QLONE grid with model

The app offers the option of saving the scanned models to a database and sending them as STL files via e-mail.

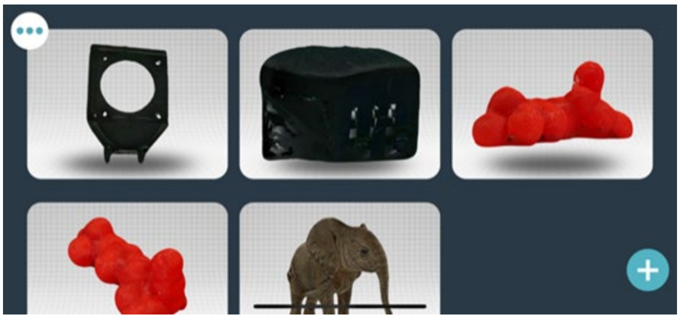

Figure 27 Screenshot iOS device with scanned items in QLONE

When using the scanner app, the software supports the user to optimise the scan. A virtual dome is displayed above the model. The user must then capture the entire model from a 360° angle several times with the camera. The correctly captured areas are then displayed in a transparent manner. Once the model has been completely captured, the result is converted to an STL file.

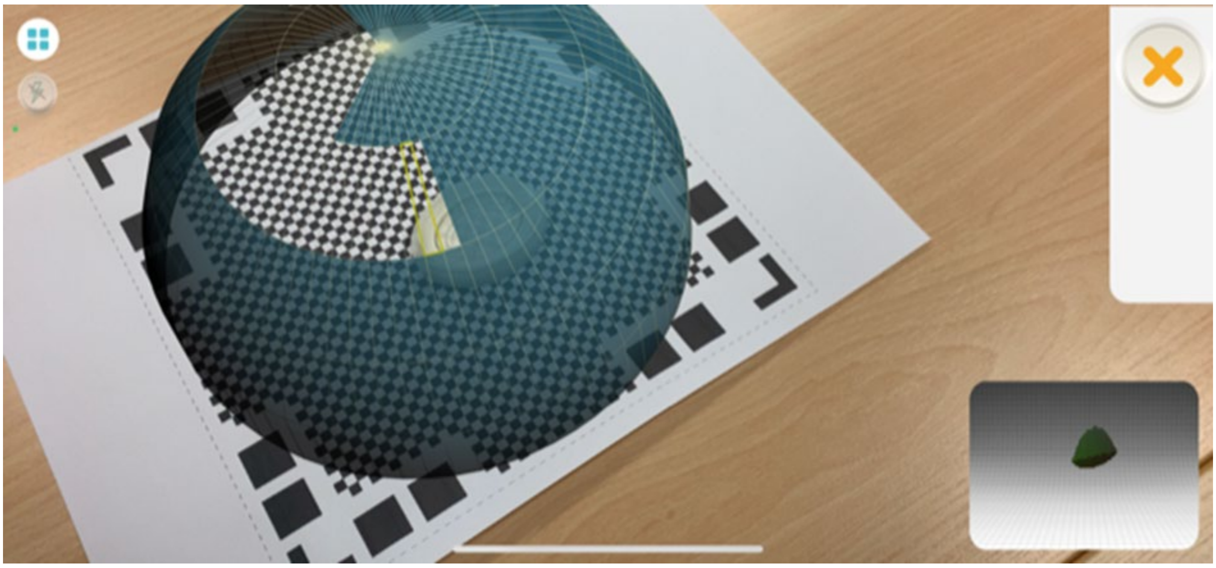

Figure 28 Active scanning process. The half-dome of scan that has been completed are visible

4.2 Structured light scanner

With structured light scanners, changing stripes are projected onto the object to be scanned using a VGA projector. The object is rotated around 360°. The varying stripe patterns enable the special software to calculate the surface. Dark or transparent objects often provide no or insufficient reflection. Therefore, they must either be sprayed with chalk spray or covered with special reflective dots.

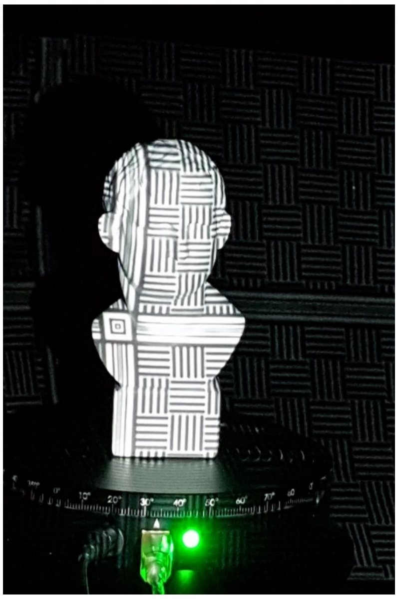

Figure 29 Projection of structured light pattern

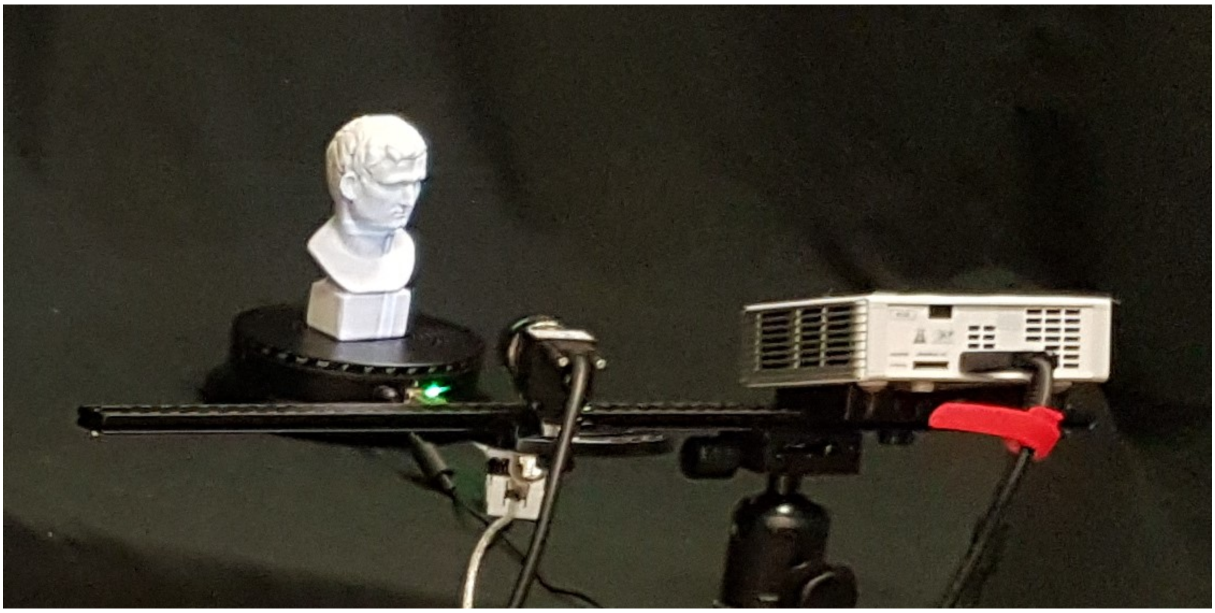

Figure 30 Structured light scanner – VGA beamer and camera on tripod

4.3 Image-based methods

Image-based methods are based on the principle of photogrammetry. Here, an object is photographed from different positions and assembled as a 3D model using software. Today, drones are used to scan particularly large models or buildings.

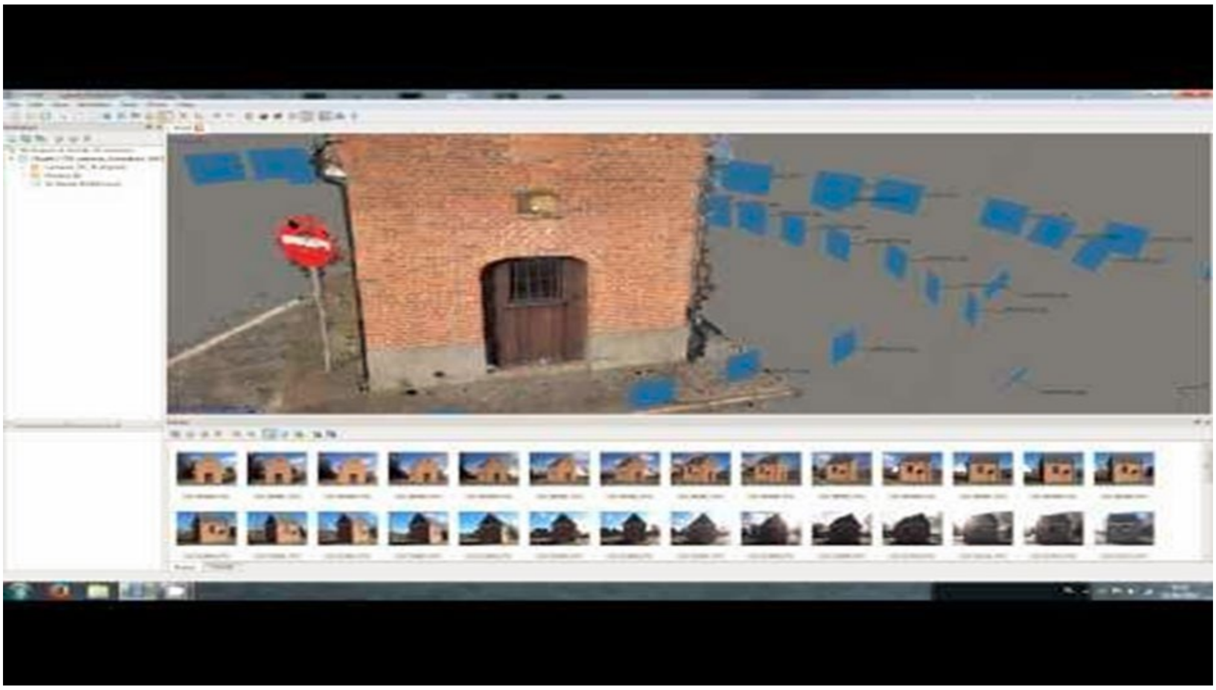

Figure 31 Photogrammetry software 3DZephyr

Glossary

3D pen (3Doodler)
A 3D pen is a pen that extrudes liquid plastic from an extruder that is integrated into the pen tip. The speed and quantity of the extruded plastic can be controlled by the user in most cases. Once the liquid plastic has been extruded, it begins to dry quickly in the air. In this way, 3-dimensional objects can be drawn from plastic. If the filament-shaped plastic (filament) is changed to a different colour during use, multi-coloured objects can also be created with a 3D pen. A 3D pen with a dual extruder is not known at this time.

3D pens first gained worldwide attention when the first prototype of the 3Doodler was presented by Maxwell Bogue and Peter Dilworth in early 2012. The idea for the 3D pen was born from a faulty 3D print. Both inventors started a crowd-funding campaign on Kickstarter under the company "WobbleWorks" with the goal of reaching $30,000. The funding goal was reached after just a few hours. On 25.03.2013, the end of the funding round, "WobbleWorks" collected more than $2 million for its 3Doodler. In January 2015, the successor 3Doodler 2.0 was released. Since then, numerous new models from a wide range of manufacturers have appeared on the market. .[1]

3D selfie
A 3D selfie is a self-portrait taken with a 3D printer. The result is a printed figure of one or more persons, which is printed on the basis of a previously created photo. An important intermediate step is to convert the photo into a CAD file before 3D printing. This requires 3D software that constructs a 3D model from the 2D image. The data is then sent to a 3D printer that builds the selfie layer by layer.[2]

ABS
ABS filament for 3D printers (acrylonitrile butadiene styrene) is a synthetic terpolymer and belongs to the amorphous thermoplastics. In the FDM process of 3D printing, ABS filament is equally important as PLA filament, but differs in certain points.
ABS filament offers high heat resistance and a hard, scratch-resistant surface. Due to its many positive properties, ABS plastic is used in many household and consumer products beyond the 3D printer.
ABS filament is slightly more difficult to process than PLA filament. The biggest difficulty is the strong tendency to warp – here a heated printing plate and/or a closed installation space of the printer helps.
In order to prevent premature detachment of the print from the printing plate, the right printing base is crucial. In this case, additional aids such as permanent printing plates or adhesive spray are available.[3]

---

[1] https://www.3d-grenzenlos.de/glossar/3d-stift/ (07.05.19)
[2] https://www.3d-grenzenlos.de/glossar/3d-selfie/ (07.05.19)
[3] https://www.filamentworld.de/produkt-kategorie/abs-filament-3d-drucker/ (07.05.19)

Autodesk Fusion 360
CAD Software
- Cloudbased
- For Mac and PC

Buildplate, print bed, heating bed
The print bed is one of the most important components of a 3D printer. This refers to the area on which the objects are built up layer by layer. Depending on the type of printer, the print bed is stationary or moves horizontally or vertically. The print bed extremely important for the print result. The first layer of the object to be printed must adhere well to the print bed. On the other hand, the object must be easy to remove from the print bed after 3D printing. These requirements were often not met by simple 3D printers in the early years of low-budget 3D printers.
With the further development and optimisation of the devices in recent years, significantly better print beds are now being built into the devices or can be retrofitted. Heatable print beds, i.e. heatbeds, have also played a significant role in this. Well-known brands for pressure beds include BuildTak, Aptotec and SainSmart. [4]

Cura
Slicing Software

Digital Light Processing (DLP)
Digital Light Processing is another resin-based 3D printing technology. It is used by DLP 3D printers. Here, the object is created by a digital light processor that serves as a UV light source and solidifies photoreactive resin. The projector built into the 3D printer can be a video projector, for example, whose resolution also determines the 3D printing resolution. Due to the light projector, the printing speed of DLP 3D printers is usually higher than with other 3D printing processes. The light projector hardens the resin layer by layer.[5]
The DLP process is very similar to the SLA process and is based on light-induced curing of photoreactive resins. With SLA printers, however, a laser is usually used. In this tutorial, both processes are simply referred to as the SLA process.

Direct Manufacturing
Components with characteristics of an end product

Direct/RapidTooling
Additive manufacturing of tool inserts, tools, gauges and moulds

Extruder, Dual Extruder,
The extruder is the component on a 3D printer that forces the melted filament out of the nozzle of the machine. A coil rotates in a tube and transports the plastic filament – or any other print material – onto the print bed. The extruder is attached to the

[4] https://www.3d-grenzenlos.de/glossar/druckbett/ (07.05.19)
[5] https://www.3d-grenzenlos.de/3d-druckverfahren/photopolymerisation/digital-light-processing-dlp/

motion rails (or arms, in the case of a delta 3D printer) of the 3D printer and rotates on the x, y and z axes. In the process, the printing material is evenly pressed out of the extruder and the object to be printed is thus built up layer by layer.
The extruder is an essential component of extrusion, the process in which malleable materials such as plastics, ceramics, biomass, foodstuffs and also metals are continuously pressed out of a shaping opening under pressure.[6]

Filament
In 3D printing, filament is understood to be thread-like plastic strands that build up the object to be printed layer by layer with the help of extrusion. Filaments are used as printing material in Fused Deposition Modelling (FDM)/ Fused Filament Fabrication (FFF). The dominant filaments on the market are ABS and PLA. PLA is more suitable for beginners because it is easier to print. With ABS print objects, the surface can be smoothed with acetone, for example, which leads to very attractive results. Problems such as the "warp effect" do not occur with PLA.
For some years now, more and more flexible filaments have been available on the market. These are thermoplastic elastomer (TPE), i.e. plastic that can withstand loads such as tension or pressure, deform and return to their original shape when the load is released. As an example, consider a rubber ball.[7]

Fused Deposition Modelling (FDM), Fused Filament Fabrication (FFF)
FDM and FFF processes belong to the extrusion processes, i.e. processes during which a thermoplastic material heated to a doughy state, is pressed – preferably continuously – through one or more nozzles and the resulting strand is deposited in a defined manner on a substrate. The energy in the material is sufficient to melt the substrate in such a way that a permanent bond is created after cooling.[8]

G-Code
In the context of 3D printing, G-code refers to print commands that are generated by software to communicate commands in the form of instructions to a 3D printer. The G-code can therefore be understood as a language between the computer/CAD software and the 3D printer.
There are different ways to prepare G-codes for use in 3D printing. In slicing, for example, there is a code for each layer. Or one works with a library that makes the printing of complicated models more controllable. The G-codes can also be written by the maker and can even be changed during the printing process. Resourceful makers also use G-codes to repair their 3D printers. This is always the case when commands are needed that the control software does not contain. .[9]

IDEX
IDEX refers to dual extruders that can print independently of each other. With IDEX it is possible to print one part with two filaments or to print two smaller parts at the same time with one of the extruders.

[6] https://www.3d-grenzenlos.de/glossar/extruder/ (07.05.19)
[7] https://www.3d-grenzenlos.de/glossar/filament/ (07.05.19)
[8] Gebhardt, Andreas: Additive Fertigungsverfahren, Carl Hanser Verlag, München, 2016, S.259
[9] https://www.3d-grenzenlos.de/glossar/g-code/ (07.05.19)

Layer
In 3D printing, a layer is each individual layer with which a 3D printer builds up the object layer by layer. A large number of layers results in a fully layered 3D object. The terms layer size, layer height and layer height are often used in connection with layers. This refers to the height of a single layer with which the 3D printer builds up the object. The layer height depends on the 3D printer used and is one of the elementary product properties for 3D printers.

Levelling
- Aligning the print bed/building platform
- Removing differences between different levels

MeshMixer
Free software for 3D modelling and simple mesh optimisation from Autodesk.

Nozzle
In 3D printing, nozzle refers to the nozzle that is part of the extruder, i.e. the print head. The consumable material, which is also referred to as filament in technical jargon, is pressed through the nozzle and applied layer by layer to the build plate or printing plate. With most 3D printers, the nozzle can be replaced. During the printing process, the nozzle is usually very hot. Depending on the material used, but also depending on the size of the opening, blockages can occur from time to time, which must be removed. At the same time, it will suffer from signs of wear over time and must then be replaced. The opening of the nozzle should be selected according to the material used and the object to be produced.
As a standard, most makers usually resort to nozzles whose opening is 0.4 mm in diameter. The choice of nozzle size can affect both print time and print quality.[10]

PETG
Filament
PETG is the abbreviation for polyethylene terephthalate, modified with glycol. PETG filament is superior to other filaments in many properties. It combines the positive properties of PLA and ABS.
Hence, PETG is very durable, has strong mechanical properties, is flame retardant, resistant to many chemicals and easy to print.
The printing speed for PETG filament varies depending on the printing temperature, the hotter the print head, the faster the 3D printer can print the PETG.[11]

PLA
Filament
Polylactides (PLA) are synthetic polymers that belong to the polyesters. They are used to make plastic that is obtained from regenerative sources (such as corn starch). This makes PLA a biocompatible raw material. 3D printing filament is often

[10] https://www.3d-grenzenlos.de/glossar/nozzle/ (07.05.19)
[11] https://www.filamentworld.de/produkt-kategorie/special-filament/petg-filament (07.05.2019)

not pure PLA, but a so-called PLA blend, whose basic structure is enriched with additives to obtain certain desired properties.[12]

---

[12] https://www.filamentworld.de/3d-druck-wissen/was-ist-pla/ (07.05.2019)

PVA
Filament
Polyvinyl alcohol (PVA or PVOH) is a thermoplastic plastic that is produced as a white to yellowish powder mostly by saponification (hydrolysis) of polyvinyl acetate (PVAC). PVA is water-soluble and therefore well suited as a support material for 3D printing.

Selective Laser Melting (SLM)
Selective laser melting (SLM) is a generative manufacturing process that belongs to the group of beam melting and powder-bed based processes. Selective laser melting is often also referred to as 3D printing and is therefore an additive manufacturing process.
In the SLM process, the material is applied as powder to the base plate and melted with the laser beam. The material solidifies and the base plate is lowered by the layer thickness so that new powder can be applied. 3D software (see also CAD) is used to create the data for the laser beam guidance. The object is then built up by the SLM 3D printer from many individual layers. This layer-by-layer construction is repeated until all layers of powder have been remelted. The shape of the object results from the areas where powder was deposited by the machine and melted by the laser.
At the end of production, the manufactured product is freed from powder residues and is ready for use. In most cases, series materials without binders are used, as these can be pulverised.
With selective laser melting, no (casting) moulds are required, thus creating geometric freedom. The production time is reduced, which leads to lower storage and production costs.

Selective laser sintering (**SLS**)
Selective Laser Sintering is an additive manufacturing (AM) technique that uses a laser as the power source to sinter powdered material. It is similar to selective laser melting and belongs to the powder-bed based processes. SLS and SLM are instantiations of the same concept but differ in technical details. In the SLM process, the aggregate state of the powder is changed by melting, the powder is liquefied and when it cools it becomes solid. In the SLS process, the laser only bonds the powder.

Slicing
To prepare for printing, the object must be optimally aligned on the building platform and divided into height layers. This is called slicing.

Stereolithography (SLA or STL)
In stereolithography, a light-curing liquid plastic (photopolymer), for example synthetic or epoxy resin, is cured in thin layers by a laser. This is done in a bath filled with the basic monomers of the light-sensitive plastic. After each step, the workpiece is lowered a few millimetres into the liquid and returned to a position that is the amount of a layer below the previous one. The liquid plastic is evenly distributed over the previous layer by a wiper. Then a laser, controlled by moving mirrors, moves over the hardening surface on the new layer.[13]

[13] Fastermann, Petra: 3D-Druck/Rapid Prototyping, Springer Verlag, Berlin Heidelberg, 2012, S. 121

STL file format
STL files describe mesh surfaces as lists of geometric features. A body is composed of three triangular surfaces consisting of a normal and 3 axes, which are described by their coordinates. The STL file format provides geometric information for the CAD programmes so that 3D printing can be used to produce three-dimensional objects. [14]

Support
Additionally generated structures to support model parts with overhangs. Without this structure, such parts would collapse.

Tank/VAT
A component of SLA printer. The resin tank is a transparent container located in the middle of the Formlabs 2 3D printer. It is made of a UV-blocking acrylic. The tanks containing the liquid resin can be removed and reinserted very quickly and easily. In addition, the reusable lid makes it possible to stack several tanks that have already been filled with resin. This means that the resin left over after a 3D print can be stored safely and easily outside the Formlabs 2 3D printer. It makes sense to have a resin tank for each type of resin. This way you can decide spontaneously at any time which material you want to work with. The iGo3D recommends that you change the resin tanks after 2-3 litres of resin consumption.
VAT is the term used for the tanks of Digital Light Processing (DLP) printers. Here, the bottom consists of a replaceable transparent film.

Thingiverse
Thingiverse is an online platform for exchanging digital design data (CAD) that can be used for 3D printers, laser cutters, CNC mills and other machines. Thingiverse is one of the world's most popular platforms of the DIY movement. The files uploaded to Thingiverse.com are open source and mainly subject to CC and GPL licences. Most of the files uploaded on Thinigverse are used for repair purposes. Nevertheless, jewellery, decorative items and creative ideas can also be found in countless variations on Thingiverse, and can be printed by anyone at home using a 3D printer, for example.
The owner of Thingiverse is MakerBot. The creators of Thingiverse are MakerBot founders Zach Smith and Bre Pettis. The platform has been online since November 2008 and is available in English. Thingiverse was founded by Zach Smith. [15]

Z-Wobble / Z-Wobble
A Z-Wobble (alternatively spelled Z-Wobble) occurs when lateral forces act on the nut on the threaded rod. This can lead to a rotation of the Z-axis in some 3D printers. As a result, the extruder shifts in both the Y and Z directions.

---
[14] https://www.sculpteo.com/de/glossar/stl-definition-de/ (29.04.2019)
[15] https://www.3d-grenzenlos.de/glossar/thingiverse/ (25.04.2019)

5 List of illustrations

6 Bibliography

Scopigno R., Cignoni P., Pietroni N., Callieri M., Dellepiane M. (2017). "Digital Fabrication Techniques for Cultural Heritage: A Survey". *Computer Graphics Forum* **36** (1): 6–21. DOI:10.1111/cgf.12781. read: 24.03.2021

Wikipedia (2021); 3D printing processes; https://en.wikipedia.org/wiki/3D_printing_processes#Material_extrusion; read: 01.05.2021