PROFESSORSHIP FOR POLYMER ENGINEERING

The Professorship for Polymer Engineering supports higher education in plastics. This is achieved by conducting research, teaching and setting up projects.

This book is the result of the 3D printing project and serves the goal of giving small and medium enterprises insight into the possibilities 3D printing might offer them. It also provides the basic knowledge and tools to get started with 3D printing. For this project 10 cases have been worked out with companies.

Other projects by the professorship are Recycling Rubber, Recycling Composites, Plastics in Machinery, Plastics in Medical Applications and New Materials for 3D printing.

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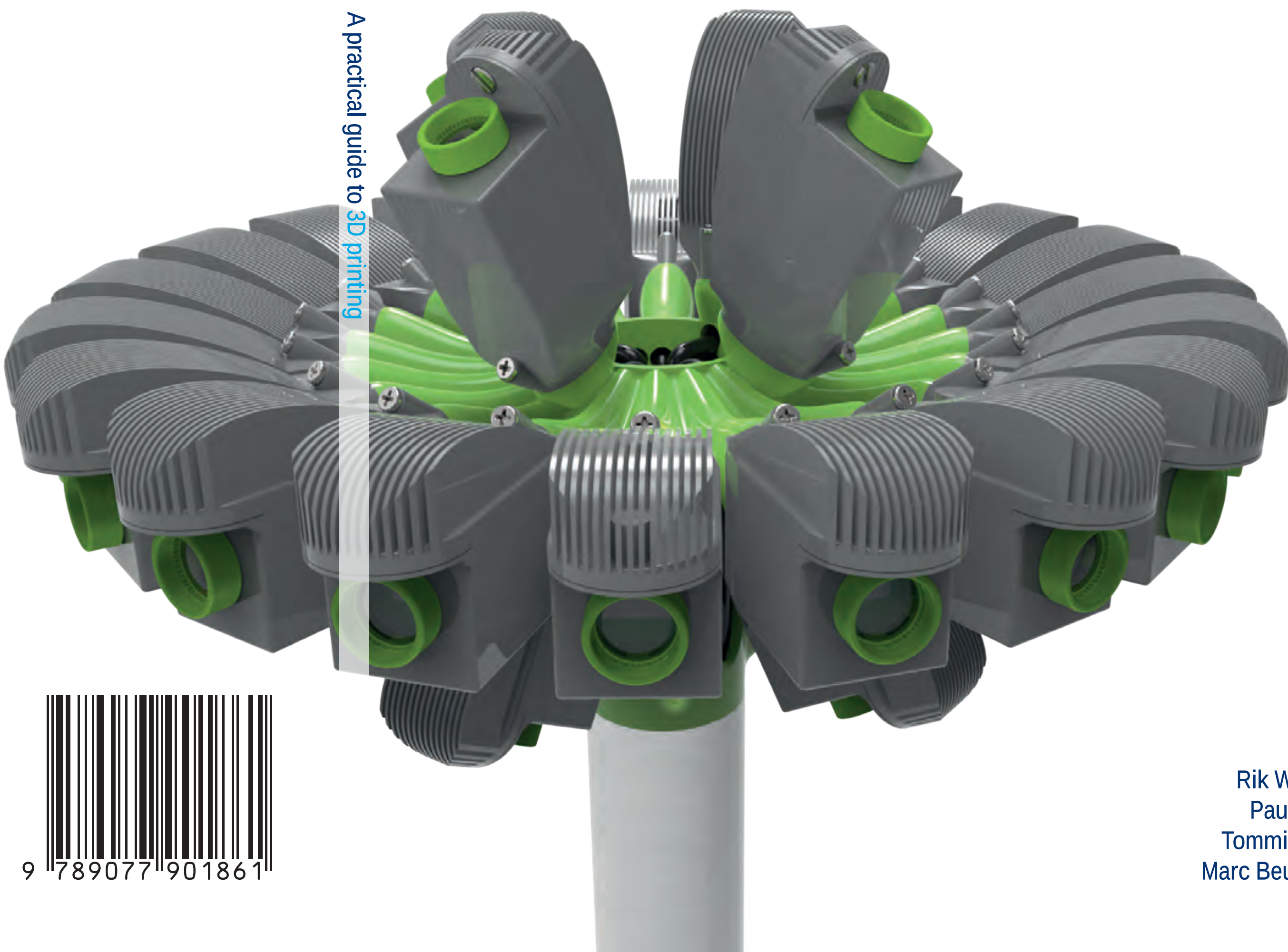
A practical guide to 3D printing

A PRACTICAL GUIDE TO 3D PRINTING

OVERVIEW OF TECHNOLOGIES
AND THEIR APPLICATIONS
IN THE INDUSTRY



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Colophon

Title
A practical guide to 3D printing -
Overview of technologies and their applications in the industry

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This book is a result of a research project on 3D printing, conducted as a collaboration between Windesheim University of Applied Sciences, Stenden University of Applied Sciences, and the companies mentioned throughout this book.

This study was financially supported by Green Polymer Application Centre (GreenPAC).

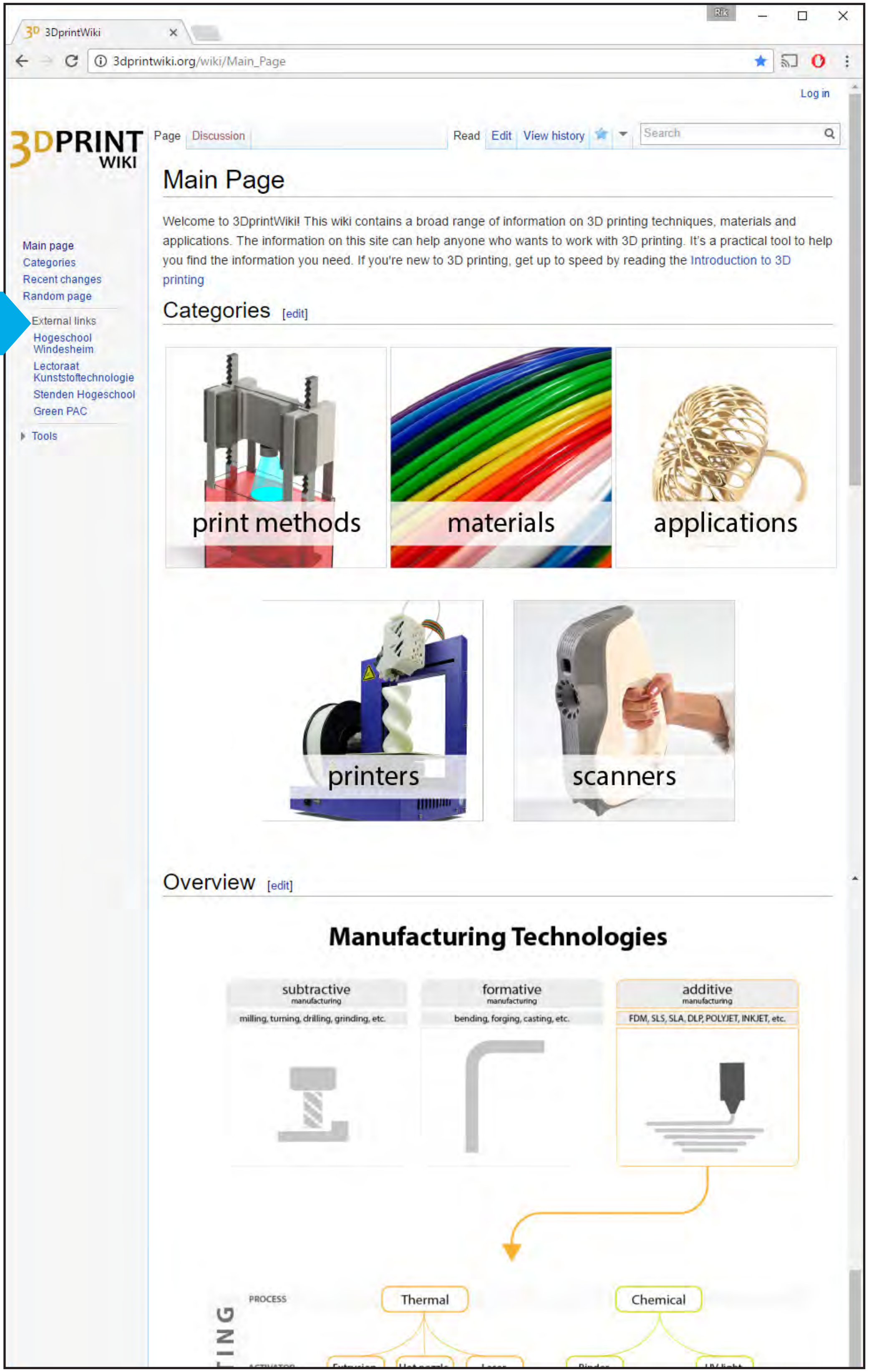
Windesheim Stenden GreenPAC Polymer Application Centre

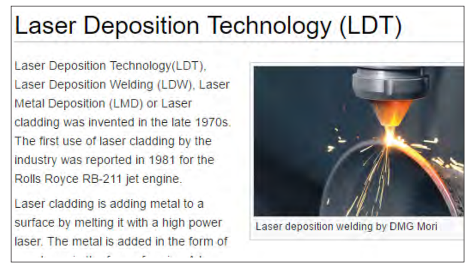
Preface

In 2014 *"Printen in de derde dimensie"* - a booklet on 3D printing and its applications within small and medium enterprises - was published as the result of research conducted by the Professorship for Polymer Engineering. It showed the rapidly growing possibilities resulting from the accelerating technological developments in the area of 3D printing.

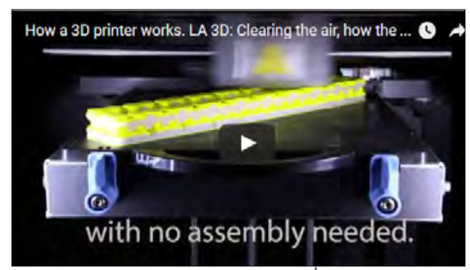
Its success and the ongoing developments made us decide to continue on this path and to create an updated, accessible and easy-to-use catalogue. Because of the rapid and ongoing developments in the area of 3D printing, we decided not only to create this booklet, but to also create a website - 3DprintWiki.org - that contains a range of information on the subject. Whereas this booklet focusses on basic information and example cases of use, the website functions as a live platform and provides more detailed information, including videos, printing methods, materials, decision models and examples.

We will regularly refer to the website using QR codes that can be scanned with any QR scanner App on your smartphone.

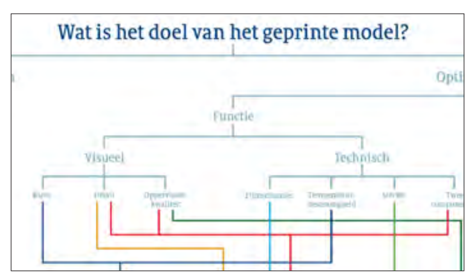




OTHER PRINTING METHODS



EXPLANATORY VIDEO'S



DECISION-MAKING MODELS

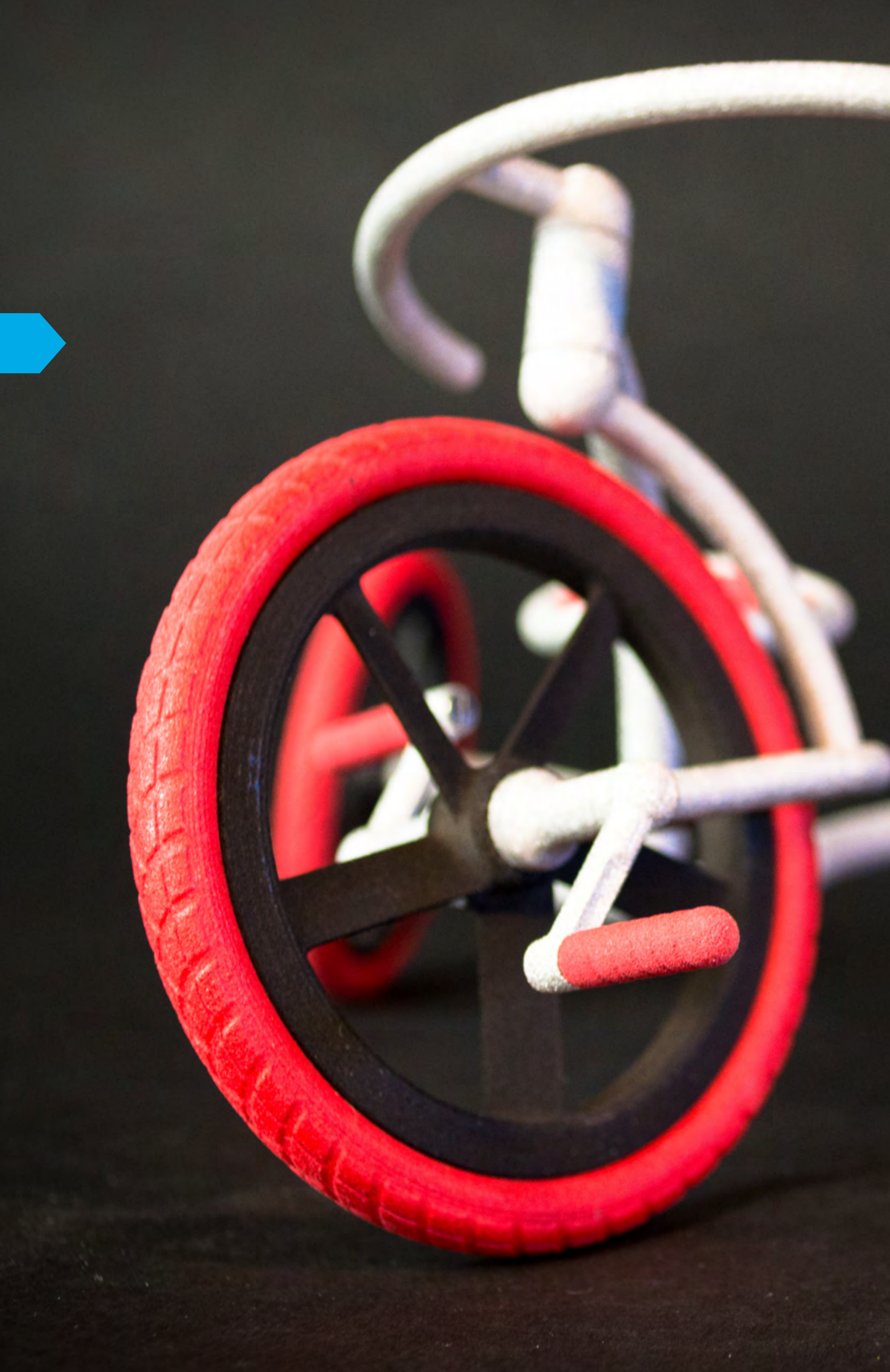
3DprintWiki.org

The goal of the the 3DprintWiki is to create an accessible source of information on 3D printing. It's primarily targeted at SMEs, but can be used by anyone who wants to get involved in 3D printing.

3DprintWiki is a starting point to get to know the area of 3D printing. You can browse through the different methods, materials, applications, printers and scanners, and build up your knowledge on the subject. This website will help you with the first steps, point you in the right direction and show you what is possible with 3D printing. Content can easily be updated to keep track of new developments.

Scan the QR-codes with any QR-code scanner App on your smartphone to get more information on the subject of that page.

3DPRINT WIKI



Contents

Introduction to 3D Printing

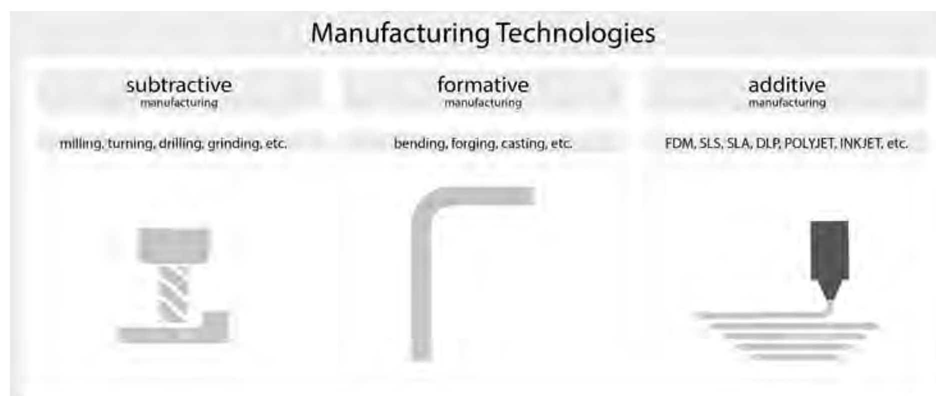
Additive Manufacturing

Manufacturing technologies can be divided into three categories: subtractive, formative and additive.

In subtractive manufacturing the desired shape is created by removing material from a base material. This can be done, for example, by drilling, turning or milling and is used a lot in woodworking and in the metal industry.

In formative manufacturing the base material can be formed by bending, forging or casting. Examples of products manufactured this way are the bended metal tubes for streetlights and injection moulded plastic parts in many consumer products.

Additive manufacturing (AM) is the newest category and is also referred to as 3D printing. The desired product shape is created by adding material layer by layer. This can be done using a wide variation of technologies. The most popular ones are based on plastics, but there is currently a rapid development in new technologies to use AM for metals or composites.



AM in Industrial Settings

With just some basic knowledge, consumer-level 3D-printing is easily accessible nowadays. You can simply buy a 3D-printer and some material, download the required software (free of charge in most cases), design or download a digital 3D-model and start printing.

However, additive manufacturing can also be highly effective in industrial settings. Currently, additive manufacturing is primarily being implemented in high-end applications (aerospace, automotive industries), but is also attracting interest from more and more producers.

Replacement for Conventional Production Techniques?

Using additive manufacturing techniques, virtually any shape can be made from a wide range of materials. But does this mean it can replace all other production techniques (e.g. milling, turning, injection moulding, etc.)?
For now, the answer is no. Especially when dealing with higher production volumes, use of conventional production techniques will generally result in a higher output at lower cost.

"Impossible" Products

3D-printing becomes interesting when a part or product requires features that cannot (or can only with great difficulty) be made with conventional techniques. This involves, for example, strong and lightweight lattice structures, curved and/or non-circular channels through a solid or products with features in locations where conventional tools cannot reach.

The fact that AM makes it possible to produce such complex parts also means that different parts can be combined and produced as one piece. This reduces or even eliminates the need for assembly, which can result in a cost reduction. Example: GE's new line of airplane engines (LEAP-series) that use 3D-printed fuel nozzles (19 per engine), by which 18 components per nozzle are reduced to just one.

Spare Parts Management

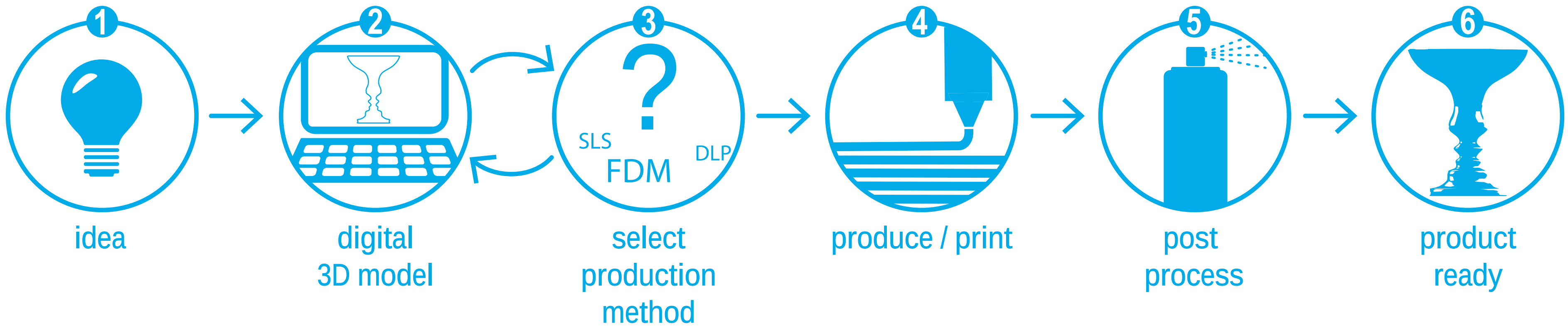
Production facilities that manufacture (complex) machines usually require a stockroom for spare parts and/or production tools (e.g. injection moulds) to facilitate after-sales service. By implementing 3D-printing techniques, it is possible to digitally maintain the spare parts portfolio. This reduces, or potentially even eliminates, the need for stockrooms as the spare parts can easily be produced on demand.

Automated AM Facilities

Recent developments (especially in metal AM) show a trend towards further automation of the fabrication process, reducing the amount of manual labour and post-processing. Possibilities to embed multiple 3D-printers into an automated production facility for example, include automated material supply, cleaning stations, build job preparation and unpacking.

Bigger, Better, Faster

3D-printer manufacturers are constantly improving their product line-up. Build volumes are getting bigger, enabling their customers to produce larger parts or to print more separate parts at once. Since larger print jobs take more time to complete, manufacturers are constantly looking for possibilities to speed up the process without neglecting the print quality. Apart from the chosen printing method and the product, manufacturing speed and quality are highly dependent on the material used. Numerous new materials, blends and alloys are developed each year, stretching the possibilities of additive manufacturing to new levels.



The Process of 3D Printing

3D printing is a process of creating products based on a digital 3D-file. In this process the product is built up layer by layer. This allows you to print almost every product you can design on your computer. It even allows printing a product assembly with moving parts at once: a ball inside a larger ball or a network of organic shapes.

There are different types of printers and there is a great variety of materials that can be used, each of them having its pros and cons. Plastics are most often used, but printing with other materials, such as ceramics and metal, is becoming more and more popular.

The overall process from idea to final product is very much like other industrial production methods.

Steps

1. 3D printing begins with an idea. The user has an idea for a specific three-dimensional object. The required specifications of the model (such as stiffness, transparency, heat resistance, colour, etc.) are defined.
2. The next step is to digitize this idea. It has to be converted into a digital 3D model, most commonly an STL-file has to be generated. Digitizing can be achieved in different ways: the model is created using 3D-modelling software or the model is scanned using special 3D-scanning devices.
3. After the digital model has been created, the user chooses the required 3D-printing process (see "3D Printing Methods"). *
4. The three-dimensional product is created.
5. Subsequently the model is post-processed.
6. Now the user can enjoy a real life 3D-representation of his/her idea!

* The digital model will often have to be updated to suit the requirements for the selected production/print method.

Preparing

The process starts with the digital 3D file. This file is created in a CAD (computer aided design) program or by scanning a product. The 3D CAD file is commonly saved as an STL file*, which every 3D printer can read.

The printer's software will now slice the STL file into tiny layers which will be printed one by one. The height of these layers determine the accuracy of the printed model. If required, the slicing software will add support material for overhang elements.

* STL is the most common file format for 3D printing, but other file types, such as OBJ, 3MF, VRML, could also be used depending on the 3D printer software.

Printing

There is a variety of printing methods, but one thing they all have in common is: the printing is done layer by layer. When one layer is printed, the next one will be laid on top. This process will be repeated until the complete model is created.

Post Processing

If any support material is used, it needs to be removed after printing. How this is done varies per print method, but it can often be broken away or dissolved .

Most of the time the model will be post processed using sanding and painting for better optical performance. It can also be post pro- cessed to enhance strength or to make it airtight.

The amount of post processing required to achieve end-user product quality is one of the bottlenecks for upscaling 3D printing for production quantities.

Characteristics of 3D Printing

To make the best use of additive manufacturing, there are some fundamental characteristics to take into consideration.

Adaptivity

3D printers do not require moulds or additional tools to create a geometry. This makes it relatively easy and cheap to produce small series or even 'one-off' products and it results in a short lead time for production.

Design Freedom

Building layer-by-layer makes it easier to produce complex shapes and enables production of designs that normally cannot be produced as a single component. It also enables optimization facilitating the use of material only where it is required (topology optimized structures).

Support Material

During production, some elements of a product may create an overhang or floating structure that cannot support its own weight until the model has been fully printed. This problem is solved by either making a design that fully supports itself or adding a support structure that is removed afterwards.

Accuracy

Perpendicular to the layers, accuracy is limited to the thickness of a single layer. The layered structure may be visible and, thus, affect aesthetics. These aspects may be improved by post-processing the model.

Material Properties

The strength between layers (Z-direction) is usually lower than the strength of the material within a layer (X & Y directions). This must be kept in mind when the part is subject to loads and stresses.

Cost Breakdown

Production time and costs are coupled to how much material is printed. This means model size and wall thickness make a significant contribution to overall costs. Post-processing is often also expensive, so avoiding it can save a lot of money. The cost of product design and data preparation becomes increasingly important in the overall costs as production quantities of a model decrease.

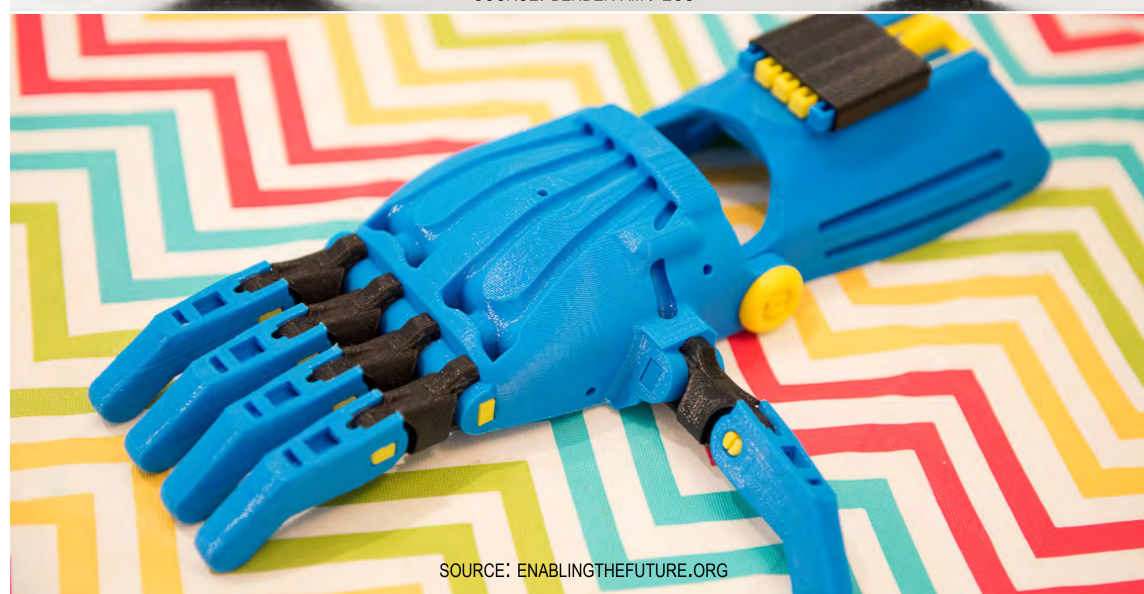
SOURCE: BENDER AM / EOS

Areas of Application

Applications of 3D printing are very diverse and constantly expanding. In a design process, printed models can be used to test and discuss product functions with a client. It can also be used to personalize products or to produce small production batches, not requiring any expensive production tooling like moulds.

Some areas where 3D printing is used are: consumer products, industrial applications, small series production, jewellery, medical, fashion, automotive, architecture, dentistry, aerospace and education.

SOURCE: BENDER AM / EOS



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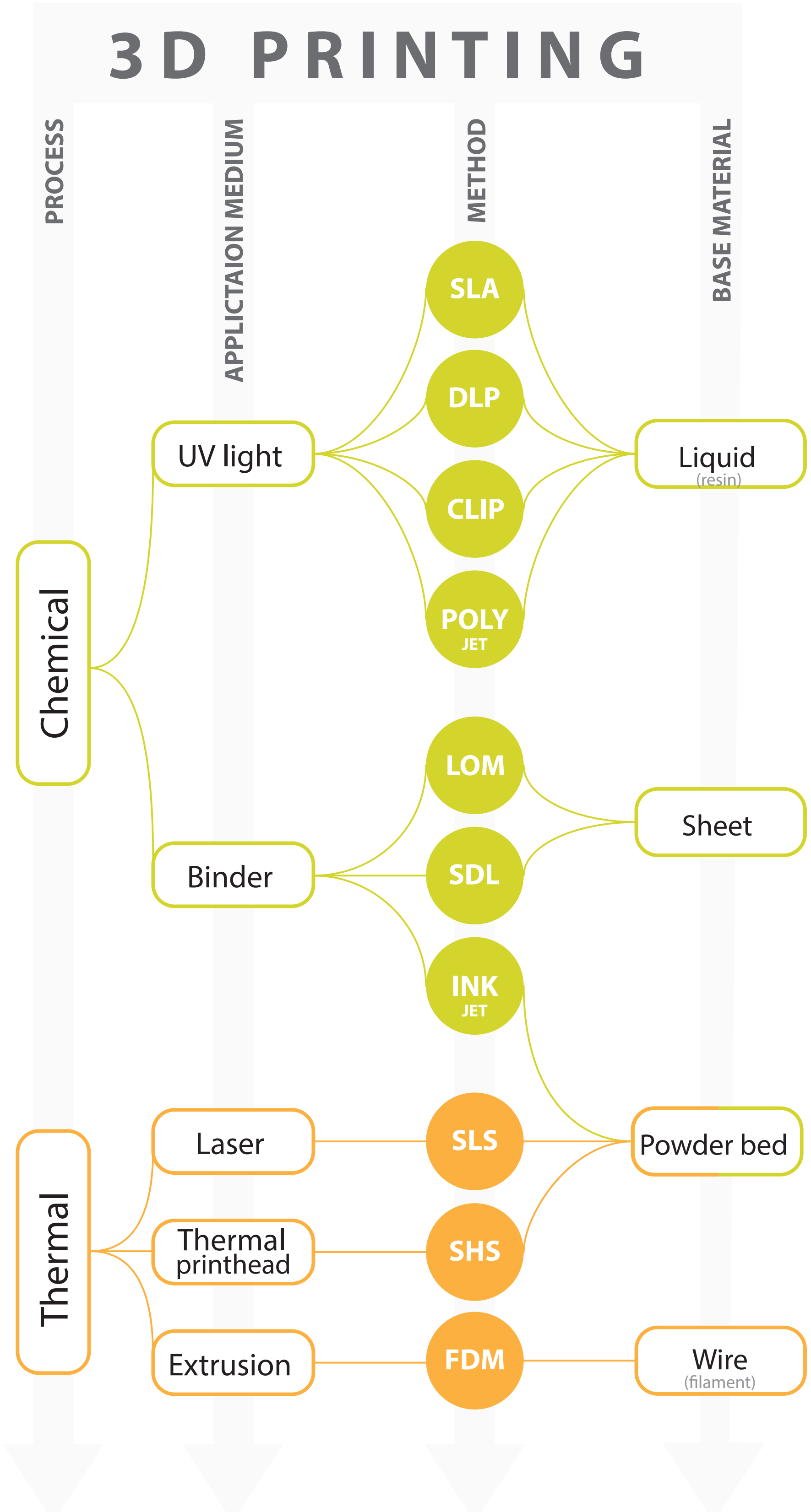


3D Printing Methods

The world of 3D printing is rapidly growing and so is the diversity of printers. Prices are dropping, making higher quality printers more affordable for SMEs or even consumers. At the moment, plastics are the most popular material for 3D printing. For the high-end industrial applications metal printers are being used more and more often. The costs for metal printing are still quite high, but in a couple of years we expect them to be a serious option for a larger part of the manufacturing industry.

In this booklet we will focus on the 3D printing methods most used by SMEs, which are all in the area of plastics.

Overview of 3D printing methods

There is a wide variety of 3D printing methods, but they all use some fundamental principles. Below is a brief description of these principles and their general advantages and drawbacks.

Process type

Chemical

The material converts into a plastic or bonds material together with a chemical reaction. This method is mostly – but not exclusively – used for thermoset materials.

+ Wide variety of material properties may be achieved.

- Safety and health precautions must be taken to process reactive materials.

Thermal

The material is heated up into a pliable molten mass, shaped and cooled down. This method is only used for thermoplastics.

+ Uses thermoplastics, which are widely used and its properties well known.

- Not all thermoplastics have suitable properties for 3D printing.

Application medium

UV-light

A polymerization process is initiated by exposure to UV-light. This method is used only with resins.

+ High detail is possible.

- Material properties are highly dependent on the curing process.

Binder

A base material is bonded together.

+ Some materials may be printed that cannot

be processed otherwise (such as plaster or paper).
- Mechanical properties are usually inferior.

Laser
A deposited layer of thermoplastic powder is melted by the addition of heat by a laser. The material is usually pre-heated for favourable processing conditions.
+ High detail is possible.
+ Strength in the Z-direction (between layers) is favourable.
- Machines are relatively complex and expensive.

Extrusion
Material (thermoplastic) is extruded through a heated nozzle into the desired shape.
+ Many machines are available, from hobby to production grade.
+ Widespread use has made the technology accessible and affordable.
- Strength in the Z-direction (between layers) is low.
- Layers are very visible.

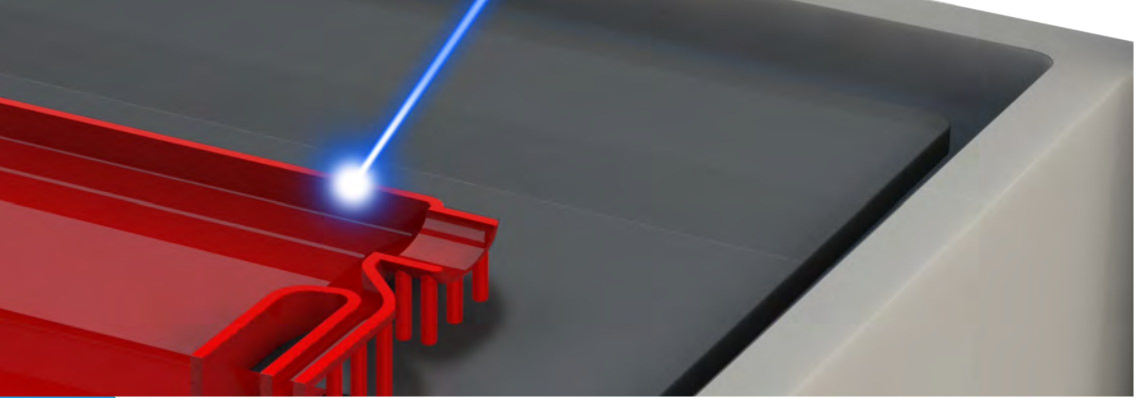
Base material

Liquid (Resin)
Base materials that undergo curing by UV-light are in liquid form before processing.
+ Layers (Z-direction) are less visible.
- The material degrades by prolonged exposure to UV-light, limiting service life.

Sheet
The base material is a sheet, from which a layer is cut out.
+ The method is suitable for specialty purposes, such as film hinges (of a single layer thickness) and full-colour models (paper).
- An entire sheet of material is used regardless of the cross-section of the printed product.

Powder bed
A layer of powder is deposited each time and a portion of that layer is bonded or melted together to form the cross-section of the product. The unprinted powder serves as support material.
+ There are, almost, no limitations to the shapes that can be printed.
+ A support structure does not need to be printed, because unused powder functions as support. There are no marks of support material on the product.
- Powder stays behind in areas of a product that are hard to reach with sandblasting, pressurized air, brushes and other tools.

Wire (Filament)
Thermoplastic wire is wound on a roll. This is the common form of material used for printing with extrusion.
+ Handling and storage of the material is generally easy.
- The rolls must be prevented from unwinding themselves (which can cause problems in processing).



Print Method:	**SLA**
Principle:	UV-sensitive resin, UV-laser
Materials:	Wide variation of UV-sensitive resins comparable to ABS, PP, PE, PC and more.
Support material:	Yes
Minimal layer thickness:	0.025 mm
Advantages:	Good surface quality, accurate
Disadvantages:	Not UV-stable

Stereolithography

SLA (Stereo Lithography Apparatus) is a printing technique based on photopolymers. These liquid UV-sensitive resins, which contain the building blocks of the final material, are solidified with the aid of a UV-laser. The printer consists of a bath containing a UV-sensitive resin, a photo-polymer, which is cured by the laser beam. The laser beam, controlled by means of a movable mirror, follows the contour of the model which is then cured forming a complete layer. Then, the table moves down one layer in thickness, so that a thin layer of resin comes to lie on top of the model. The next layer of the model is then cured and this process is repeated until the complete model has been built.

Some printers work the other way around: the model moves up and is lifted out of the resin layer by layer. In this case, the laser is positioned underneath the resin.

When printing with SLA, thin pillars have to be constructed that serve as support for the over-hanging portions. These pillars are easily removed from the printed object, but will leave marks.

Post-curing is required to obtain optimal mechanical properties.

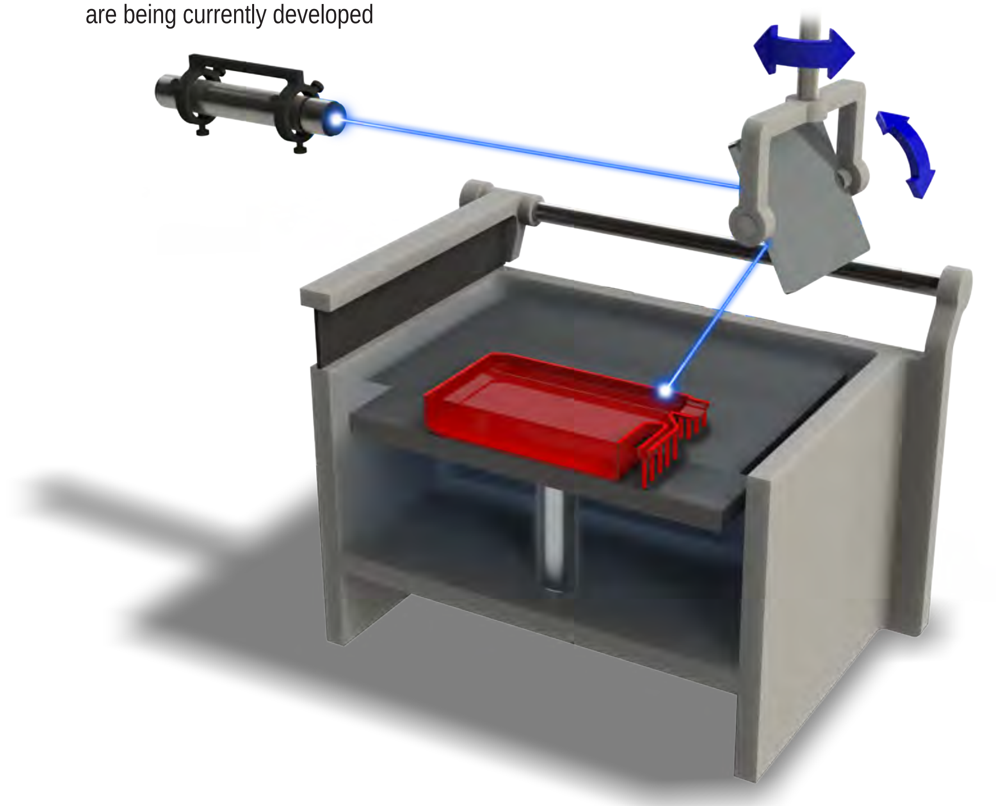
Advantages

- Very accurate, allowing models with a high level of detail in the design.
- Good surface-finish reduces the necessity for post-processing.
- Can easily be painted.
- Limited waste material, only the used supports are wasted.
- Variety of resins available and many more are being currently developed

Available materials can be comparable to real plastics (ABS, PP), flexible, transparent, high-temperature resistant, etc.

Disadvantages

- Materials are not UV-stable. Can discolour and become brittle over time.
- Removing support can be quite some work.



3DPRINT WIKI

CASE

Mobile Lighting

Background

Spanninga Metaal BV is a well-known name in the area of bicycle lights and accessories. The R&D department is constantly developing new lighting concepts. A sound user experience is crucial for these products. To test these lighting concepts in a realistic setting, all functions need to be incorporated into a prototype.

Important requirements: 1. Material properties in line with production version; 2. Functional prototype (e.g. snap joints and lenses).

Research

Most of Spanninga's products are made from injection moulded nylon. For the components that will be exposed to mechanical loads, nylon products are printed using an SLS printer. The mechanical properties of these prints are quite close to the injection moulded parts.

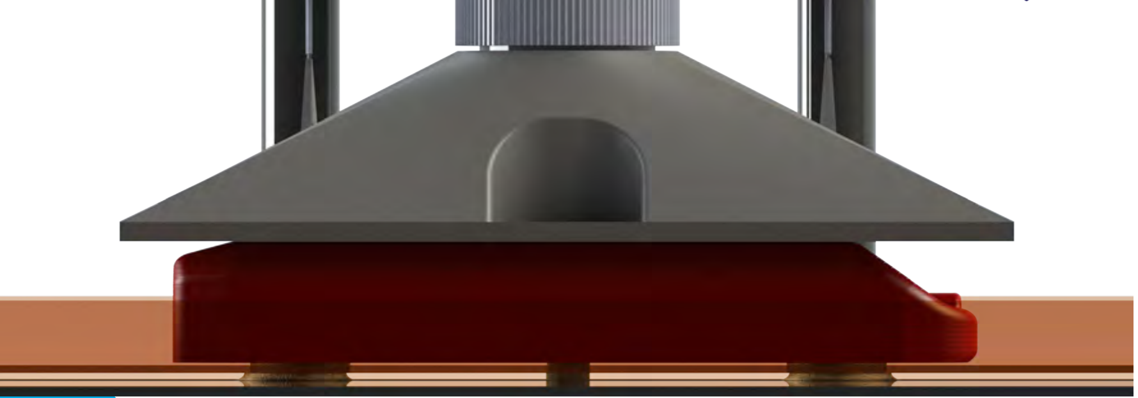
For the optical parts of the model, transparent material is required. Using an SLA printer and fully transparent material an accurate model was created. Polishing was required to make these lenses completely smooth.

Result

This case required the use of two different printing techniques and resulted in a completely functional prototype with properties comparable to a final produced version. With the electrical components embedded in the prototype, a realistic and fully functioning model was created. The implementation of the functional lenses resulted in a product that can be used not only as a visual model, but also as a functional model for testing.

Company: Spanninga

* Due to confidentiality, the actual product could not be shown here. The image shown provides an indication.



Print Method:	**DLP**
Principle:	UV-sensitive resin, beamer
Materials:	Wide variation of UV-sensitive resins comparable to ABS, PP, PE, PC and more.
Support material:	Yes
Minimal layer thickness:	0.0125 mm
Advantages:	High resolution, fast
Disadvantages:	Smells, difference in preciseness, expensive resin

Digital Light Processing

Digital Light Processing (DLP) is a technique using a light sensitive resin and a beamer to cure the resin. There are two common implementations of this method: Bottom-Top and Top-Down. The technique is similar to SLA, but uses a different light source.

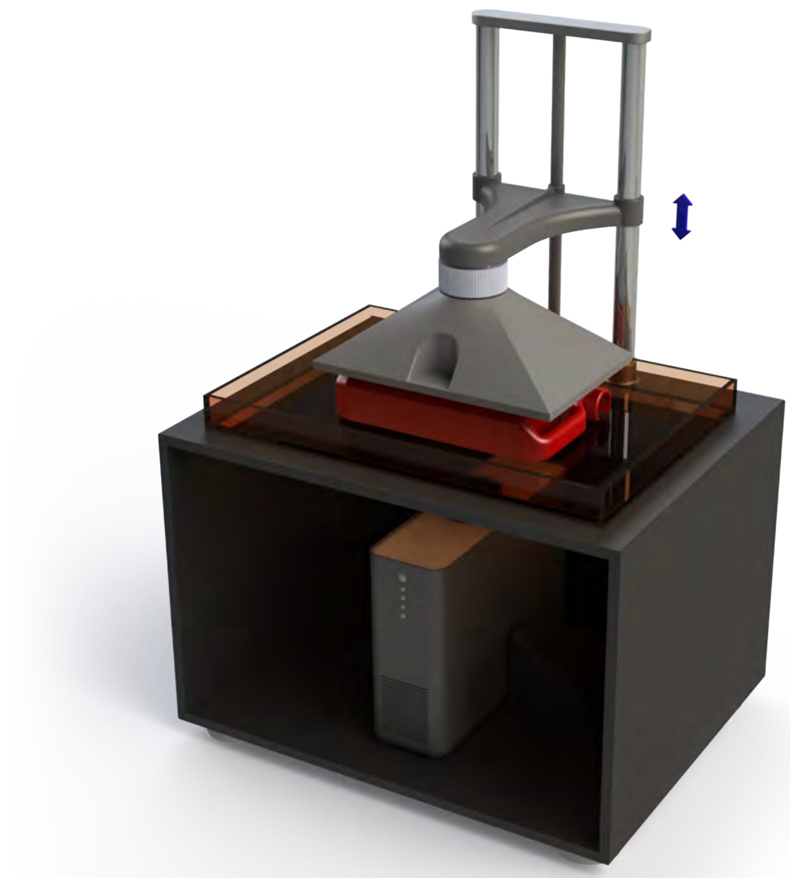
Bottom-Top uses a light sensitive resin and a beamer. The bed on which the model is created is immersed in a bath of resin. A UV-beamer lights the resin from underneath through a translucent bottom, curing the resin. When a layer has cured, the bed holding the model moves upwards by one layer of thickness. The surrounding resin, in which the bed is immersed, flows underneath the model and is then lit, curing the new layer. This process repeats itself until the model is finished.
Top-Down is a method very similar to the one described above. Although here the model is not pulled out of the resin moving upwards, but is pulled down lowering the object into the resin and placing it back at exactly one layer in thickness underneath the surface and subsequently being cured by a UV-source from above. Post-curing is required to obtain optimal mechanical properties.

Advantages

- DLP works fast, because a complete layer of the model can be printed at once. The size of the layers don't influence to the processing speed, because the whole layer is being lit at once.
- DLP has a high resolution, layer thicknesses vary in eight steps from 0.0125 to 0.1mm.

Disadvantages

- The centre of the model is more exact than the edges, because of the scattered light from the beamer.
- Materials are not UV-stable. Can discolour and become brittle over time.
- Removing support can be quite some work.



Impression Tray

Background

In dentistry, individual impression trays are used to create accurate impressions of the patient's teeth. An accurate impression is required for a good fitting, but the process of creating individual impression trays takes about 30 minutes. Using 3D modelling and printing drastically reduces processing time as well as the amount of waste.

3D printing could offer a solution if the following requirements can be met: 1. High accuracy; 2. Retain shape; 3. Suitable for in-mouth application (non-toxic).

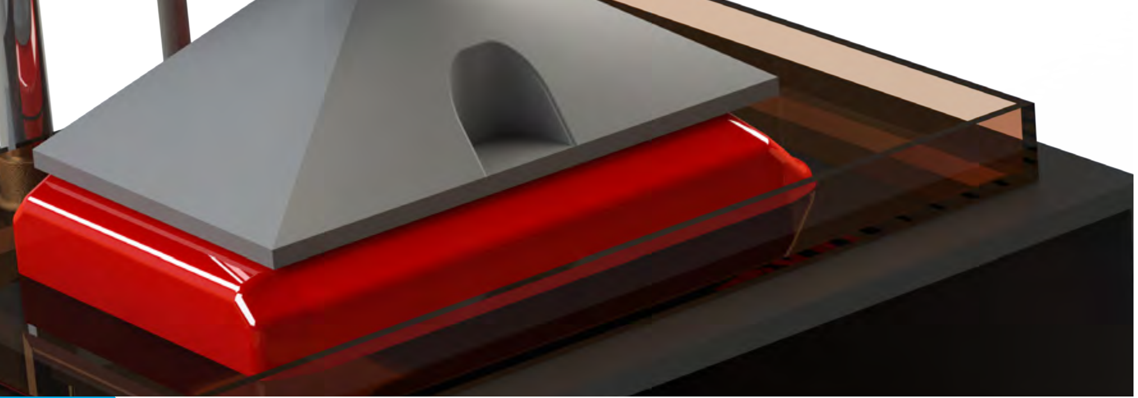
Research

Several impression trays have been printed using a DLP printer and suitable non-toxic materials. The models have been tested for accuracy. Clinical trials have not yet taken place.

Results

The 3D printed impression tray is made from a suitable non-toxic material and is accurate enough for its purpose. The design software (for modelling in 3D) is a hurdle for commercial success, and would have to be developed further. Suitable 3D printers are still quite expensive. For this reason Level by Level is now developing a more affordable printer.

Company: Level by Level



Continuous Liquid Interface Production

CLIP is a 3D printing method that is based on the DLP technology. A light-sensitive resin is cured using LED lights. The model is hanging on the platform and lifted up in a continuous movement.

CLIP does not cure layer by layer, but instead pulls up the component with a constant speed whilst continuously curing the cross-section of the object. An oxygen permeable window prevents the resin from curing and sticking to the window. The absence of a layered structure is reported to give the Z-direction strength comparable to the other directions, similar to moulded components.

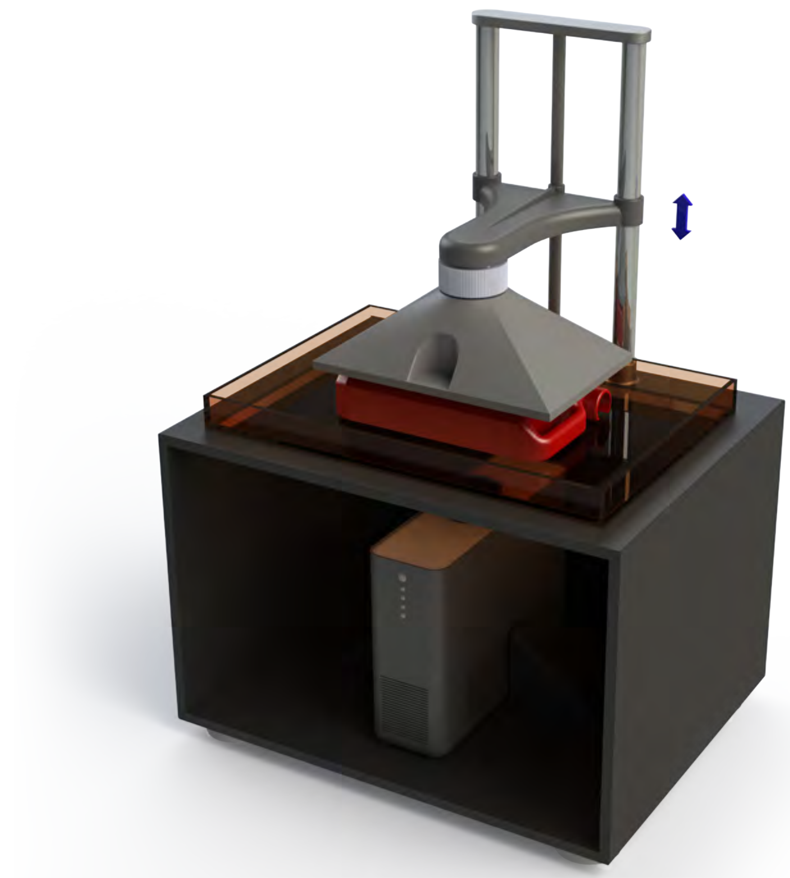
Advantages

- Layerless printing results in a better structural integrity and the material properties are claimed to be the same in each direction.
- Very quick method, making it more suitable for production.
- High surface quality .

Print Method:	**CLIP**
Principle:	UV-sensitive resin, LED, continuous vertical movement
Materials:	UV-sensitive resins
Support material:	Yes
Minimal layer thickness:	None
Advantages:	High quality, material properties comparable to Injection Moulded product
Disadvantages:	No hard evidence of quality as yet

Disadvantages

- Very new method, only a few printers available at this moment.
- No hard evidence of the claimed quality has been produced.
- Post-curing could be a bottleneck for productivity.



Print Method:	**Polyjet**
Principle:	UV-sensitive resin, UV-light
Materials:	UV-sensitive resins with properties similar to ABS, PP and rubber
Support material:	Yes
Minimal layer thickness:	0.016 mm
Advantages:	Multi-material, no post-processing
Disadvantages:	Poor heat resistance

Polyjet

Polyjet is a printing technique using a UV-sensitive resin and a UV-light. The print-head consists of several small nozzles and is also equipped with a roller and a UV light. The nozzles spray small droplets of resin onto the printing bed according to the contours of the model. The droplets are spherical at first and are rolled flat using the roller, then they are cured using the UV-light. When a layer has been printed the bed moves down by one layer, so a next layer can be printed.

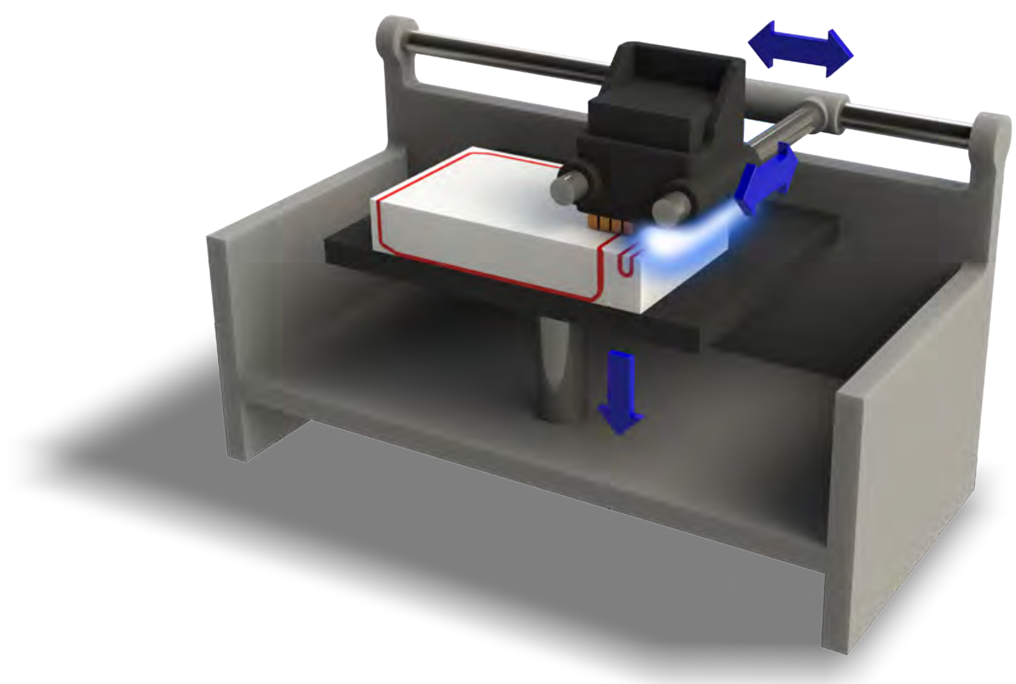
This process repeats until the complete model has been built. This technique allows for printing with multiple materials. It allows for full colour printing and adjusting material stiffness. This feature is often used for models with hard and soft features, like a toothbrush having a hard base and soft grips. The support material for this technique is a gel that can be easily washed off after the model has been printed.

Advantages

- High resolution.
- Full colour printing.
- Multi-Material: Polyjet is a unique technology that can jet multiple materials in a single print run. This means that you can selectively position multiple materials and colours in one print.
- Minimal post-processing: very high resolution, full colour and multi-material advantages also result in a minimal of post-processing.

Disadvantages

- The materials used are not very heat resistant. The "heat deflection temperature", the temperature at which the material can be deformed, is at 55ºC for most materials.
- Expensive resins.
- Expensive machines.



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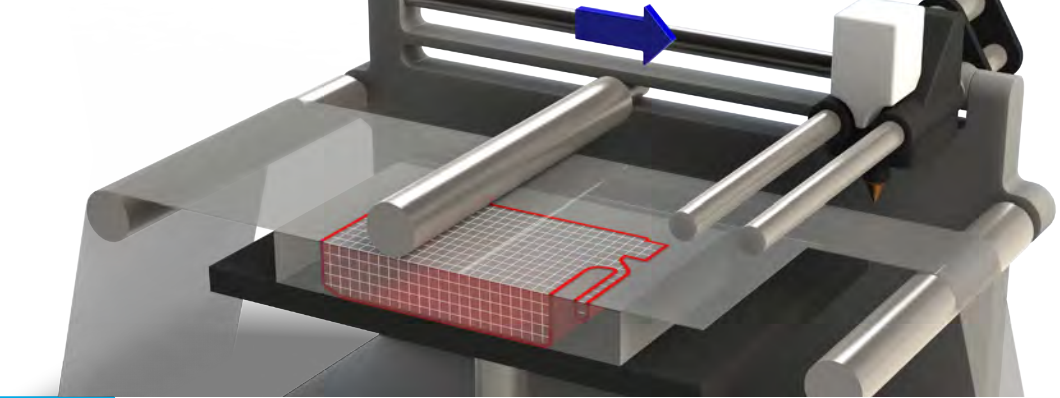


LOM

Laminated Object Manufacturing

LOM (Laminated Object Manufacturing) is a 3D print method that uses a knife or laser to cut layers of adhesive coated foil. An anti-stick layer is applied on areas that are not part of the printed object. These areas can be removed afterwards.

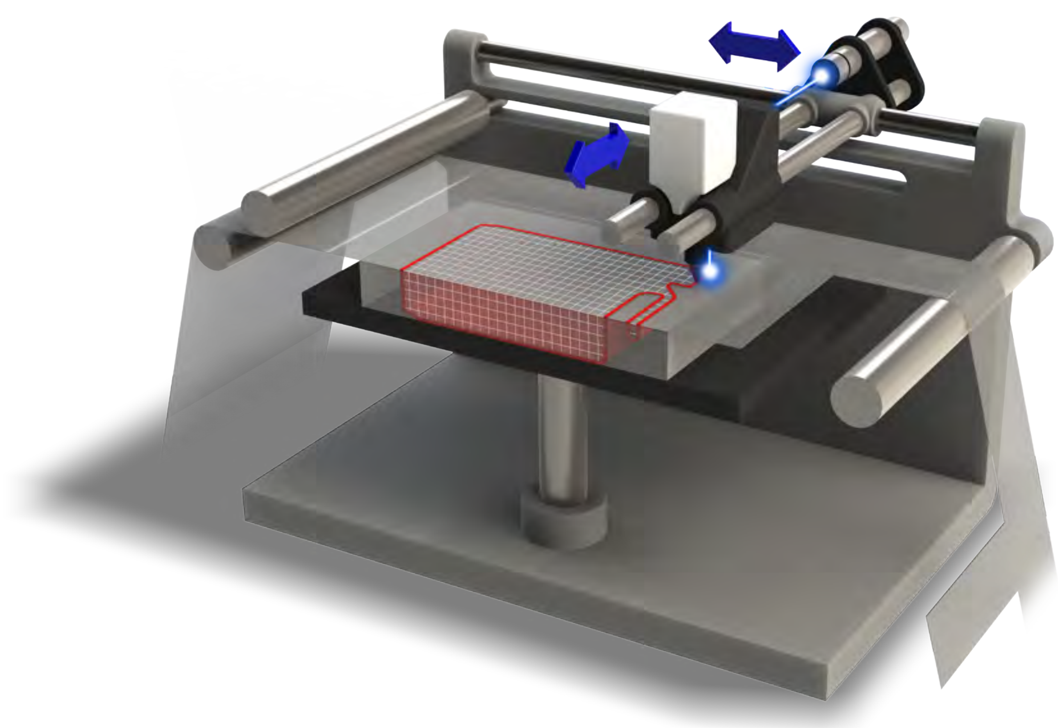
Advantages

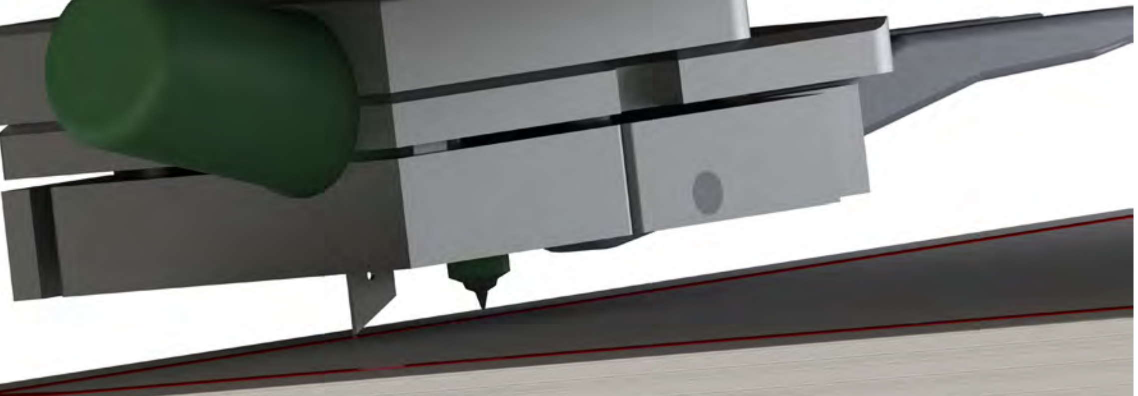
- A major advantage of LOM is that it uses flexible materials such as paper and PVC, while other 3D printing methods mostly use hard and brittle materials. This allows for working film hinges.
- No support structure printed: the product is supported by the foil.

Disadvantages

- The full width of the foil is always used. This results in a lot of waste material.
- Removing surplus material on the inside can be a lot of work, if not impossible.

Print Method:	**LOM**
Principle:	Foil, knife or laser
Materials:	PVC-foil, paper
Support material:	No
Minimal layer thickness:	0.1 mm (80gr paper), 0.165 mm (PVC)
Advantages:	Flexible materials, film hinge possible
Disadvantages:	A lot of waste material, removing this is a lot of work.





Print Method:	**SDL**
Principle:	Printed paper, cutting knife
Materials:	Paper
Support material:	Yes
Minimal layer thickness:	0.1-0.19 mm
Advantages:	Full colour, low material cost, stable
Disadvantages:	Breaking away excess material is a tricky job

Selective Deposition Lamination

Selective Deposition Lamination is a printing technique related to LOM, by which sheets of full colour printed paper are layered to create a 3D model. These sheets are bonded together by applying tiny drops of glue only where necessary.

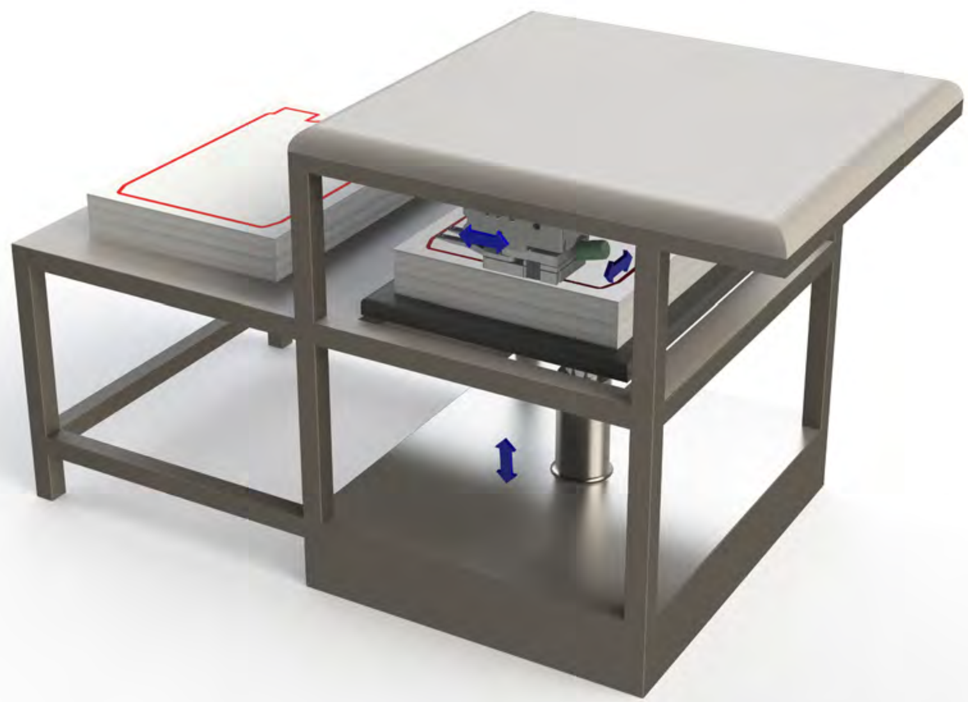
Every layer of the model has a full colour print around the edges of the model and is cut at the contours. Areas that function as support for the model, are cut and bonded in small blocks to aid removal after printing

Advantages

- Full colour models: Each layer of the model can be printed in high resolution resulting in precisely coloured objects.
- Very suitable for printing realistic textures.
- Strong and stiff objects can be created, especially after coating is applied.
- Post-processing: The material can easily be coated with traditional paper coatings (high gloss, water resistant, hardness, etc.).

Disadvantages

- Breaking away the support/waste material can be a tricky job.
- Edges cannot be bonded by the printer. This causes delamination if the model is not coated.
- Not moisture resistant (unless is it coated).
- Thin, long and/or sharp details may not stay intact when removing support material.



CASE

Luxury Perfume Sample

Background

A well-known British luxury fashion house - that designs and sells a wide range of products like clothing, bags, wallets, belts, umbrella's, sunglasses, watches, jewellery and perfume - was looking for a unique and more luxurious perfume sample. Current perfume testers are sprayed onto a strip of paper which absorbs the perfume quite well, but the customer experience of this piece of paper is not in line with their vision and brand identity. For the introduction of their latest perfume they would like to have a miniature perfume bottle that is identical to the new perfume bottle as a sample giveaway.

Research

In this case there are three important criteria: 1. Price per sample should not be too high; 2. The 3D printed material must absorb the perfume; 3. The 3D print process and material must not add any odours that could mix with the perfume.

Most 3D printing methods use plastics as 3D print material which does not absorb perfume. The selected SDL printer uses paper for 3D printing combined with water-based glue that does not add any odour when printing, which is exactly what is currently being used, making it the most logical first test.

Results

Myeasy3D created a 3D model of their latest perfume bottle, printed miniature versions using the 3D SDL printer and tested them. The 3D printed perfume bottle is used as-is and absorbs the perfume very well. A substantial amount of these bottles were printed.

Company: MyEasy3D

Shop Display Fruit

Background

A new product was sought for displaying artificial fruit in the display window of a patisserie. Current artificial fruit is too fake and shiny, and the choice is limited. Real fruit is also not an option, as it would have to be replaced too often.

The requirements for the 3D print for this case are: 1. Realistic 3D prints in full colour; 2. Affordable and durable prints; 3. UV protection.

Research

To create realistic 3D models of the fruit, real fruit was scanned using a 3D scanner. Using an SDL printer, an affordable full-colour 3D model could be printed out of paper. A UV protective coating was applied to prevent discolouring by exposure to sunlight. UV coating can be easily applied to 3D paper printed products and it also protects the object from humid environments. Full colour 3D printed products from materials such as sandstone will fade in colour over time, are easily stained by water drops and are quite fragile.

Results

The matted surface and textures on the outside and inside of the fruit made it look quite realistic. In addition, a standard well-tested UV coating for the paper 3D printed fruit was used to protect colours from fading.

Other 3D printing methods would have required at least a decent paint job by hand, to create realistic looking fruit, while the selected SDL 3D printer enables the fruit to be directly painted with vivid and realistic colours at an affordable price.

Company: MyEasy3D

myeasy3d®
3D Print Concepts & Services

CASE

Chocolates From 3D Scanned Faces

Background

There is a growing demand for personalized food gifts, and a birthday cake with your name on it may no longer suffice. To offer a completely unique food experience this patisserie wanted to create chocolate in the shape of people's faces and full body figurines.

The requirement for such a product and system are: 1. Mobile scanning solution to enable to scan faces and/or a complete body (figurine); 2. A low cost 3D print suitable for creating the mould.

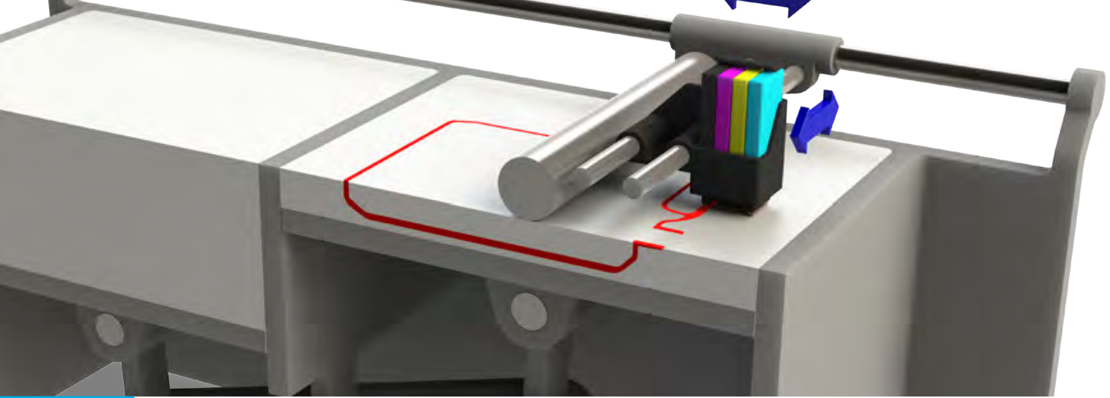
Research

An iPad equipped with a 3D scanner driven by specifically developed software for this purpose was used as a mobile solution for scanning people. Then a full 3D or 2 ½ D print was made using an SDL printer. The printed object was then used to create a mould suitable for casting chocolate.

Results

Turnaround time for the process from scanning to the final chocolate product takes less than 48 hours. The chocolate product is a very unique and personal gift already created for a diversity of clients.

Company: MyEasy3D



Print Method:	**Inkjet**
Principle:	Gypsum, binder
Materials:	Gypsum
Support material:	No
Minimal layer thickness:	0.089 mm
Advantages:	Multi-coloured models, heat resistance
Disadvantages:	Brittle, low surface quality

Inkjet

Inkjet printing is a technique using plaster and a binder. This technique has similarities to conventional Inkjet printers. Alongside the tricolour cartridges allowing models to be fully coloured, a cartridge with a binder is used to stick the coloured gypsum together. The print-head with the binder moves over the right-hand container to print the binder in accordance with the contours of the model. When the digital 3D-model is textured with one or several colours, this colour is added to the outer layer of the model. When a layer has been completely printed, new gypsum from the left-hand tray is moved over to the right-hand bin. This process is repeated until the complete model is built. On completion, the model should be at least one hour in the printer in order to cure the binder. Subsequently, the excess plaster can be removed with a spatula, brush or by compressed air. Finally the model needs to be reinforced by impregnating it with epoxy, glue or wax.

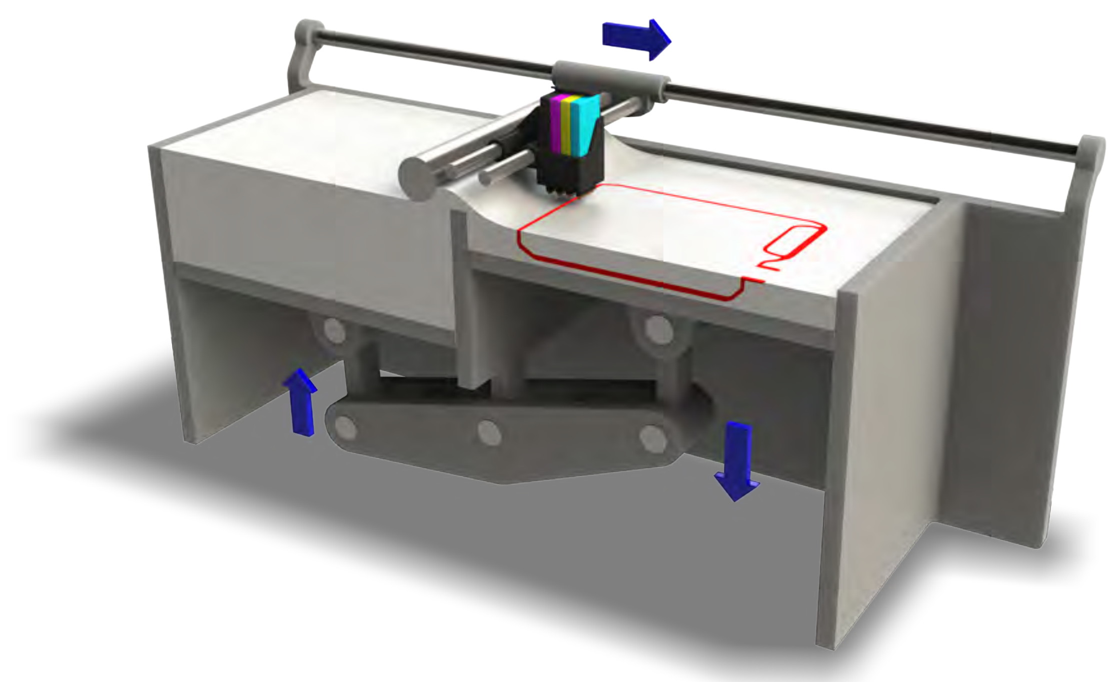
Techniques similar to Inkjet are SLS and SHS, but whereas they use a thermal process, Inkjet uses a binder.

Advantages

- Full colour: The biggest advantage to this technique is that it can produce full colour models.
- No support: Inkjet does not need any printed support, the unused gypsum serves as a support.
- The excess material is easily removed using a spatula, brush or compressed air.
- Heat resistant.

Disadvantages

- The biggest disadvantage of this technique is that the models are brittle, especially without any post-processing, making post-processing necessary. Often the model is impregnated with epoxy, glue or wax, making the model stronger, but it will always remain brittle.
- Removing excess gypsum can be labour intensive with more complex shapes, because places can be difficult to reach and the model is brittle.



Heat Resistant Component

Background

Kumagaya has developed a new rotation moulding process that only heats the mould instead of using an oven. The machine required a new type of electronic contact to be designed (carbon brushes). To increase working speed and reduce costs, the possibilities of 3D printing the casing for these carbon brushes was researched.

The requirements for this case are:
1. Heat resistance; 2. Strength.

Research

When the design of the casing was finished it was first tested using an FDM printer and PETG filament. To improve manufacturability of this product, the design was split up into several smaller parts.

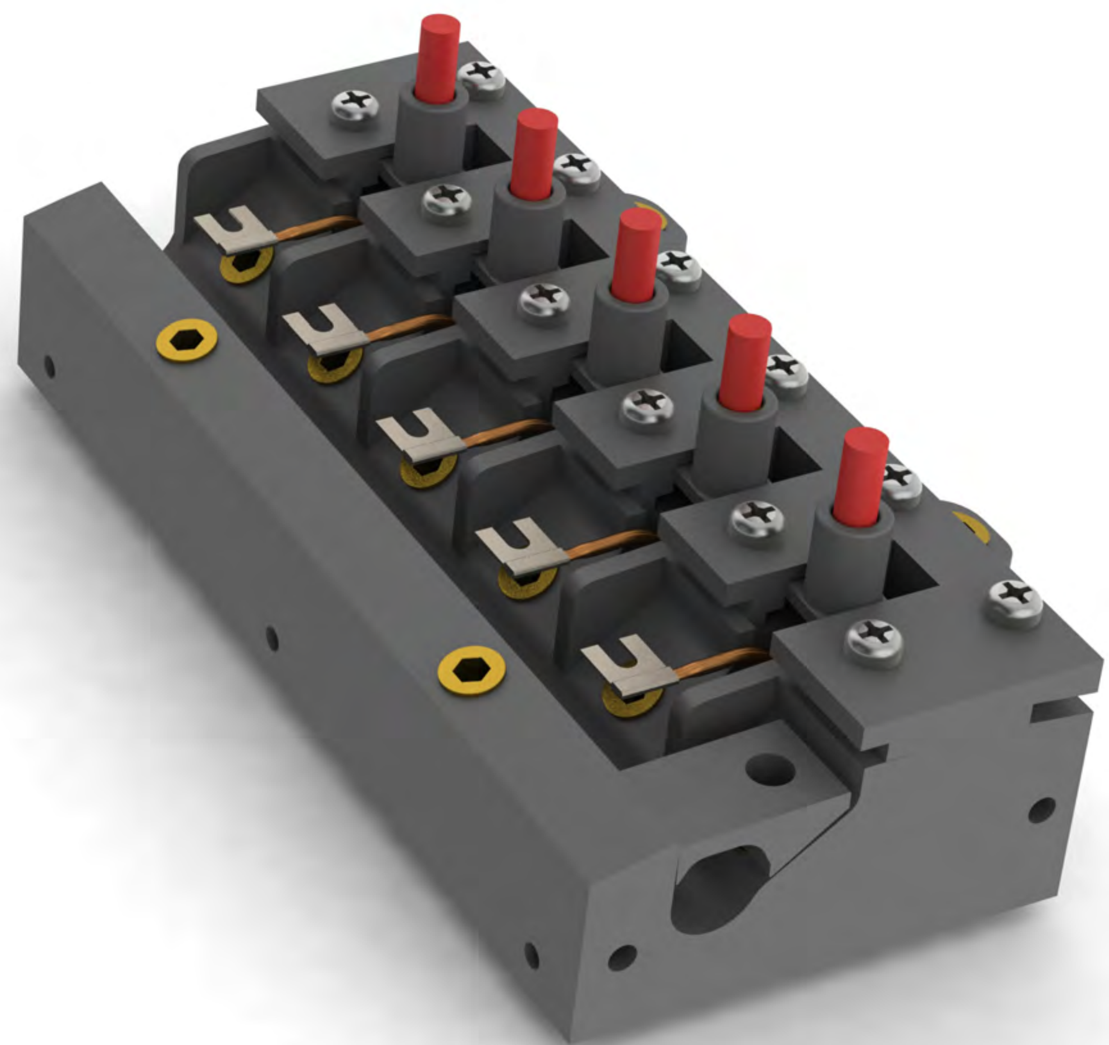
In addition to the FDM model, a more heat resistant model was printed using an Inkjet printer.

The two most important questions were:
1. Is the FDM model heat resistant enough for this application?
2. Is the Inkjet model strong enough for this application? (Inkjet models can be quite brittle)

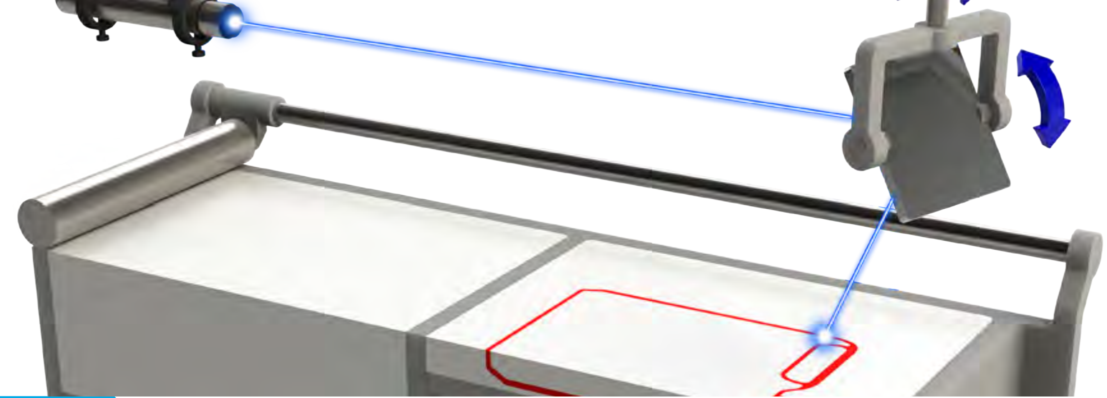
Results

The FDM models are very usable, but only if the product is not placed directly onto the mould: it needs to be placed at an offset for heat isolation. This is a good solution. The inkjet model could be placed closer onto the mould, but appeared to be too fragile for this application and could, therefore, not be used.

Company: Kumagaya Kunststoffen



KUMAGAYA
KUNSTSTOFFEN



Print Method:	**SLS**
Principle:	Thermoplastic powder, preheating, laser.
Materials:	Many, e.g. (glass-filled) PA, PS, Glass, PS, PP, PEEK, TPU
Support material:	No
Minimal layer thickness:	0.06- 0.10 mm
Advantages:	Good mechanical properties, many parts in one print-job, suitable for final products
Disadvantages:	Post-processing may be desirable

Selective Laser Sintering

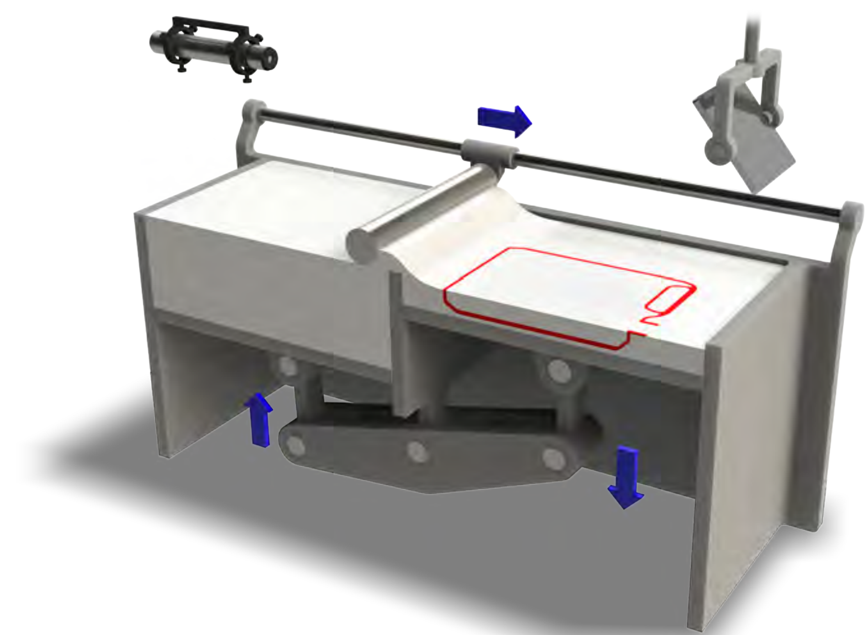
SLS is a printing technique that works using a thermoplastic powder as its base material. The powder is fused together by a laser spot, which is positioned using a moveable mirror. In order to prevent oxidation and shrinkage, the process takes place in a closed chamber heated to +/- 170ºC filled with an inert gas. When a complete layer of the model is melted together, a new layer of powder is added. The right-hand bin moves down while the left-hand bin moves up, so that from the left-hand side a small layer of powder is being rolled over to the right. A new layer can now be sintered. This process is repeated until the complete model is built. This technique does not require the printing of support material. The powder that has not been melted together acts as the supporting material, which also means objects can be stacked on top of and inside each other. Although unused powder can partially be re-used in other models, a significant amount of powder will still be waste. The finishing of the model consists of the removal of the loose powder using glass bead blasting.

Advantages

- It is possible to reach densities that are similar to densities of conventional techniques, meaning that the model can obtain good mechanical properties.
- The creation of realistic prototypes or a small series of complex products is possible.
- The material is strong and fairly flexible (when printed in thin walls).
- Mechanical properties are so good that it is possible to produce working snap hooks and even spring systems, making this technique outstanding for creating mechanical prototypes.
- Design freedom, thanks to the method of support during printing.
- The models can easily be painted.
- Print many parts in one print-job.

Disadvantages

- The material becomes soft and can swell on coming into contact with water (impregnating will solve this issue).
- The surface of SLS models is fairly precise, but grained and post-processing may be desirable.
- Sanding the material is a hard job, so tumbling is often used instead.
- Material waste.
- Expensive machine.



3DPRINT WIKI

CASE

Modular Proof of Concept

Background

Vuurs is a start-up company founded with the plan of creating a new generation of wood-burning stoves. The technical principles were tested and proven, so it was time to design and develop a product. A modular design was made using CAD software. In order to check whether the product would assembled as on the pc, a physical scale model was made and tested. As an added benefit the model could also be used as a demonstrator during pitches for potential investors.

For this case the most important requirements are: 1. Accuracy; 2. Finishing; 3. Low cost

Research

The first test samples were created with FDM printers. Several models were created using different printers and thread thicknesses. Unfortunately, the accuracy was insufficient (design details got lost) and some slight sagging appeared.

New tests were conducted using an SLS model for its accuracy and ability to print multiple parts at once, therefore reducing printing time and costs.

Results

A highly detailed model was printed clearly demonstrating the modular capabilities of the product. The model gave a clear insight into fittings, product assembly and stability.

The model has been, and is still being used for product pitches and demonstra- tions. All the insights gained from the 3D-printed model were used in the creation of the first prototype, which is currently fully operational.

Company: Vuurs / Tjelp

Machine Part

Background

Moba is a manufacturer of egg grading, packing and processing machines. For many old machine parts, the mould is no longer available or is worn out. Spare parts for these machines will still need to be produced on demand and in small numbers. To still be able to provide spare parts for these machines, the possibilities of 3D printing these parts has been researched.

For this case the most important requirements are: 1. Strength; 2. Chemical resistance; 3. Hygiene.

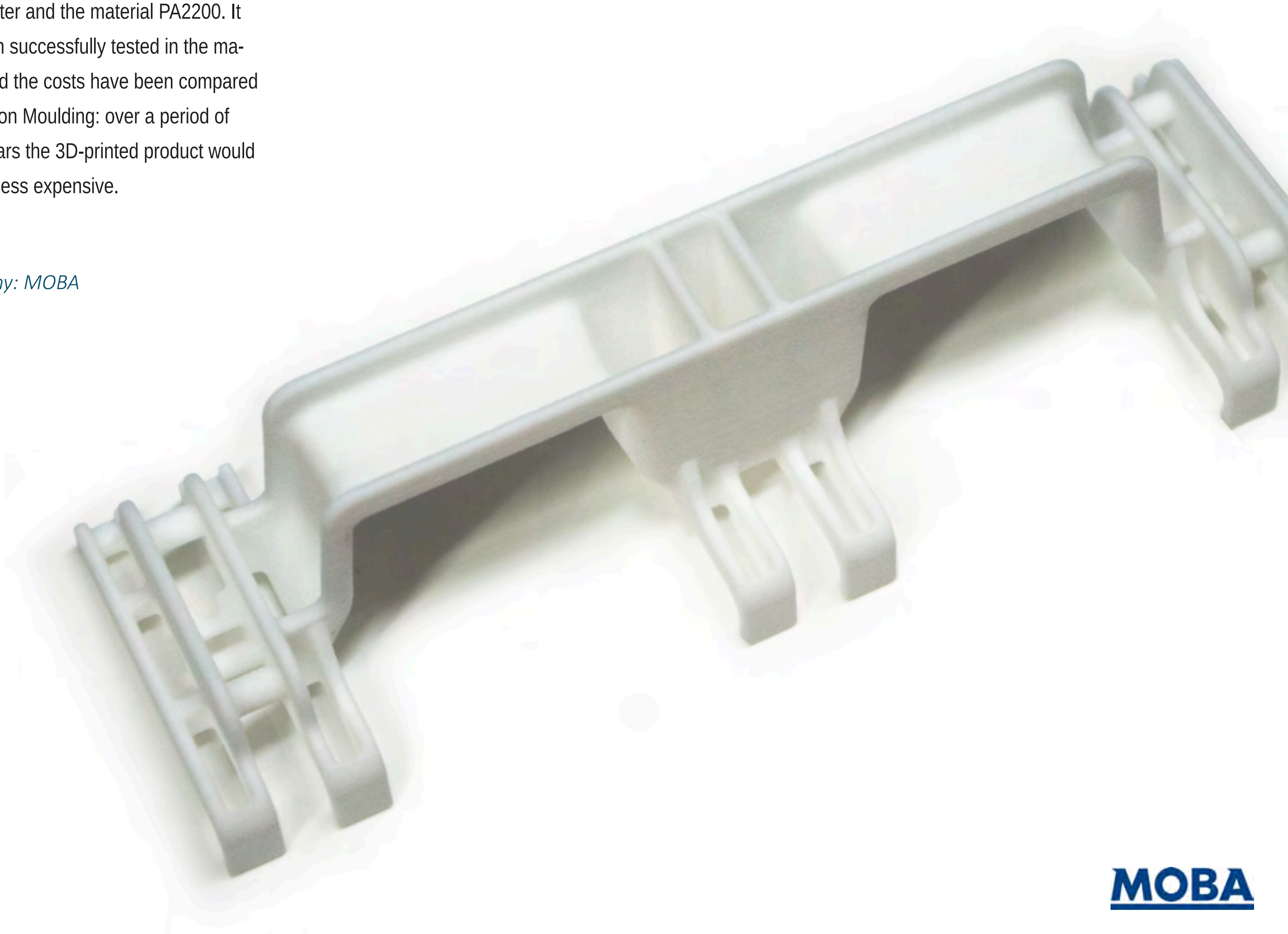
Research

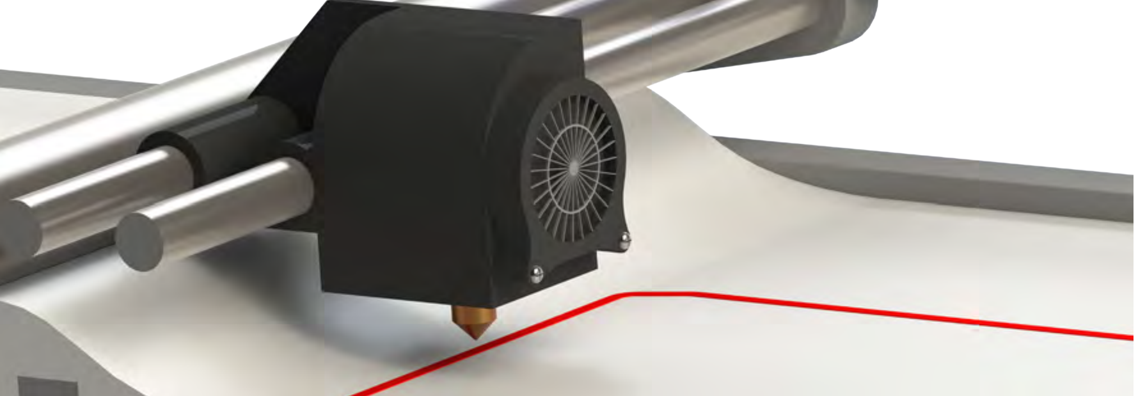
Based on the product's technical specifications, several 3D-printing technologies and materials have been researched and a cost calculation has been made to compare the costs for 3D printing and Injection Moulding. A selection model developed by MOBA and the Professorship for Polymer Engineering at Windesheim has been used for this. The product has been redesigned based on the requirements and the 3D printing design guidelines.

Results

A product has been 3D-printed using an SLS printer and the material PA2200. It has been successfully tested in the machine and the costs have been compared to Injection Moulding: over a period of three years the 3D-printed product would be 44% less expensive.

Company: MOBA





SHS

THERMAL - THERMAL PRINTHEAD - POWDER BED

3DPRINT WIKI

Selective Heat Sintering

SHS is a technique that works on a very similar principle as SLS, but uses a thermal print-head instead of a laser to melt the thermo-plastic powder.

The machine has two containers of powder on each side of the build chamber. A thin layer of powder is applied on top of the bed, while an infra-red light moves over it to melt the powder where needed.

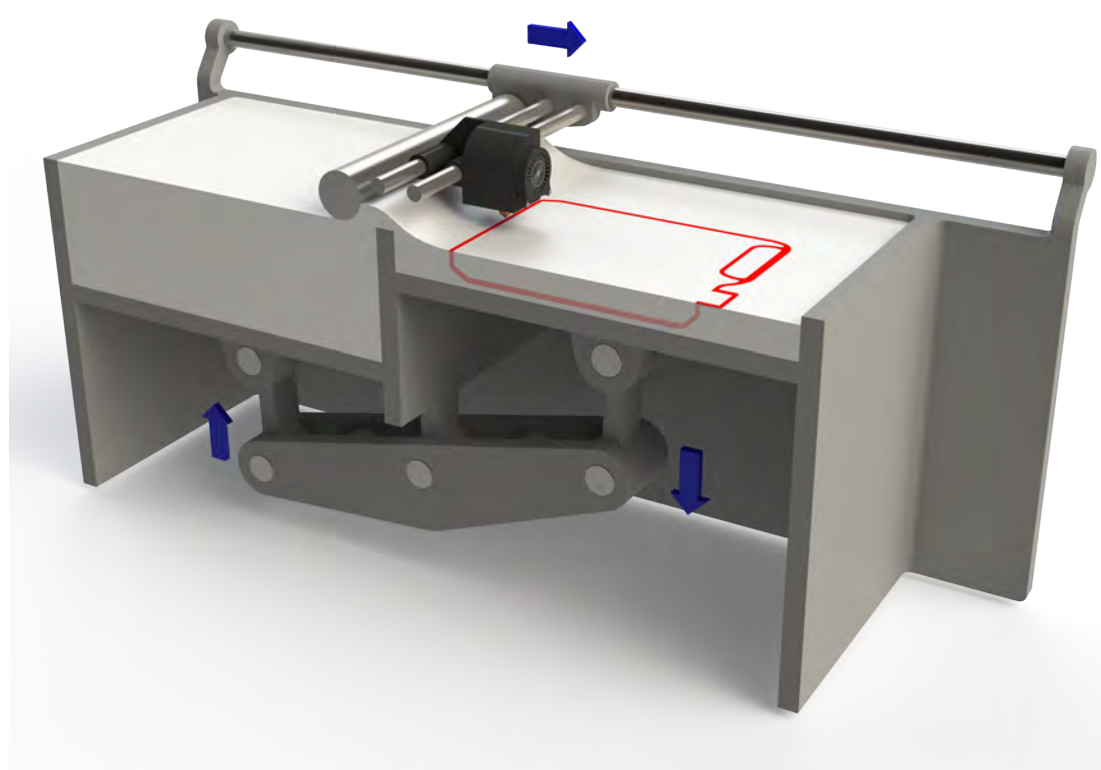
Advantages

- SHS offers the possibility to print several different products at the same time.
- No need for additional support materials, as models are supported by the powder in the build chamber.
- Products are fairly flexible. Excess powder is reusable.
- SHS was developed as a low-investment alternative for SLS printed PA12.
- No waste material: in contrast to SLS, the unfused powder has better re-usability thanks to processing at lower temperatures.
- Design freedom, thanks to the method of support during printing.

Print Method:	**SHS**
Principle:	Thermoplastic Powder/ Thermal print-head
Materials:	Thermoplastic Powder (PA12)
Support material:	No
Minimal layer thickness:	0.10 mm
Advantages:	No support needed, more than one products in one container
Disadvantages:	Rough surface finish, no variation in materials

Disadvantages

- Rough surface finish. This is because around the sintered edges unsintered powder sticks to the model.
- More brittle than - and not as strong as - prints from an SLS printer.
- Post-processing like sanding and varnishing the models may be required.
- No variation in materials available.



Muscle Sensor

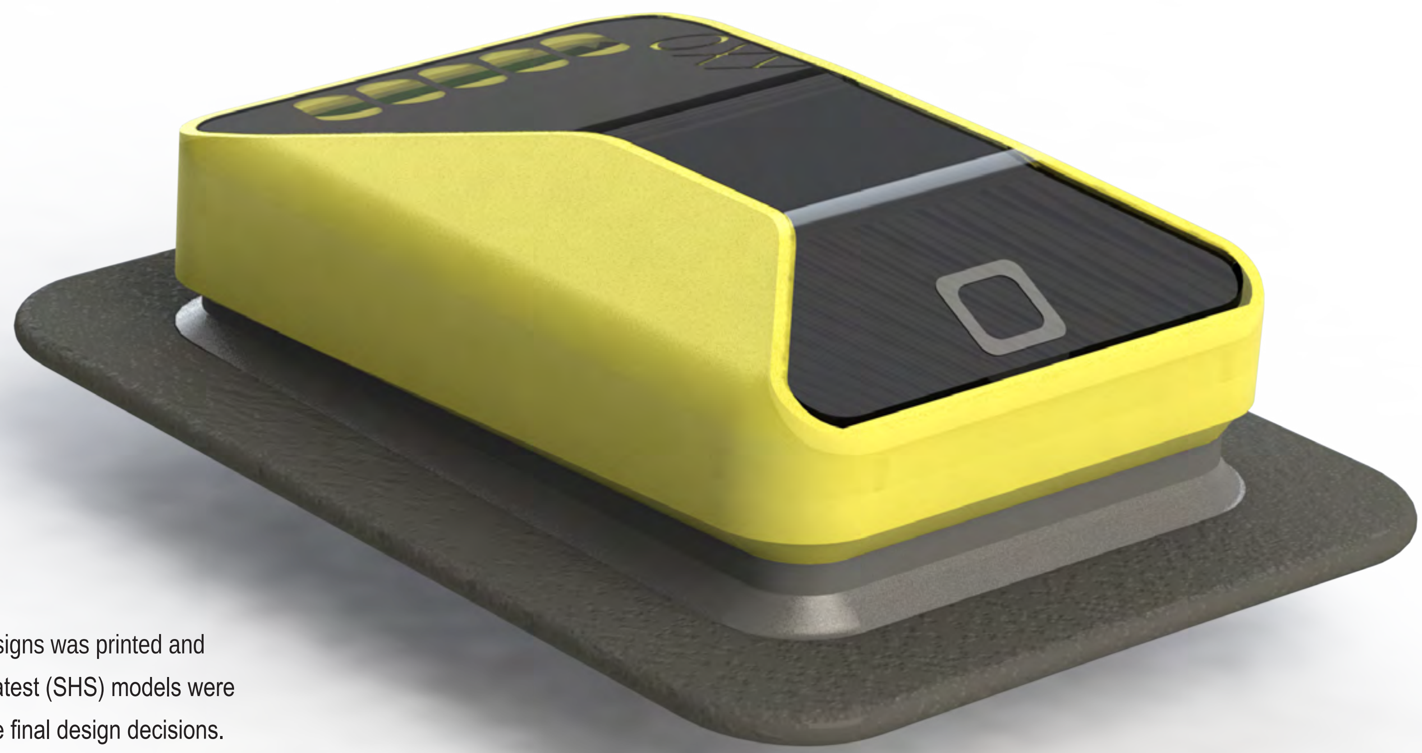
Background

Arexx designs and manufactures a wide range of technical products. During the design process of a new product – a wearable muscle sensor – they want to be able to regularly check the design for compatibility with the electronic components. The 3D-printed models should be as close as possible to the product that will be produced.

For this case the most important requirements are: 1. Allow for thin walls (1mm); 2. Accurate and high quality; 3. Affordable.

Research

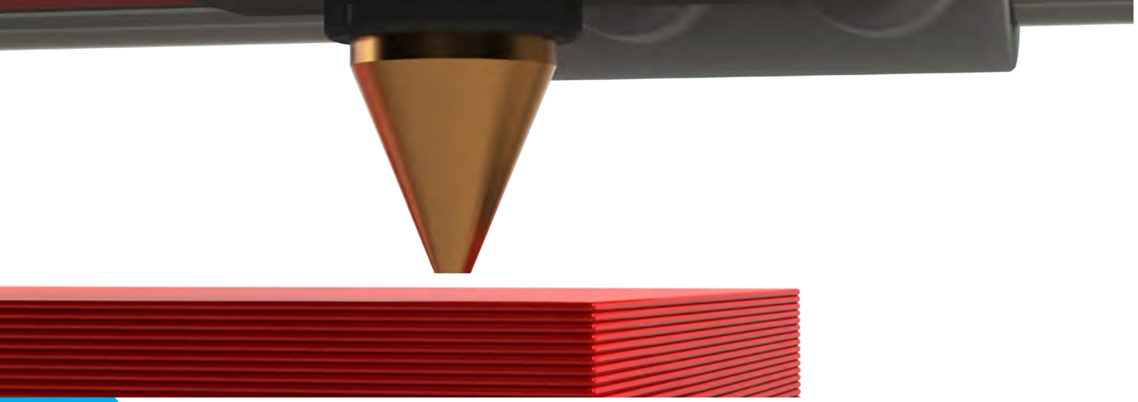
First tests with an FDM printer proved that this technique is not a viable option to produce this prototype. Lots of support material was required and due to the small wall thickness, the FDM technique was unable to build a sufficiently strong part. An SHS printer was selected because it is relatively affordable, accurate, allows for a wall-thickness of 1mm and no support material is required. These models were used to determine the design details for the electronics.



Results

A variation of designs was printed and evaluated. The latest (SHS) models were used to make the final design decisions. At this point a final design will be made and printed again, as a final check before starting production.

Company: Arexx



Fused Deposition Modelling

FDM, also known as FFF (fused filament fabrication), is a 3D print method that uses a plastic thread – a filament – to build the 3D model layer by layer. The filament melts when passing through a heated nozzle, which moves in the horizontal plane to build each layer of the model. When one layer is completed, the model moves down (or the nozzle moves up, depending on the printer design) one layer of thickness and the next layer is printed on top. This process is repeated until the model is finished.

Advantages

- The most affordable 3D printing method.
- Wide range of materials and suppliers available. Varying from very cheap to more expensive engineering materials.
- Uses 'real' plastics. Allows for production of final products.
- When the FDM printer has two nozzles, it is possible to use a soluble support material.
- FDM models can easily be post-processed by sanding and spray painting. Other post-processing methods can, for example, make the model watertight and airtight with a high-gloss finish (using a solvent).

3DPRINT WIKI

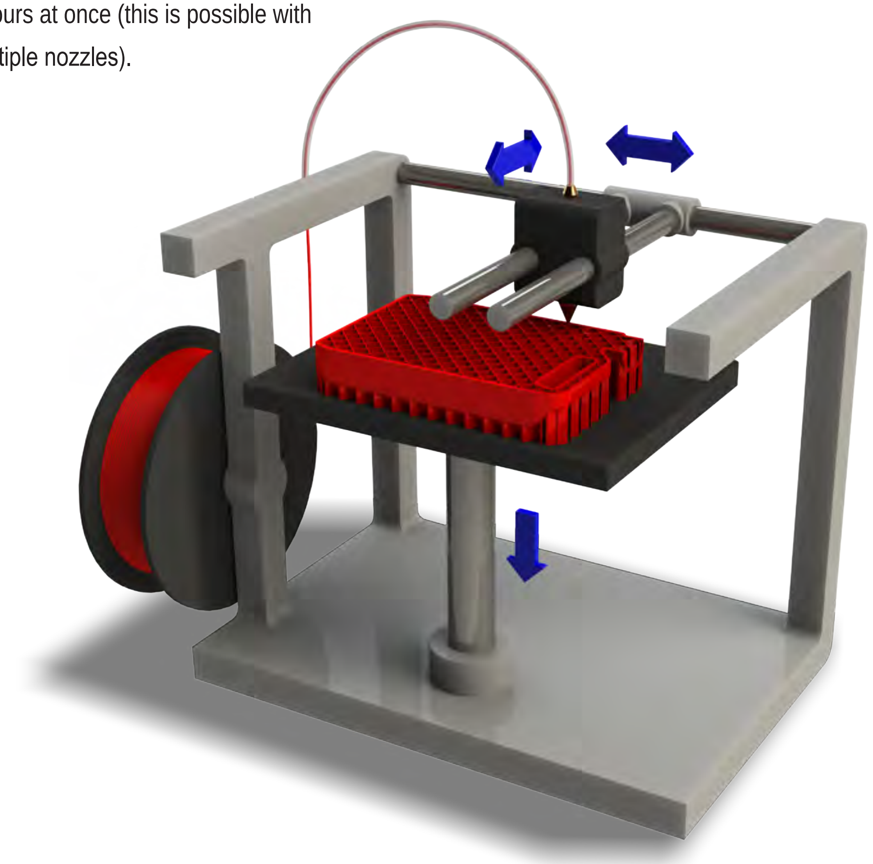
Print Method:	**FDM**
Principle:	Filament, nozzle
Materials:	Many: e.g. ABS, PLA, PC, ABS-PC, Heat-conductive, etc.
Support material:	Yes
Minimal layer thickness:	0.1 mm (depends on printer design)
Advantages:	Cheap, real plastics, soluble support material possible, easy to post process, easy to use.
Disadvantages:	Surface quality, layer strength.

Disadvantages

- Without post-processing/finishing, the FDM model has a low surface quality.
- The layers are clearly visible.
- The model is porous.
- Filament is available in many different colours, but with just one nozzle it is commonly not possible to print multiple colours at once (this is possible with multiple nozzles).

Filaments

There are many types of filaments and many more will be available in the near future. Each filament has its unique material properties. Filaments can, for example, be heat-conductive, fibre reinforced, flexible, fluorescent or contain wood, cork, bamboo or many types of metal.



CASE

Heat-Conductive Filament

Background

FDM printing is an outstanding technique to create complex geometries, such as one would need to create heat sinks. However, most plastics that are now used in FDM printing do not have good thermal conductivity. This, of course, limits FDM in its use for functional prototyping in certain applications in which heat is generated, such as in clusters of cameras for shooting 360 degree film footage.

The challenge of Bond BV and Green-PAC/Windesheim was to consider what an improved camera cluster design would look like and how it would behave in the event that thermal conductive material is available.

Research

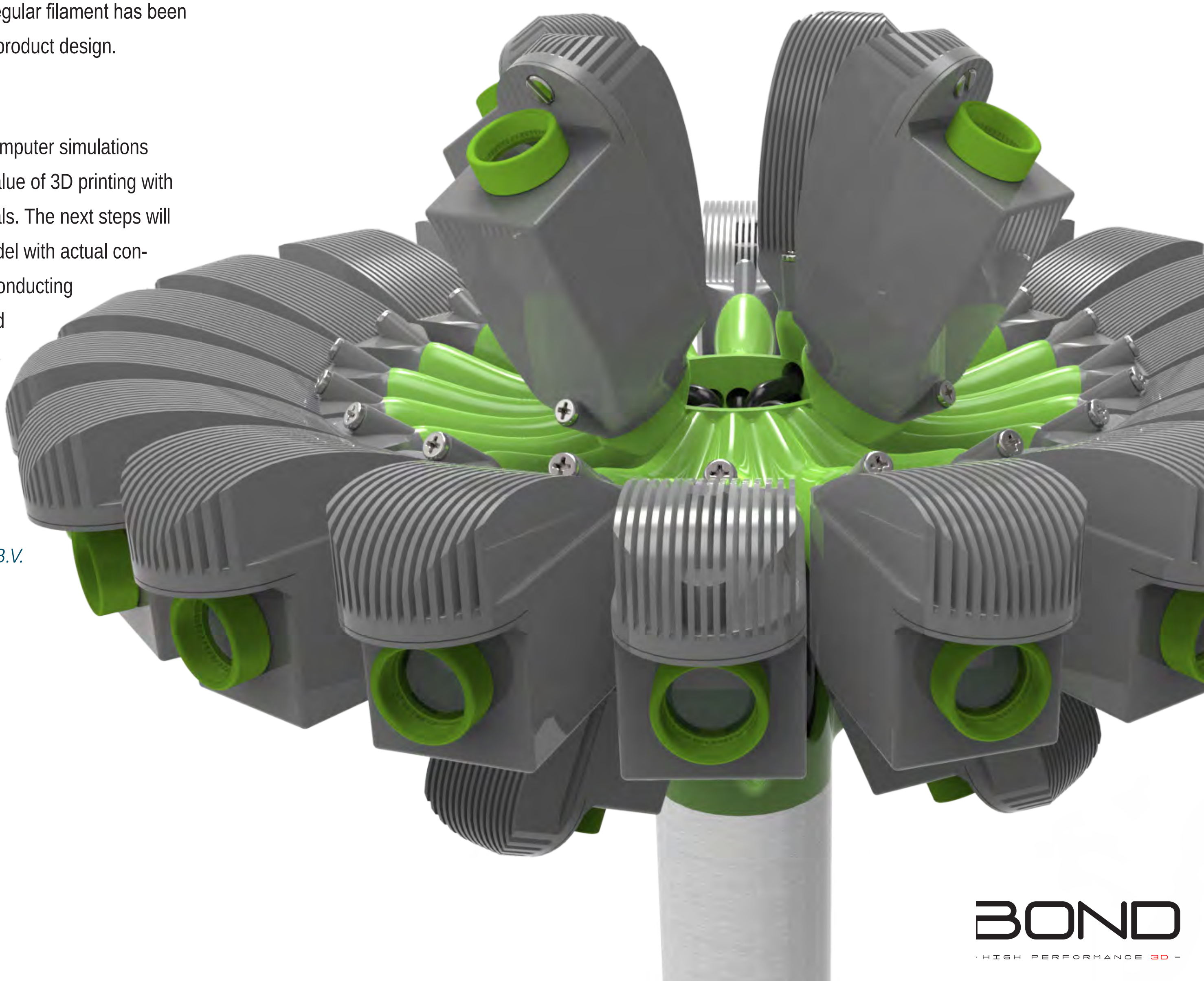
CAD designs of an individual camera bracket are made and supported by computer simulations of the thermodynamic behaviour. Bond BV is continuously improving its technology to use conductive materials as well as other advanced materials for FDM.

A 3D model with regular filament has been printed to test the product design.

Results

The design and computer simulations show the added value of 3D printing with conductive materials. The next steps will be printing the model with actual conductive material, conducting measurements and using these results to perform more realistic simulations.

Company: Bond B.V.



Print Methods:	**DMLS, SLM, EBM, LMDW**
Principles:	Melting metal powder, welding
Materials:	Many alloys have been or are being developed for this. Some examples are: stainless steels, aluminium, titanium, nickel, cobal and copper-based alloys
Support material:	Yes
Minimal layer thickness:	0.03 - 0.12 mm (varying per method and material)
Advantages:	Strength, temperature resistance, conductive, durability
Disadvantages:	Expensive, post-processing, surface quality

Metal Printers

There are several technologies for printing metal products. Although the materials and printers are still quite costly, additive manufacturing using metal already brings clear advantages:

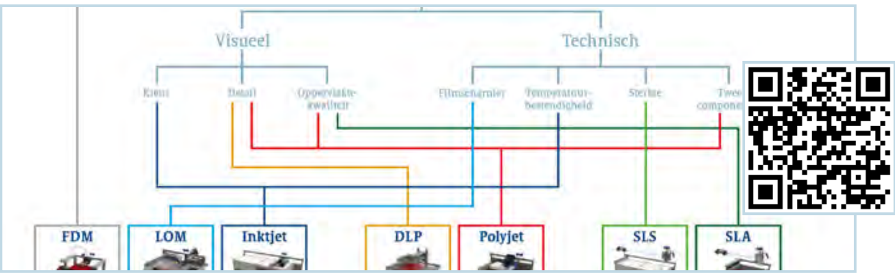
1. Weight reduction thanks to the design freedom 3D printing offers.
2. Creating complex products out of one part.

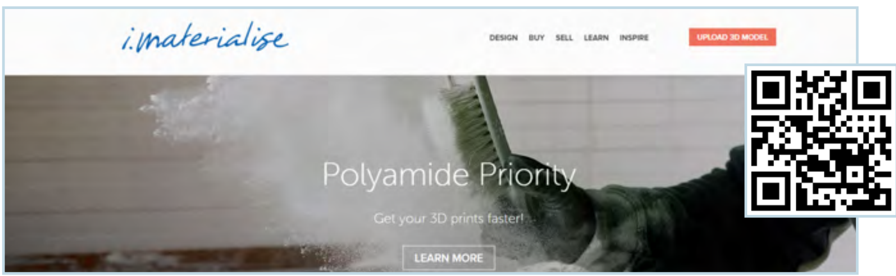
If you can reduce the weight of an armrest for all chairs in a plane, you can reduce the fuel costs. Even if the armrest itself is more expensive, you can still have a return on investment based on the reduced fuel costs.
Creating one complex product instead of ten parts that need to be assembled can also result in a considerable cost reduction and a higher level of efficiency.

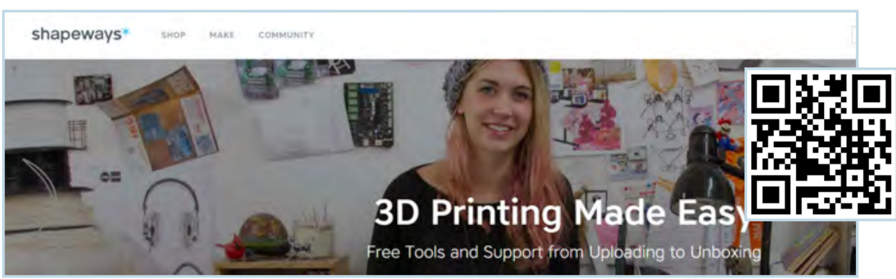
Popular methods for 3D printing metal are:

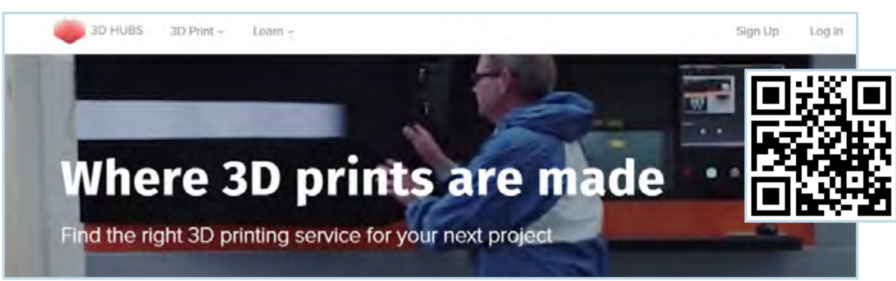
- DMLS: Direct Laser Melting
- SLM: Selective Laser Melting
- EBM: Electron Beam Melting
- LMDW: Laser Metal Deposition Welding

IMAGES OF 3D PRINTS BY EOS









Which Print Method to Use?

Ownership versus Outsourcing

If you want to 3D print a model you have two options: you can do it yourself or you can let your model be printed elsewhere. Each option has its own benefits and disadvantages to consider.

3D printing yourself may be cheaper if you print regularly. It leaves you in control of when and with what quality a product is printed. It also, however, requires investment in machinery, maintenance and, in many cases, knowledge about the production process.

Outsourcing 3D printing to companies (e.g. Shapeways, Materialise and 3D Hubs) is interesting if you want freedom of choice for every print or only occasionally need 3D printed parts. These companies may also offer consultancy for the most suitable printing methods and offer post-processing of your print. The downside is the dependence on delivery times and higher costs per product.

Selecting a 3D Print Method

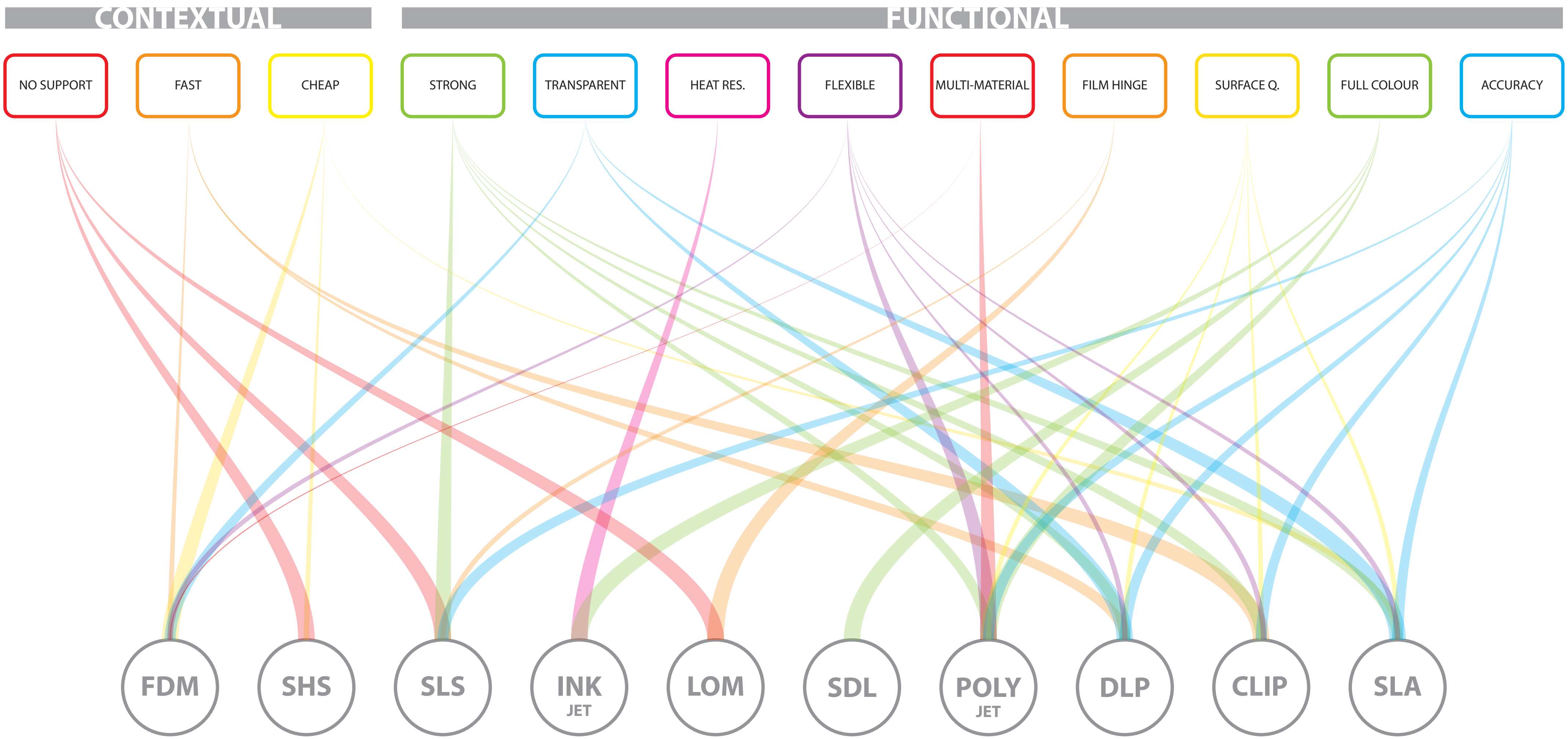
There are many different 3D printing methods and even more materials that can be used with it. If you are not an expert on this matter, how do you know which method is most suitable for your situation?

In our previous booklet on 3D printing a goal-based selection model was created. For more information on this selection model, follow the link on the left page (top image). Based on that model and new information we have created a new overview that can be used to select a method. This overview focusses on contextual and functional requirements (see next page). Please note that this overview guides you in the right direction, but it does not tell you which method and material to use. There are simply too many variables to take into account and, in many cases, there are multiple options to choose from.

You can use this model in two directions:

1. Start from your requirements and see which methods are suitable;
2. Start from the 3D print method and examine the advantages (and disadvantages).

3D Print Methods and their Qualities



SOURCE: BENDER AM / EOS

Future Advancement in AM

So far this publication has emphasized the current possibilities, technologies and applications of Additive Manufacturing of polymers. The AM industry is expanding rapidly and the following advancements are expected in the future.

More Functionality

AM offers design and production capabilities that other methods cannot offer. In 2016, HP introduced Multi Jet Fusion technology, combining printing of thermoplastics in full colour with mechanical properties approximating those of SLS printed parts. Another recent development is the introduction of machines that combine subtractive and additive manufacturing in one process. This enables precision of subtractive manufacturing in areas in which post-processing cannot take place traditionally. Such advancements increase the functionality of AM, and it is expected that the advantages of AM over traditional manufacturing methods will continue to increase.

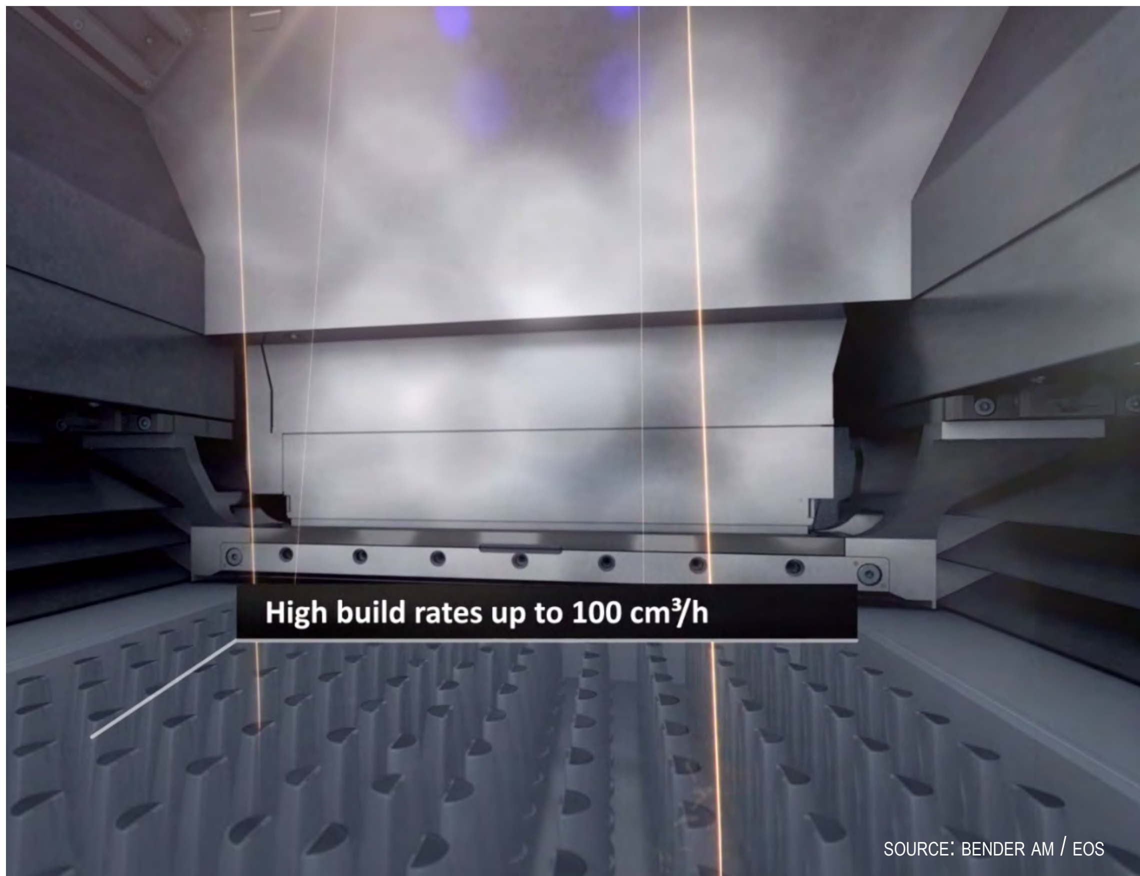
Higher Productivity

The unique capabilities of AM have created a demand to make AM viable on a large scale. AM processes are becoming increasingly consistent, productive and automated. An example is the ‘Figure 4’ technology recently introduced by 3DSystems, by which a printing method similar to CLIP is used in conjunction with automated build-tray removal, cleaning and post-curing. AM has already replaced traditional manufacturing methods for some products (e.g. for the aviation industry). Further advancements in productivity will increase the application of AM for the production of a wider variation of products.

Increased Convenience

In addition to productivity and functionality, there is a growing demand to make AM convenient. Software and machine interfaces are becoming more intuitive and user-friendly. Production by AM is also becoming more streamlined and embedded with design software. Such developments lower the bar to use AM within production facilities and design firms, but could also lower the bar to use AM in environments such as healthcare and education.

SOURCE: UP3D.COM



SOURCE: BENDER AM / EOS

Cooperating Companies

Level by Level (LBL) responds to the developing opportunities for 3D-printing on the medical market, focussing on dental applications.

www.levelbylevel.nl

Bond BV is a Dutch company in high performance 3D-printing, bringing advanced FDM printing technology and materials together to new industrial applications.

Inspired by our values, Spanninga's vision focuses on a strong link between technology and design to ensure security of bicycle users. Our motivation being people, innovation and efficiency.

www.spanninga.com

VUURS will renew fire. With the newest materials, technologies and an innovative design we will give fire the strength to bring us further once again.

www.vuurs.nl

Myeasy3D fully embraces 3D printing. Making it accessible and affordable by designing and developing turnkey solutions for the entire process. From the designer to the consumer.

www.myeasy3d.com

AREXX Engineering and its Far East Partners design, manufacture and distribute a wide range of electronic products for hobby, professional and educational use.

www.arexx.nl

Kumagaya is an expert in rotation and vacuum moulding. Our expertise and in-house development of new methods allow us to create specialized and very accurate products.

www.kumagaya.nl

The Moba Group is the world leading manufacturer of egg grading, packing and processing machines. Moba offers global solutions and is close to its customers at the same time.

www.moba.net

Glossary

Additive Manufacturing (AM)
A manufacturing process by which products are created by adding material layer by layer. It is often referred to as 3D printing.

Binder
A material that binds/glues powdery base material together.

CAD
Computer Aided Modelling. Used to create digital 3D models.

Filament
Wire used as base material for 3D printing using FDM/FFF.

Overhang
The part of the product that hangs free.

Photopolymer
Liquid UV-sensitive resins which are solidified with the aid of a UV-light.

Post-processing
The work that has to be done after the 3D print leaves the printer, such as removing support, sanding the product and painting it.

Post-curing
A curing-treatment conducted after 3D printing a photopolymer to enhance material strength and stability, often using a UV-chamber and an increased temperature.

Support
A structure that is printed to support overhanging elements in the 3D printed product. Has to be removed in post-processing.

STL-file
STL is the most common file format for 3D printing.

Sintering
The process of heating material up to just below the melting point. Contact points between the powder will partly merge together, creating a solid product.

Slicing Software
Software used to 'slice' the 3D CAD file into printable layers. All actual print settings can be set here (layer thickness, print speed, infill type, etc.).

SME
Small and Medium Enterprises

Thermoplastic
A plastic that becomes pliable above a certain termperature and solidifies when cooled.

Thermoset
A plastic which is irreversibly solidified by curing.