HANSER

Sample Pages

Disruptive 3D Printing

Ralf Anderhofstadt and Marcus Disselkamp

Print-ISBN: 978-1-56990-918-8
E-Book-ISBN: 978-1-56990-925-6
E-Pub-ISBN: 978-1-56990-931-7

For further information and order see

www.hanserpublications.com (in the Americas)

www.hanser-fachbuch.de (outside the Americas)

© Carl Hanser Verlag, München

Contents

Preface

Additive manufacturing processes were initially a marginal phenomenon in the last three decades. In the meantime, however, progress in 3D printing has provided a tremendous boost. Manufacturers of a wide variety of goods and retailers from a wide variety of industries are showing more and more acceptance and interest in the potential of the new technologies. This rethinking is leading to a multitude of innovations. More economical and environmentally friendly production processes are one aspect, flexibility in production and the digitization of existing processes are additional factors. Industrial 3D printing thus breaks with many existing concepts: companies take over the functions of their previous suppliers in the sense of "do it yourself", intermediaries lose their livelihood through disintermediation, manufacturers relocate their production to decentralized locations and (end) customers are becoming much more intense "prosumers" than marketing ever imagined.

The business models of many existing companies from very different sectors are becoming toxic, i.e. endangering their existence, such as in the areas of logistics and warehousing, industry, services, trade or service. Conversely, there are also many opportunities for modern, livelihood-securing business models, which this publication will deal with in more detail. Increased demand in many areas reflects the interest of the market—not only in aerospace, automotive industry, real estate industry, food industry or medical technology. Progressive digitization and standardization of 3D printing are currently topical. They are also a prerequisite for further penetration of series production with additive manufacturing processes.

For this reason, 3D printing has been gaining increasing attention, especially in recent years. In addition to research and science, large and small companies are interested in the use of additive manufacturing in an industrial environment. Global developments show new trends and predict a major upheaval in the field of industrial manufacturing—and beyond. 3D printing and the opportunities it brings are disruptive. That means nothing other than that we are already seeing serious changes with 3D printing in many areas of production and will experience more. A large number of sectors are affected by this: Components are not only produced from the 3D printer in the automotive or aviation industries. In the meantime, the use of additive manufacturing technologies has gone far beyond the construction of a few prototypes—they have arrived in series production. What's more, medical prostheses are now being manufactured individually by specialized companies, food is produced using printing processes—even in restaurants—and entire houses are made from 3D printers. In the following chapters you will find some interesting examples.

The possibilities of additive manufacturing are seemingly limitless. The previous potential having been exhausted, there are new approaches to long-term and sustainable strategies with regard to further possible uses. In addition to technological trends, this also includes new business models. Value chains that have been tried and tested for a long time are being questioned: the digitization already cited is leading to a massive rethink in industry. Traditional factories, machines and even workplaces are no longer needed in the form and scope we are used to. The associated dematerialization affects many areas, not just production! Products are "rethought": existing functions are combined with new offers and new business ideas and income opportunities are created from them. The focus is not only on cost optimization, but also added value for customers and companies—the goal: operational excellence AND customer experience.

The various chapters of this book provide an overview of additive manufacturing technologies and the entire environment: starting with an insight into the current 3D printing processes and continuing to the wide range of available materials and thus the possible uses of 3D printing, followed by the serious, even disruptive effects on companies and entire value chains and, at the end of the discussion, on the business models urgently needed for additive manufacturing, without which 3D printing will remain just a new technology without generating new income opportunities and competitive advantages.

Another note on the terms used in the text. The terms additive manufacturing and 3D printing are used synonymously here. This parallelism is also widely found in scientific and practice-oriented publications. The actual difference lies in the fact that the term additive manufacturing essentially refers to the method behind the manufacturing process.

Neu-Ulm and Munich, February 2023

The Authors

Ralf Anderhofstadt is head of the Center of Competence Additive Manufacturing and the consulting unit “AMS—Additive Manufacturing Solutions—Daimler Truck” as well as project manager of the cross-functional 3D printing project within Daimler Truck. For several years he and his teams have been in charge of introducing industrial 3D printing into the various processes at Daimler Truck. This includes the management and integration of numerous national and international areas within the group, with the aim of developing a digital 3D printing business model. At the same time, he is active in the VDI expert committee “Legal framework conditions for additive manufacturing”, works as a lecturer with focus on 3D printing and is a trainer for numerous training courses within the field of additive manufacturing. Additional to this he is a member of the advisory board of Verband 3D-Druck e.V. His first book *Disruptiver 3D-Druck* (Disruptive 3D Printing) was published in German by Hanser Verlag in August 2022.

Dr. Marcus Disselkamp is a recognized expert on corporate strategies in times of digital change and one of the TOP 100 trainers in German-speaking countries. For decades he has been supporting companies in entrepreneurial competitiveness, the digital transformation and improving the efficiency of investments. He has already convinced several thousand participants in strategy and (digital) innovation projects as well as management training with his practical, holistic and dynamic manner. He teaches “(digital) competition and growth strategies” at several international universities and business schools, is a specialist author, podcaster and a member of several advisory and administrative boards (*www.disselkamp.com*).

1 Additive Manufacturing—The Next Level of Industrialization

In recent years, the use of additive manufacturing processes has increased significantly in many areas and also in many industries. However, industrial use began as early as the 1980s, when the automotive industry discovered the method for itself, as it could be used to produce prototypes particularly efficiently. Compared to previous, conventional production methods, objects no longer had to be machined in several steps, but could be built up layer by layer in one piece. Prototypes were produced faster and with less material, but these first objects were usually not very stable and were sensitive in many respects.

With increasing digitization, the methods and processes of additive manufacturing were improved and further developed. As a result, important quality features and properties of the 3D-printed objects were also significantly improved. Due to the higher quality of the products, additive manufacturing also attracted growing interest in other areas—including beyond those of classical mechanical engineering. Other industries gradually began to discover the advantages of 3D printing for themselves and to use the possibilities of additive manufacturing for their products. New, additional technologies were developed or adapted for industry-specific needs. The rapid spread of 3D printing can be attributed, among other things, to the ever-faster development and adaptation of processes.

Interview with EOS

"We believe that innovation and technology can help make a better world possible for everyone. We shape the future of sustainable manufacturing. Our goal and corporate purpose are to combine groundbreaking digital innovations in industrial 3D printing with sustainable practices."

Björn Hannappel, Head of Sustainability EOS GROUP (Source: EOS)

Added to this is the constantly growing number of materials that can be used. In the beginning, it was only plastics that lent themselves to additive manufacturing processes, but today a large number of materials are available for a wide variety of applications. Metals and ceramics are used as well as gypsum, depending on the industry and what needs to be manufactured. Many companies are now working flat out in their research areas to develop and optimize their own materials for specific applications, often in cooperation with universities.

In order to keep an overview of the growing number of processes and materials—or to give interested parties an initial insight into methods and possibilities—standards and guidelines have now been drawn up by national and international committees. The Association of German Engineers, for example, has written a whole family of guidelines. In the VDI 3405 guideline, for example, the most common processes or characteristic data for materials are recorded. One of the goals when creating it was to support companies in choosing both the most suitable process and the "optimal" material for the specific application.

3D printing is the generic term for a growing number of different manufacturing technologies. The processes differ not only in terms of the materials used, but essentially in the way in which objects are constructed from the materials.

A wide variety of approaches are now being used here, which are described and illustrated in more detail in the following chapters.

All additive manufacturing processes have one thing in common: for all of them, **a digital model of a three-dimensional object using CAD programs is created**. These 3D data models are in turn converted into machine-readable data sets using suitable software and then transferred to a 3D printing system. There, the objects are built-up layer by layer—additively.

This makes 3D printing very different from conventional machining processes, which are known as "subtractive manufacturing".

Although 3D printing is a young manufacturing process, there are many reasons for the ever-growing interest in it. This is due to the many advantages of producing parts and objects with a 3D printer. For example, no molds or tools are required and material consumption is significantly lower compared to conventional manufacturing processes. 3D printing enables economical application—especially for the smallest production quantities (down to a batch size of 1)—and makes additive manufacturing processes ecologically sustainable and cost-efficient. In addition, 3D printing enables complex objects to be manufactured in one step that would otherwise have to be manufactured from multiple parts and then assembled using traditional methods. Having initially been used for applications in industry, 3D printers have now also conquered many fields in the private sphere.

Interview with Messe Frankfurt

Additive manufacturing (AM) is more than pure technology. "AM will have a significant impact not only on our industrial future, but on our future lives. Why is that? As the organizer of Formnext, the most important trade fair for industrial 3D printing, when I look back on the last few years I can see that, since 2015 alone, an incredible amount has happened in the application of additive manufacturing and AM technologies. Just a few years ago, "3D printing" was still being presented in the daily and business press in such a way that we as consumers would soon each have our own printer at home and print the most wondrous things from it ourselves. This somewhat over-hyped idea has not come true. Rather, the additive joining together of small and tiny material particles, calculated to the nearest micron, whether made of plastic, metal, ceramics, CFRP, and others such as glass or wood, including some mixtures of the same plus printed electronic components or even organic cells, has become a—if not *the*—future technology of industrial production developed par excellence."

In Sascha Wenzler's experience, the most diverse application areas—be they automotive, mechanical engineering, aerospace, medical technology, dental technology, jewelry, shipbuilding, rail transport, electrical industry, packaging, tool making, niches such as offshore or oil and gas exploration and many others—are spawning designs, products and applications that were simply unimaginable just a few years ago. "A new way of thinking is created by AM. From the product designer to the development engineer to the person responsible for production and the CEO, the freedom and possibilities of printing in the third dimension are discovered. Medical technology remains particularly fascinating for me; here it is particularly tangible how additive manufacturing helps people as patients and creates real value in life. In large-scale industry, but also more and more in medium-sized companies, stringently calculated business cases are also emerging. Industrial 3D printing is also able to turn supply chains upside down and create resilience. Additive manufacturing has long been on the way to becoming a regular manufacturing technology that complements, but also competes with, traditional processes. The near series production stage has already been reached and we are still only at the beginning of the journey. Personally, it remains a particular pleasure for me to help shape and accompany this journey with Formnext."

Sascha F. Wenzler, Vice President Mesago Messe Frankfurt GmbH

1.1 Introduction to Additive Manufacturing

Since time immemorial, people have been making things for everyday use that are supposed to make life easier. It started with simple tools that our ancestors made out of wood and stone. Over time—more precisely with the discovery of metals and new materials—the tools and workpieces have become more varied and complex, and with them the methods and processes for production have also become more and more complex. The classic manufacturing technologies usually have one major disadvantage in common: the workpieces (or components thereof) are cut out from solid blocks of raw material. This method is also referred to as **subtractive manu-**

facturing. In conventional manufacturing processes, a large proportion of the raw material is often lost as waste. With complex workpieces, up to 90% of the material used sometimes falls victim to machining! In addition, complex components often have to be built from several individual parts, which requires additional time for assembly.

Figure 1.1 shows a schematic of how a component is manufactured using conventional manufacturing processes: Until now, complex components have usually been constructed from individual components. First, the components of the part to be manufactured are made individually. In most cases, the manufacture of these individual parts frequently leads to a very significant proportion of the material being lost as waste through machining processes.

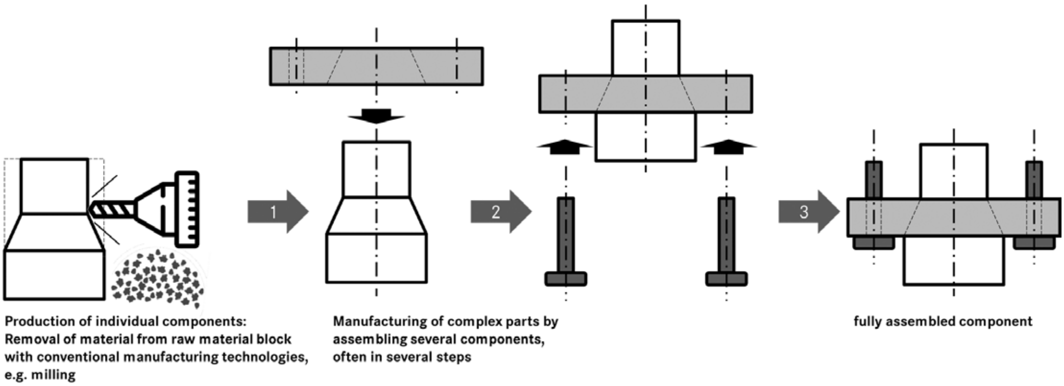


Figure 1.1 Conventional manufacturing methods

But thanks to additive manufacturing processes, things are now different. The Belgian comic author Hergé had a vision as early as the 1970s: in one of his comics, he describes how his comic heroes Tintin and Snowy visit Professor Calculus and marvel at his latest invention: a 3D copying machine. With this machine, the professor is able to recreate an object in one operation—by building it from raw material. The special thing about it is that it all works without the previously necessary machining processes such as turning, milling or drilling. Was this just the fantasy world of comics? Or was the basic idea of additive manufacturing revealed here. That would be tantamount to a revolution, like the invention of the wheel in primeval times.

It then took about ten years before Chuck Hull, an American engineer, succeeded in putting the first 3D printing process into practice. In 1986, this process, known as stereolithography, was patented as the first additive manufacturing technology. The special and new thing about this process from Hull was that he managed to build up workpieces in individual layers with the help of 3D construction programs by materializing specific points in space.

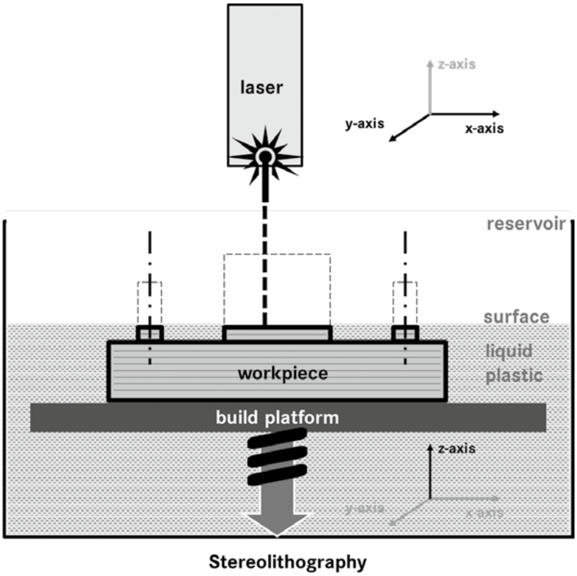


Figure 1.2 Stereolithography

Figure 1.2 shows the principle behind the solution patented by Chuck Hull. In what he called stereolithography, point-by-point materialization of plastic (polymer) from a liquid bath takes place through targeted irradiation with a laser. After completing a layer, the build platform is lowered by one layer thickness and the next layer is applied.

In the years that followed, the development of additive manufacturing—better known as 3D printing—picked up speed. Within a few years, rapid prototyping first became known as a new manufacturing process. With rapid prototyping, it was possible for the first time to produce sample parts without manual effort. All that was needed was the CAD (computer-aided design) data of the object, which had to be converted into machine language for 3D printing and then transferred to the 3D printer. Rapid prototyping thus represents the beginning of 3D printing in industrial applications.

Product development and prototype construction were therefore also the first areas in which the new technology was used. The decisive factor was that the time required from the development and construction of a product to its market launch could be significantly reduced. And the same applies to the costs: with rapid prototyping, designs can be verified before investments in tools have to be made.

Interview with 3D Alliances

An award-winning 3D printing consultancy company that supports the business acceleration of innovative 3D printing companies

"Additive manufacturing (AM) has a bright future, no doubt about that. The question is, how fast it will be adopted in design and manufacturing processes of industrial manufacturers that aim to change the way things are made.

As of today, the majority of AM solutions offer affordable tools for producing prototypes, before moving on to full production by traditional methods. This phase is important for increasing the awareness of AM and the advantages it can provide. It offers an easy way to "think 3D" and understand its full potential.

To shift from traditional manufacturing methods to digital manufacturing, the industry will have to provide a high-standard process that will include a full end-to-end workflow, the right materials, and the speed, accuracy, and repeatability that are required to manufacture end products. Once this has been achieved, manufacturers can start to plan and design their products for additive manufacturing and to further develop and expand their digital fabrication capabilities.

The industry is set to achieve this goal in the coming decade, through increased investments and a large number of companies developing new AM technologies. I trust we shall witness the successful evolution of the AM industry toward full-scale digital manufacturing."

Gil Lavi, Founder & CEO of 3D Alliances, a printing industry veteran with over 25 years of professional experience, previously worked for industry leaders such as Kodak, HP & Stratasys

In the meantime, another positive effect of the growing spread of 3D printing can be seen: with the increasing development and maturity of technologies and materials, the costs of 3D printing are also falling—and this in turn enables the economic use of additive manufacturing in industrial series production and a further spread of the technology into the production of end products.

1st paradigm shift

In the beginning, 3D printing was mainly used to produce small batches and prototypes. In the meantime, there are already many applications in **series production**.

Interview with Breuninger Management Consulting for 3D-Printing

"Since the emergence of the 3D printing industry through Jack Hull's patent in 1986, the AM industry has continuously evolved. From an initial few printing processes, today there are over 50 different printing technologies with over 250 key suppliers.

AM industry revenue was $12 billion in 2021, according to Wohlers. This revenue will double in the next few years.

To date, very few AM companies are profitable and some industry segments, such as metal printing, are overcrowded. Therefore, the AM industry is currently experiencing many acquisitions. This is needed to maintain a good growing and profitable industry structure, which is absolutely necessary.

Thus, the industry is currently in an all-encompassing consolidation process.

Industry upheavals in the direction of 3D printing are proceeding like falling dominoes. In the U.S., for example, the hearing aid industry was converted to 3D printing within 500 days. Those who didn't follow suit were out of business.

The AM industry is firing up the global manufacturing technology with a fantastic new mind-set, new approaches to digitalization, new application forms and high impact to more sustainability. The AM industry is indispensable for the development of humanity and has gigantic impact on our technological development despite the small size of the industry."

Hans-Alfred Breuninger, Breuninger Management Consulting for 3D-Printing (Source: Breuninger)

Like the end products that have been manufactured in the traditional way up to now, the properties and functions of objects printed in 3D correspond exactly to the specifications that were specified in the product development process. This new way of manufacturing a product is called **direct manufacturing**. The aim of direct manufacturing is to provide parts required or requested by customers within a short period of time—and of course in the usual high-quality and competitive design. This method supports a current trend in the market: individualization of objects with little effort and manufacture in small quantities. Nothing now stands in the way of meeting the growing demand for personalized products!

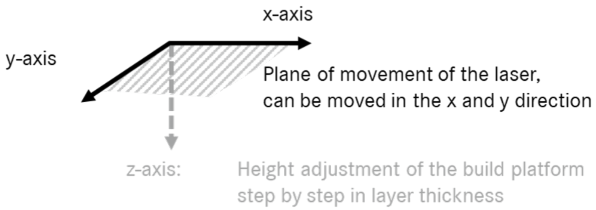


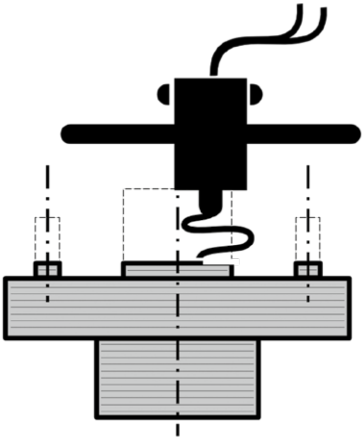
Figure 1.3 Creation of three-dimensional components in 3D printing

The representation in Figure 1.3 shows how the three-dimensional structure of an object takes shape. Let's stay with the example of stereolithography for now. The laser is moved in the x-y plane based on the geometry data of the object and initiates a targeted materialization of the material on the surface of the plastic bath. Once a level (layer) has been processed, the build platform is lowered in the z-direction (down) by one layer thickness and the next level is processed. By gradually adjusting the height of the build platform in the z-direction, three-dimensional geometries can be created layer by layer.

Definition of additive manufacturing

Today, 3D printing or additive manufacturing refers to all manufacturing processes with which three-dimensional workpieces can be manufactured in layers ("additively"). Different materials can be used, and are added in layers to create a component. This type of production of objects is made possible by the increasing use of digitization. Shapes and dimensions of the objects are created and described as three-dimensional models in CAD programs. The components are then built up layer by layer in a 3D printing system based on the CAD data set. No component-specific tool is required for their manufacture. The construction of the workpieces is computer-controlled, without the need for manual intervention.

Figure 1.4 shows the creation of a workpiece using 3D printing, i.e. the layered structure. The result after this process is a three-dimensional graphic.



Additive manufacturing technologies: layered construction of objects by applying material

Figure 1.4 Building up a workpiece "layer by layer"

3D printing systems use either **physical or chemical hardening or melting processes** to build the workpieces from the mostly amorphous raw material. The raw material is solidified by the action of an energy source such as heat or laser beams. The finished workpiece is created by connecting the layers one after the other. For this reason, the process is often called generative manufacturing.

A special feature of additive manufacturing is the shaping process, which, however, does not require any special molds to create the geometry of a workpiece. The materials used include powdered, rod-shaped and liquid materials. Plastics as well as fiber-reinforced plastics, ceramics and metals are currently used. In the meantime, work is also being done on materials made of carbon and graphite materials for use in 3D printing to produce parts made of carbon.

Additive manufacturing technologies are therefore among the most important developments of recent years and also make progressive digitization tangible for customers in the truest sense of the word. For, digital models or print templates that can be viewed on the computer become high-quality products. Even complex, three-dimensional shapes can be produced cost-effectively–if necessary, even on site or directly at the customer's. This brings many advantages for companies and customers which can also be directly attributed to increasing digitization. Therefore, more and more industries are using 3D printed parts in a wide variety of areas.

In preparation for 3D printing, a **three-dimensional digital model** is broken down into a large number of individual superimposed levels (layers). These levels are then transferred to the 3D printing system and processed there one after the other until the workpiece is completed.

Workpieces or objects are created on the computer using suitable software (usually CAD programs) as a digital model and saved as a data set. If the workpiece is to be printed, this data record is called up and "translated" into a machine-readable format using the appropriate software. The geometric data of the individual layers and other parameters that the 3D printer needs to produce the workpiece are stored in this machine-readable format. In addition to the control variables such as layer thickness and temperature, these parameters include characteristics of the material used. The principle of this process from design to finished product in 3D printing is shown in Figure 1.5.

Figure 1.5 Additive manufacturing, from the digital model to the product

3D printers are now used in industry and research, in model making and often in the consumer goods sector. The industrial production of models, patterns, prototypes and tools is now widespread. Industrial end products and private use are becoming increasingly important. In addition, more and more sectors such as the construction trade are discovering the possibilities of using additive manufacturing.

> There are three **possible uses** for additive manufacturing, as structured in the VDI 3405 guideline: prototypes, tools and end products.

The beginnings of additive manufacturing processes lie in the construction of prototypes. Hence the name of the first of the mentioned application possibilities: **rapid prototyping**. Rapid prototyping is actually a higher-level term and stands for different processes with which sample components—i.e. prototypes—can be produced quickly and directly from design data. However, 3D printing is the most common rapid prototyping process, and so rapid prototyping is sometimes used as a synonym for the term 3D printing, even though 3D printing can (and is) used for many more applications.

Rapid tooling , on the other hand, is directly assigned to 3D printing by definition. The production of tools or tool parts using 3D printing represents a special type of tool and mold construction and is often used to manufacture plastic injection tools.

Over the past few years, the methods have been further developed and become more versatile. This has also significantly improved the quality of the parts that are manufactured using 3D printing. 3D-printed objects are now often so good that they can be used directly as finished products, if necessary after post-processing such as painting. Various potentials can be derived from the new manufacturing processes in order to significantly reduce both the manufacturing time and costs of components. At the same time, the functionality of the parts can often be increased. With guideline VDI 3405 Part 3, a working basis was developed for companies and designers, which is intended to support the selection of a suitable 3D printing process for specific requirements. In particular, the guideline applies to the laser sintering of plastic components (VDI 3405 Part 1) and the jet melting of metal components (VDI 3405 Part 2).

In many areas of construction, there are currently no or only a few empirical values concerning the differences—or strengths and weaknesses—of the individual processes. The VDI guideline is intended to provide orientation and support in order to recognize the multitude of possibilities arising from the new freedom of design.

With 3D printing, **shapes and geometries can be implemented that were previously scarcely imaginable** as parts and that could not be produced with conventional processes.

The properties and special features of the 3D printing process described in the guideline offer detailed and specific information for development departments and designers, e.g. for component production using laser sintering from plastic materials. In addition to the description of the advantages, the VDI guideline also lists process-related restrictions on the respective processes and so these can therefore already be incorporated into the design of parts.

The VDI Society for Production and Logistics (GPL) also publishes additional information and status reports on additive manufacturing processes and their potential in the field of mechanical engineering on their website at: *www.vdi.de/statusadditiv*.

Here is a brief summary of the three possible uses according to VDI Guideline 3405:

1. **Rapid prototyping for building prototypes quickly**: This technology has been used for decades. In general, it is usually understood to mean archetype processes that can be used to create objects from shapeless materials. Additive manufacturing is particularly suitable for rapid prototyping, since with 3D printing the sample parts are produced directly from the created CAD data set without molds or tools and often without any manual effort at all.

2. **Rapid tooling for the rapid manufacture of tools**, tool components and other tools in tool making or mold making, especially injection molds for thermoplastic melt processing: Rapid tooling aims to produce molds or models that are easy to reproduce. 3D printers can also be used to produce simple tools directly on site in the assembly areas. In this way, the cost of warehousing can be significantly reduced. In addition, with 3D printing, cooling channels can be integrated into tools or tool inserts without any additional effort. Compared to tools made of solid material, these tools often have an optimized cooling capacity—or can also be used for temperature control during production. This enables shorter cycle times in production, reduces thermal distortion of components and has a positive effect on component quality.
3. **Direct manufacturing of end products**: This method, in which the manufactured objects are used directly as the end product, has already proven itself in medical technology, e.g. for hearing aids, temporary prostheses or in the field of dental treatment, and is commonly employed in the aerospace industry for highly complex components such as injection nozzles for turbines. In the automotive sector, the process is gradually being used by all well-known manufacturers, even in series production. The aim is to use the advantages of conventional series production. These include high production output with low unit costs, dimensional accuracy and interchangeability of the workpieces with reduced personnel costs, while at the same time minimizing the disadvantages such as capital expenditure and throughput times in connection with the use of tools.

Practical example: Automotive industry

According to its own publications (*press.bmwgroup.com*), the automobile manufacturer BMW already achieved an annual production of over 300 000 parts with the help of 3D printing in 2019. In June 2020, the BMW Group then opened its 3D Printing campus. The focus there is on the production of prototype and design parts, but also series components, research and the qualification of employees in a single location. At the time of opening, around 80 employees were already working in this center, equipped with around 50 industrial 3D printing systems for metal and plastic parts. In addition, more than 50 other systems are in use at various locations.

1.1.1 Competitive Advantages Thanks to 3D Printing

As already described, additive manufacturing has developed step by step over the last 30 years. Today, the different technologies and processes of 3D printing provide the basis for manufacturing a wide range of products and at the same time

Index

T

U

V

W

X