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Additive Manufacturing

The path toward individual production

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Hessen Nanotech

Additive Manufacturing

The path toward individual production

Volume 25 of the Technologielinie Hessen-Nanotech Publication Series

Imprint

Additive Manufacturing

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Content

Preface

It is Friday evening and you are taking a shower when suddenly the water turns freezing cold. Although the plumber arrives immediately, the necessary spare part will not be available until next week. Would it not be fantastic if the plumber had a 3D printer and could simply print the necessary part right there?

Yet what might sound like a futuristic dream is already becoming reality in some fields. Up until a few years ago, the potential of 3D printing was restricted to prototype construction. However, the development of 3D printing technology continues to progress unabated, extending its reach to include private households. Today it is even utilised in demanding fields such as aerospace technology. Airbus, for example, manufactures parts for the A350 via additive manufacturing, which also includes 3D printing.

Resource efficiency is one important benefit, which has remained underappreciated by the broader public. Whereas classic machining removes material from a large block of material until only the desired form remains, 3D printing takes the opposite approach. It places material in precisely the position where it is required, similar to the natural growth process. That is why it is also significantly easier to transfer natural structural principles to technical systems when using this process. As a result, this offers a major potential for bionic developments, an area with opportunities that have thus far remained untapped due to a lack of suitable production methods.

The expected proliferation of additive manufacturing techniques will also call into question existing value chains and enable new business models and logistics processes. In future it will be possible to manufacture spare parts directly on location at vehicle workshops, and also print customised products at businesses for electrical devices or design articles, for example. The digital blueprints can be made available on Internet platforms.

Another field in which completely revolutionary products and applications also appear realistic is biomedical engineering. Customised implants and dental prostheses are already a success on the market. Health professionals now hope to treat burns by means of bioprinting, namely by "printing" human tissue such as skin.

I am excited to see how these developments progress, as they have gained significant momentum in recent years and promise so much. We hope that this brochure will provide you with thought-provoking impulses for innovative projects.

Tarek Al-Wazir

Tarek Al-Wazir
Minister of Economics, Energy, Transport and Regional Development – State of Hessen

1. Introduction: Additive manufacturing – Potentials within the context of Industry 4.0 – the vision

The development of additive manufacturing processes in the 1980s laid the groundwork for the fourth industrial revolution, or Industry 4.0. Whereas the first industrial revolution refers to the transfer of manual labour to mechanised processes powered by water and steam from the second half of the 18th century, the second industrial revolution saw the rise of mass production on electrically powered assembly lines. The third major developmental leap for industrial processes was based on the use of information technologies to automate production. The intelligent organisation of decentralised production units by linking information and production technology in the Internet of Things will form the foundation for the fourth industrial revolution. Experts regard this development as a major opportunity for the German economy in the face of global competition.

In future, customers will likely be able to purchase a product via an Internet portal, access the component data, and modify, archive and monitor the status of a production order. The manufacturing process will be carried out via decentralised production units where it is most effective in terms of the customer's location and the use of the manufacturing units' capacities. Instead of the products themselves, only their production data will be sent around the globe. Furthermore, this data can be adapted to individual requirements even at advanced stages of the production process. These digital factories will no longer be located only in the Far East. Instead, there will be decentralised production units located in regional proximity, which will enable 'single units off the line' at prices comparable with mass production.

Products, machines and transport boxes are connected with the web via microchips. The Internet of Things will enable the autonomous organisation of intelligent production procedures, resulting in an increase in productivity of up to 50 per cent. In addition, saving raw material information in the product will enhance the recycling capabilities and enable closed material cycles. Experts forecast potential savings for energy and resources of 20 to 25 per cent over the middle term.

Additive manufacturing processes are expected to play a critical role in the context of the fourth industrial revolution. The generative nature of these technologies will completely revolutionise the previous paradigm of conventional technologies which are based on material removal. These include milling, drilling or turning. This will not only save resources and prevent production waste but will also enable product parts with complex geometries impossible to replicate using conventional methods such as casting processes.

Experts assume that additive manufacturing will initially establish itself as a supplement to the existing production processes. One striking aspect is the large number of small businesses already being founded as a result of the ongoing development of the production processes. The ability to operate mini-factories with new business models and customised products has enabled 3D printing entrepreneurs to become established in almost all major cities. Furthermore, they have also succeeded in obtaining the necessary capital via the Internet and social networks through crowdfunding campaigns (see Horscher, Florian: 3D-Druck für alle – Der Do-it-yourself-guide. München, Wien: Carl Hanser Verlag, 2014).

"There will be a vast range of niches," predicts the Internet visionary, Chris Anderson, for the future of 3D printing. "We will simply see more of everything: more innovation, in more locations, from more people, who will focus on more niches and narrower niches. Together, all of these new products will reinvent industrial economy. Often there will only be a few thousand units in a single run. However, these will be precisely the right products for increasingly demanding consumers."[1] (Source: Anderson, C.: Makers. Das Internet der Dinge: die nächste industrielle Revolution. München, Wien: Carl Hanser Verlag, 2013)

1 Translated from German quotation

The use of additive techniques for the construction of a space station on the moon (Source: ESA, Foster+Partners)

This development also appears to be an attractive option for countries which have allowed an enormous decline in industrial production in favour of the service sector in recent decades. Additive manufacturing technologies have been identified and perceived as the key to re-industrialising economies.

During his speech on the State of the Nation in February 2013, the United States president, Barack Obama, described additive manufacturing as the foundation for new growth in US production. For this reason the White House intends to provide one billion US dollars in funding and establish a network of funding institutions for the American economy. With the Horizon 2020 research programme, the European Commission also aims to support the expansion of additive manufacturing in Europe and strengthen this field through investments. Whereas US companies are the key players in the field of extrusion processes, three German equipment manufacturers – SLM, Laser Concept and EOS – largely dominate the important metal systems for industrial production in the automotive and aerospace sectors.

However, the Western world is not alone in striving to make greater use of additive manufacturing processes. Certain Asian countries are also paving the way for future developments by providing financial backing. In China and Singapore funding in the three-digit million range has been made available with the aim of preparing the local industry for the process of transformation into the Internet of Things era. China already expects a turnover of 1.6 billion US dollars to be generated by Chinese companies utilising additive technologies in the coming years (Source: VDI: Statusreport "Additive Fertigungsverfahren", Verein Deutscher Ingenieure e.V., September 2014).

The market for additive manufacturing is still in its infancy. Nevertheless, there is no doubt that the transformation process toward a greater use of additive manufacturing technologies is inevitable for a number of applications and industries. Numerous different factors will influence the speed of the transformation process. The procedures have not yet achieved mass production capabilities. Above all, the time and labour commonly required for reworking additively fabricated components indicates a need for extensive development. The issue of which product areas and applications will be best suited for additive manufacturing is currently a topic of intense discussion. It remains to be seen whether we can truly describe this transformation as an industrial revolution. However, the developments on the market over the last two years indicate the promise of major potential especially for German and, thus, Hessian companies. In view of this, the following chapters will describe the key technological conditions governing additive manufacturing processes and their potentials for the various industrial sectors in greater detail.

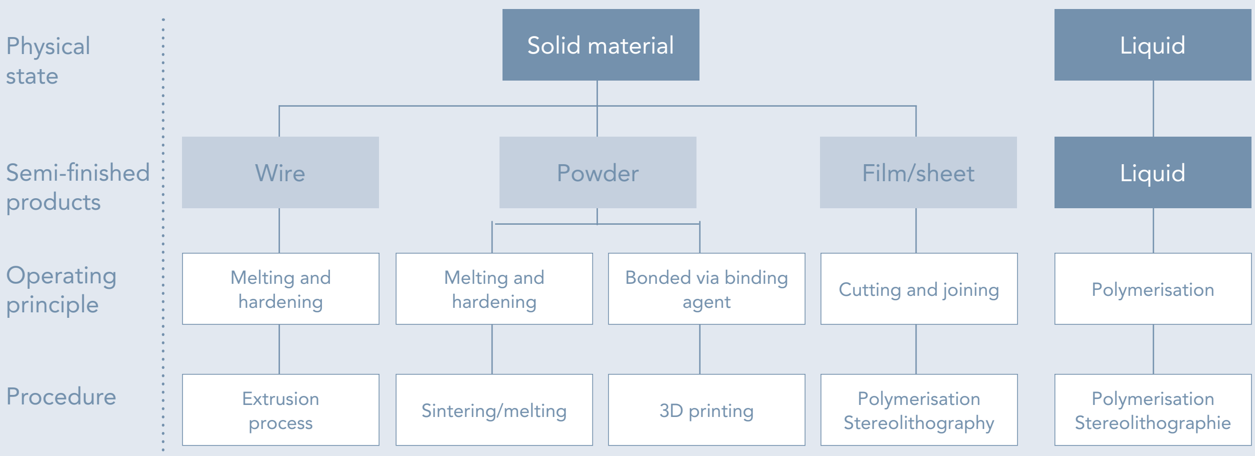
2. Additive technologies and manufacturing procedures

In the science fiction saga Star Trek, the term 'replicator' refers to a system which is capable of assembling entire components and weapons, food and beverages from individual atoms at will. In 1987, Marshall Burns named his idea of a digital home factory the 'Fabber'. These are small decentralised manufacturing units which would make the vision of individual component production a reality. More than 20 years have passed since then. However, the ongoing development of production technology, software and materials is making this future scenario increasingly realistic (Peters 2011). Additive manufacturing principles form the basis for this development. In contrast to conventional production processes which remove material (such as turning, drilling, sawing or milling) or reshape materials (such as bending or drawing), this approach is based on addition or generation. Hence, the term additive (sometime called generative) manufacturing has become established in technical literature. As a result of the considerable sales in areas ranging from consumer systems to private systems, the term '3D printing' has also established itself as an alternative, yet somewhat too succinct, description.

2.1 Fundamental principles and procedures

Today's common additive manufacturing procedures and types of systems can be categorised into five additive manufacturing principles, based on the materials utilised. This classification is based on differing semi-finished products used as precursors and various operating principles utilised to assemble the components layer by layer. As such, the broad range of systems can be divided into the following processing groups: stereolithography, laser sintering/laser melting, 3D printing, fused layer modelling or layer laminate manufacturing.

A selection of the individual technologies is generally based on the materials which can be used, the precision which can be achieved, the potential mechanical quality, the maximum system construction space, along with the cost framework. Given the current market dynamics, the conditions are in a constant state of flux. The following table is intended to serve as a guide:



The fundamental principles of additive manufacturing processes (Source: based on: Gebhardt, A.: Generative Fertigungsverfahren: Additive Manufacturing und 3D Drucken für Prototyping – Tooling – Produktion. München, Wien: Carl Hanser Verlag, 4. Auflage, 2013)

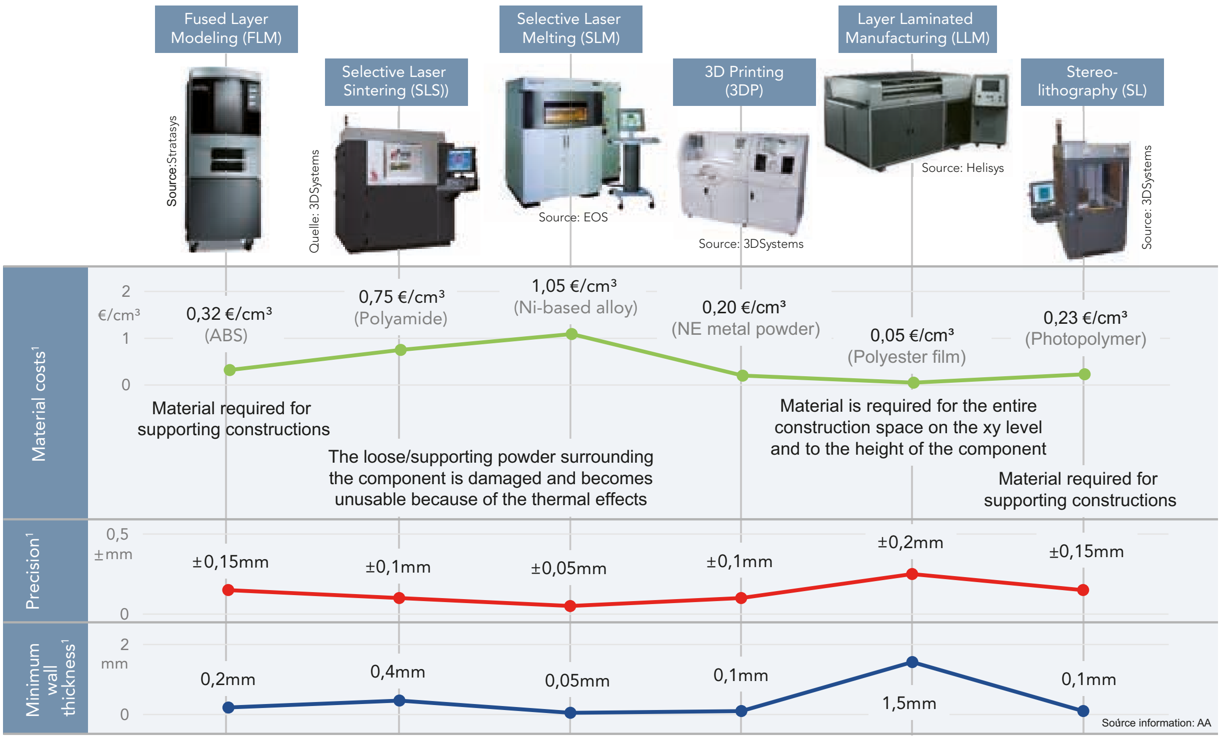


Table: Comparison of additive manufacturing processes (Source: Anderl, R.: Additive Manufacturing oder generative Fertigungsverfahren – vom Prototypen zur Massenfertigung? Lecture at the „Additive Manufacturing" event held by the Ministry of Economics, Energy, Transport and Regional Development – State of Hessen, Hanau, 23rd September 2014)

2.1.1 Stereolithography

Stereolithography (SL) was developed at the University of Texas in Austin at the beginning of the 1980s and is regarded as the oldest additive manufacturing process. Chuck Hall patented the stereolithography process in the year 1984. 3D-Systems Inc. presented the first system at the end of 1987 and has commercialised and marketed it ever since. Stereolithography currently achieves the greatest possible accuracy. As a result, it is the most important technique for creating master forms for fine casting, polyamide and vacuum casting. FormLabs launched the first SL desktop system in 2012.

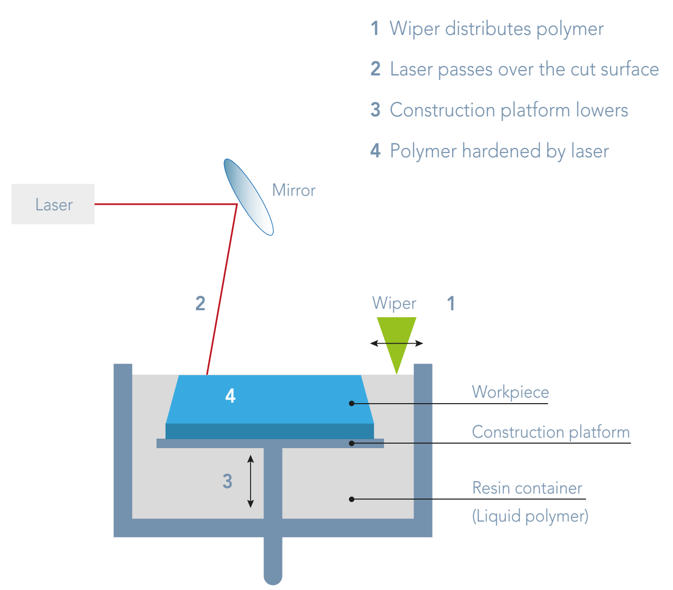


Diagram: The stereolithography process

The process

Stereolithography creates component geometries based on 3D CAD data by means of locally hardening (curing) a light-sensitive photopolymer with the help of a laser beam. Photopolymer resin is first filled into a resin vat and the component platform is submerged below the surface to a depth equal to the thickness of one layer. Exposing the lines or layers of the shaped part geometry to the laser hardens the photopolymer. This creates the first layer of the desired component. The component platform is progressively lowered in steps equal to the thickness of one layer. The resin flows onto the platform from the side and a blade distributes the resin equally across the hardened structure before the next layer is exposed to the laser. The process is repeated until the shaped part has been completed and the desired component height has been reached. Thin supporting structures are required to prevent the deflection of the overhanging layers in the resin bath. These have to be detached from the component platform after removing the component. The stereolithography components then have to be stored under UV light in order to completely harden the material. As an alternative to the laser, some systems utilise UV lamps and a screen. This eliminates the complex mirror unit required to control the laser beam.

Transparent finish of a stereolithography component (Source: Materialise)

Materials

Stereolithography systems can only process liquid photopolymers such as epoxy resin or acrylic resin. After hardening, these materials possess adequate stability and temperature resistance. The thin-wall version creates semi-transparent components and the interior wall structures and reinforcements shimmer, depending on how the light falls. However, this processing technology also has a number of disadvantages. The classic approach with the resin bath does not allow the use of different materials during a single working process. Resin systems in liquid form also have a significant environmental impact and, moreover, a limited shelf life. The ongoing development of the resin primarily focuses on improving the thermal stability.

Component sizes, precision, reworking

Stereolithography can achieve the highest precision among additive manufacturing processes. This is primarily due to the thin layers with a detailed resolution of 0.02 millimetres. The components possess very good surface qualities, they are smooth and the layer structure is imperceptible. Standard systems have a construction space with dimensions between 250 x 250 x 250 millimetres and 1000 x 800 x 500 millimetres. Larger components can be assembled from multiple smaller components. Subsequent surface treatment using varnishing, coating or metallising is common. However, the semi-transparency of the material is lost as a result. The surface quality can be further enhanced by polishing or machining.

Samsonite S'cure prototype in the Mammoth stereolithography system (Source: Materialise)

Application

Stereolithography is highly important for model construction as a means of manufacturing demonstration objects. Given the very high quality, the components are also suitable for use as functional prototypes or master models for fine casting and vacuum casting. However, stereolithography components cannot generally be used directly due to their low thermal stability. Process variants can now also be utilised to generate nanostructures and microstructures.

Cost-effectiveness

By virtue of its history, stereolithography is the most frequently used additive manufacturing technology. The prices for common stereolithography systems have decreased in recent years. Nevertheless, they still exceed 50,000 euros. A number of service providers have been established as a result. Since 2012 desktop systems and kits with lower precision have been available for approximately 3,000 euros. However, the material is four times as expensive as that used in extrusion systems such as FLM (fused layer modelling; see chapter 2.1.3). Furthermore, as the excess material remains in the construction space after the manufacturing process, a higher material consumption than the component volume has to be reckoned with.

Special processes and system types

Mammoth stereolithography

The service provider Materialise from Belgium has commissioned a mammoth stereolithography system in order to address the rising demand for large components and models with short process times. This system is capable of generating components with maximum dimensions of 2,100 x 700 x 800 millimetres within a period of four to eight days. In addition, Materialise offers a metal coating for creating functional components. There are four different resin systems to choose from, each displaying different qualities.

PolyJet Modelling (PJM)

The polyjet technology is comparable with inkjet printing. A printhead applies layers of liquid photopolymer to the component platform. These layers are directly hardened using UV light. In this case, the resin bath can be eliminated. However, supporting structures also need to be printed to generate protruding elements. Polyjet modelling achieves very high levels of precision of 16 microns for the z-axis and 42 microns for the X and Y axis. Furthermore, it is the only system technology capable of utilising three different materials in one process to create multimaterial applications.

Micro-stereolithography (MSL)

In 2013 Professor Jürgen Stampfl and his team at the Technische Universität Wien developed the world's smallest stereolithography printer, weighing only 1.5 kilogram and with the dimensions of a milk carton. It works with liquid resin, which is selectively hardened through the use of LED light. The layers have a thickness of 0.05 millimetres. Other research institutions are also working on micro-stereolithography given that the technology is regarded as having major potential for future applications.

The world's smallest stereolithography printer (Source: TU Wien, Prof. Jürgen Stampfl)

Digital Light Processing (DLP)

Digital light processing is another variant of the stereolithography process and works with UV light to harden the photopolymer layer by layer. The light first hits the surface of a microchip into which numerous movable micro-mirrors are integrated. The beams of light are then reflected into the areas of the construction space to be hardened, and serve to successively generate the component structure. DLP systems are very compact, comparatively affordable and are the preferred system in the jewellery field, for example.

3D laser lithography

Nanoscribe, a spin-off of the Karlsruhe Institute of Technology (KIT), commenced the commercialisation of 3D lithography in 2008 with structures that can be implemented in nano dimensions. The technology is based on multiphoton polymerisation in which high-resolution 3D structures are printed in photosensitive materials. A light-sensitive coating is exposed to pulses of light and hardens. The excess material is then washed out.

Lithography-based Ceramic Manufacturing (LCM)

A technology for the additive manufacturing of high-performance ceramics was likewise developed at the TU Wien, also in the research group headed by Professor Jürgen Stampfl. The LCM process is based around a photosensitive and initially viscous plastic and ceramic particle mixture (mixing ratio 1:1). This is applied in layers and hardened to form fine structures using a specially developed LED projection system. After the additive process, debinding of the resulting plastic-ceramic blank takes place in a thermal process. The polymer component is completely burnt out and the ceramic particles sintered. The components have a density of 99.4 per cent and retain their actual geometry after shrinkage, namely the volume change without material removal or the application of pressure.

3D lithography in the nano dimension (Source: Nanoscribe)

2.1.2 Selective Laser Sintering

Selective laser sintering (SLS) utilises powdered raw materials which are then melted using a laser. The process was developed in the mid-1980s at the University of Texas by Joe Beaman and Carl Deckard. Laser sintering is extremely important for the industry because of its ability to achieve qualities approaching the series material. It is utilised for both prototype and tool construction, and also for direct component manufacturing (direct digital manufacturing). At the beginning of 2014 a number of key patents for selective laser sintering expired, allowing a decrease in the consistently high prices for components and systems prevalent in the recent years. The term selective laser melting (SLM) is now utilised when referring to processing metal powders. As a result of the use of multiple lasers in one system, a productivity increase of 100-fold to 1,000-fold is expected in the coming years.

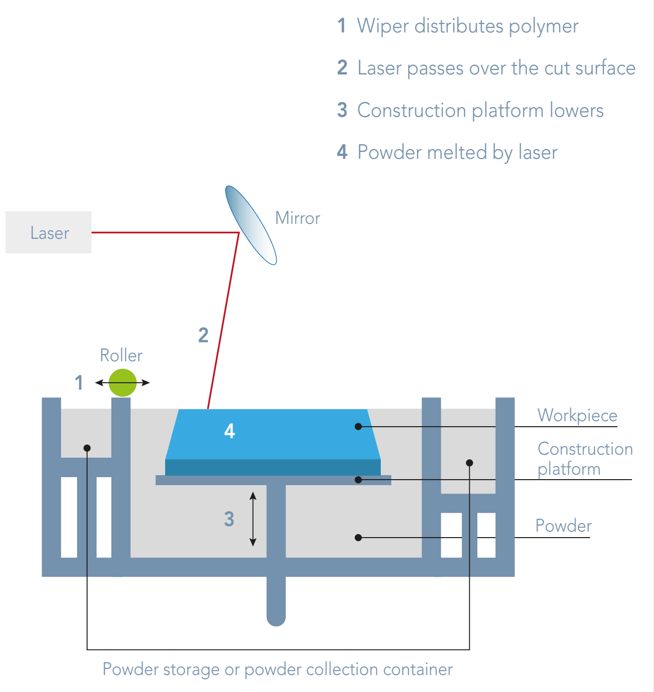


Diagram: The selective laser sintering process

The laser sintering process (Source: EOS)

The process

Laser sintering is based on the local sintering and melting of powdered materials through the heat emitted by a laser beam, utilising 3D CAD data. A roller-shaped coating unit applies a thin, even layer of powder to the printing bed and smooths it. Melting layers or lines of the corresponding area and the subsequent cooling and hardening creates complex shaped part geometries on a powder bed. Once the exposure of a component layer has been completed, the printing bed moves downward one layer and material powder is applied again (material thickness between 0.001 and 0.2 millimetres) and the sintering process is repeated for the next layer structure. Because the solidified material composite is surrounded by loose powder, a supporting structure is not required to construct protruding elements. However, additional structures are required to hold the component in position when working with high-energy lasers. The entire printing compartment on most systems is heated to a temperature below the melting point of the powdered material used to reduce the process time. The entire printing compartment has to be cooled evenly over a period of several hours before removing the finished component from the powder bed. Unused powder can be reused.

Component removal from the powder bed (Source: Evonik Industries)

- Polyamide powder: VESTOSINT®
  has very low water absorption. It is the most commonly used material for laser sintering. Parts manufactured with the material demonstrate very good mechanical properties and good surface quality.

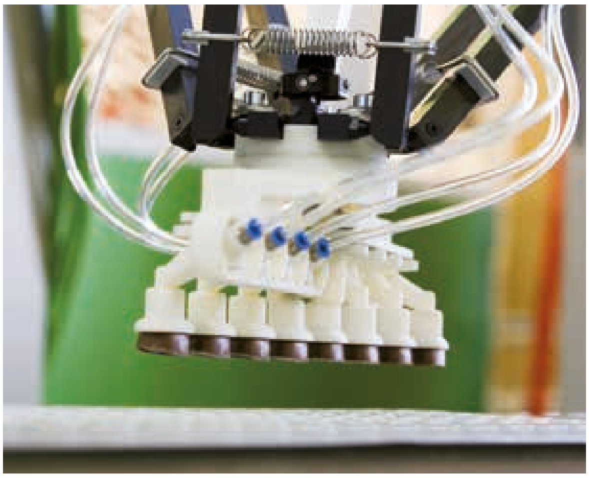
- PEBA powder: VESTOSINT®Z2611
  has eight times greater flexibility and five times greater tensile strength in comparison to the standard material.

- PEEK powder: VESTAKEEP® PEEK
  is renowned for its high temperature resistance and chemical resistance. It is also distinguished by a very high melting point of 340 degree Celsius.

Table: Laser sintering materials offered by Evonik (Source: Evonik Industries)

Materials

Essentially every material which can be melted and manufactured as a powder is suitable for use with selective laser sintering. Numerous plastics (for example PA 22, PA 12, PS, PEEK, thermoplastic elastomer), ceramics, metal alloys (tool steel and stainless steel, aluminium, titanium) and quartz sand are commercially available. The powders are generally manufactured synthetically because of the need for evenly sized grains. When handling powdered materials with grain sizes between 20 and 100 microns the existing legal regulations regarding work safety apply. Furthermore, experts such as representatives from the Federal Institute for Occupational Safety and Health (BAuA) strictly advise caution when handling the powder as the ultrafine particles can enter the human lung. As such, wearing a mask is recommended. When processing metallic powder, a protective gas (generally nitrogen or argon) is normally used inside the compartment to prevent oxidation. Researchers at the Fraunhofer Institute for Laser Technology (ILT) in Aachen have succeeded in additively manufacturing components consisting of different copper alloys with a density of 99.9 per cent by integrating a 1,000 watt laser system into an existing SLM system. Furthermore, the process also enables objects to be manufactured out of high-strength zirconium oxide ceramic and aluminium oxide ceramic.



Laser-sintered handling system (Source: Robomotion, Fraunhofer Institute for Manufacturing Engineering and Automation IPA)

Cynara – laser-sintered light (Source: CIRP, design: Sven Eberwein)

Component sizes, precision, reworking

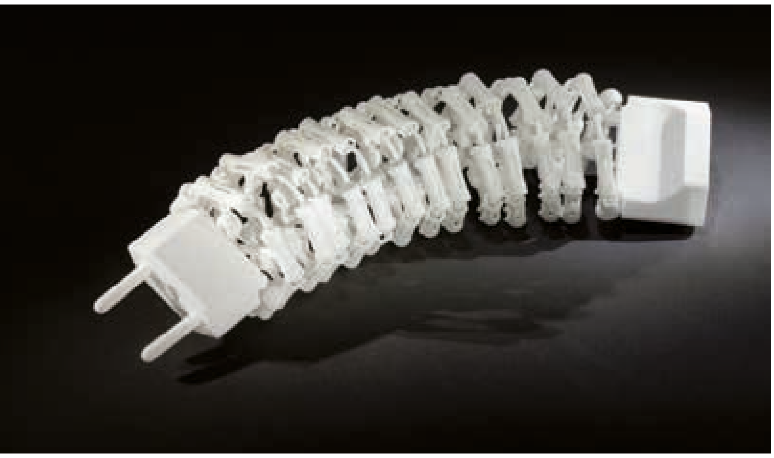
The construction spaces of laser sintering systems are currently between 250 x 250 x 150 millimetres and 720 x 500 x 450 millimetres. Some large systems work with two lasers to shorten the processing time. The generation rate for metal systems is currently approximately one cubic centimetre per hour. Systems with up to eight lasers are currently in development. Laser-sintered components have rough surfaces as a result of the grain sizes of the powder. As a rule, the components have a precision of +/- 0.1 millimetres, while values of +/- 0.02 millimetres have now been achieved for metal components. The usual layer thicknesses for metals such as stainless steel and tool steel are 20 microns or 40 microns. The layers are 30 to 50 microns thick in the case of aluminium. Whereas creating highly dense metal components required infiltration with low-melting metals up until a few years ago, laser melting now generates highly dense components with very good mechanical characteristics. In fact, the material strength actually exceeds that of commercially produced components in some cases. Depending on the component geometry, significant warpage must be factored in as a result of the thermal influence of the laser, in particular for the SLM of metal parts. The rough surfaces can be smoothed to a glossy finish. Before starting a new SLM process the component platform must generally be face milled.

Applications

Up until a few years ago laser-sintered components were primarily utilised as technical prototypes or functional prototypes. Today, laser sintering or laser melting can also be employed to directly manufacture customised components and small series. The typical areas of application include biomedical engineering (such as implants and prostheses), tool and die manufacturing (alloy die casting and fine casting, for example) along with mechanical engineering and aerospace. Robot grippers, for example, have been manufactured by means of laser sintering. Laser sintering has also been utilised in the design and jewellery industry for approximately a decade. GE Aviation is currently constructing a site with additive production facilities in Alabama (completion in 2015), where laser sintering systems will be used to manufacture fuel nozzles for aircraft engines.

Cost-effectiveness

Because of the high system costs (average price of an industrial system: 80,000 US dollars; Horscher, Florian: 3D-Druck für alle – Der Do-it-yourself-guide. München, Wien: Carl Hanser Verlag, 2014) the use of laser sintering and its process variants must be carefully calculated. The construction platform is generally densely packed to make operating the system financially viable or profitable. The costs for laser-sintered components range from a few hundred to several thousand euros, depending on the material used. As a result, the costs are higher than those of other processes, which tends to exclude its use in a small-company context. As such, service providers are common.



SLS extension cord ‚Double helix CABLE' (Source: CIRP, design: Yusuke Goto)

Special processes and system types

Electron beam melting (EBM)

In one process variant an electron beam is used instead of a laser to achieve a higher power output (10 kilowatt in comparison to 250 watt for laser sintering). This enables even high-strength steels to be manufactured with a shorter processing duration. Electron beam melting enables the direct manufacturing of metallic components. For this reason, the Swedish systems manufacturer Arcam AB markets its EBM systems under the brand name 'CAD-to-Metal'.

Selective mask sintering (SMS)

Selective mask sintering is currently in development as an alternative process to laser sintering in order to significantly reduce the process duration of laser sintering. This process works with powder made of plastics (such as polyamide) which is applied in layers. In contrast to laser sintering, the particles are not melted by a laser but rather an area is illuminated by an infra-red lamp. A mask serves to ensure that the component geometry is only generated in places where the light can pass through the mask. As with SLS, supporting structures are not required. The process enables similar levels of mechanical quality but is currently in the testing phase.

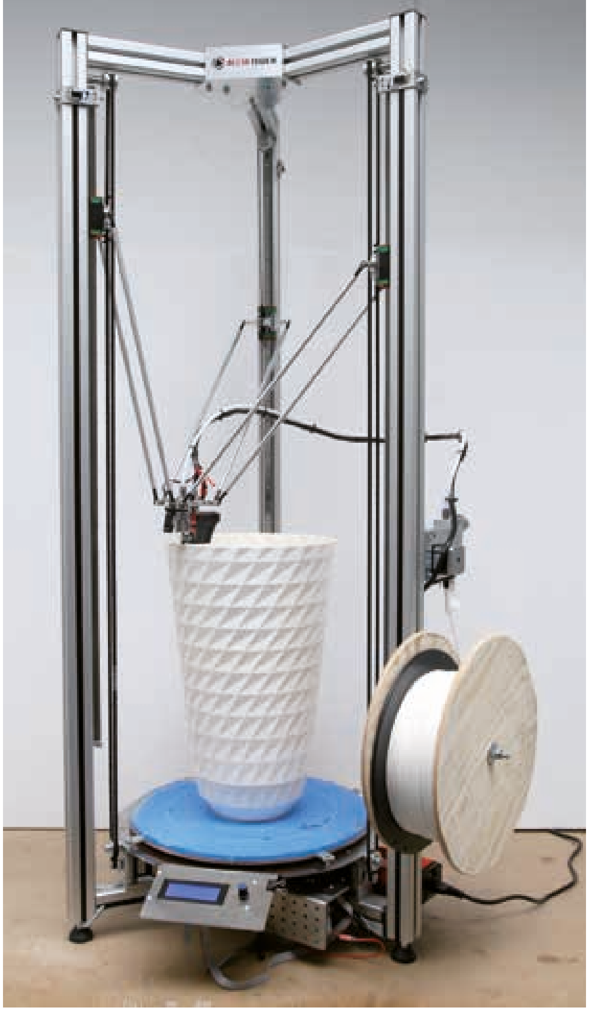
Solar sintering

The German designer Markus Kayser has developed a solar sintering system which only requires sand particles and sunlight for additive component manufacturing. A lens focuses the sunlight on a point in the bed of sand. The process then follows the familiar pattern. A solar-powered 3D printing unit serves to lower the component layer and apply the next layer of sand. Tests in the Sahara demonstrated that the resulting heat energy is sufficient to melt the silicate particles together and cool them as glass.

The German designer Markus Kayser with his solar sintering system at work (Source: Markus Kayser)

2.1.3 Fused layer modelling

As a result of the expiry of a number of industrial property rights in 2009, fused layer modelling processes have developed into the most important additive manufacturing techniques for use in creative professions and private contexts. This is due to the less complex design of the systems, the easy handling and the broad range of available materials. The good mechanical qualities also play a role. Because the systems generally work with filament materials the terms fused filament fabrication (FFF) and fused layer modelling (FLM) have become prevalent. The commonly used term fused deposition modelling (FDM) is a trademark of the American company Stratasys Ltd.



The extrusion process in operation (Source: Delta Tower, Thorsten Franck)

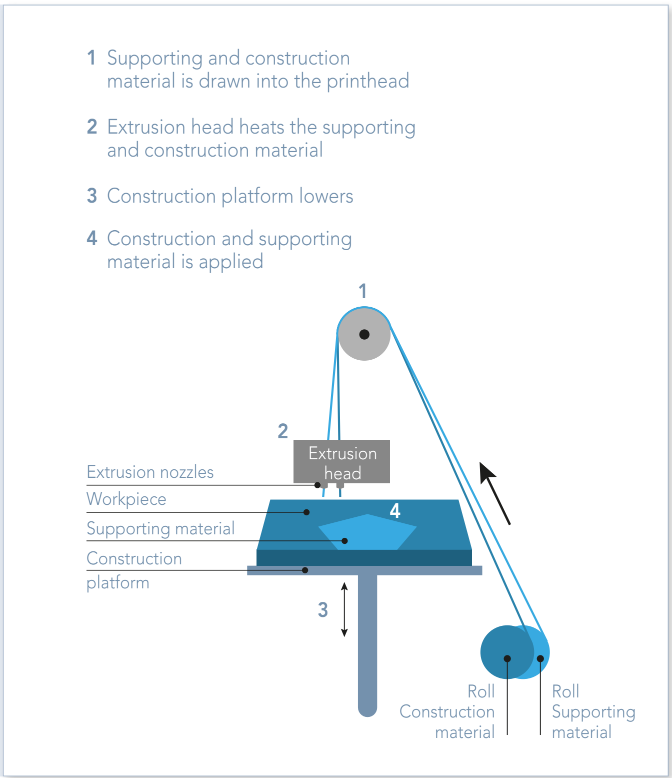


Diagram: The extrusion process

The process

Fused layer modelling processes work with a material which softens when heated. Similar to a hot glue gun, the material is pressed through a heated nozzle and applied either in lines (for example FLM) or in droplets (for example freeformer). A control mechanism regulates the distribution of the layers of the material on the component platform or on the existing structure, where the material then immediately cools and hardens. The component is manufactured successively by fusing the individual layers. The print bed is lowered a fraction of a millimetre after every layer. The layer thickness is determined by smoothing with the nozzle. The common layer thicknesses are between 0.025 and 1 millimetre. Undercuts and hollow spaces are only possible to a limited degree with this process. As such, fine supporting constructions are required to manufacture steep component geometries. On new system types the supporting material is simultaneously supplied from a second coil and applied. The supporting construction has to be removed after printing. The use of a water-soluble (such as polyvinyl alcohol) or an alkaline-soluble thermoplast (such as Belland) is recommended.

Materials

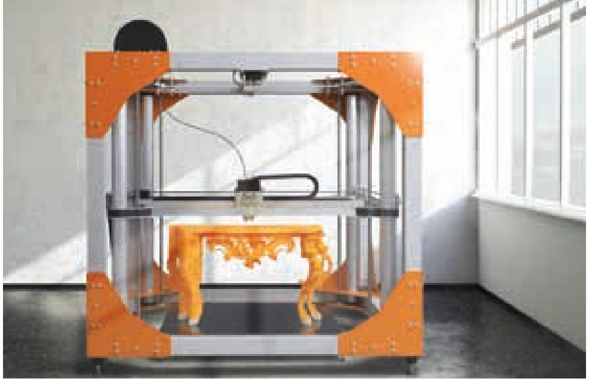
For many years the materials which could be utilised for fused layer modelling were restricted to a few thermoplastic materials such as acrylonitrile butadiene styrene (ABS), polyester or polycarbonate or various types of wax. With the invention of bioplastics, polylactic acid (PLA) became the new standard material. Due to the widespread use of additive extrusion systems in creative professions, the market reacted with new materials and composites to meet the demand for more versatile design options. Filaments are now available which are capable of generating wood-like (such as LayWood), ceramic (such as LayCeramic) or sandstone-like surfaces (such as LayBrick) or which have electrically conductive properties. In 2014 filament innovations appeared on the market, which also enable the implementation of 3D membranes and porous filters, along with flexible and rubber-like objects. The BioFabNet project has been developing organic-based materials solutions for printers in the consumer sector, in particular, since the end of 2013. The German start-up company twoBEars was the first company in the world to develop a biodegradable filament. Bio-Fila with its two variants, linen and silk, is produced from renewable raw materials and breaks down completely into lignin. In autumn 2014 the American Mark Forged from Boston presented the world's first carbon fibre filament printer.

LayWood wood filament (Source: ccproducts)

Component sizes, precision, reworking

The extruder's robot-controlled process means that the processing technology is not limited to one construction space. The available sizes on the market range from just a few square centimetres to more than one square metre. Reworking is a complex process, given that thermoplastics are generally used. ABS surfaces, for example, can be vaporised, edged and smoothed with acetone. Imprecision along the Z axis must be factored in because of the nozzle diameter, in particular with small components. In this situation, individual layers may become de-bonded.

Small system for private usage (Source: 3D Systems)



BigRep in use (Source: BigRep)

Application

Although additive extrusion systems were primarily used for manufacturing demonstration models, they are now seeing more widespread use in direct product manufacturing and in private households. More and more companies are entering the market for office-suitable systems. Applications for the furniture industry and interior design are currently being tested as a result of the development of higher quality materials. 3D-Systems presented a range of options at the EuroMold 2012 with the Cube-Shop.

Cost-effectiveness

Since it has been come possible to purchase construction kits on the Internet, the prices for filament-based printers have decreased enormously. They can now be purchased from trade dealers for prices between 600 and 700 euros. Construction kits are available for less than 400 euros. However, the low-cost systems do not deliver high precision. Higher quality systems in the consumer sector are available for prices between 2,000 and 3,000 euros and industrial systems are available for a price of 10,000 euros. The filaments are offered for 30 to 40 euros per kilogram.

Special processes and system types

BigRep: The world's largest serial 3D printer

With a construction space of 1.3 cubic metres (1.5 x 1 x 1.2 metres) and a weight of 240 kilograms, the BIG-REP One is currently the world's largest serial 3D printer. It was developed by Marcel Tasler and Lukas Oehmigen to manufacture life-sized objects. The printhead is designed as a double extruder and processes the material (PLA or ABS) and the supporting material at resolutions between 100 microns and 1 millimetre. The system is sold from Berlin-Kreuzberg and the basic version costs approximately 30,000 euros.

Printed table (Source: BigRep)

Large FFF system with multiple extruders

At the EuroMold 2014 the German systems manufacturer German RepRap, a spin-off of TU Darmstadt, presented a new system which numbers among the large systems utilising FFF technology and has a construction space of 100 x 80 x 60 centimetres. The multiple extruder control and a new filament management system enable it to work with several different materials. Large components can be manufactured within a realistic time period through the use of layer thicknesses of up to 0.5 millimetres.

Fibre additive manufacturing

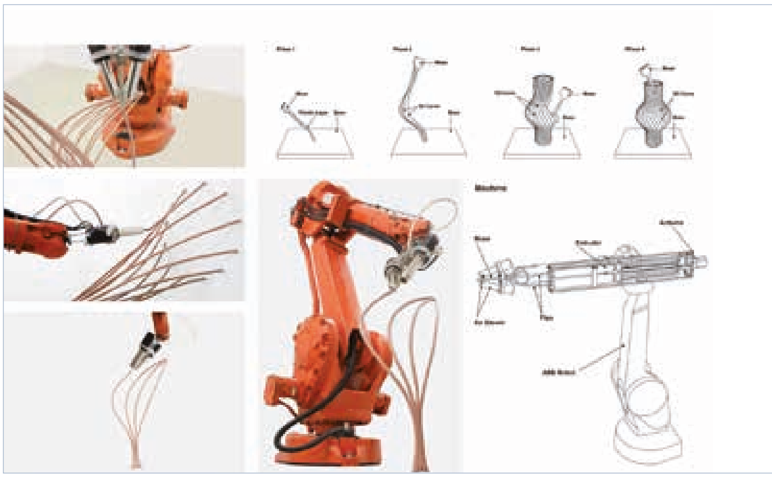
At the end of 2014, the American company Markforg3D presented the world's first FLM system capable of manufacturing fibre-reinforced components. This system utilises both carbon fibre and also glass fibre reinforcement, and has a maximum construction space of 305 x 160 x 160 millimetres. A price of 5,000 US dollars is quoted on the manufacturer's website. According to the information provided by the developer, the carbon fibre reinforced components are 20 times more rigid than ABS components and also have better mechanical properties than aluminium components.

Fibre reinforced 3D printing (Source: Mark Forged)

Freeformer
The die casting systems manufacturer Arburg entered the additive manufacturing market at the end of 2013 with the freeformer. As such, the engineering company is the first manufacturer to use commercially available material in the form of standard granulate. This is melted in a heated plastifying cylinder and applied as plastic droplets. The patented nozzle cap utilises high-frequency piezo technology which enables rapid opening and closing, along with precise material application. Using the standard material generates components which have 70 to 80 per cent of the strength of comparable die-cast parts. The freeformer has a construction space of 130 x 130 x 250 millimetres.

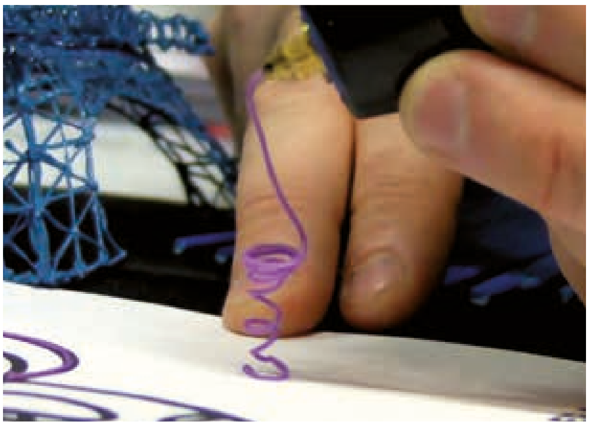
Freeformer in use (Source: Arburg)

Anti-gravity object modelling
In 2013, in a research project at the Institute for Advanced Architecture of Catalonia IAAC in Barcelona, Petr Novikov and Saša Jokić developed and patented a robot-assisted technology for the angle-independent generation of architectural structures without the use of an additional supporting structure. The head of the nozzle is guided by a robot arm, which enables the material to be applied within a free space, without being restricted to a construction space. In contrast to other processes, a duroplastic material is used instead of a thermoplastic material. This hardens soon after it leaves the nozzle, almost entirely eliminating gravity-related deformation.



Robot-assisted extrusion process (Source: Advanced Architecture of Catalonia IAAC)

3D printing pen
At the beginning of 2013 Doodle was the first 3D printing pen to be launched which enables free modelling of spatial drafts. It works with a wire made of the thermoplastic material acrylonitrile butadiene styrene and was developed in Boston by the games manufacturer WobbleWorks. The wire is heated inside the head of the pen until the viscous mass can be easily distributed. The material cools, hardens and is strong enough for drafts. A metering unit enables users to adjust the feed speed themselves.



3D printing pen (Source: WobbleWorks)

4D printing with shape memory material

The team of researchers headed by Skylar Tibbits at the Self Assembly Lab at the Massachusetts Institute of Technology was the first to successfully perform 4D printing. The scientists utilised a shape-memory material developed specially by the US systems manufacturer Stratasys which changes its geometry when influenced by temperature, light or water. In the wake of the discovery, the researchers claim that the process could be utilised beneficially for self-constructing structures in space, for water pipes or furniture. The Laser Zentrum Hannover is already working on potential applications for 4D printing for biomedical engineering. These include implants which are individually matched to the body and can even adapt as children grow.

4D printing (Source: MIT/Stratasys)

2.1.4 Three-dimensional printing

The 3D printing process was developed at the beginning of the 1990s by Emanuel Sachs and Michael Cima at the Massachusetts Institute of Technology (MIT) in the USA with the goal of providing a technology for use in office environments. Owing to the cost structure, extrusion systems are the favoured option for these operating environments. Thanks to the ability to colour the printed components, the 3D printing process has found a large number of applications among private users in recent years, such as manufacturing human images.

ColorJet printing – 3D printing system (Source: Materialise)

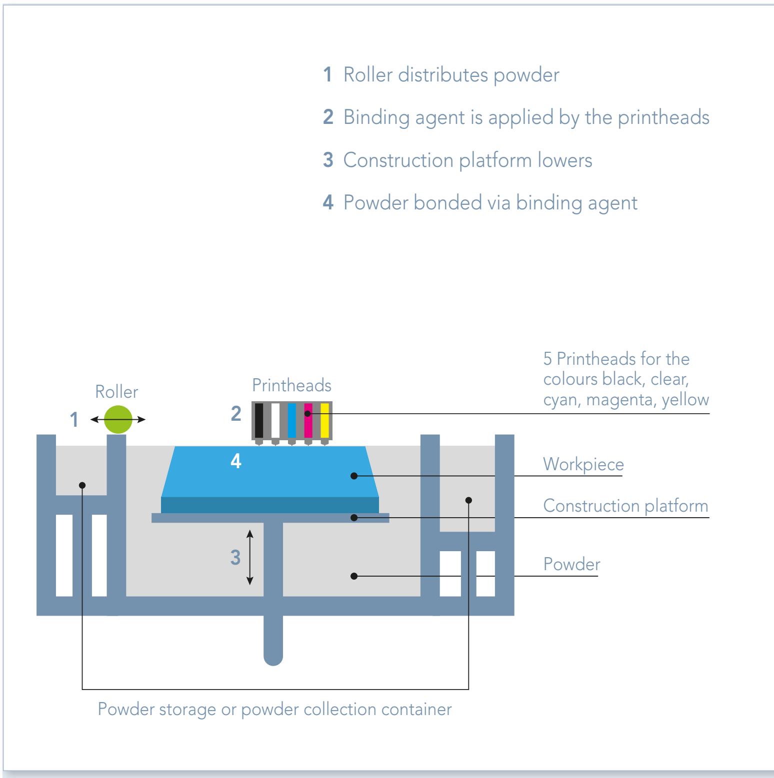


Diagram: 3D printing process

The process

The process is similar to laser sintering and is based on bonding particles with each other. However, unlike selective laser sintering, these particles are not melted with a laser, but rather bonded locally through the use of a binding agent. The system utilises a printhead which is managed by a control unit and moves in layers over the powder bed. It applies droplets of the adhesive substance to the newly applied layer of powder. The binding agent penetrates the layer below and binds the new layer of powder with the existing printed geometry. Before starting to generate the next layer, the print bed is lowered by the thickness of one layer and the process begins again. Since the component is completely surrounded by powder during the manufacturing process, supporting constructions are not required for protruding elements, unlike laser sintering. The components can be infiltrated with resin or wax in order to increase the mechanical strength of the printed components.

Printed selfies with coloured binding agents (Source: 3D-Scaper)

Because the process is oriented on conventional printing techniques, 3D printing is capable of achieving very high speeds in comparison to other additive processes. In addition, the components can also be coloured with more than 16 million colours. Unused powder in the construction space can be reused.

Materials

Materials based on starch, plaster or ceramic composites are the common materials utilised for three-dimensional printing. A number of systems manufacturers also supply powders made of various metals for use in dental medicine or offer mixtures for industrial applications and casting moulds. When working with ceramic or metal powders the object undergoes a sintering process in a furnace after printing which further bonds the particles with each other up to a structural density of 60 per cent. The subsequent infiltration with low-melt metals (such as bronze) fills the pores and increases the density to up to 95 per cent.

Component sizes, precision, reworking

As a result of the mature inkjet printing head technology, three-dimensional printing numbers among the fastest additive processes. Systems with a construction space of up to 4 x 2 x 1 meters are now available. A precision of 600 dots per inch can be achieved. However, the components always have a rough surface with visible printing lines due to the grain size of the powder used. These can be reduced through mechanical reworking. For this reason, current research is focusing on improving the mechanical qualities of the printed components. As a result of work carried out at the Fraunhofer Institute for Structural Durability and System Reliability (LBF) in Darmstadt, new material systems and printable inks have been improved to the extent that three-dimensional printing is capable of achieving similar strengths to die casting.

Printed architectural columns with internal cavities infiltrated with sand and epoxy resin (Source: Daniel Büning)

Application

Until recently, most small systems capable of tinting with more than 16 million colours were primarily utilised for rapid visualisation during the drafting process. Due to the large construction spaces, 3D printers are now becoming more widespread for industrial applications and can be employed for series production. Metal and ceramic moulds generated using 3D printing and then sintered are utilised for industrial mould construction, for example. The quiet manufacturing process also makes 3D printers suitable for use in office environments.

Cost-effectiveness

The system prices range from between approximately 20,000 euros to prices in the six digit range. Therefore, usage in a personal or small-business environment is largely ruled out. As a result, there are numerous service providers which enable the implementation of components at realistic prices.

Special processes and system types

ExOne – Large printer for sand and metal

ExOne is one of the largest providers of 3D printers with an especially large construction space for additive production of shaped parts made of sand or metals. The possible construction space for 3D printing with sand is 1,800 x 1,000 x 700 millimetres and for metals 780 x 400 x 400 millimetres. Today, sand shapes and cores can be manufactured without tools as part of a complete digital process chain. A subsequent firing and sintering process is required to achieve the desired strength for metallic components.

voxeljet – Continuous component production

At the EuroMold 2012, voxeljet presented the first continuous 3D printer with a revolutionary design and a horizontal conveyor. The printing process is carried out at the infeed of the conveyor belt on a horizontally tilted surface. The components are manufactured in a construction space of 850 x 500 millimetres and have a resolution of 600 dots-per-inch. The conveyor belt moves the printed components to the side so that manufacturing and packaging can be carried out simultaneously without having to interrupt the process. According to the manufacturer, this results in operating and procurement costs that are lower than for alternative systems.

VXC800: Continuous 3D printing with an inclined printing bed (Source: voxeljet)

2.1.5 Layer laminate manufacturing

Layer laminate manufacturing (LLM) consists of systems based on the use of individual films or paper layers. In recent years, the systems have not developed as positively as other types of system because it is difficult to implement hollow spaces and the excess material must be removed manually. The term laminated object manufacturing (LOM) is also common and is a protected trademark of the American manufacturer Helisys Inc., which has marketed the first systems since the mid-1990s. When working with paper, the term paper lamination technology (PLT) is also common.

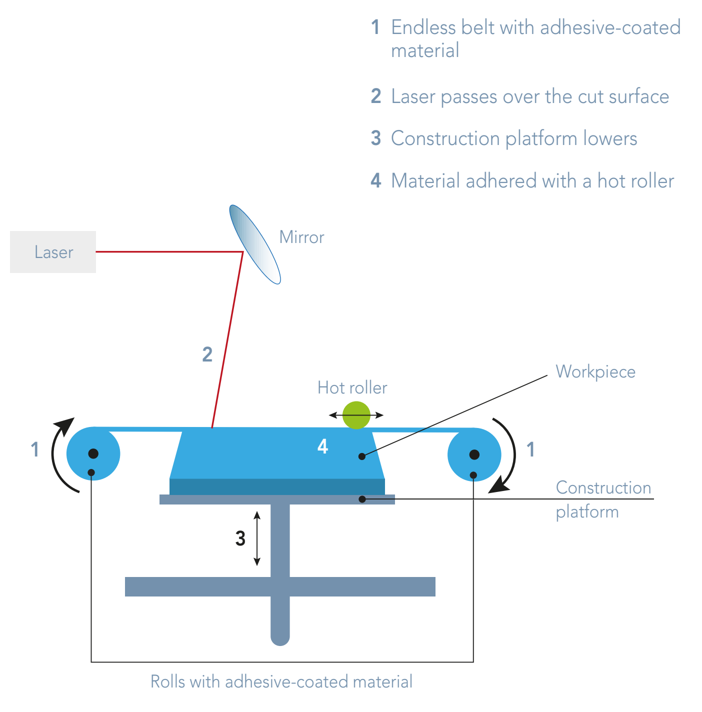


Diagram: The layer laminate manufacturing process

The process

LLM systems manufacture components by bonding layers of individual films or thin sheets with each other. First, the initial layer is placed on the component platform and the contour of the layer is shaped with a laser, a sharp blade or a hot wire. The platform moves downward and a new material film is moved into place and adhered to the layer below using a thermal roller with a temperature of approximately 300 degree Celsius. The next contour cut is made and the process is repeated from the beginning. The excess film material is cut into small square pieces in order to simplify removing the component at the end of the process. The resulting cubes can be disposed of easily. At the same time, the excess material also serves to support protruding elements, eliminating the need for any additional supporting constructions. The process can be stopped to integrate functional elements or to remove excess material from the hollow spaces. Due to the nature of the process, layer laminate manufacturing is regarded as an additive process but demonstrates fewer benefits with regard to resource saving in comparison to other additive manufacturing processes.

Materials

A variety of different film materials and coated papers are available on the market for layer laminate processes. These range from a variety of different plastics (such as polyester) to fibre-reinforced composite materials. Furthermore, ceramic and metal films have also been processed successfully in trials. When working with metal materials, the individual layers are not adhered but welded. Although processing paper creates an appearance which resembles wood, a special system variant was developed for generating wooden components. With this system the component platform is located at the top and the material is milled with a cutter head. This arrangement makes it easier to implement hollow spaces because gravity causes the excess chips to fall out of the construction space.

Component sizes, precision, reworking

The layers processed with LLM systems range from between 0.8 and 0.25 millimetres with the most common thickness being 0.1 millimetres. A number of manufacturers also specify the material thickness of standard paper used with the conventional grammage. In this case, 80 grams per square metre is typical. LLM systems available on the market have a maximum construction space of 800 x 600 x 550 millimetres with a precision of +/- 0.15 millimetres. The mechanical strength of the components depends on the construction. As such, the direction of lamination must be considered when reworking. When using paper the surfaces must be subsequently sealed with clear varnish as a result of their hygroscopic properties.

Construction space of a MCor system after the layer lamination process (Source: 3D-Picture, photo: Dieter Bielert)

Application

Owing to the component-dependent process speed, LLM processes are especially advantageous when creating particularly large part geometries with limited complexity. No tension occurs when bonding the layers and largely distortion-free shaped components can be manufactured as a result. This process is used frequently for model construction (such as for foundry models). Yet, the process has clear disadvantages in comparison to other additive processes because the contours of the hollow spaces can only be implemented to a limited degree. A paper-based layer laminate system for office usage is now available on the market.

Cost-effectiveness

LLM systems are relatively cost intensive in comparison to other types of system and prices begin at 4,000 euros. Moreover, the low-cost systems are also bound to specific film materials.

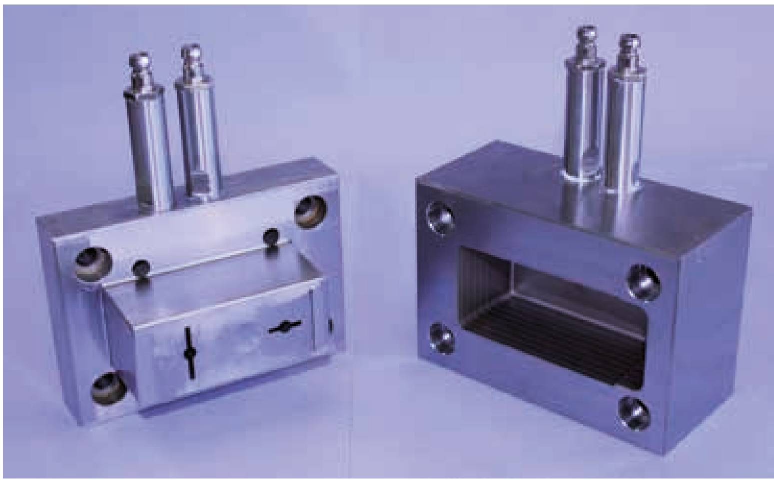
Special processes and system types

MCor paper-based layer laminate system

The company MCor was founded in Ireland in 2005 and manufactures layer laminate printers that work with conventional A4 letter paper. As such, the operating costs are significantly lower in comparison to other additive manufacturing technologies. The layers of paper are adhered to each other, the layer contours cut and then tinted using conventional printing technology. Given that more than one million colours are available, photo-realistic objects can be implemented. The ink penetrates the individual layers of paper and creates a saturated colour effect. The colour resolution along the component axes is 5,760 x 1,440 x 508 dots-per-inch (x-y-z). A maximum component size of 25.6 x 16.9 x 15 centimetres can be constructed.

Plate press brazing

Neue Materialien Bayreuth GmbH developed a new additive process under the name of plate press brazing (PPB). It is based on a combination of milling and brazing and offers the option of generating large-surface tooling inserts with complex internal structures such as contoured cooling ducts. Four-millimetre thick metal plates coated with brass solder serve as the basic material. The layer geometry is milled on the individual panel, the panels then stacked to form a perfect fit, and permanently bonded with each other by means of contact soldering. Uneven areas are removed by specifically applied pressure via the closing device. The process is now so advanced that a precision of 80 microns can be achieved.



Toolpiece manufactured using plate press brazing (Source: Neue Materialien Bayreuth GmbH)

2.2 Data generation and the additive manufacturing process chain

In addition to access to a production system, designing a component geometry with additive manufacturing technology also requires the complete 3D geometry information. 3D CAD programs can be used to create the geometry information and can convert the three-dimensional data into a facet model (STL, AMF). The facet model is required for the entire additive production process. The shaped part surfaces are approximated using triangles (triangulation). As such, a certain level of imprecision and deviations from the actual component draft may occur with curved surfaces, depending on the number of triangles used. The data quantity increases with the number of triangles and the desired precision. The triangular facets, which can frequently be identified on printed components, are the result of the geometry approximation via the STL format.

System	Manufacturer	Operator	Platform dependency
123D Design	Autodesk Inc.	Entry-level	Windows and Mac OSX
CATIA	Dessault Systèmes	Industry	Windows
Cubify Invent	3D Systems Corporation	Entry-level & advanced	Windows
FreeCAD	FreeCAD Community	Advanced	Linux
Inventor	Autodesk Inc.	Advanced & professional	Windows
Rhinoceros	Robert McNeel & Ass.	Creative professionals	Windows and Mac OSX
Solid Edge	Siemens Industry	Industry	Windows
Solid Works	Dessault Systèmes	Advanced & professionals	Windows

Overview of selected 3D CAD systems (according to Horscher, Florian: 3D-Druck für alle – Der Do-it-yourself-guide. München, Wien: Carl Hanser Verlag, 2014)

If existing objects or bodies are utilised to generate the data then tactile or optical measuring techniques now provide the ability to do so (for example 3D scanning). In recent years a variety of technologies have been developed which are capable of generating the data with different resolution qualities. Working with photos is the simplest option for 3D scanning. Today, a digital camera is sufficient to generate a 3D model through the use of at least 20 photos of an object, and with the help of software. What is currently the world's largest mobile 3D scanner is offered by the start-up company botspot from Berlin, and has 60 integrated cameras for scanning bodies and large objects. In addition to working with photos, 3D scanning can also be carried out using light-sections or stripe projections. The procedures are more expensive; however the quality is generally higher. Lines or striped patterns are projected onto an object, the object is rotated and the changes to the angles recorded. Software can transform these into a 3D geometry model.

The world's largest mobile 3D scanner (Source: botspot)

Regardless of whether the data is created with a 3D CAD system or by means of tactile techniques, the subsequent preparation of the data represents a critical step within the additive manufacturing process. The reason for this is that errors often occur in the course of deriving the facet model from the CAD data, which then delay further processing. Such errors include the incorrect orientation of individual facets, gaps between the triangles or duplicated triangulation. These errors have to be rectified manually.

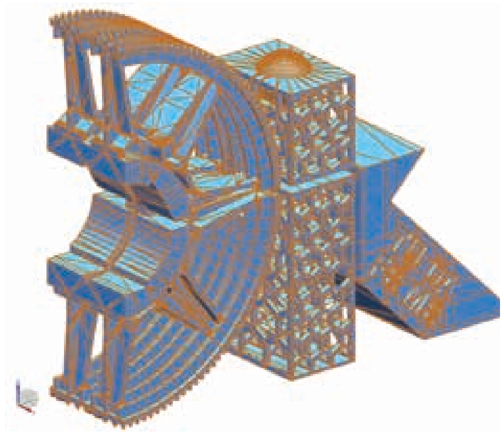


Image: 3D data in the STL format (Source: Anderl, R.: Additive Manufacturing oder generative Fertigungsverfahren – vom Prototypen zur Massenfertigung? Lecture at the „Additive Manufacturing" event held by the Ministry of Economics, Energy, Transport and Regional Development – State of Hessen, Hanau, 23rd September 2014)

In the case of slicing, the STL data is converted into the layer information (SLI data) required for the additive process via a separate software application. To make optimal use of a system's construction space, multiple components are distributed on the component platform and aligned in such a way that there is no need for supporting constructions. If, however, supporting constructions cannot be omitted, then these are incorporated into the slicing process. The necessary software is available from the systems manufacturers and is delivered as part of the purchase. Defining the process parameters, such as the laser speed for SLS or the layer thickness for FLM, can have a decisive influence on the quality of the component surfaces and the manufacturing duration. The SLI data subsequently enables precise control of the machine.

Laser-sintered handles of the Nikon Metrology Scanner with flocking (Source: Materialise)

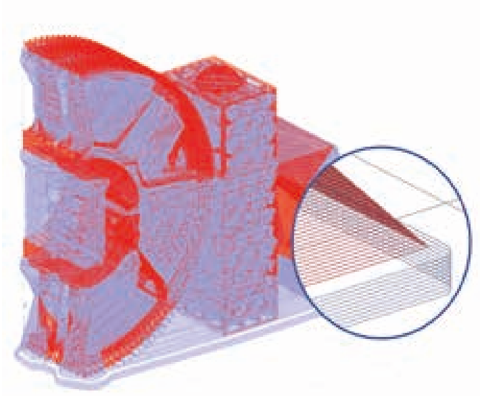


Image: SLI data with supporting constructions (Source: Anderl, R.: Additive Manufacturing oder generative Fertigungsverfahren – vom Prototypen zur Massenfertigung? Lecture at the „Additive Manufacturing" event held by the Ministry of Economics, Energy, Transport and Regional Development – State of Hessen, Hanau, 23rd September 2014)

The parts may require subsequent cleaning after additive manufacturing of the component geometry, depending on the process utilised. For example, the supporting structures need to be removed in the case of some processes. Components can also be subjected to further treatment to improve the mechanical stability or the surface quality. The options range from simply polishing the component surfaces to the infiltration of porous structures with low-melt materials, or flocking or metallising to refine the shaped parts.

2.3 Process chains integrating additive manufacturing procedures

Since additive manufacturing became prevalent for prototype construction in the mid-1990s, it has also been utilised for over ten years in toolmaking. Given that these are generally complex shaped parts, additive manufacturing procedures have significant cost advantages in comparison to conventional techniques. Where the direct manufacturing of tools by means of laser sintering and laser melting of metals is the focus of the development in an industrial context, lower cost processes are now in use among the trades. In this case, the additive techniques are generally integrated into a process chain. Laser melting or laser deposit welding can also be utilised for tool repairs.

Tool shape additively generated by laser sintering (Source: Fraunhofer Institute for Production Technology IPT, Peters 2011)

Glass-blowing

One variant of the integration of additive manufacturing procedures is the manual glass-blowing of large bodies, which is almost impossible to carry out with conventional process steps. The glass body is first designed three-dimensionally on the computer and then printed as a shaped part using a large-scale FLM system. This is followed by moulding with plaster and the implementation of two tool halves which are then utilised for the actual glass-blowing and enable highly precise manufacturing of the desired component. Currently the use of low-cost 3D printers in combination with materials such as metal or porcelain is expanding exponentially.

Housing produced from an additively manufactured master form for a hand scanner from Nikon Metrology (Source: Materialise)

Fine casting

When cast parts with a complex shaped part geometry need to be manufactured as cast metal for the aerospace industry or biomedical engineering, then additively manufactured master forms also represent a suitable means of shortening the process chain. Previously, the master form had to be created in a complex process. Today, only a few hours are usually necessary to generate the model geometry. Stereolithography is the common choice due to the fact that high surface qualities can be achieved.
Following additive manufacturing, the model is reworked and a ceramic coating is applied which becomes the fine casting forming tool after the master form has been burnt out. The process chain described can create cast components with a length of up to 1.20 metres. The shaping accuracy is very high. The deviations amount to a maximum of +/- 0.2 per cent.

Vacuum casting

Function models made of two-component polyurethane can generally be created in small batches by means of vacuum moulding. An additively manufactured master form produced using stereolithography or laser sintering is suitable for the manufacturing process. This is formed out of silicone and cut into two halves with a view toward the necessary parting planes. The casting process takes place in a vacuum to prevent air bubbles or hollow spaces. Owing to the high complexity of the silicone forms even undercuts and complex structures can be implemented.

Reaction injection moulding (RIM)

Reaction injection moulding is a well-established process in the automotive industry for manufacturing plastic parts in small batches through the low-pressure injection of thermoset resins. To manufacture the necessary tool shapes a master form first has to be additively produced on the basis of 3D CAD data, and this form then shaped with silicone or resins. Depending on the material selection, the low-pressure forming process can implement different batch sizes. Today, epoxy resin layers with glass fibre reinforcement are generally selected for especially large components.

Silicone tools	(up to 25 – 50 injections)
Hybrid tools	(50 – 100 injections)
Glass fibre reinforced resin tools	(200 – 300 components)
Resin tools with aluminium reinforcement	(up to 300 – 1,000 components)

Material selection for the tool and achievable quantities (Source: Materialise)

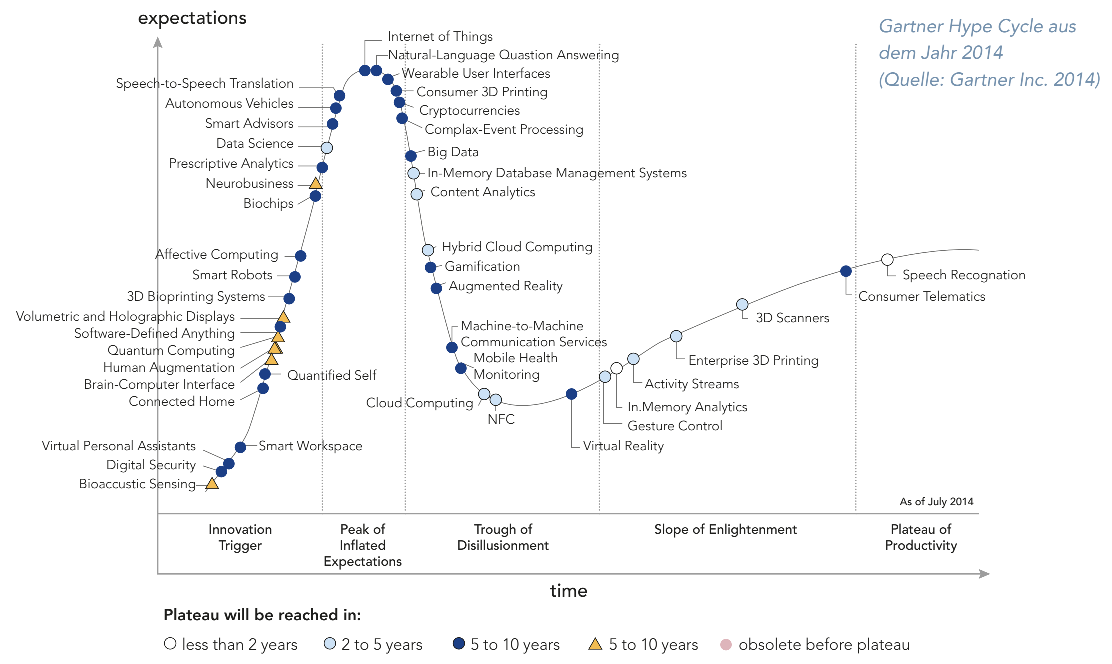
3. New value creation with additive manufacturing

Additive manufacturing principles have the potential to partially replace conventional production techniques such as milling or turning, and develop new value creation opportunities. In particular when combined with digitalisation and increased flexibility of large-scale industrial production right up to aligning production processes toward batch size 1, additive manufacturing processes offer options that classical processes only provide to a limited extent. Additive technologies provide qualities which make them essential for implementing the 'Zukunftsprojekt Industrie 4.0' (Industry 4.0 project for the future) as part of the German government's high-tech strategy.

The current keen interest in additive manufacturing processes and the media attention over the last two or three years is primarily due to the convergence of two developments. Firstly, the manufacturers have improved the manufacturing and material systems to such an extent that they can compete with classical processes. As a result, they can now be utilised in many areas of direct production. Secondly, the expiry of a number of patents for important processes has triggered a wave of development and innovation which has made additive manufacturing attractive for end consumers. Between 2008 and 2011 the systems manufacturers in the low-cost sector (systems up to 4,000 euros) achieved annual increases of 346 per cent. In 2013, approximately 70,000 systems for the consumer sector were sold. In the same year, professional systems sold a total of 9,832 units (Wohlers, T.: Wohlers' Report 2013. Wohlers Association, 2013).

The 'Hype Cycle' published annually by the Gartner Incorporation lends itself well to a detailed examination of the development and illustrates the technological developments, the expectations placed on them and the media interest using a curve graph. In the experience of market researchers technical developments follow the following pattern: When a high level of media interest combined with a high level of expectation occurs after a specific technological innovation becomes public, this is followed by a phase of disillusionment regarding the forecast potentials and thus a decline in the estimated value with regard to the financial opportunities. A sustainable development toward a productive technology does not take place until after this phase. Every new technology passes through the hype cycle at a different speed. However, one assumes a period of at least ten years.

The hype cycle from 2014 clearly shows that additive manufacturing has developed into a promising technology in the industrial context, and that it is being actively used in production in a variety of different industries. In contrast,



Gartner Hype Cycle aus dem Jahr 2014 (Quelle: Gartner Inc. 2014) market researchers believe that the hype of recent years surrounding the use of 3D printing in the consumer sector has peaked. In the subsequent consolidation phase the economic potential and the opportunities will be critically examined. The productive use of 3D printers in a private context will not develop until after five or ten years. In contrast, Gartner believes that bioprinting technology is about to reach the pinnacle of the hype. This primarily includes systems for applications and technologies for the additive processing of organic substances for medical purposes, such as the ability to additively manufacture implants or even tissue replacement.

3.1 Market assessment

The overall market for additive manufacturing has grown by an average of 24.1 per cent in the last 25 years. In fact, the annual increase between 2010 and 2012 amounted to 27.4 per cent as a result of factors such as new value chains in the consumer sector and the use of additive technologies for direct component manufacturing (Source: Wohlers' Report 2013). Based on their qualitative disadvantages with regard to the strength and stability requirements, up until approximately ten years ago additive technologies were exclusively restricted to rapidly manufacturing prototypes (rapid prototyping) and tools (rapid tooling). Currently, the market is undergoing a transformation and a redistribution. As such, in 2013 the use of additive technologies and production had already reached a share of approximately 29 per cent. Other important areas of use continue to include prototype construction with approximately 37 per cent, along with direct tooling with 26 per cent.

Market shares for additive manufacturing (Source: Abele, E.: Einordnung und Ausblick von additiven Fertigungsverfahren aus produktionstechnischer Sicht. Lecture at the „Additive Manufacturing" event held by the Ministry of Economics, Energy, Transport and Regional Development – State of Hessen, Hanau, 23rd September 2014)

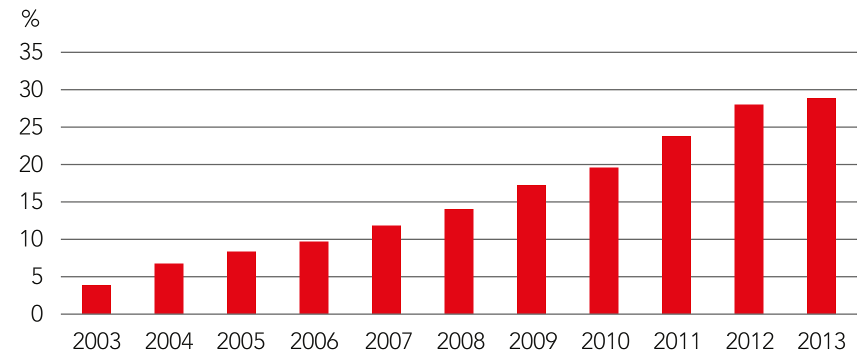


Image: The use of additive manufacturing for direct production (Source: Breuninger, J.; Becker, R.; Wolf, A.; Rommel, S.; Verl, A.: Generative Fertigung mit Kunststoffen: Konzeption und Konstruktion für Selektives Lasersintern. Berlin, Heidelberg: Springer Verlag, 2013)

According to information from market researchers from Lux Research this trend will continue and the proportion of additively manufactured components in applications for aerospace, biomedical engineering, the automotive industry and architecture, along with electronic devices and consumer articles will continue to increase. Lux Research forecasts a total market of 12 billion US dollars for the year 2025. Parts production will represent the majority with a share of 8.4 billion US dollars. In 2013 this amounted to 684,000 US dollars, which would mean annual growth rates of more than 21 per cent (Source: Lux Research: How 3D Printing Adds Up: Emerging Materials, Processes, Applications, and Business Models. 30th March 2014).

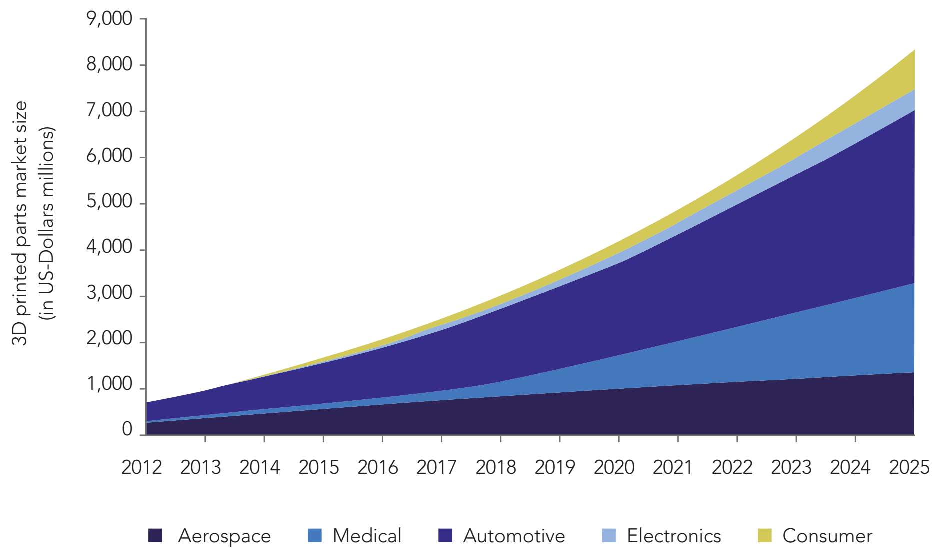


Image: Forecast market development for direct additive parts production 2012 to 2025 (Source: Lux Research: How 3D Printing Adds Up: Emerging Materials, Processes, Applications, and Business Models. 30th March 2014)

3.2 Qualitative economic feasibility study

The meaningful use of additive technologies in production is already possible to a far greater extent than is currently being discussed (see Breuninger, J.; Becker, R.; Wolf, A.; Rommel, S.; Verl, A.: Generative Fertigung mit Kunststoffen: Konzeption und Konstruktion für Selektives Lasersintern. Berlin, Heidelberg: Springer Verlag, 2013). In addition to the material and machine costs, additive processes can also reduce a number of other costs which previously resulted from the necessity of production-oriented design, material usage and the logistics of semi-finished products and waste materials in conventional production processes.

Resource efficiency, weight reduction and assembly work

Since the component complexity does not have an influence on the production costs, merging design elements can reduce the number of parts and the amount of assembly work. This has a positive effect on both the production costs and also on the ability to reduce the resource and material usage through complex hollow structures which are impossible to manufacture using conventional techniques.

Design work and drawing creation

Reducing the number of parts also reduces the company's overall design and development work. Although the component constructions must be designed for the corresponding additive system technology, the additive manufacturing principle enables designs which were previously only possible with a significant amount of work. Furthermore, merging parts also reduces the necessity of creating drawings for the production. The simplified data management represents another potential saving for the production industry.

Semi-finished product expenses and waste management in production

When operating additive production facilities one can also expect reduced logistics overheads for the provision of semi-finished products or materials compared to those previously required when operating conventional production facilities. This applies to the provision of cooling lubricants and also to the disposal of waste material resulting from manufacturing via machining. Furthermore, neither the clamping devices nor equipment still found in classical production operations are required.

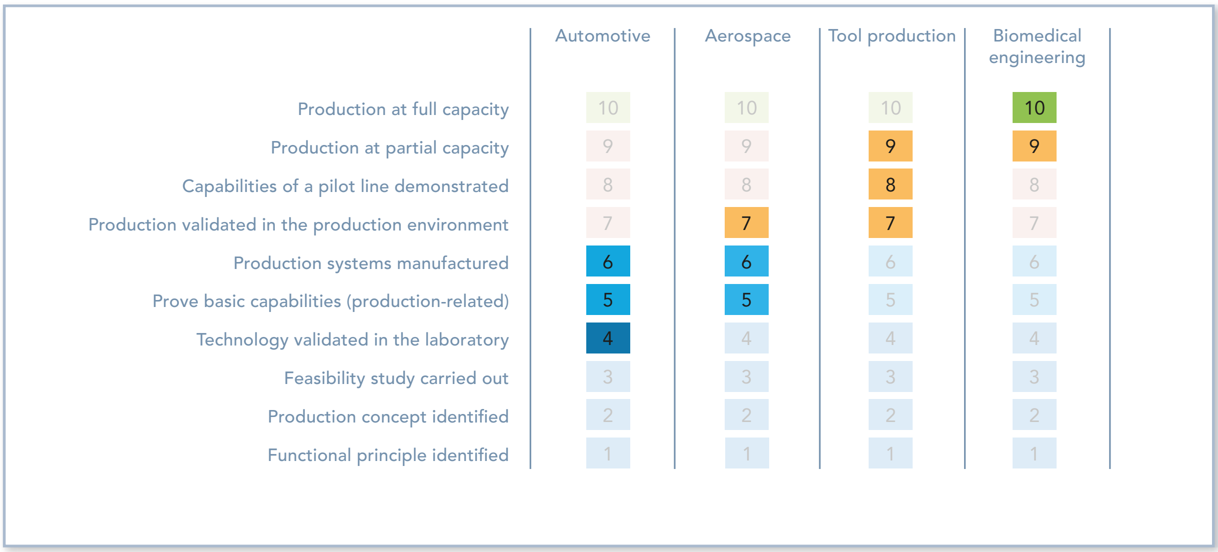
Using the services offered by 3D printing service providers or by operating low-cost systems in an office or private context can also create even greater savings potentials in comparison to the conventional process between production, assembly, packaging, logistics and sales. Downloading component data from the Internet combined with additive production and the ability to directly use the component significantly shortens the classic value chain. In 2013 researchers from Michigan Technological University discovered significant savings potential in comparison to the store price when comparing 20 printed test objects for products from the electronics and consumer goods sectors.

Product	Mass (gramme)	Power Consumption (kilowatt hour)	Cost of Plastic	Cost of Electricity	Total RepRap Cost	Total Retail Cost Low	Total Retail Cost High
iPhone 5 dock	46,2	0,28	1,62	0,03	1,65	3,56	29,99
iPhone 4 dock	19,5	0,1	0,68	0,01	0,69	16,99	39,99
iPhone 5 case (custom)	7,5	0,04	0,26	0,00	0,27	20,00	56,00
Jewelry Organizer	19,63	0,08	0,69	0,01	0,70	9,00	104,48
Garlic Press	45,01	0,26	1,58	0,03	1,61	5,22	10,25
Caliper	6,37	0,05	0,22	0,01	0,23	6,08	7,88
Wall Plate	15.,7	0,07	0,55	0,01	0,56	2,30	22,07
Shower Cutrain Ring (12 pcs)	33,6	0,24	1,18	0,03	1,20	2,99	2,99
Shower Head	71,32	0,27	2,50	0,03	2,53	7,87	437,22
Key Hanger (3 hooks)	17,03	0,08	0,60	0,01	0,61	6,98	49,10
iPad Stand	11,24	0,1	0,39	0,01	0,41	16,99	49,00
Orthotic	39,08	0,13	1,37	0,02	1,38	99,00	800,00
Safety Razor	9,9	0,09	0,35	0,01	0,36	17,00	78,00
Pickup	39,31	0,19	1,38	0,02	1,40	9,99	22,99
Train Track Toy	11,27	0,06	0,39	0,01	0,40	39,48	58,98
Nano Watchband (5 links)	9,15	0,05	0,32	0,01	0,33	16,98	79,95
iPhone Tripod	12,88	0,08	0,45	0,01	0,46	8,50	29,95
Paper Towel Holder	63,44	0,31	2,22	0,04	2,26	11,20	25,00
Pierogi Mold	18,9	0,07	0,66	0,01	0,67	6,95	24,99
Spoon Holder	11,6	0,06	0,41	0,01	0,41	4,95	15,00

Image: Savings potentials for manufacturing products based on open source designs through the use of a 3D printer from the American company RepRap; all costs and prices in US dollars (Source: Michigan Technological University, Joshua Pearce)

3.3 Application scenarios and industries

The following illustration of the technology maturities indicates that the opportunities that additive manufacturing offers for the main industrial branches are developing in different ways. It can clearly be seen that additive principles have already become established in biomedical engineering and have gained a certain importance in toolmaking. A major leap forward in development is also expected in the next ten years for the aerospace industry. In contrast, a major effort will be required to increase the application diversity in the automotive industry to transfer the systems from their fundamental suitability for the industry to mass production capability.



Maturity of additive manufacturing for different sectors (Source: Roland Berger)

Increasing sales figures for the metal systems and, in particular, the increase in sales revenue for systems for the additive manufacturing of metallic components in 2013 indicated that the industry is preparing to increase the use of additive manufacturing procedures.

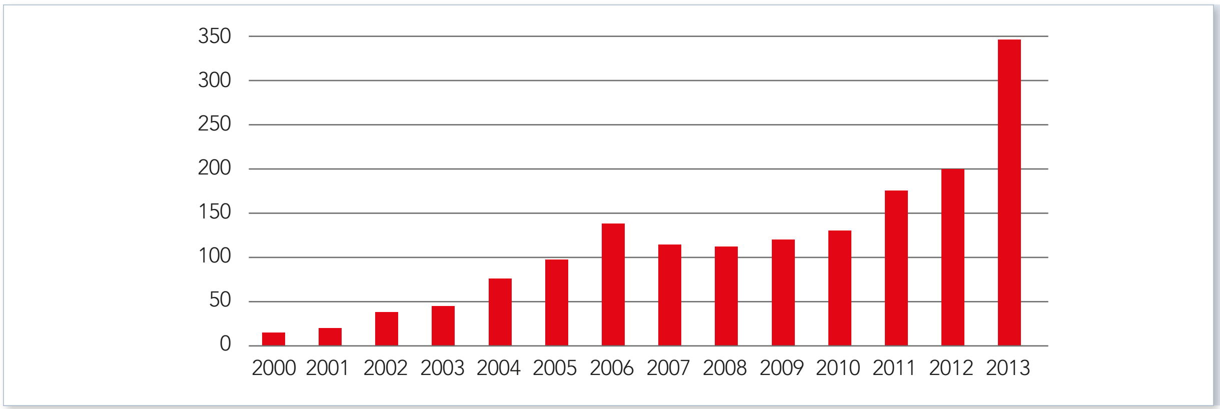
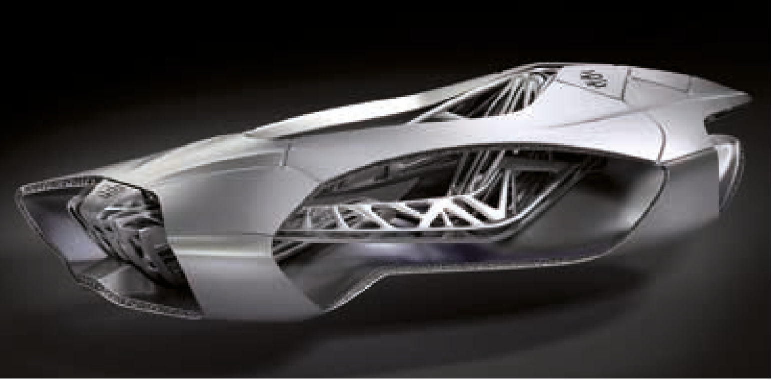


Diagram: Sales figures of metal systems (Source: Wohlers' Report 2013)

3.3.1 Vehicle industry

Vehicle manufacturers number among the first companies to adopt additive technologies as part of development processes for rapid prototyping, and have used the technologies since the mid-1990s. However, in contrast to the aerospace industry, the quantities are so large that the integration of additive manufacturing techniques into the automotive industry's automated production processes has not been possible thus far. Although complex individual components and spare parts are produced using additive manufacturing principles in individual cases, widespread usage has not yet taken place.

Not yet motorised but a pioneering role on the path toward a completely additively manufactured chassis: in February 2014 the first bicycle frame was presented which was manufactured out of a titanium alloy exclusively using additive processes. (Source: Renishaw)



GENESIS Study (Source: EDAG)

The large number of projects from recent months in which the direct additive manufacturing of vehicle components including complete chassis elements has been tested already indicates the approaching entry of additive production methods into the automotive industry. EDAG Engineering located in Fulda, in particular, has presented two highlights on that front. In March 2014 the Hessian company presented its GENESIS study at the Geneva Motor Show and the presentation of the "Light Cocoon" is planned for the same event in 2015. EDAG's designers primarily regard additive manufacturing processes as an opportunity to implement lightweight structures based on nature to reduce the vehicle weight.

Market potential

Due to the fact that the mass-production capability of additive manufacturing processes only exists to a limited extent for the automotive industry, hybrid approaches are being developed for the middle term and include the integration of laser deposit welding into a classical processing centre (Abele 2014), for example. As a result of the enormous potential savings with regard to component weight and resource usage resulting from the direct production of components within the context of automotive production, the worldwide market is set to grow to approximately four billion US dollars by 2025 (Lux Research 2013). Furthermore, the ability to manufacture 'on demand' will also transform the value chains and production will take place exactly where a suitable component or spare part is required.

Projects and special developments

Cordless screwdriver race – Printed lightweight construction from HAWK

At the seventh cordless screwdriver race in Hildesheim in 2011, design students were challenged to compete against each other using unusual designs and the motors from two conventional cordless screwdrivers. The race not only focused on speed, but also on the weight of the vehicle along with the design and technical implementation of the lightweight construction. The faculty for design at the University of Applied Science and Art Hildesheim (HAWK) modelled its vehicle with a biomimetic appearance on the computer and utilised an FDM technology from Stratasys for the printing, with the largest construction space possible at the time: 900 x 600 x 900 millimetres. Production took a total of ten days. 36,000 layers with a thickness of 0.25 millimetres applied at a constant temperature of 60 degree Celsius were required to complete the weight-optimised construction of the entire vehicle. Given that material was only applied where it made sense from a static, aerodynamic and aesthetic perspective, the vehicle weighed just 8.3 kilograms.

Strati – additively manufactured vehicle chassis

The chassis for STRATI from Local Motors was additively manufactured in September 2014 live at the International Manufacturing Technology Show (IMTS) with a manufacturing time of only 44 hours. The vehicle design was the winning submission from the '3D Printed Car Design Challenge' with more than 200 entries from 30 countries. The company held the competition until June 2014.

Submission from the HAWK Faculty for Design – lightweight design through additive 3D printing (Photo: Johannes Roloff)

Strati with a printed chassis (Source: Local Motors)

However, in the case of STRATI only those parts were additively manufactured which did not have a mechanical function or were required to guarantee the propulsion. After adding mechanical components such as the battery, motor, wiring and suspension, an initial test drive was carried out on 13th September 2014.

Spare parts logistics with additive processes

The use of additive manufacturing processes to provide spare parts in the vehicle industry is currently the subject of intense discussion. The additive techniques are not only an interesting option for classic vehicles, for which spare parts are no longer available. Converting to a system utilising additive manufacturing could also prove worthwhile for vehicles more than ten years old. The data is simply made available to the workshops and they can print the desired component on site and as needed. This would eliminate the manufacturer's need to stock spare parts. In the 'Car Service Engineering 2020' project, Professor Rolf Steinhilper, who holds the Chair for Environmentally-Oriented Production Technology at Bayreuth University, is currently examining the option of reducing spare parts requirements through repairs. Instead of replacing an entire component, the defective area can be scanned and a new component additively manufactured. This resource-saving method could reduce the repair costs for vehicle owners and the workshops would retain the value creation.

3.3.2 Biomedical engineering

Additive manufacturing methods are extremely important for biomedical engineering because they enable the implementation of individual geometries with a batch size of 1. Furthermore, the layered construction provides the ability to create hollow interior structures such as those found naturally in bones, for example. This was not possible with conventional techniques such as milling or turning. Additive processes have the inherent potential to mix materials in order to precisely adapt shaped parts to the individual requirements of the human body, whether in the form of implants, prosthetics or dental prostheses. In recent years, bioprinting has developed into a new field for additive technologies. This refers to processes with the ability to manufacture human or animal tissues through the 3D printing of previously cultured cells in an organic ink by utilising tissue engineering techniques.

Artificial blood vessels from additive manufacturing processes (Source: Fraunhofer Institute for Mechanics of Materials IWM)

Additively generated jaw bone structure (Source: Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM)

Additively manufactured cell washing system for blood group serology (Source: Hettich, EOS)

Market potential

Lux Research estimated the proportion of biomedical engineering in comparison to the total market volume for additive manufacturing at six million US dollars for 2013. Given the major potential of the field, this will probably increase to more than 391 million by 2025. The increase will primarily result from the manufacturing and adaptation of prosthetics and implants.
Other typical fields and applications include dental technology, medical device manufacturing along with single-use surgical instruments. The market for bio-printing is not expected to develop until after 2025 (Lux Research 2013).

Manufacturing steps of a laser-centred model casting prosthetic: Dental prosthetic immediately after the manufacturing process, support structures removed and surface polished, after completion (Source: EOS)

Projects and special developments

Dental implants manufactured using selective laser melting (SLM)

Because of their ability to handle the complex geometry and a batch size of 1, additive production methods have established themselves in the market as alternatives to conventional approaches for manufacturing individual dental prosthetics. Until a few years ago bridges, inlays and crowns were manufactured using a complex manual process. In contrast, the fully digitalised CAD/CAE process chain which ranges from recording the data for the tooth form to additively manufacturing the dental implant using SLM (selective laser melting) with a metal powder material offers true added value for both patients and dentists. The world's first functioning process chain was developed in cooperation with Fraunhofer ILT and commercialised by BEGO Medical from Bremen in 2004. The company DeguDent, based in Hanau, is also involved in the additive manufacturing of dental prosthetics. At the Philipps-Universität Marburg a team is researching manufacturing parts of the jawbone out of bioceramics using SLM. According to the systems manufacturer EOS, the dental sector is already one of the largest markets.

RoboHand/Project Daniel

Additive manufacturing has particular potential for medical care in communities in Africa's underdeveloped nations. The Robohand Initiative targets the low-cost provision of arm prosthetics for people in civil war regions. The initiative originates from Mick Ebeling and his Californian company, Not Impossible Labs. It is already possible to download 3D data from the Internet to manufacture an arm prosthetic with a conventional 3D printer for a material price of less than 100 US dollars. According to information provided by the company, the data has been downloaded more than 80,000 times.

Project Daniel – Robohand for civil war injuries (Source: MakerBot)

Dental prosthetic manufactured using laser melting (Source: Fraunhofer ILT)

Bio-printing/tissue engineering

A number of institutes worldwide are currently working on options for additively manufacturing organs and human tissue. The middle term goals are to create organs for testing purposes and produce human tissue for implants. Biological ink containing human cells is used to construct the organic tissue structure layer by layer. Numerous scientific publications have already reported the reproduction of human skin (Wake Forest University), the creation of an artificial meniscus (Cornell University) and an auricle (University of Melbourne). A team of scientists headed by James Yoo has reported successfully printing a large section of skin on the back of a pig. However, creating a complete organ consisting of multiple types of tissue remains just as impossible as manufacturing a network of functional blood vessels. In view of this, a mature system for artificially creating organs will not be available for the next ten to 15 years.

Bioprinters are currently available from manufacturers such as Envision Tech, Organova and Advanced Systems, and are primarily utilised for scientific purposes.

3.3.3 Aerospace industry

Since components manufactured by means of laser melting have been able to demonstrate similar mechanical strengths as those made using conventional milling technologies, additive manufacturing processes have become increasingly important in aircraft construction. In mid-2011 Southampton University announced the first successful additive manufacturing of an unmanned aircraft. In recent months connecting elements for the Airbus A350 XWB have also been additively generated. In September 2014 NASA sent the first 3D printer to the International Space Station ISS. In addition to the freedom in design and geometry, laser melting also provides faster processing times in comparison to conventional casting or milling processes, along with reduced total costs as well as significant resource savings. Cost reductions ranging from 50 per cent and a weight reduction of up to 40 per cent were successfully achieved for a number of selected components. Whereas milling aircraft components resulted in a waste quantity of approximately 95 per cent, laser melting reduces the waste to five per cent. Furthermore, additive processes provide the ability to create a design aligned with the lines of force and address the lightweight design requirements even more effectively. In view of these benefits, Airbus plans to additively process approximately 40 tonnes of metal powder per month using 100 systems.

HTP guide blades manufactured via SLM (Source: Fraunhofer ILT)

The use of additive processes in the aerospace industry will create new design options with regard to the complexity and functionality of components. This, in turn, will have a positive effect on flight behaviour and energy consumption. This also applies to implementing cooling ducts and the geometry of entire structural components for the wings and engines. Aircraft manufacturers are already examining the possibilities for implementing designs based on nature's role models through the uses of additive technologies.

"There is a good reason why nature has optimised functional and lightweight design principles over millions of years and cleverly minimised resource usage. Airbus is currently carrying out a structured analysis of the applicability of these natural solutions," said Professor Dr.-Ing. Emmelmann (CEO, Laser Zentrum Nord GmbH, Hamburg; www.maschinenmarkt.vogel.de/themenkanaele/additive_fertigung/ articles/461436/index3.html). He sees major potential with regard to structural components with dimensions of up to one metre, in particular, along with engine components.

Laser-sintered turbine wheel made of the nickel alloy IN718 (Source: Morris Technologies, EOS)

Market potential

Additive manufacturing is primarily of interest to the aerospace industry given that the sector tends to work with small and medium-sized quantities. High tool costs have a significantly greater influence on the production costs than those of the automotive industry's mass production. As such, additive manufacturing procedures are expected to provide a significant reduction in the cost per unit. Furthermore, experts also expect an additional, positive cost effect through the transformation of spare parts logistics toward 'on demand' supply. Decentralised supply networks could safeguard on-site supply and reduce the delivery times for spare parts, along with the downtimes and inspection times. As a result, lower operating costs are also expected for the airline companies. According to calculations carried out by Lux Research, the market for components in the aerospace industry manufactured directly by additive processes will have approximately tripled by the year 2025.

Projects and special developments

GE Aviation

As one of the pioneers in the aerospace industry, GE Aviation is constructing a manufacturing facility in Alabama with additive production technology for manufacturing engines and intends to establish additive technologies as a long-term solution. The facility with an area of 27,900 square metres should be completed in 2015. This should provide space for 50 additive manufacturing systems and jobs for 300 employees. Since 2011 GE has already invested 125 million US dollars and plans to continue expanding its use of the technology. GE Aviation intends to achieve long-term cost benefits through the use of additive manufacturing processes. The components require less material and are also more durable than those manufactured using conventional production processes. By the end of the decade up to 10,000 components per year shall be manufactured using additive processes. In mid-July 2014 GE Aviation officially announced the purchase of 100 SLM systems from the German company EOS at the aerospace exhibition in Farnborough.

Engine components and connecting elements

When manufacturing complex components for engines and turbines, the use of additive manufacturing processes can generate highly positive effects, which proves especially profitable with small quantities. Those components already manufactured by means of selective laser sintering include guide blades, fuel systems or heat protection components. In 2014 a development by Airbus was awarded the 'Innovationspreis der deutschen Wirtschaft 2014' (German Industry Innovation Award). Structural elements for aircraft, such as brackets, were produced from titanium using additive manufacturing for the first time, and weigh 30 per cent less than conventional milled aluminium parts. The jury rated the development as an interdisciplinary innovation leap which could fundamentally transform the production of structural elements for aircraft and lightweight design for civilian aircraft.

Additively manufactured injection nozzle (Source: Morris Technologies, EOS)

Titanium connecting element for the Airbus A350 XWB generated using laser melting (Source: Airbus, Laser Zentrum Nord)

SULSA – the first additively manufactured aircraft in history

In 2011 the University of Southampton became the first research institution to successfully test an unmanned aircraft produced completely by means of additive manufacturing technology. The aircraft was given the name SULSA – Southampton University Laser Sintered Aircraft – to reflect the fact that it was manufactured using laser sintering. SULSA had a wingspan of two metres and an elliptical geometry with a shape designed for optimum aerodynamic drag. One major advantage of laser sintering was the ability to use elliptical wing profiles without additional cost, due to the fact that these generate less aerodynamic drag. Furthermore, the flexibility of the sintering process also enabled the design team to try out groundbreaking techniques and ideas which would be too expensive to implement using conventional technology. The use of snap connection technology enabled the individual parts to be assembled without fastening. The aircraft is powered by an electric motor and achieves a maximum speed of approximately 160 kilometres per hour.

SULSA (Source: Southampton University)

3.3.4 3.3.4 Construction industry and architecture

Additive processes (in particular LLM processes) have been used successfully for model construction for a number of years. However, the fact that additive technologies may also be suitable in construction and for manufacturing architectural structures has become a topic of discussion once again since the European Space Agency ESA announced a project to construct a space station on the moon. Dr. Behrokh Khoshnevis was one of the first scientists to develop a concept for the use of additive technologies for construction at the University of Southern California in 2004 with the name 'Contour Crafting'. The system utilises a portal robot to spray rapidly hardening special concrete onto the surface in layers to create buildings according to digital construction plans in less than 24 hours. In addition to constructing private residences, the application scenarios are visualised for situations in which architectural structures have to be constructed in remote regions in the shortest possible time. Series maturity was initially forecast for 2008. However, difficulties with the strength of the construction material, along with problems implementing the floor slabs and overhanging structures, have continued to delay the developmental maturity.

Lunar Contour Crafting (Source: University of Southern California)

Minibuilders robots for creating printed architecture (Source: IAAC, Barcelona)

Erecting additively manufactured building components (Source: WinSun Decoration Design Engineering)

In the context of the NASA Innovation Advanced Concepts Program (NIAC) a robot-controlled solution for constructing a space station on the moon was presented in 2012, and is based on the previously developed concept. In spring 2014 the Chinese construction company WinSun from Shanghai announced the successful development of a simple building structure with the help of an additive manufacturing process. According to the developers' statements, it should be possible to construct a building with the shape and size of a garage in less than 20 hours for under 5,000 US dollars.

The use of robot-guided systems will be highly important for implementing additive technologies for the construction industry as this eliminates the restrictions arising from the construction space of conventional systems. The systems currently on the market for additively manufacturing sand structures primarily serve to create sand shapes and cores using three-dimensional printing. The largest system from ExOne has a construction space of 1,800 x 1,000 x 700 millimetres. The additive creation of cement-bonded materials was also investigated by the University of Kassel in a project run by Dr. Asko Fromm and subsidised by the Central Innovation Program for Medium-Sized Companies (Zentrales Innovationsprogramm Mittelstand ZIM) from the Federal Ministry for Economic Affairs and Energy (see chapter 4.7).

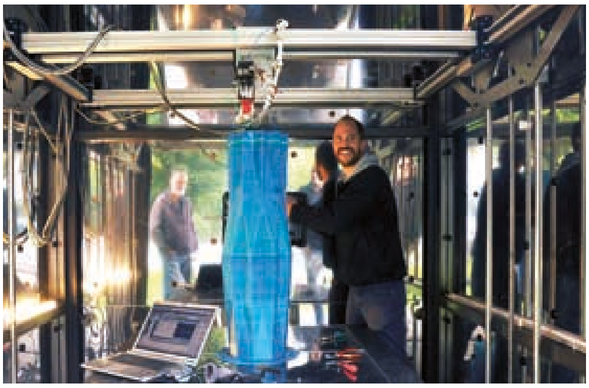
Market potential

The use of additive procedures in construction is currently in an early phase of development. The market researchers' analyses rarely define the size of the market. However, one can expect this situation to change in the near future.

Projects and special developments

Kamer Maker

DUS architects from Amsterdam were among the first to test the application for directly creating architectural structures in an experiment in mid-2013. The experiment involved a conventional FLM system (Ultimaker) being installed in a three and a half-metre high container with the goal of constructing a complete canal house. Due to a lack of alternatives, the architects utilised conventional plastic filaments made of polypropylene or polylactic acid. Manufacturing a three and a half-metre high block took one week.



Kamer Maker project in Amsterdam (Source: DUS Architects)

Natural Column project

The Berlin architect Daniel Büning presented a project named 'Natural Column' in January 2014 at the Printshow in New York. This was the world's first free-standing column with a three-dimensional interior hollow structure. The iterative forming method utilised a structural simulation process aimed at creating a geometry optimised for a specific load case and reminiscent of natural systems, while also minimising material consumption. The 'Natural Column' was created with a 3D printing system from Voxeljet utilising quartz sand and a mineral binding agent. The entire structure is 1.73 metres high, was generated in 65 hours with 0.3 millimetres thick layers and has a total weight of 1,065 kilograms. In view of the benefits with regard to resource usage and the ability to implement a complex interior design with a heterogeneous structure, further research is expected in this direction.

Stone Spray robots for bridge construction (Source: Anna Kulik, Petr Novikov, Inder Shergill)

Stone Spray

In the 'Stone Spray' project between 2012 and 2013 three students in Barcelona developed a robot which is capable of constructing high-strength structures based on sand and a road building binding agent. Trials utilising a support fabric for applying the sand mixture were very promising. The geometry of a stool was successfully implemented in approximately three hours. The developers primarily see potential applications for the technology for constructing bridges and other architectural structures in disaster areas.

Natural Column and the hollow interior structure (Source: Daniel Büning)

Saltygloo

In 2013 the architects from Real San Fratello in Oakland drew attention to themselves when they were able to create architectural structures through the use of layers of natural salts and a binding agent. The salt originates from San Francisco Bay and was extracted cost-effectively by means of evaporation basins using renewable energy. The structures resemble igloos and are based on aluminium rods fastened to 336 individual panels made of the salt-adhesive mixture. In comparison to similar constructions, the structure weighs less and is translucent, allowing light and sun rays to enter, yet still has a water-resistant consistency.

Microbiological sandstone production with the help of a 3D printer (Source: Ginger Krieg Dosier, Biomason)

Biobrick

The assistant professor of the American University of Sharjah in the United Arab Emirates, Ginger Krieg Dosier, is currently developing a microbiological process analogous to coral growth in the ocean to create cement-like construction materials based on sand through the use of bacteria and without emitting carbon dioxide. Every year the cement industry generates 800 million tonnes of carbon dioxide worldwide. The biotechnical process for manufacturing 'biobricks' would represent an alternative to the conventional, energy-intensive technology. Production only requires bacteria and their nutrients, along with sand, nitrogen, calcium and water.

Under climate conditions similar to a greenhouse the bacteria generate calcite and bind the grains of sand to create a stone-like structure similar to cement. Dosier plans to develop the process in such a way that in future a biobrick can be manufactured using a 3D printing kit which distributes the bacteria for calcite production on the sand layer by layer. The microbiological process takes five days.

3.3.5 Design industry, jewellery, interior

Additive manufacturing has always been highly attractive for the creative sector. The reason behind this is that additive technologies seem to enable the implementation of designs which previously required an extensive knowledge of manufacturing processes or which were simply impossible to implement due to technical or financial restrictions. Additive manufacturing even permits products and concepts with complex geometries, hollow spaces, undercuts and movable components to be created. This changes the way in which the designers and product developers work due to the fact that only a limited knowledge of production-oriented design is required. As a result of new material developments, additive technologies are currently being utilised in the fashion industry.

Additively generated armband ‚ADINKRA UNION' (Design: Nando Nkrumah)

The availability of construction kits and information about the design and operation, along with the software and component data has resulted in a flood of developments by designers and architects. Representatives of the creative economy have developed a vast array of new systems and patented some of these, transforming them into a successful business model. For example, the first FLM system for implementing fibre-reinforced components originates from a designer in Boston. Creative developers from Barcelona have carried out tests examining the robot-guided use of extrusion technology for architecture and furniture construction. With solar sintering, the German designer Markus Kayser has developed an additive sintering technology which only requires sunlight and sand (Peters 2011).

Market potential

Additive manufacturing offers an enormous range of opportunities for the creative and design sector. As such, a separate market specifically for members of the creative economy will arise in the future and possess its own products, scenarios and business models. This will focus less on business processes in terms of mass production as per the conventional understanding and more on solutions with an individual or customisable design, functionality and manufacturing method. In the jewellery industry, in particular, additive manufacturing processes are already utilised as an alternative to the conventional process chains.

Projects and special developments

7Tage7Hocker project

At the end of 2014 the designer Thorsten Frank clearly demonstrated how additive technologies will influence design work in the future with his project 7Tage7Hocker. The use of the Delta Tower enables the creation of several different seating furniture designs within one week, combined with a minimum of energy and resource usage. The shape can be created out of an endlessly drawn line by means of an extrusion process. The designer expects that additive processes will be able to replace injection moulding in many areas of furniture and consumer goods manufacturing in the coming years.

7Tage7Hocker – Printed seating furniture (Design: Thorsten Frank)

endless flow – robot-guided extrusion printing
(Design: Dirk Vander Kooij)

‚endless flow' robot-supported furniture manufacturing

The Dutch designer Dirk Vander Kooij presented one of the first robot-guided extrusion methods for furniture manufacturing at the Dutch Design Week 2011 in Eindhoven, and won the design festival's award as a result. Plastics gained from shredded waste are melted in a container. A robot-guided nozzle applies then the viscous mass in layers to manufacture furniture. The surface structure with large lines resulting from the width of the nozzle is a striking feature. In 2014 Dirk Vander Kooij presented the RvR Chair, the first chair generated in three dimensions via extrusion technology.

Open Innovation 3D ceramic printing process

At the dpz digital production centre of the HBKsaar (Hochschule der bildenden Künste Saar) a research project is currently investigating whether techniques for the computer-based 3D printing of plastics can be transferred to ceramic components while maintaining the design standards and professionalism. A 3D ceramic printer was developed with the help of open source hardware and software, and which is capable of creating objects with chambers, undercuts and ornamental structures. Craftsmanship and digitalised production processes were integrated with additive manufacturing.

RvR Chair - the world's first three-dimensionally extruded chair
(Design: Dirk Vander Kooij)

Shaped parts from the ceramic printer
(Design: xm:lab - Hochschule der Bildenden Künste Saar)

Habitat imprimé – printed interior

In 2012 the designers François Brument and Sonia Laugier, working in cooperation with Voxeljet, unveiled an interior concept which was manufactured completely using a large-format printer. The construction time with component dimensions of 4,650 x 1,400 x 2,200 millimetres and a weight of 700 kilograms amounted to 375 hours with a layer thickness of 0.15 millimetres. Polymethyl methacrylate (PMMA) plastic was utilised to fabricate the model of a bedroom with an integrated shower and walk-in wardrobe. The room layout can be varied as a result of the digital process chain. The surfaces can be structured as desired.

Project DNA – tailored haute couture from the 3D printer

Until now, the opportunities offered by additive manufacturing were rarely used in the fashion industry due to the unappealing materials, the small construction space of most systems and also the lack of flexibility of the shaped parts. In her DNA project the designer Catherine Wales attempted to manufacture clothing articles without a specific garment size as part of her Master's thesis at the Royal College of Art. The clothing was produced on the basis of an avatar and a 3D scan of the person by combining a corset, shoulder pieces and chest panels.

Kinematics

Shaped parts with movable joints and elements can be created using selective laser sintering. Since 2013 the designers from Nervous System in Boston have utilised this quality to additively manufacture flexible unfolding pieces of jewellery and chain mail. The result is a collection of objects which consist entirely of linked, triangular components.

Mycelium Chair

In October 2013 the Dutch designer Eric Klarenbeek presented a piece of work at the Dutch Design Week in Eindhoven in which he combined the principles of 3D printing with organic growth processes. The designer began by manufacturing the thin skin of the furniture out of a bioplastic using a printing process and then allowed the organic material to grow into it. A material mixture consisting of mycelium, chopped straw and water was utilised.

Laser-sintered nylon neck band (Design: Nervous System)

Mycelium Chair (Design: Eric Klarenbeek)

3.3.6 Food industry

In 2014 the market for 3D printing processes also expanded in the food industry as a result of the food printer. The costs for the systems lie in the four-digit range and, thus, operating a system is currently only profitable in the restaurant and catering industry, and for creating unique products. This includes customised baked goods, cakes or pralines, along with sculptures made of sugar or chocolate. Furthermore, the Italian food company Barilla is currently working on a system for additively manufacturing pasta. In the USA a system is being developed to produce meat by printing animal muscle cells.

Market potential

It is very difficult to assess the development and overall potential as the market is still in its infancy. Food printers will enable the restaurant and catering sector to implement new business models which will include themed and event gastronomy. Private usage is definitely linked with the price of the system and the availability of the ingredients.

In addition to the gastronomy industry, Dutch scientists also see food printers as having the potential to provide foodstuffs with personalised nutrient contents for the medical sector. Special nutrients or omega-3 fatty acids could be added to foods in the future, for example. Furthermore, foodstuffs could also be printed using more

Foodini pizza printer (Source: Natural Machines)

sustainable caloric sources by processing algae proteins instead of resource-intensive animal proteins. In addition to the economic potential, this would also serve as an opportunity to reduce greenhouse emissions resulting from livestock farming.

Projects and special developments

Sugar Lab/ChefJet

In autumn 2013 3D-Systems became one of the first major systems manufacturers for additive production to enter into the emerging food printer market. The company took over Sugar Lab in Los Angeles, a company run by an American designer and an architect, after they created a sensation in May 2013 when they presented an exhibition of printed sugar sculptures.

The two designers created the sculptures with a colour jet printer and utilised sugar powder together with an edible, coloured binding agent. In January 2014 3D-Systems presented the first ChefJet at the CES electronics exhibition. The basic variant has a price of approximately 3,600 euros and it is primarily offered to bakeries, confectioners and for designer gastronomy.

Foodini / Natural Machines

After NASA presented the concept for a pizza printer in 2013, the start-up company Natural Machines from Barcelona set out to launch and market the first pizza printer, the Foodini. In addition to the Italian speciality, the Foodini can essentially be used to prepare any type of food which requires a paste-like mass, or where the ingredients can be melted by means of heat. As such, the Foodini is also suitable for producing baked goods such as cookies, chocolate sculptures or dishes made with minced meat. The ingredients are supplied in a heated stainless steel cylinder and applied via a nozzle. Every individual ingredient is contained in a cartridge which is pressurised in accordance with the consistency of the mass. Recipes can be downloaded from the Internet.

Chocolate printer/Choc Edge

A British company has launched a 3D printer for chocolate products with the name Choc Edge Creator. The device is intended for use by chocolatiers, confectioners and restaurants. In future, the company expects specialised chocolate businesses to develop in our cities in which customers can print chocolate sculptures based on their own personal designs. The first version of the printer, the Choc Creator V1, is available for a price of approximately 3,500 euros.

Printed sugar sculptures (Source: 3D-Systems)

Printed chocolate with the Choc Edge printer (Source: Choc Edge Ltd UK)

Printed snacks (Source: TNO)

Pasta printer/Barilla

In collaboration with the Italian pasta manufacturer Barilla scientists at the Dutch TNO are currently working on developing a 3D printer for pasta. However, the device is not intended for mass production, but rather private usage or at restaurants. In a manner similar to a coffee dispenser, the goal is to operate the printer with cartridges which contain the ingredients for a variety of different pasta types. Barilla aims to achieve a manufacturing time of two minutes for 15 to 20 pieces of pasta. The development has now reached the prototype phase. The first systems have already been tested at a number of restaurants in Eindhoven.

Meat printer/Modern Meadow

In October 2012 the American start-up company Modern Meadow announced the first successful additive manufacturing of a cube of meat made from living animal muscle cells. These cells were applied in layers using a 3D printer and held together using bio-ink containing the various cell types. The cube of meat received its final consistency in a subsequent process in a bioreactor. The technology should have a significantly better environmental balance than meat produced through normal animal breeding and help to reduce mass livestock farming. The technology can also be utilised to manufacture leather.

Modern Meadow incubator (Source: Modern Meadow)

However, additive manufacturing processes in the food industry essentially differentiate between the applications. In the case of simple, more design-oriented applications, such as 3D printing of sugar icing or chocolate sculptures, one can expect that the products will be readily accepted and labelling for the new products will not necessarily be mandatory. However, innovative applications such as the additive manufacturing of complete, in some cases customised, foodstuffs represent a different situation. Certification, acceptance and labelling obligations for such products are fundamental issues. Furthermore, ecological and ethical issues also play a major role and need to be taken into consideration.

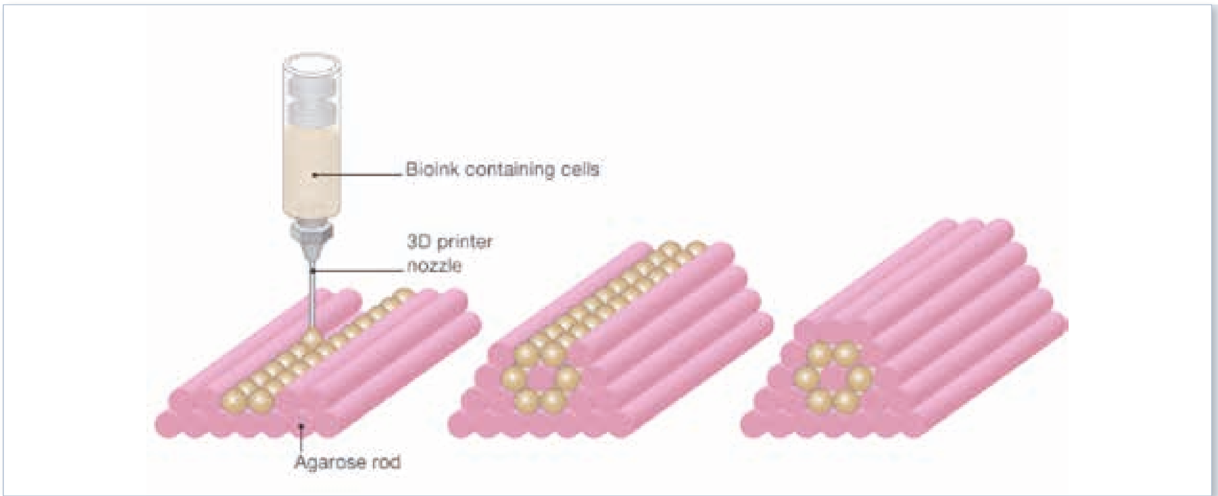


Image: How the meat printer functions (Source: Modern Meadow)

3.4 3D print service providers and content platforms

Given the high purchasing costs for industrial systems using additive processes service providers have already become established on the market. Whereas they formerly worked primarily for company development departments, which did not wish to operate their own systems, the increasing interest in direct additive production for the creative economy and among private individuals has now seen online platforms become established on the market. Data of 3D parts can be uploaded and the construction ordered with a specific material and the desired colour. A number of service providers also support the generation of the required data and offer contacts with designers.

The online print services generally also provide an overview of the available final designs which can be selected and customised. A number of print service providers (such as 3D-Print Barometer, Materialise) also provide online support for the pricing.

Overview of 3D print service providers

- 3D-Colorprint: www.3d-colorprint.de
- Fabberhouse: www.fabberhouse.de
- Materialise: www.imaterialise.com
- Ponoko: www.ponoko.com
- Sculpteo: www.sculpteo.com
- Shapeways: www.shapeways.com
- Trinckle: www.trinckle.com

In recent months the platforms have been increasingly expanded and have a more user friendly design. In addition, the business model of a number of platforms is developing in a direction which offers new sales opportunities for product designers and artists. These portals enable them to upload data and sell the data while paying a commission to a third party. In some cases it is also possible to download the 3D blueprints and modify them to a certain degree.

In addition to the online print service providers, content platforms have also become established on the Internet, and allow users to store and share their own 3D designs and component plans. A search function can be used to find the desired design for one's own print from among the thousands of object data sets. Generally, one or more STL files are available for downloading. On some platforms the source data is also available in addition to the STL data.

Archive 3D: www.archive3d.net
more than 40,000 data sets; focus: furniture, interior, accessories

Fabbulos: www.fabbulos.com
(under development; focus: premium design)

GB3D Type Fossils: www.3d-fossils.ac.uk
(under development; focus: 3D models of fossils)

GrabCAD: www.grabcad.com
(more than 520,000 data sets; focus: technical parts and components)

Thingiverse: www.thingiverse.com
(more than 130,000 data sets; focus: small parts, accessories, lamps, games)

Trimble 3D-Warehouse
(more than 5,000 data sets; mostly 3D architecture)

TurboSquid: www.turbosquid.com
(more than 300,000 data sets; mostly buildings and 3D architecture)

Yeggi: www.yeggi.com
(more than 160,000 data sets; focus: technical components, small parts, accessories)

Local print service providers are now present in a number of cities, in addition to the online service providers. Their services range from a complete service with multiple systems to do-it-yourself print shops, as well as FabLabs and 3D Hubs. As a rule, 3D print shops sell both finished printed components as well as printing services for customers. In the case of DIY print shops, it is possible to rent a 3D printer and carry out the printing process at home or at the office.

The idea of the FabLab originates from the MIT Media Lab in Boston. The first FabLab (fabrication laboratory) was opened here in 2001 under the supervision of Prof. Neil Gershenfeld. This refers to a small workshop with its own printers and other systems such as milling or laser cutters which can be used by a community utilising open source software together or under the supervision of voluntary helpers. The community idea ensures that every single individual has access to all of the technical options of additive manufacturing and also receives the necessary software. The individual FabLabs are run as associations, are organised regionally and form a network with other FabLabs. A code of conduct and self-commitment for all of the open workshops are compiled in the FabLab Charter which is published by the Fab Foundation. Open FabLab appointments are generally arranged for beginners so that everyone can use the printers and software independently. A FabLab with the name FabLab FFM is also due to open in Frankfurt in the near future.

The community idea not only extends to the workshops that maintain the printers, but also to private individuals who have purchased an additive manufacturing system but do not utilise it around the clock. The 3D Hubs business model originates from the Netherlands. A platform lists 3D printer owners who allow other people and companies to use the system for a fee. This allows the systems to be used to capacity and also enables the printer owners to generate revenue. With every order processed via 3D-Hubs the platform operators from Amsterdam also earn revenue due to the commission of 15 per cent of the printing price. More than 7,000 systems operators are now registered worldwide. The platform was also launched in Germany in autumn 2013. Berlin currently has 34 registered systems, Frankfurt 22, Hamburg 20 and Cologne 12 (status: 15th September 2014).

3D print service providers in the Rhine-Main region (map based on www.3dhubs.com)

3.5 Legal issues in the context of additive manufacturing

DISCLAIMER

It must be explicitly stated that the information provided in this chapter represents neither a conclusive presentation nor individual legal advice. The information solely serves to illustrate current issues and perspectives in order to provide an overview of the problems described and the context. The information is in no way intended to replace individual legal consultation from appropriately qualified persons.

An increasing number of questions regarding the legal conditions have arisen, in particular since the emergence of the first platforms for sharing 3D printing data. Although the legislation regarding the development, sale and use of three-dimensional objects and products has a broad scope with the copyright, brand, patent, utility model and design laws, the digital exchange and replication contains a number of risks of legal violations of which the user may be unaware. These include claims for damages in the event of failure of an additively manufactured component, the use of privately printed objects on commercial premises or scanning a legally protected product to generate data for 3D printing. The distribution of data for constructing weapons via the Internet represents the most obvious legal problem.

As a rule, the issues do not differ with regard to the private or commercial use of a printed component or product due to the fact that copyright and trademark laws apply equally in both cases. Legal violations can occur when recording the data of a protected product, when sending or accessing three-dimensional data and also through the additive manufacturing of a component geometry or its sale.

Copyright

Copyright serves to protect a person's 'intellectual property' which reaches a certain threshold of originality. This refers to works of literature, photography, film and music, as well as scientific works and free and applied art. Copyrights can be asserted without having to register a creation as such with the patent and trademark office. In the context of additive manufacturing, this primarily applies to three-dimensional works of art and sculptures, along with design objects and pieces of furniture. Copying for private use may be permissible provided that no data which has obviously been published illegally is utilised. Depending on the case at hand multiple copies are permissible. However, sending the data to a service provider is not permitted. The duplication for commercial purposes without the permission of the originator can be prosecuted. Even the digitalisation of a work protected by copyright represents a copyright-relevant action. Only the copyright owner is permitted to obtain or scale digital data from his or her own work (VDI: Statusreport "Additive Fertigungsverfahren", Verein Deutscher Ingenieure e.V., September 2014). The copyright does not expire until 70 years after the copyright owner's death.

Design rights

In addition to copyright claims the design of products and consumer goods can be further protected by designers or a company through registration with the patent and trademark office. The registered design is protected for a period of 25 years. Novelty and uniqueness are prerequisites for the registration but are not checked by the patent and trademark office. The reference to a registered design can prohibit both the duplication of a product, consumer good, designer and/or fashion article, along with the marketing or use thereof. As such, these design rights also have a strong influence on issues regarding the legal framework for additive manufacturing.

Utility model protection and patent law

Patents and utility models are industrial property rights which afford the inventor and/or company the protected commercial use of a technical invention. Whereas granting a patent requires a significant level of invention, utility models only represent an inventive step. As such, the protective framework for patents is significantly greater and the maximum protection duration of 20 years far exceeds the ten years for utility models. Possible patent rights should be checked when reproducing parts or components of a product by means of additive manufacturing. After the expiry of a patent the technical solutions published in the course of the patenting process become freely available. The issue of whether copying design features of a product represents a direct breach of patent has not yet been resolved. In view of the prevailing jurisprudence the concrete copying of geometry data appears to be sufficient to represent a breach of patent (VDI: Statusreport "Additive Fertigungsverfahren", Verein Deutscher Ingenieure e.V., September 2014).

Trademark law

Trademark law enables the protection of the labels of a product or a company in the form of images (logo), words (word mark), their combination (word mark and logo) or graphical illustrations in two-dimensional and three-dimensional form. Products and goods with protected trademarks may not be reproduced, offered or marketed in an identical or similar form. Due to the fact that the protected marks on a product may be reproduced as a result of the increasing popularity of 3D printers and scanners for recording 3D geometries, legal violations cannot be excluded. Thus far only a few legal violations within the context of additive manufacturing are known. However, in view of the growing market for additive manufacturing this could grow in a manner similar to the situation observed in the music and film industry at the beginning of the millennium.

Liability issues

In addition to the possible violation of proprietary rights, the issue of product liability for the market with additively manufactured products has not yet been clearly resolved. Product liability law provides for possible claims against the manufacturer or seller with regard to faulty parts or components. Due to the fact that additive manufacturing allows the production of products in a private context based on 3D CAD data, this gives rise to new liability issues. The current jurisprudence assumes that the producer is liable for damages to legal assets which result from an incorrectly manufactured product. Whereas the Federal Court of Justice (Bundesgerichtshof – BGH) emphasises the product liability as a result of a behaviour-related error, the European product liability law does not focus on the incorrect behaviour of a company when assessing the liability issue but rather the product fault as such.

In view of the fact that the design, fabrication and assembly take place virtually in additive manufacturing, and are often carried out at different locations and by different people and companies, the "special aspects of the division of labour are particularly visible" (VDI: Statusreport "Additive Fertigungsverfahren", Verein Deutscher Ingenieure e.V., September 2014). One can assume that within the context of industrial manufacturing the final manufacturer will be liable for product errors with a view toward the design responsibility and liability claims will arise within the internal relationships in the case of faulty designs. However, differences arise within the context of additive manufacturing when the manufacturing is carried out for a private individual as the end consumer. In this case, the final manufacturer can be made comprehensively liable for the errors of an additively generated product. The lawyer Dr. Markus Bagh advises companies who are intending to do business creating 3D prints to include an 'exclusion of liability for print on demand' clause in their terms and conditions (Horscher, Florian: 3D-Druck für alle – Der Do-it-yourself-guide. München, Wien: Carl Hanser Verlag, 2014).

It remains unclear whether the jurisprudence with regard to the situation as to whether a private individual can become the manufacturer within the context of the product liability law by operating his own additive manufacturing system. According to paragraph 4 of the Product Liability Act the manufacturer of a product is the party "which has manufactured the end product, a basic material or a sub-product". Given that the legislative authority always uses the product term as per paragraph 2 of the Product Liability Act together with the manufacturer term, lawyers doubt whether a liable independent action on the part of a private individual can actually occur in the case of the private generation of a product with the help of an additive manufacturing system on the basis of finished design data. If the data is not independently modified then printing a component can also be regarded as a pure assembly activity in accordance with the manufacturer's specifications. As a result, the designer would then be responsible (VDI: Statusreport "Additive Fertigungsverfahren", Verein Deutscher Ingenieure e.V., September 2014).

A clear judgement has not yet been achieved regarding liability in the context of consequential damages – where an additively manufactured component causes damage to the machine in which it is constructed – and the effect this then has on warranty, guarantee or compensation for damages.

4. Additive manufacturing: Selected success stories, potentials and projects from Hessen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Philipps Universität Marburg

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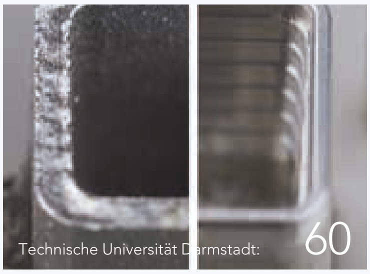
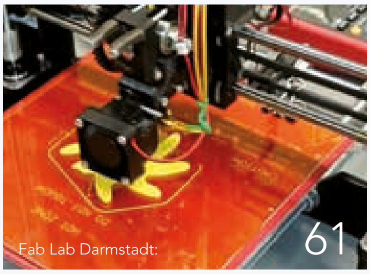

Technische Universität Darmstadt: 60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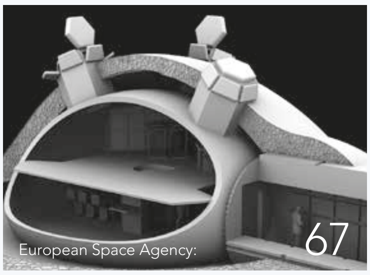
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4.1 Adam Opel AG: Assembly aids for finishing from the 3D printer

IWhereas utilising additive technologies for directly manufacturing components in vehicle production remains a scenario for the future, additive processes such as 3D printing are already being used as support aids in production. One example is Adam Opel AG, where small lots of assembly tools for the production process are manufactured using 3D printers. Approximately 40 assembly aids for windscreens and running boards have been in use since autumn 2014 for the production of the ADAM ROCKS Opel model. 3D printers make the manufacturing process far more cost-effective and faster. Whereas the final assembly tools were previously manufactured with a milled mould and hand-laminated resin forms, the devices are now available within only eight hours when manufactured with the 3D printer and are also up to 70 per cent lighter.

Design and modification of the assembly tools carried out on the computer (Source: Adam Opel AG)

Many people are convinced that more and more printed assembly aids will be integrated into the production process and that additive manufacturing will play an increasingly important role. The tools were drafted on the computer during an early phase of the ADAM ROCKS development. This enables the parts to be adapted rapidly, and if any aspect of the vehicle design is modified, the tool can also be adapted with just a few clicks. This significantly reduces the production costs.

As part of the production of the Opel ADAM ROCKS an assembly aid manufactured via a 3D printer is used to attach the vehicle lettering to the rear side windows, for example. (Source: Adam Opel AG)

Mit einer von Opel entwickelten Verbindungstechnik ist Adjoining technology developed by Opel also makes it possible to generate assembly tools which are larger than the printer's construction space. The assembly aids for the side skirts for the rear spoiler of the ADAM ROCKS, for example, consist of multiple smaller elements. This also appears to simplify reworking. This is due to the fact that shaped parts printed using plastics can be processed both mechanically and chemically, and can also be combined with other materials. In particular, the ability to adapt the ergonomics to the specific assembly technician within the space of a few minutes using a computer provides additional benefits that promote the use of additive technologies in automotive production. In addition to the ADAM ROCKS, the Insignia and the Cabriolet Cascada now also benefit from assembly tools manufactured via 3D printers. Additive manufacturing shall be successively expanded to include other Opel models such as the Corsa, Vivaro and Mokka. As a result, Opel will play a leading role in the use of additive manufacturing principles within the General Motors corporation.

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4.2. EDAG Genesis / Light Cocoon: Additive technologies for manufacturing a vehicle skeleton framework

The EDAG Genesis Study was presented at the Geneva Motor Show in March 2014 and represents a visionary look at the future of automotive manufacturing. In view of the opportunities offered by additive production through laser sintering, 3D printing, stereolithography and so forth, it will be possible to manufacture a complete chassis as a single piece in future. The developers and designers from EDAG presented the futuristic vehicle sculpture as an analysis of the current opportunities and attempted to present a timeline of the potentials for additive manufacturing using a chassis structure.

EDAG GENESIS takes its inspiration from a turtle, whose armour plating provides protection and shock absorption, and is also merged with the movement skeleton. The exhibit's skeleton frame resembles a naturally grown bone structure which cannot be created using conventional production techniques. EDAG's developers are already profiting from the enormous range of freedom and the new design options that additive manufacturing processes offer designers and engineers.

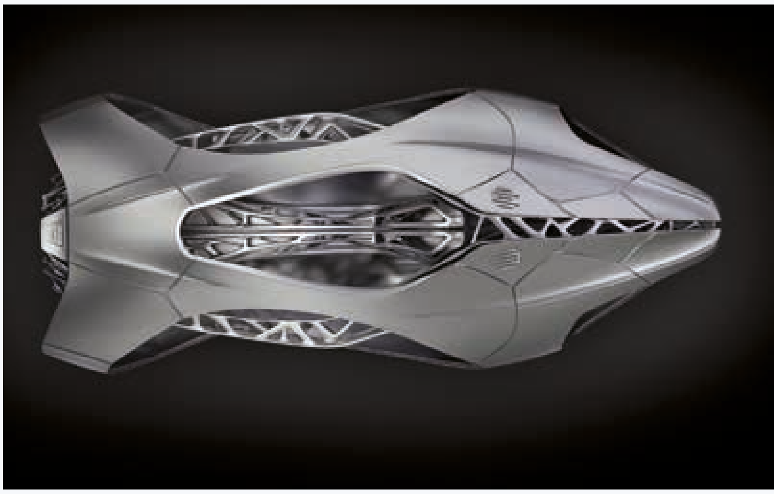
"Initially we definitely had to justify why we had selected a sedate turtle as the basis for a vehicle concept," explained Johannes Barckmann, lead designer and bionics innovator at EDAG. "Turtles are impressive swimmers underwater but not necessarily the fastest creatures on land. However, the aspect that inspired us to use the turtle's shell as the inspiration for Genesis was the simple fact that we are talking about passenger protection, a feature that nature has perfected over the course of millions of years. This is something an engineer could never invent!" (www.edag.de/edag/das-unternehmen/edag-stories/bionik.html, Version: 03.02.2015)

EDAG GENESIS Study – Single-piece vehicle chassis (Design: EDAG)

An interdisciplinary team consisting of EDAG designers and specialists from the EDAG Competence Center Lightweight Construction investigated the potentials of the most promising additive technologies and held discussions with experts from research institutions and the industry. The technologies ranged from selective laser sintering (SLS), to selective laser melting (SLM) and stereolithography (SLA), along with fused layer modelling (FLM). To carry out the evaluation the technologies were quantified in a specially developed matrix, taking into consideration criteria such as structural relevance, possible component size, manufacturing tolerance and manufacturing costs.

The results indicated that an enhanced FLM process represented the most promising candidate. In contrast to the other technologies, FLM provides the option of manufacturing components with almost any desired size. As such, there are no restrictions resulting from a specified construction space. Instead, the structures are generated by the application of thermoplastic materials by robots. Complex structures are manufactured in free space entirely without tools and jigs. Furthermore, the ability to integrate endless carbon fibres into the manufacturing process enables the components to achieve the desired strength and rigidity characteristics.

Following the success of the EDAG GENESIS the company has continued developing its vision of a bionically inspired chassis structure. The potentials offered by additive manufacturing are also being used to implement nature's bionic construction principles and strategies in producing the "EDAG Light Cocoon". Its premiere is planned for the Geneva Motor Show 2015. "We are pursuing the vision of sustainability – the way nature has shown us: light, efficient, without waste," said Barckmann, explaining the new project. "The results of the "EDAG Light Cocoon" demonstrate a stable, branching supporting structure manufactured using a 3D printer which only applies material where it is actually required." (www.edag.de/edag/news-detail/getarticle/News/detail/natuerlich-ultimativ-leicht-der-edag-light-cocoon.html)



EDAG GENESIS Study – Single-piece vehicle chassis (Design: EDAG)

From today's perspective, manufacturing components, and in the next step modules, is achievable. However, the goal of being able to manufacture an entire chassis by means of additive manufacturing processes is still far from being able to be applied on an industrial scale, and currently remains a desirable vision for the future. The EDAG Group has set itself the goal of implementing valid applications for the use of additive technologies for vehicle manufacturing in the coming years.

EDAG Light Cocoon Study (Design: EDAG)

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EDAG Light Cocoon Study (Design: EDAG)

4.3 FKM Sintertechnik: The factory of the future for the additive manufacturing era

FKM Sintertechnik has been active as a laser sintering provider for more than 20 years. The company has long regarded laser sintering as a fully viable production process extending beyond prototype construction. When the company opened its new plant in Biedenkopf near Marburg in July 2014, it put into operation a complete manufacturing facility with laser sintering systems, bringing additive manufacturing up to the level of industrial production. The unique aspect: The new production facility is designed consistently to industrial standards while taking into consideration demanding environmental principles. The energy requirements, for example, are met using green electricity. Furthermore, the consistent recuperation of heat energy from the production process allows the factory to function without a heating system. The energy recuperated is sufficient to heat both the warm process water and the building itself down to an external temperature of -15 degree Celsius.

New laser sintering factory in Biedenkopf (Source: FKM Sintertechnik)

The heart of the facility is a manufacturing hall with approximately 3,000 square metres and 25 laser sintering systems for manufacturing finished plastic and metal components. The facilities are primarily supplied with powdered material via a fully automatic system consisting of a closed-circuit with multiple silos and a central distribution station. All of the upstream and downstream processing activities are carried out in a process-optimised infrastructure. A flexible production steering system manages and monitors all of the processes from the quality-control of the delivered powder material to the quality assurance of the finished sintered parts. "This enables us to guarantee the optimal use of the systems and the customers profit from shorter lead and delivery times," explains Jürgen Blöcher, Managing Partner of FKM Sintertechnik.

A variety of different materials can be used for the manufacturing process, depending on the customers' individual requirements. Polyamides such as PA 11 and PA 12, the flexible elastomer TPU (thermoplastic polyurethane) with its rubber-like properties or the chemical and heat-resistant polyetheretherketone PEEK HP3 can be used as plastics. The metals include tool steel, stainless steel and aluminium, along with DirectMetal 20, a bronze-based metal powder, or Inconel 718, a nickel-chrome alloy which is resistant to extreme environments and used for high-temperature applications such as turbochargers or turbine blades.

View on the materials silos and the central distribution unit in the new laser sintering factory (Source: FKM Sintertechnik)

One impressive example for the performance capabilities of additive manufacturing is a system-relevant component for painting robots in the automotive industry, which was further developed as part of a joint project between FKM Sintertechnik and the customer. "The starting point was a cylindrical aluminium component. It was originally 120 millimetres long due to the necessity of integrating approximately 40 ducts in different directions by means of drilling. Thanks to our design specially developed for laser sintering, consisting of intertwined, closely spaced ducts, the component length was successfully reduced

Manufacturing hall with 25 laser sintering systems and automatically controlled material cycles (Source: FKM Sintertechnik)

to 21 millimetres", asserts Blöcher when explaining the showcase project. The component was manufactured using the high-performance polymer PEEK HP3, which also served to reduce the weight from the original four kilograms to only 230 grams. "Naturally, because we changed the material we first had to prove that our products could match up to the aluminium pieces," continues Blöcher. "However, tests with prototypes not only proved that we could achieve the same performance but actually demonstrated that the painting robots perform significantly better using the new, laser-sintered components." The component has now been integrated into the painting robot's series manufacturing and FKM Sintertechnik had already delivered thousands of these components by the end of 2014.

Additively manufactured PEEK component for painting robots (Source: FKM Sintertechnik)

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4.4 sauer product: Faster launches through additive manufacturing

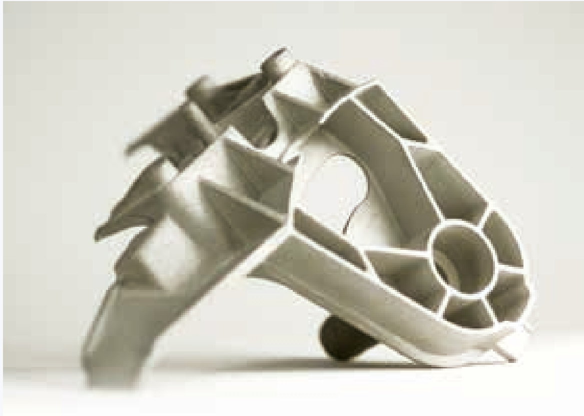
sauer product, a company from Dieburg in southern Hessen, is an additive manufacturing pioneer and has been using the technology since 1988. Over the course of time new technologies have arisen in combination with new materials. To be able to offer optimum solutions for specific applications, the company provides a broad spectrum of prototyping technologies. The product portfolio includes both conventional processes as well as innovative technologies such as laser sintering.

As a result of the company's extensive experience, sauer product is now capable of manufacturing even those workpieces with extremely complex geometries rapidly, at affordable prices and with the precision required for the application. The company is one of the pilot users and has already been utilising SLM processes for ten years. It has gained in-depth experience and now numbers among this technology's leading providers.

A future technology – metallic 3D printing

sauer product offers materials including stainless steel, hot-working tool steel and cobalt-chromium steel, along with aluminium and titanium. As such, the company offers a broad range of metallic materials for additive manufacturing.

Additive manufacturing procedures have proven highly successful for prototype construction. One outstanding example is the "Carrier and covering panel for a vacuum cleaner" project carried out by sauer product. This seemingly simple component required a prototype for stress and functional testing. However, using conventional methods this prototype can only be manufactured using an expensive, multi-stage forming and punching tool. The SLM process utilised by sauer product is an entirely different case: Based on the 3D CAD volume model, the production process was programmed in only one hour, while the approximately 90 x 230 millimetre carrier panel was manufactured in twelve hours by the fully automatic system. The user received the finished prototype for testing only one week after placing the order.



Metallic 3D printing of a structural component (Source: sauer product)

In fact, the significant time savings that sauer product was able to offer were more valuable than the savings in tool costs for manufacturing the prototype. Alone manufacturing of the conventional tools themselves would have taken approximately four weeks. Thanks to additive manufacturing using SLM processes and sauer product's expertise the customer was able to reduce the originally planned time to market by approximately 15 per cent. The critical factor was that the additively manufactured workpieces possessed the same mechanical characteristics as the conventionally processed original material.

sauer product also creates benefits when it comes to specially designed unique systems such as those for power stations. These components are often subject to highly specific requirements. In view of this, the SLM process often proves to be the prevailing method for series production given that the "series" in this case consists of small quantities.

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4.5. Philipps-Universität Marburg: Additive manufacturing of individual dental prostheses and jawbones

Given the individual nature of dental prostheses and the individual pieces required, additive processes have developed into a viable alternative to traditional manufacturing methods. Additive processes have also become increasingly important when replacing jawbones, compensating for tissue atrophy (known as resorption processes) which occurs after tooth loss or with tissue that has to be removed as a consequence of accidents or tumours. Replacing missing teeth through tooth implants has now become a routine activity in modern dental medicine. However, due to the resorptive processes following tooth loss, the jawbone volume first needs to be restored before the dental prosthesis can be implanted. The areas of the jawbone requiring restoration are even more extensive in the case of cancer. The jawbone is generally restored by removing bone material from another part of the body (such as the fibula) and applying it to the jawbone. However, this treatment method occasionally results in complications with the jawbone and also at the site where the bone material has been removed.

At the Philipps-Universität Marburg the dental specialist Christine Knabe-Ducheyne has been researching new bioceramics for additive manufacturing since 2011. These are intended for restoring collapsed jawbones and stimulating the growth of the body's own bone growth before disappearing naturally after a period of three to six months. In a series of tests carried out on sheep, she successfully demonstrated the bioactivity of calcium alkali orthophosphate as a replacement material. A current research project is investigating manufacturing bone material by means of tissue engineering with additive manufacturing processes. The geometry of the jawbone is first scanned by means of computed tomography and the required bone structure generated three-dimensionally. The structure is then printed using a bioceramic material. The scaffold can then be enriched with bone cells and growth hormones and may also contain microscopic blood vessels. When attached to the jawbone, the scaffold then stimulates the bone growth and should merge with the natural tissues before disappearing after a few months. The implant can be fitted after this procedure.

Professor Knabe-Ducheyne has been pursuing this goal for more than 25 years. The process is currently being tested on animals as part of an endowed professorship financed by the Hanau company Heraeus-Kulzer with one million euros. Scaffolds containing blood vessels are implanted in the femur, the tissue growth examined and the resorption characteristics of the bioceramic tested.

"In the series of tests we are examining a variety of different scaffolds in order to optimise the materials and conditions. We then want to carry out large animal tests with the scaffold," adds Christine Knabe-Ducheyne, describing the research project's approach. "It would be wonderful if I could spare patients the unpleasant bone removal process in the future." (www.uni-marburg.de/aktuelles/unijournal/uj44/muj44herbst2014.pdf)

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4.6 4D Concepts: ‚Customised' sports shoe insoles by additive manufacturing

The company SEE Sport Equipment Eichinger in Mitterskirchen has developed a device for manufacturing individually customised insoles for sport shoes with the motto 'Your sport is our mission'. Today the Vaku-Fit is primarily utilised by specialised sports stores and orthopaedic shoe makers.

Customers stand on a silicone pad filled with microspheres to create their unique footprint. A vacuum solidifies the microspheres and the resulting form is inserted into the heated insole. A second fitting with the customer creates the perfect insole. This is then fitted into the shoe and offers perfect wearing comfort without pain and pressure points during sport.

Shaping the individual footprint using a silicone pad filled with microspheres (Source: 4D Concepts)

Based on this idea, 4D Concepts created the 3D CAD design for SEE. Since completing development, 4D Concepts has manufactured the silicone pads for the Vaku-Fit devices in series via vacuum casting. Vacuum casting with a medically suitable silicone material has established itself as an efficient production process for this product in view of the quantities required and the different colour variants. The benefits for SEE lie in the rapid availability of smaller quantities, along with the flexible production of different colour variants.

The moulds for the vacuum casting are manufactured by shaping a master model produced out of silicone rubber via 3D printing. Subjecting it to a vacuum ensures perfect mould filling and forming of the surface quality of the master model. Vacuum casting is especially suitable for manufacturing plastic parts with series-like material characteristics and small to moderate quantities and has established itself as the ideal production process for the Vaku-Fit.

4D Concepts is an innovative company focusing on the additive manufacturing of plastic parts in the Rhine-Main region and has been manufacturing products for almost every industry using various additive processes such as laser sintering, stereolithography or the MultiJet since 1995. The additive manufacturing processes are supplemented by further services such as 3D scanning, digital modelling and 3D CAD design along with conventional manufacturing techniques such as milling, vacuum casting, laser cutting and various surface refinement processes for customer projects beginning with the initial idea and extending to the series part.

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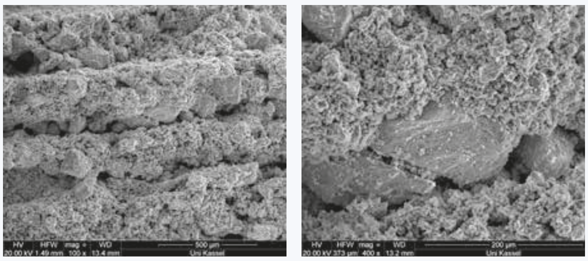
4.7 Universität Kassel: 3D printing of cement-bound shaped parts

3D printing technologies have remained largely unexploited in the architectural field, where large-scale and geometrically complex components are often required in small quantities. Cement material is a familiar material, and is also of interest for this manufacturing technology given that it is inexpensive and thus also suitable for large-scale parts.

As part of a research project initiated by the University of Kassel and carried out together with industrial partners, a process for additively manufacturing cement-bound shaped parts was developed in 2012 and 2013. The viability of the resulting products for the architectural field and construction industry was also investigated as part of a dissertation in the field of supporting structures and massive construction.

In this process a cement material is combined with additives and applied in layers in a construction space of up to eight cubic metres using a system from Voxeljet. The mixture is also hardened selectively and in layers with an aqueous solution. Processing a cement material using 3D printing represents a fundamental break from the former processing methods given that the conventional mechanical mixing to ensure an even mixture of liquid and cement powder no longer takes place.

Investigations have shown that the physical properties of the final product change considerably as a result. This is due to anisotropies which occur as a result of the layered structure and can be seen in the following scanning electron microscope picture.



Layered structure of a cement-bound material after processing in a 3D printer (Source: University of Kassel, A. Fromm)

In trials accompanying the development strength deviations of up to 50 per cent were found, depending on the angle of incidence to the layer. These undesired effects can be reduced through subsequent treatment, and simultaneously increase the overall strength. When the DIN EN 1992 standard is applied to such products for exterior usage then the specified characteristics have not yet been fulfilled. However, regardless of this, the goal could be to manufacture a cement-bound shaped part using an additive process which offers the designer the greatest degree of design freedom achieved using the 3D printing process.

For this reason further testing is required to utilise these new products in the architectural field and construction industry due to the fact that long-term studies found unexpected deterioration of the strength of the cement materials used. Furthermore, strategies for permanently monitoring the production process also have to be developed.

Prototype of a parametric module without formwork (Source: University of Kassel, J. Frankenstein-Frambach, A. Fromm)

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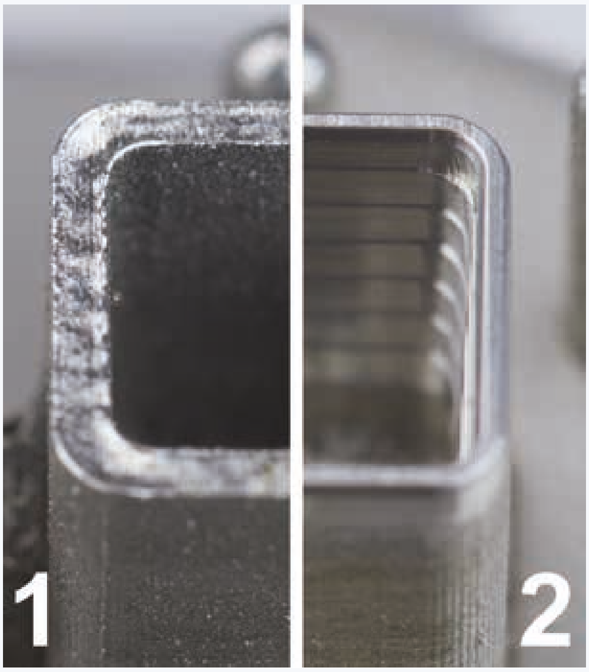
4.8 Technische Universität: CAD / CAM process chain for digital production

Products for biomedical engineering largely remain invisible to the public with the exception of artificial joints. In the field of dental technology patients in Germany received approximately 63 million tooth fillings along with two million bridges and one million crowns in 2009. One third of the bridges and crowns are already manufactured using semi-automated procedures. The entire sector is seeing a development away from production using manual labour toward the use of the latest additive and erosive automated manufacturing technologies. In the lead market for biomedical engineering the challenge consists of effectively combining medical and technical competencies in order to address the increasing cost pressure in the health system.

The aim of the COMMANDD research project is to achieve parallel development of the product and the simultaneous provision of an integrated and hybrid production system for dental indications. This process of semi-automated medical device manufacturing serves to shorten existing process chains and lead times while safeguarding the quality and value creation. Examining this value creation network results in improved patient care (quality-of-life) and also reduces healthcare costs. The existing process chain is structured with a uniform, future-safe data system which also increases productivity. In addition, the data transfer interfaces are standardised. Furthermore, both additive (generative) and erosive manufacturing technologies for various indications (product classes) are also linked in a sequential and economical process chain.



Additively manufactured SLM semi-finished product (1) and SLM semi-finished product reworked via machining (2) in comparison (Source: Technische Universität Darmstadt)

The project results are transferred directly to the dental specialists at TU Darmstadt by means of a process chain demonstrator. The entire manufacturing system for individual mass production can also be transferred to the decentralised manufacturing of individual patient endoprostheses. In other industries, such as general engineering, prototype construction and manufacturing machining tools, there is a major loss of efficiency at the interface between the virtual product creation and production as a result of the shifting fields of competence. By integrating special production knowledge from the field of product design this interface has been expanded to form an intersection. In the second phase, individual areas of the project are transferred to the sectors described above with an interdisciplinary user workgroup.

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4.9 FabLab Darmstadt: Digital production and founding

A FabLab was opened in Darmstadt on 7th April 2014. It is located on the premises of the Fraunhofer Institute for Computer Graphics Research (IGD) and as part of the Fabbing & Founding research project (digital production and founding) on which the Technische Universität Darmstadt, the House of IT and the Fraunhofer IGD are working together. The FabLab provides those interested, creative people, technical enthusiasts, researchers and programmers the space to try out the opportunities offered by digital fabrication, and test the potentials of additive manufacturing in a protected environment. The idea of the FabLab originates from the USA where Neil Gershenfeld founded the first 'fabrication laboratory' at the Massachusetts Institute of Technology (MIT) in 2002.

"This consists of an open, non-commercial space in which private individuals can use technologies free of charge that are also utilised for industrial production," states Professor Peter Buxmann from the Technische Universität Darmstadt, explaining the concept. "The offer is especially appealing to start-up companies and young entrepreneurs who can manufacture prototypes and individual pieces here, and also profit from the creative exchange at the FabLab." Even less experienced amateurs can also try out the new technologies, develop their own ideas and obtain advice about the implementation. The knowledge developed as part of the Fabbing & Founding project will be passed on to companies, start-ups, founders and students by means of special workshops.

The Hessian Ministry of Economics praised the initiative as exemplary support for small and medium-sized companies and invested 150,000 euros from the European Regional Development Fund in subsidising the implementation and setup. "By establishing the FabLab the ICT location of Darmstadt once again delivers proof of its innovative potential," declared State Secretary Mathias Samson upon his visit to the FabLab. "Founders and companies in Hessen have the opportunity to utilise the chances offered by digitalisation to rapidly transform ideas into marketable products through access to the cutting-edge technology".

In addition to operating the FabLab, the Fabbing & Founding research project also analyses the effects of digital production on the economy and the potentials for small and medium-sized companies. Companies also benefit as they can both receive advice and attend training seminars at the FabLab.

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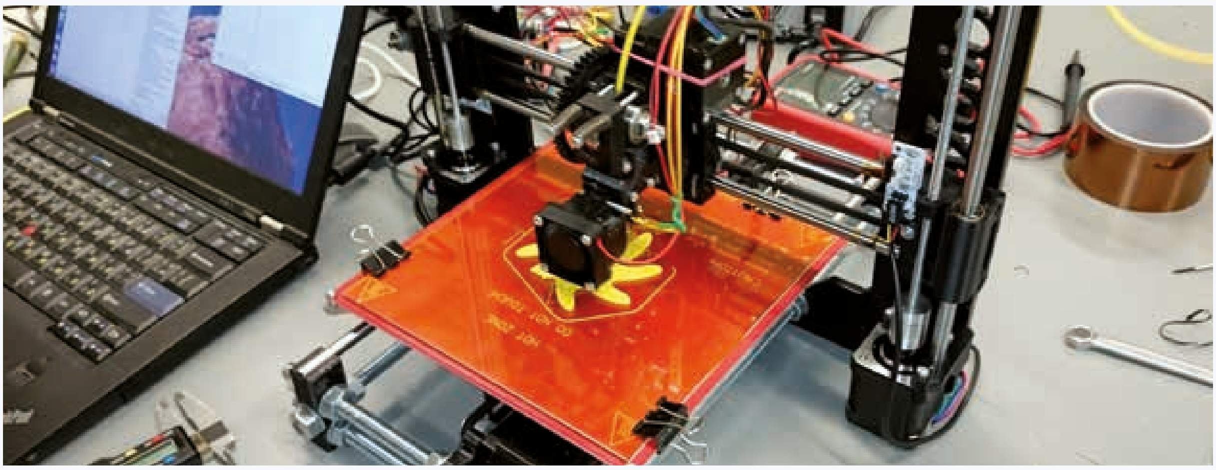

Fabber in action (Source: Technische Universität Darmstadt)

4.10 Fraunhofer LBF: Polymerisable printing inks for low-porous 3D printing and piezo actuators with an SLM housing

A number of projects at the Fraunhofer Institute for Structural Durability and System Reliability (LBF) focus on the advancement of additive manufacturing technologies or their application within the context of direct product manufacturing. As part of his dissertation in 2013, Christoph Kottlorz described a project for developing polymerisable inks and rapidly soluble powder for three-dimensional printing (3D-P). Despite the simple process, which is similar to conventional 2D printing and the ability to simultaneously utilise multiple printing jets, 3D printing is not yet being used to its fullest potential for manufacturing plastic parts in small series. There are numerous reasons for this and many arise from the porosity of the components and the low mechanical strength. That is why the goal of the project was to develop new material systems for printing low-porous bodies with significantly higher strength.

The project tested both new inks based on radically polymerisable monomers along with the rapid, yet controlled polarisation with new powder mixtures. A two-component initiator system was used for the polymerisation of the monomer ink. The powder primarily consisted of a soft elastomer and a small amount of hard polymethyl methacrylate (PMMA). The best results were achieved with HEMA (hydroxyethylmethacrylate) as the polymerisable monomer. During 3D printing the pores in the powder were able to be filled with sufficient quantities of ink and the porosity significantly reduced. As a result, the first low-porous and mechanically stable test part geometries with adequate translucency were successfully manufactured using 3D printing. Practical testing determined a similar strength and elasticity as with the injection moulding of comparable industrial polymers.

Another research area of the Fraunhofer LBF focuses on developing adaptronic systems to enable advanced methods of structural dynamics and signal processing including the use of new forms of actuators and sensors. Mass production processes such as injection moulding have not been suitable for manufacturing durable housings for piezo actuators. That is why scientists at the Fraunhofer LBF have been working to use additive technologies. In one project they have successfully tested the construction of a monolithic housing for a piezo stack actuator manufactured by selective laser melting (SLM).

In the SLM process a laser beam heats metal powder to its melting temperature, fusing the individual particles together. This approach enabled the researchers from the Fraunhofer Institute in collaboration with the Institute of Production Management, Technology and Machine Tools (PTW) at the TU Darmstadt to generate a sealed and durable housing and individually adapt the characteristics to the corresponding task. The process successfully eliminated the majority of the work for toolmaking and noticeably reduced the manufacturing costs of the complex component produced in a small quantity. The researchers selected a commercially available piezo-ceramic stack actuator with the dimensions 7 x 7 x 32 millimetres and a maximum blocking force of two kilonewtons with a maximum extension of 45 microns.

The greatest challenge consisted of integrating the piezo actuator into the housing being produced during the additive manufacturing process itself. The layer by layer laser melting process was paused, the actuator inserted and the process continued. At the same time, the heating of the powder bed had to be taken into consideration. The process temperatures ultimately had a positive effect. The thermal contraction resulting from cooling served to mechanically preload the actuator inside the housing, which had a beneficial effect on the drive performance without impairing the hermetic seal.

According to Professor Tobis Melz, the Head of the Fraunhofer LBF, additive manufacturing processes enable additional design options and, thus, optimised product topologies. Print materials have been developed at the Fraunhofer LBF which now enable similar strength and elasticity to conventional injection moulding. In addition, working together with the PTW department at the TU Darmstadt under the supervision of Professor Abele, a process for additively manufacturing housed piezo stack actuators was patented, enabling a completely new range of applications such as for vibration reduction and energy harvesting.

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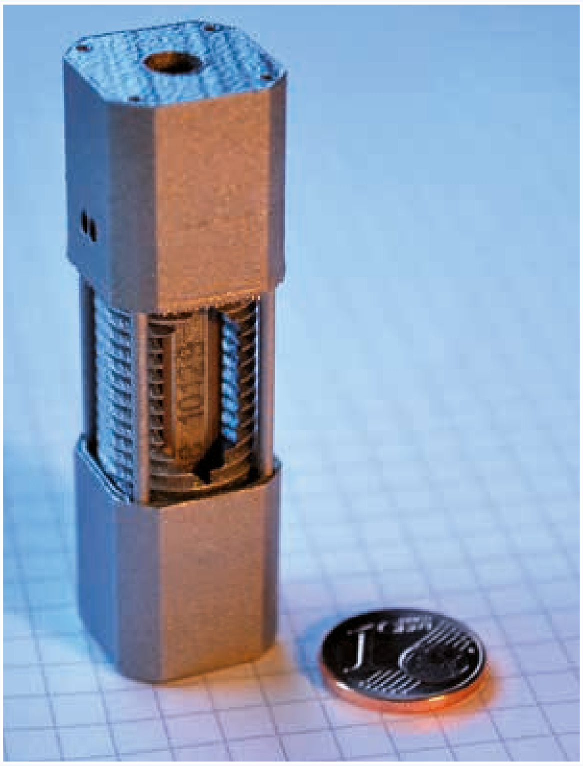


Piezo stack actuator installed in a monolithic housing manufactured using SLM (Source: Fraunhofer LBF)

4.11 Hochschule für Gestaltung Offenbach: Additive technology projects

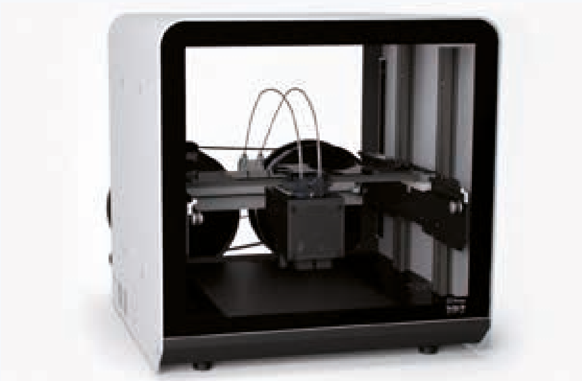
Due to the high degree of freedom offered by additive manufacturing processes and the ability to rapidly implement components with individual geometries the process chain for additive manufacturing is the subject of research and development projects at numerous design universities. The Hochschule für Gestaltung Offenbach, in particular, and the work group headed by Professor Frank Georg Zebner has made a name for itself by advancing the development of additive processes and the development of application scenarios with a number of outstanding projects:

COBOT – 3D printer and dual extruder

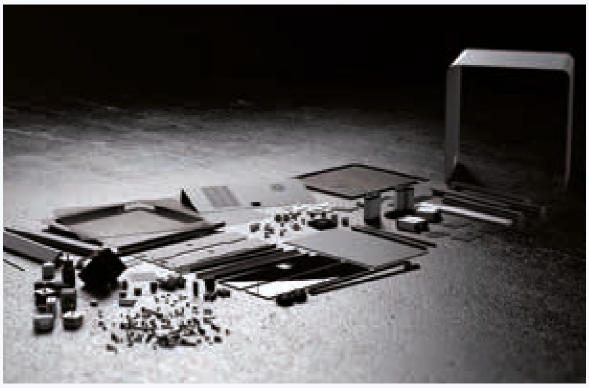
Design: Raoul Wilken, Nils Mayer, Marc Schömann

One of the most outstanding projects carried out in the context of the additive manufacturing chain is the development of a 3D printer with a dual extruder which operates on the principle of an FLM system. The three industrial designers justified their desire to develop their own 3D printer owing to their personal high quality standards when implementing their own design drafts. "In the past, comparable 3D printers were unreliable and the components were not sturdy enough," explained Raoul Wilken. "That is why we have developed a solution with two parallel extruder nozzles. While one works on the supporting structure, the second implements the form geometry in parallel." The low number of components makes the printing process faster, more affordable and more precise in comparison to other 3D printers. The system can work with both standard materials, such as acrylonitrile butadiene styrene (ABS), polylactic acid (PLA), or exotic materials, such as LayWood, LayBrick, conductive ABS or flexible PLA.

The designers primarily intend COBOT's target group to be engineers, industrial designers and architects. The developer team integrated a number of technical innovations into the system so as to meet the target group's demanding quality requirements. The entire construction consists of high-precision components. The use of polymer plain bearings and linear sliding guides made of aluminium guarantees low-maintenance and constant operation. To achieve high printing quality and a larger construction space, the design consists of an unconventional Z-axis drive, a fixed heating bed and a housing plate only three millimetres thick on which both the internal components and the axes are mounted. The extruders can be replaced easily to increase productivity and the work plate on which the model is generated does not have to be replaced after every printing process. The size ratio of the construction space to the housing is unusually large with this system.



The COBOT 3D printer. Top: Assembled and functional; Bottom: Dismantled into its individual parts (Design: Raoul Wilken, Nils Mayer, Marc Schömann)



AudioView earplug system (Design: Frauke Taplik)

AudioView – orientation by sound

Design: Frauke Taplik

One example for the use of additive technologies in the biomedical engineering sector is the AudioView earplug system developed by the designer Frauke Taplik. This enables blind people to acoustically locate objects marked by RFID. It consists of a customised earbud generated with a 3D printer and a serial transmitter or speaker. The system determines the position of obstacles in the room and uses acoustic signals to indicate the location to the blind person. The signals are only audible for the wearer and simplify orientation. The shape of the earplugs has been designed so that the auditory canals remain open.

Formetric 4D –
3D/4D spinal column and posture measurement

Design: Stephan Brühl

Formetric 4D, a device for optically measuring the spinal column for posture analysis, was developed in cooperation with Diers GmbH. A graphical striped pattern developed by an optical company is projected onto the patient's back and is then recorded with a camera system. Software calculates the position of the spinal column and the hips using anatomical fixed points and derives a three-dimensional model. This enables postural defects to be diagnosed while the patient is standing, along with the analysis of sequences of movements. The mammoth stereolithography manufacturing technology developed by Materialise was utilised to produce the system. This is the first technology capable of additively generating components with a length of more than two metres. The additive manufacturing principle made it possible to reduce the material requirements and wall thickness to a minimum. A diamond-shaped internal geometry analogous to the spinal column was used as reinforcement, and is visible from the outside due to the semi-transparent resin.

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Formetric 4D system for spinal column and posture measurement (Design: Stephan Brühl)

4.12 3D Scaper: Selfies in the third dimension

Berlin, Munich, Cologne… In recent months the first 3D printing businesses have opened up in most major cities. One such business has also existed at the Bockenheimer Warte shopping gallery in Frankfurt-Bockenheim since the beginning of 2014: the "3D Scaper". The business models look similar: Private individuals who do not want to operate their own 3D printer yet still want to use the opportunities provided by additive manufacturing have a place to print their own designs or designs downloaded from the Internet. A self-designed mobile phone case, customised shoe designs, a special interior accessory or a spare part for the coffee machine: The opportunities appear almost unlimited even though self-made designs currently remain a rarity.

Printed Selfies
(Source: 3D Scaper)

However, the business of manufacturing three-dimensional selfies is developing very well. This refers to images of people looking to record moments in their lives as a printed figure: Women during their pregnancy, a grandchild starting school or a married couple who want their own figures on the wedding cake. The 3D Scaper Studio is equipped with a scanner for recording three-dimensional geometries with more than 60 cameras to capture the body data. The person stands in the middle of the room and the cameras simultaneously take one digital photo each. These images are transformed into a three-dimensional volume model on the computer and then converted into digital layer information.

The 3D printer can generate miniature human images layer by layer out of a combination of plaster powder and a polymer binding agent. Since the binding agent can be coloured during the printing process the finished images are deceptively similar to the original. Depending on the size of the print the printing process can take several hours with a layer thickness of 0.1 millimetres. A 15 centimetre high figure/sculpture costs 230 euros and a height of 35 centimetres costs 890 euros. More affordable variants in white from the FLM system are available at prices starting from 79 euros. Due to the fact that the additive process uses plastic melted from a roll and applied in layers the image is not quite as precise and only one colour can be generated. In addition, 3D Scaper also offers printers and filaments along with 3D objects from selected artists, which is also a rapidly expanding market.

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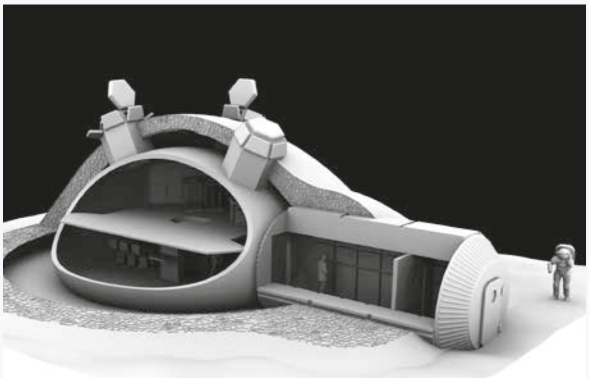
4.13 European Space Agency: Lunar space stations made of printed rock

The European Space Agency (ESA) is currently cooperating with the British architectural office Foster+Partners based in London to test the possibility of utilising additive technologies to construct a space station on the moon. The idea is to use the moon's rock material for the construction and transform it into a stone-like solid body by adding a binding salt. Complex building structures have already been generated on earth using 3D printing processes. The project consortium is currently investigating whether this technology could be used in a similar fashion to construct a lunar habitat.

3D print of a lunar station (Source: ESA, Foster+Partners)



Design of a lunar station for 3D printing (Source: ESA, Foster+Partners)

The intention is for a cylindrical module transferred from the earth to serve as the starting point for the construction. The rooms would then be created by inflatable domes which are connected to the model. A layer of the moon's loose sediment (regolith) will then be deposited on the roof and is then bound with a salt to form a solid body. The 3D printer would generate structures with a speed of three and a half metres per hour and be capable of manufacturing one building per week, according to the ESA. The British company Monolithe manufactures the printing technology and has used the manufacturing process to create sculptures and generate artificial coral reefs. Additive manufacturing processes are extremely resource-efficient because they only utilise material where it is actually required. The number of manufacturing steps is reduced. In addition, excess material can be reused. This enables weight savings ranging from 50 per cent to 95 per cent.

D-Shape printer (Source: Enrico Dini, London)

For testing purposes, a team at Foster developed a dome construction out of cell-structured walls which can be sprayed onto a six-metre high frame made of sand-like particles and a high-strength bonding agent in layers using printing jets. The result is a hollow, sealed cell structure comparable with that of avian bones and provides a good combination of stability and weight. A one and a half tonne block of simulated regolith has been successfully printed to date. The volcanic rock originates from a lake in central Italy and is 99.8 per cent identical to the sediment on the surface of the moon. As part of the 'Clean Space' initiative, the ESA is investigating additive layer technologies in order to reduce the effects of the space industry on the environment.

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4.14 Heraeus: 3D printing will change the "metallic world"

3D printing is everywhere: In fashion, in medicine, in the aerospace industry, and also in the foodstuffs industry. Although prototype production currently dominates the additive manufacturing market, perfectly customised applications will drive the propagation of the technology in the year 2020. With its own „3D Printing" start-up, Heraeus also is shaping this transformation – through targeted research into new materials and the development of suitable processing parameters.

The technology group from Hanau focuses on developing high quality metal powders adapted for 3D printing, researching new special alloys that can only be processed additively, as well as the development of the parameters of the materials being processed. The team has access to a variety of manufacturing systems, which can also be used to produce components ordered by customers.

Many benefits, many challenges

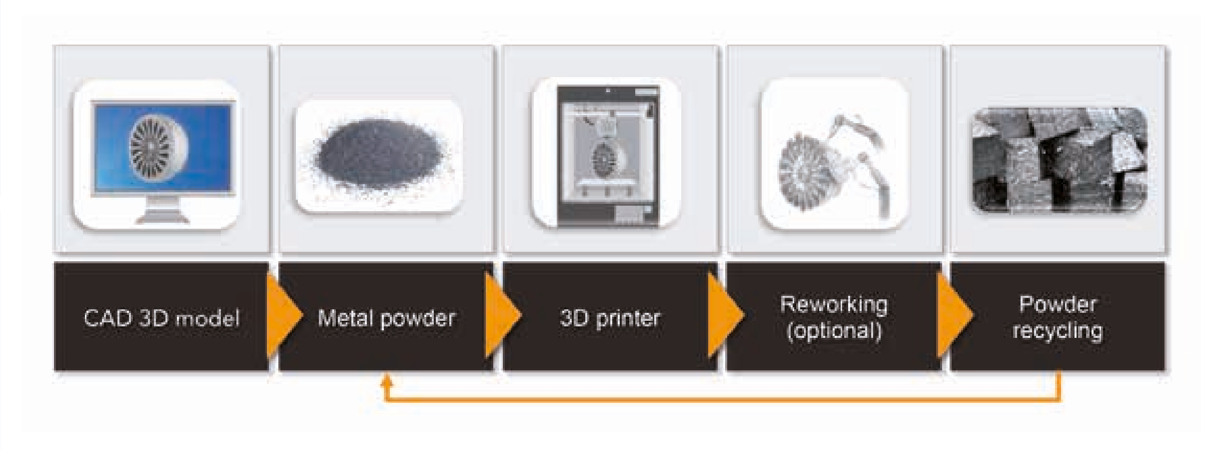
Additive manufacturing offers numerous benefits, but is anything but trivial, especially when processing metallic powders. The challenges begin with the production of the powder itself. The materials with a melting point of over 2,000 degree Celsius generally require containerless processing to produce suitable powders with the required purity. The quality of the powder, namely preventing gas cavities and satellites along with a clearly limited particle size distribution and a high level of sphericity, is influenced by key parameters such as fluidity and bulk density. In turn, this influences the quality of the laser or electron beam melted components.

Heraeus' satellite thruster nozzle produced by additive manufacturing (Source: Heraeus)

Only perfectly spherical powders with a precisely defined particle size distribution, in combination with the appropriate processes, enables the additive manufacturing of complex components without problematic porosity or other component defects. After examining these challenges for a number of years, Heraeus founded the 3D Printing start-up at the beginning of 2015. The technology company employs more than 165 years of experience with metals, in particular refractory and precious metals, and their processing. Heraeus' key approach is to cover the entire additive manufacturing process. Understanding the relationship between material, process and manufacturing equipment for achieving the desired material properties of the additively generated component is critical to manufacturing functional components with consistently high quality.

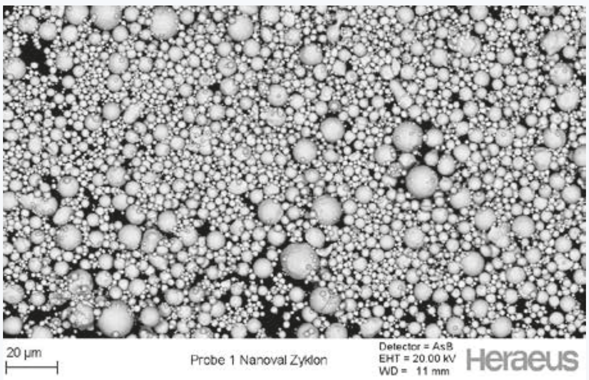
Satellite thruster nozzle as the first milestone for Heraeus

The company has celebrated a major milestone with the first additively manufactured control thruster for satellites. Durable thruster nozzles for satellites made of a platinum-rhodium alloy are ideal for the extreme conditions in space. An operating temperature of more than 1,250 degree Celsius, more than 600 ignitions without wear or fatigue – these are perfectly normal requirements for the highly complex thruster nozzles in satellite propulsion systems. However the control thruster, which successfully passed ignition testing at the Airbus Defence & Space site in Lampoldshausen in 2015 as part of a project by the European Space Agency (ESA), is something unique: The thruster nozzle made of a platinum-rhodium alloy is the first to be manufactured entirely using a laser sintering system. Up until now, the control and propulsion units with a length of just eight to ten centimetres were assembled using numerous individual components, for which Heraeus has manufactured the precious metal alloys for some years. However, thanks to additive manufacturing the assembly process is faster, and also utilises fewer resources due to the reduced waste.



Additive manufacturing process chain (Source: Heraeus)

Heraeus developed the "printable" precious metal powder utilised for this test. The focus was on optimising powders made of platinum, rhodium and iridium for manufacturing highly-durable components for the control thrusters in navigation satellites. During the course of the project, the Heraeus developers gained extensive experience in how the metal powder and the parameters for additive manufacturing have to be coordinated and optimised to produce the finished object with the correct material properties. Heraeus now has a modern 3D testing centre with its own laser and electron beam printers at its premises in Hanau, with the just right equipment to enable the company to manufacture the control thrusters using the metal powders. Although the time has not yet come for an industrial breakthrough and complete substitution of the conventional manufacturing process, the next milestones have already been determined. Currently, the Heraeus team is working on powders made of an even more durable platinum-iridium alloy, and the launch of the first satellite utilising additively manufactured control thrusters is already planned for 2017.



Precise control of the material properties is of high importance for additive manufacturing processes (Source: Heraeus)

Summary: Additive manufacturing using powders with high melting points represents a market with major potential for Heraeus, but by no means a „plug & play" situation. Material and process expertise is critical because the metallic powder and the printing process have to be specifically configured for the individual component.

With smaller, lighter, more robust, more complex or more customised parts – completely new designs become possible. But without rethinking the design approach and thinking beyond the boundaries of the possible and the feasible, the ground-breaking technology will not achieve a breakthrough.

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4.15 Kegelmann Technik: Greater freedom in the interaction between design and engineering

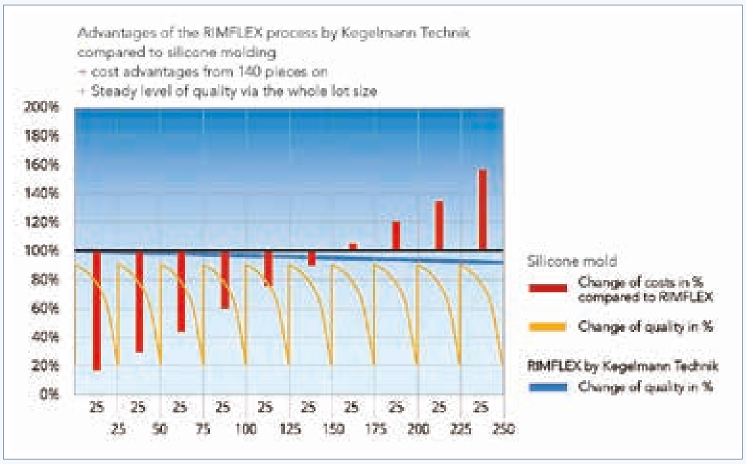
These few words contain massive opportunities, competitive advantages, true innovations and perhaps even new business models for companies – when design and engineering work more closely together. And it is precisely at this interface that Kegelmann Technik, a company from Rodgau-Jügesheim specialising in additive manufacturing processes such as 3D printing, contributes its creativity to the processes and development.

Additive manufacturing processes make things possible that once upon a time could not be manufactured at all – neither at low cost nor in small batches. The innovative process of "connected prototyping" plays a key role at Kegelmann Technik, and represents the driving force and the success factor for achieving competitive advantages drawn from a greater degree of freedom. Lightweight design, cost reduction, risk minimisation, functional integration, individualisation, organic class-A free-form surfaces and bionics are the keywords. This development method serves to parallelise and link design, development and process engineering through close cooperation between scientists, engineers, designers and other creative minds. Customers primarily consist of automotive companies and suppliers for whom the prototypes are manufactured in small series. However, several thousand units of designer glasses also leave the plant every month. The unique aspect here is the series production focusing on batch size 1, meaning that every glasses frame is individually manufactured for the customer.

When producing larger polyurethane components, such as bumpers or headlight housings for the automotive industry, the engineers from Kegelmann Technik utilise the company's own, innovative procedure, which almost completely eliminates the gap between unit costs and quality from the conventional silicone forming process. RIMFLEX®. Due to the nature of the silicone moulding process, a new mould needs to be manufactured for approximately every 20 to 25 pieces to maintain the viable quality of the prototypes. This creates two problems for batch sizes greater than 50: drastically fluctuating quality among the individual prototypes, along with rapidly rising per-unit costs.

Consistent quality for the entire batch

The "Advantages of the RIMFLEX process in comparison to silicone moulding" diagram illustrates the development of the per-unit costs and the unit quality for silicone moulding with batches exceeding 300 units. It is clear to see how the rapidly declining quality requires a new mould after only 20 to 25 moulds, which results in drastically rising costs as batch sizes increase. However, more important than the cost-advantage is the consistently high quality provided by the RIMFLEX procedure. Ultimately, decisions regarding investments in the millions are made on the basis of the prototypes. When comparing the development of the per-unit costs and the quality of silicone moulding with the corresponding cost development when using the RIMFLEX process, then the cost and quality benefits are obvious.



Advantages of the RIMFELX process (Source: Kegelmann Technik)

The component size is another important parameter when deciding on the optimum manufacturing process. In particular parts with large surface areas, such as bumpers, have clear disadvantages when manufactured using silicone moulding techniques. Due to their flexibility and high weight resulting from the extensive amount of material used, the components are not rigid, and often sag or deform. This causes problems with dimensional stability or the wall thickness of the polyurethane parts. In view of this, the benefits of these prototypes as the basis for a decision regarding subsequent tests such as summer or winter trials are questionable.

Head-light housing produced by the RIMFLEX process (Photo: Kegelmann Technik)

Closer to the future series quality

In cooperation with RAMPF Polymer Solutions, a globally active manufacturer of customer-specific plastics, Kegelmann Technik has developed a special polyurethane recipe providing material advantages that conventional vacuum cast resins cannot offer.

Based on a material approved by a Swabian automotive manufacturer for use with prototypes, the impact resistance, dimensional stability under heat and elastic modulus approach the future series quality through the addition of approximately 30% short glass fibre. Due to its viscosity, this material can only be processed using a RIMFLEX mould developed by Kegelmann Technik in a low-pressure RIM (Reaction Injection Moulding) procedure.

Almost six-figure potential cost reductions

The following calculation based on a practical example demonstrates how much can be saved using the RIMFLEX process.

Some 150 sets of headlight housings (left and right) are required for the prototypes of a new vehicle. A detailed cost-benefit analysis indicated that the prototype manufacturing with silicone moulding would have cost approximately 200,000 euros. The short service life of the silicone moulds with the required quality requirements, and the high level of material expenditure due to the component size were the primary cost drivers. In contrast, production using the RIMFLEX process offers a potential cost reduction of 35% – while also providing a higher overall prototype quality. In the specific case (batch size of 150, right and left), this represented a saving of more than 80,000 euros. As such, the customer did not hesitate to choose the RIMFLEX process.

Broad range of innovative manufacturing processes

To avoid any misunderstandings: Combined with a knowledge of the limits of the process in terms of the batch sizes and component sizes, vacuum casting with silicone moulds is an important element of rapid prototyping, and is frequently used at Kegelmann Technik. However, the RIMFLEX process increases the scope of innovative manufacturing processes offered by the Rodgau company, and offers greater opportunities and possibilities for product development in terms of the cost, quality and component size. That is why Kegelmann Technik is fully integrated into the value creation process with customers who expect top-class performance in a challenging field, and also plays a key role in the successful development and design of innovative products.

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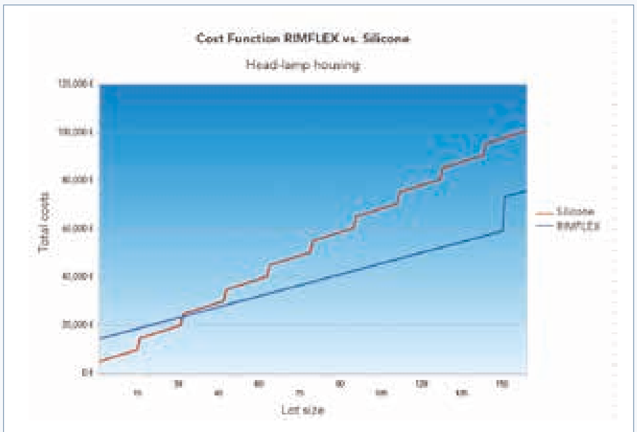

Cost function diagram (Source: Kegelmann Technik)

The company's headquarter in Rodgau-Jügesheim (Photo: Kegelmann Technik)

5. Companies, universities, research institutes and organisations from Hessen involved in additive manufacturing

5.1 Hessian companies and research institutions

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6 Literature

Abele, E.: Einordnung und Ausblick von additiven Fertigungsverfahren aus produktionstechnischer Sicht. Vortrag anlässlich der Veranstaltung „Additive Manufacturing“ des Hessischen Ministeriums für Wirtschaft, Energie, Verkehr und Landesentwicklung, Hanau, 23. September 2014.

Anderson, C.: Makers. Das Internet der Dinge: die nächste industrielle Revolution. München, Wien: Carl Hanser Verlag, 2013.

Anderl, R.: Additive Manufacturing oder generative Fertigungsverfahren – vom Prototypen zur Massenfertigung? Vortrag anlässlich der Veranstaltung „Additive Manufacturing“ des Hessischen Ministeriums für Wirtschaft, Energie, Verkehr und Landesentwicklung, Hanau, 23. September 2014.

Breuninger, J.; Becker, R.; Wolf, A.; Rommel, S.; Verl, A.: Generative Fertigung mit Kunststoffen: Konzeption und Konstruktion für Selektives Lasersintern. Berlin, Heidelberg: Springer Verlag, 2013.

Gebhardt, A.: Generative Fertigungsverfahren: Additive Manufacturing und 3D-Drucken für Prototyping – Tooling – Produktion. München, Wien: Carl Hanser Verlag, 4. Auflage, 2013.

Fromm, Asko: 3D-Printing zementgebundener Formteile. Grundlagen, Entwicklung und Verwendung. Kassel, Hessen: Kassel University Press, 2014.

Horscher, Florian: 3D-Druck für alle – Der Do-it-yourself-guide. München, Wien: Carl Hanser Verlag, 2014.

Lux Research: How 3D Printing Adds Up: Emerging Materials, Processes, Applications, and Business Models. 30. März 2014.

Peters, S.: Materialrevolution – Nachhaltige und multifunktionale Materialien für Design und Architektur. Basel: Birkhäuser Verlag, 2011.

Peters, S.: Handbuch für technisches Produktdesign. Hrsg. Kalweit, Paul, Peters, Wallbaum. Berlin: Springer Verlag, 2. Auflage, 2011.

Peters, S.: Materialrevolution II – Neue Nachhaltige und multifunktionale Materialien für Design und Architektur. Basel: Birkhäuser Verlag, 2014.

VDI: Statusreport „Additive Fertigungsverfahren“, Verein Deutscher Ingenieure e.V., September 2014.

Warnier, C.; Verbruggen, D.; Ehrmann, S.; Klanten, R.: Dinge Drucken – Wie 3D-Drucken das Design verändert. Berlin: Gestalten Verlag, 2014.

Wohlers, T.: Wohlers`Report 2013. Wohlers Association, 2013.

Nano-Sicherheit.de information platform for the responsible use of nanotechnology

"Germany is one of the leading nanotechnology regions in Europe. With this platform we intend to simplify the safe use of these technologies, in particular, for small and medium-sized companies." The Hessian Minister of Economics, Tarek Al-Wazir, announced the relaunch of the completely revised information platform www.nano-sicherheit.de in August 2014 with this clear commitment to the safe and peaceful use of nanotechnology.

Nanotechnology is inarguably a key technology for resolving current and future challenges in numerous areas. For example, it makes solar cells more effective, facilitates new medical treatment methods and reduces raw material consumption. However, substances at this scale evolve new properties or enable applications which require a re-evaluation of the risks.

"Our goal is to achieve the greatest possible transparency and availability of information so that nanotechnology is used responsibly and to the benefit of humanity," stated Minister Tarek Al-Wazir. That is why www.nano-sicherheit.de provides users with all of the relevant information: national and international regulations; guidelines for safely using nanomaterials or risk assessment studies. In addition, the website also offers a research box for national and international stakeholders and projects.

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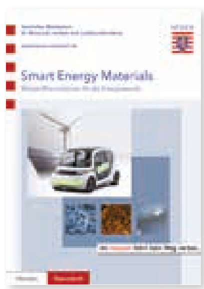

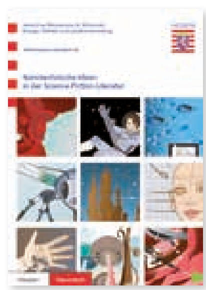

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