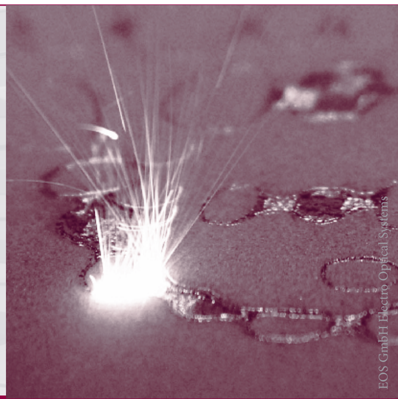
TAB OFFICE OF TECHNOLOGY ASSESSMENT AT THE GERMAN BUNDESTAG



ADDITIVE MANUFACTURING (3D PRINTING)

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Summary

- Industrial additive manufacturing technologies enable the production of highly complex components and open up new options for customised series production. Both in Germany and worldwide, most industries are still at an early stage of tapping the manifold application potentials of additive manufacturing.
- Compared to other countries worldwide, Germany's strength lies primarily on the side of developers, whereas the user side rather shows some deficiencies. This is why the major challenge for the years to come is to broaden the industrial user base in Germany.
- Overcoming non-technical barriers that often impede the introduction of additive manufacturing technologies represents a key factor in this respect – particularly for small and medium-sized companies. So far, with regard to the existing funding activities which are mainly focusing on technological development goals, only little consideration is given to non-technical fields of innovation.
- In order to optimally interlink the innovation process with society's needs, research on economic and social issues associated with additive manufacturing should be strengthened.

What is involved

With additive manufacturing (AM) technologies, the requested component is built up successively by **applying the source material layer by layer** based on a **digital 3D model**. This process enables the manufacturing of **geometrically highly complex products** which could not be realised by means of conventional manufacturing processes at all or only with great effort. Moreover, products can be easily **tailored to the customers' individual requirements**.

For more than 25 years already, AM technologies are firmly established in industry for the manufacturing of prototypes and highly specialised tools or moulds. Furthermore, for almost ten years, technological progress increasingly enables the manufacturing of **high-quality final products**, thus significantly broadening the range of industrial applications. In parallel, **3D printers which are technically simple indeed, but affordable for private users as well** have been developed. They are becoming more and more popular even among users who are less technophilic.

In the public and in the media, industrial AM technologies and 3D printers are particularly fascinating, because they generally nourish the utopia of a universal machine by means of which anyone can manufacture material objects at will. This is why the **ideas regarding the performance, potential applications and impacts of AM technologies are manifold and often highly exaggerated**. The TAB report gives guidance by presenting and evaluating the developments in this field and allows to assess the potentials as realistically as possible.

State of the art: Not yet mature for routine use in industry

During the last 30 years, a **multitude of different AM procedures** being able to **process a wide range of source materials** has been developed.

A relatively simple procedure for processing plastic materials is the fused deposition modeling, for which the source material is melted in a nozzle and then applied punctually or linearly layer by layer. Most of the currently available **3D printers for private users** are based on this technology. Another example is **stereolithography**. In this case, a photosensitive polymer is deliberately cured by means of a laser beam precisely at the points where the component is to grow further. Thus, very fine structures in the range of micrometers can be manufactured.

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Compared to plastics, **metals** have a significantly higher melting point so that **complex and expensive high-power laser systems** are typically used for metal. For **laser sintering/laser melting** – the most commonly used metal-based procedures – laser beams are fusing metal powder layer by layer at the intended points thus bonding the metal particles together. Such procedures are of particular interest mainly to industry and are rather not suitable for private users.

Currently, there are still various **technical challenges** to be met with regard to a routine use of AM technologies **in industrial production**, particularly for larger series. Especially for the manufacturing of larger components, the still rather **low build-up rates** significantly limit the range of potential applications. Another disadvantage is that there are upstream and downstream production steps most of **which still have to be carried out manually today**. Finally, there are still **considerable gaps of knowledge with regard to the mechanical properties** of components produced which, as a result, calls for complex quality checks. This is why today the **potentials of AM technologies** are considered particularly for **highly specialised applications in the production of individual components or small series**.

There are other materials as well that can be processed by means of AM principles such as e.g. **concrete/cement, textile fibres**, certain **foods** or **living cells**. In these cases, development still is in a **very early phase of research and testing**.

Applications and potentials

Corresponding with the wide range of procedures and materials, **AM technologies for the manufacturing of final products have manifold application potentials** in various industries such as mechanical and plant engineering, aerospace, automotive, electronics, medicine, civil engineering, arts, design, clothing and sporting goods, toys, food and, last but not least, even military engineering and arms technology.

Most industries, however, are still at an early stage of tapping these potentials. Pioneers in this field are the **dental industry** with more than 10 million bridges and crowns that are manufactured each year using AM technologies as well as the **hearing aid** industry where already in the year 2010 40 % of the global production of ear moulds have been manufactured additively. Here, the small dimensions of the components offer the advantage that large quantities can be manufactured additively in spite of the currently low build-up rates.

Among the classical industry sectors, **aerospace technology** is one of the pioneers. The objective is to manufacture **geometrically complex lightweight components** offering weight savings compared to conventional components. The fuel savings that can be achieved this way justify the high expenditure of AM. Another pioneering industry is **medical engineering**. Here, the focus is on manufacturing **patient-specific implants** (knee prostheses, artificial hip joints etc.).

Many potential fields of application for AM technologies include creative (e.g. design clothes or furniture), rather **playful** (e.g. sugar sculptures, toys) or **visionary applications** (e.g. house building, manufacturing of living human tissue).

Application examples of AM technologies

Stereolithography is an established procedure for manufacturing individually customised **ear moulds** for hearing aids. The required 3D model of the auditory canal is created by means of a silicone impression or via 3D laser scan.

In the **dental industry**, **laser sintering** is already one of the standard procedures. The figure shows three phases of the AM process: On the left, you can see the bridge immediately after the building process (still with support structures), on the front teeth the polished bridge and in the back the bridge veneered with ceramics.

Germany by international comparison: Strong development, rather weak application

By international comparison, **Germany's strength** lies in the **development respectively production of procedures, materials and systems** for AM, particularly in the metal sector. As a substantial discrepancy to this, however, an obvious weakness on the user side can be observed – particularly compared with the USA.

In this context, Germany's technology leadership with regard to conventional manufacturing processes might prove to be ambivalent: While other countries are only able to manufacture certain complex components through AM technologies, German companies have been manufacturing corresponding products with conventional manufacturing processes for

Images clockwise: Airbus Operations GmbH; courtesy of 3D Systems, Inc.; www.thingiverse.com/thing:275091 (CC BY-NC-SA); EOS GmbH Electro Optical Systems; EnvisionTEC GmbH many years already. Due to this, **emerging and possibly disruptive application potentials of AM technologies might be recognized and tapped too late in Germany**. This is why the major challenge for the years to come is to **broaden the industrial user base in Germany**.

It is a general problem that the **familiarity with AM technologies in German industry** regarding tangible application potentials is **rather weak so far**. This applies particularly to small and medium-sized enterprises (SMEs) for which, in addition, there is often a **lack of decision-relevant information**, as industry and technology standards for AM technologies still need to be developed. In connection with the variety of procedures, many SMEs have **difficulties identifying application potentials, new business models and the appropriate technology to get started in this field**. Moreover, they have to face challenges with regard to tapping the technical know-how, because the **required competencies and qualifications are often not available to a sufficient degree**. As, in Germany, mainly SMEs are active in the fields that show the highest application potential, these factors have a strong impact inhibiting the diffusion of AM technologies.

Great potentials are seen in the **aviation industry**. Due to its bionic structure, this bracket (bottom) manufactured by means of **laser sintering** offers a weight saving of more than 30 % compared to its conventionally manufactured equivalent (top), but meets the same requirements regarding functionality and stability.

Powdered **food** (sugar, flour etc.) can be glued by means of liquid binders (e. g. water) to form delicate figures layer by layer.

Due to the relatively simple device technology, **3D printers for private users** can be used to manufacture only comparatively **simple plastic objects** for the time being. The frequently outlined vision of private users satisfying their demand for various everyday objects by their own production is something that will not be realised for a long period of time, if at all.

There is a **wide range of options for action** in order to **support the diffusion of AM technologies in German industry**. It is of vital importance to **overcome non-technical barriers**, e. g. by means of consulting and information services, expansion of training and qualification services or the promotion of pilot lines as well as exchange and innovation platforms. So far, with regard to the existing research and development programmes which are mainly focusing on technological development goals, only little consideration is given to non-technical fields of innovation. Here, however, not only **politics** and **public authorities** (ministries, institutions of research funding), but also stakeholders from e**conomy, science and education** (universities, applied research, vocational academies) or **intermediaries** (industry associations, chambers) **are called upon**.

Consequences and risks of AM technologies

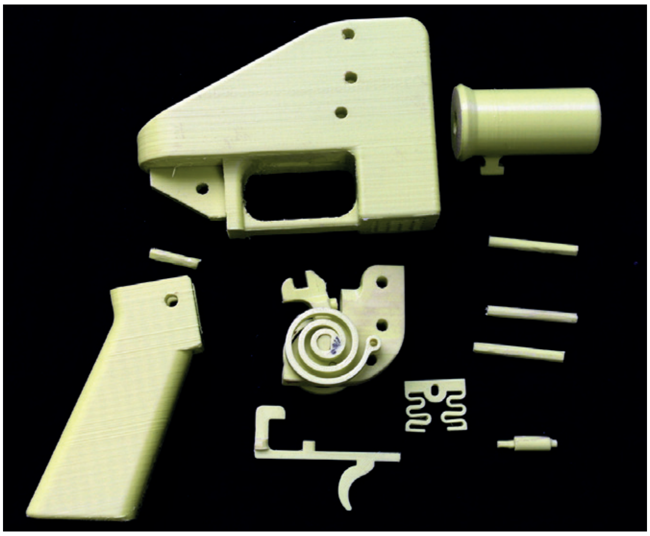
Currently, national and international research efforts on AM are dominated by technological development goals. **Economic and social research into the consequences of AM technologies is only about to start**, so that it is **currently impossible to make** any **reliable assessments or forecasts** concerning the impacts. In view of the rapid developments in this field, interdisciplinary (accompanying) research should be vigorously pursued as well.

Various economic impacts are assumed: Tool-free and widely virtual AM technologies open up new opportunities for customised, demand-oriented and/or decentralised production. In the markets concerned, this might involve **changes of the existing structures regarding production, value creation and logistics**. New actors (e. g. start-up companies, technologically less advanced countries) might – by means of AM technologies – penetrate established markets with innovative products and business models which might result in new **constellations of actors** and possibly in **relocations of production**. Finally, as it is the case for any technological progress resulting in improved production efficiency, **impacts on the type and number of employees** are to be expected as well.

Environmental impacts of AM technologies are uncertain: Both positive (e. g. high material efficiency, lightweight construction potentials) and possible negative environmental impacts can be identified (e. g. high energy consumption during the manufacturing process, complicated recycling of the products). **The question whether or not additive production scenarios have ecological benefits in the overall balance compared to conventional scenarios still remains widely unanswered.** Moreover, this question cannot be answered generally, but at best for individual product categories depending on the considered production scenarios and application contexts of the products.

Risks with regard to internal and external security: Due to their extraordinary flexibility, AM technologies are ideally suited for **dual-use applications**. They could enable the manufacturing of complex armament goods by countries that have not been able to do this so far for technical reasons or due to trade restrictions. An approach to prevent a possible proliferation of armament technologies by means of AM technologies could consist in **making the export of at least particularly powerful systems and associated materials subject to authorisation**.

Private 3D printers can be used relatively easily to manufacture **firearms and other safety-relevant objects** from plastics. These products then could be used to evade existing safety systems (e.g. metal detectors) and public protection and control mechanisms (e.g. weapons registration). Even though today firearms made by 3D printers are still rather primitive (see figure) and work extremely unreliably, **potential dangers must not be underestimated in view of the rapid technological progress**. Restricting the availability of digital 3D models for the production of weapons on the Internet or technical protection mechanisms in the 3D printers (e.g. filtering software) could be considered as possible approaches aiming at reducing the risks.



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Additive Fertigungsverfahren (3-D-Druck)

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No urgent need for legislative action in spite of the legal situation being unclear

The particularities of AM technologies bring up **numerous legal issues**. This especially concerns the **protection of intellectual property** (e.g. protectability of digital 3D models), **product safety** (e.g. manufacturer obligations for customised products) as well as **liability issues** (Who are the liable manufacturers in view of many players being regularly involved in the largely virtual product development and manufacturing process?).

The partly unclear legal situation is primarily due to the fact that a **consolidated jurisdiction specifically for additive manufacturing does not exist so far**, because the technology is still relatively young. The prevailing opinion is that the existing legislation and standards are sufficient to ensure legal clarity by way of interpretation. Thus, from today's perspective, no **urgent need for legislative and regulatory action** is to be stated.

However, it cannot be excluded that possibly existing regulatory gaps can only be identified when the first more complex legal disputes will be dealt with by the courts. For this reason, attention should be paid to the further development of jurisdiction in the context of AM technologies.

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