Manufacture the Future – Why Decision Makers Should Care about Additive Manufacturing

The first big hype about Additive Manufacturing (AM) is over. What remains is the realization that AM has now outgrown the prototype stage, and it has the potential to radically change the market.

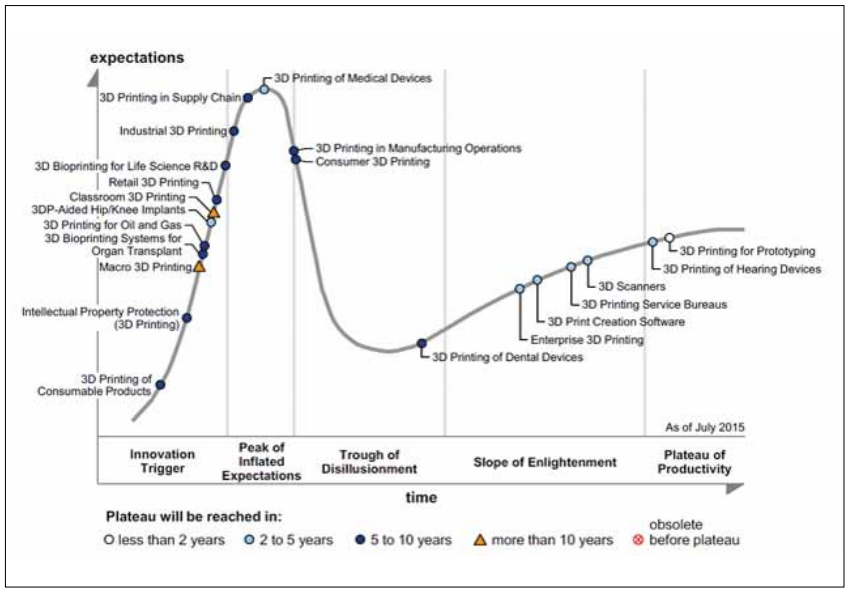

Fig. 1
Gartner's 2015 Hype Cycle for 3D-printing [3]

Introduction

"We are all interested in the future, for that is where you and I are going to spend the rest of our lives" [1].

Looking at AM and its importance for companies, it is apparent that many leading companies are thinking about the future, but have so far taken little action to deploy AM for their businesses and realize its potential.

These are the findings of a McKinsey survey among leading manufacturers in 2015. The survey reveals that companies are currently ill prepared to undertake a cross-organizational effort and identify the opportunities. Two thirds of the respondents also stated that their companies lacked a formal, systematic way to catalogue and prioritize emerging technologies in general [2].

The survey results also show that at present companies are not keeping up with the latest market developments, nevertheless AM is already state of the art in some industries. The current Gartner Hype Cycle of the Research Institute Gartner in Fig. 1 illustrates that 3D-printing for prototypes has already arrived at the last stage of the hype cycle and is on the edge of the plateau of productivity [3].

While AM is already successfully applied in many industries (especially hearing devices) with different materials (metal, plastic, etc.), the ceramics industry is still reluctant to introduce it. However, there are AM technologies which meet the high quality standards of the ceramic industry even now. The ceramics industry can benefit in different ways by applying AM. Considering the new conditions and challenges imposed on the industry, there is a growing need for AM also in the ceramics sector. Shorter product life cycles, the need for mass customization of products and the need for resource-efficient manufacturing technologies for the production of small scale series and individual pieces are drivers for AM.

Summing up the above findings, it is evident that companies are facing the challenge of integrating AM not only in their company but have the need to understand the full potential of the technology and then integrate it into their long-term strategy. AM is already becoming state of the art for some applications and provides the ceramics industry with the opportunity to create groundbreaking innovations and to develop new markets. In Fig. 2 the potential of AM is shown and then discussed in more detail below.

Keywords
additive manufacturing, ceramics, potential of additive manufacturing, innovation, scope for development

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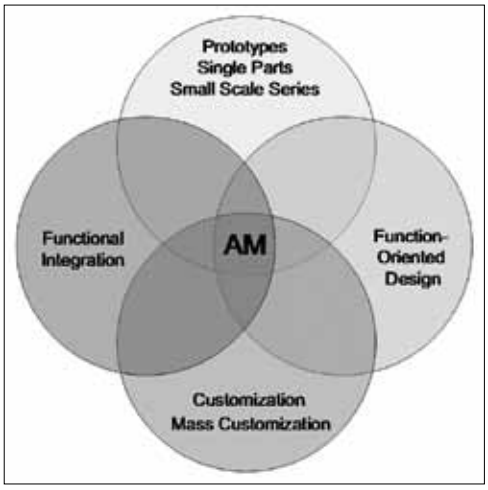


Fig. 2
The four potentials of AM for the ceramic industry

Prototypes, single parts and small-scale series

AM is often equated with rapid prototyping. This is primarily due to the fact, that in the early days of AM, the technology was only used for the production of prototypes. It was faster to manufacture the prototypes directly by an AM technologies than to make it by hand and/or by applying moulding technologies – hence, the term rapid prototyping was created.

According to the Gartner Hype Cycle this is still the most popular application and it has already reached the plateau of productivity.

When AM is solely used for the production of prototypes, the technology is taken into the company's production portfolio as an add-on production technology.

The technology complements the existing production methods and due to the tool-less manufacturing process achieves cost and time savings compared to conventional methods.

The term prototype is often associated with the notion that this is merely a not fully functional model of a future product.

AM technologies, such as the LCM (Lithography-based Ceramic Manufacturing) technology developed by Lithoz/AT or IntrinSiC developed by Schunk Ingenieurkeramik/DE are already well-above this level. Parts which are manufactured by these technologies show the same or very similar material properties as conventionally formed ceramics. This enables not only the production of fully-functional prototypes, but also of single pieces and small scale series.

However, this reveals only the first potential of AM, which can be summarized as follows:

- Avoidance of costly and time-consuming mould-making
- Simultaneous manufacturing of different geometries in a single production process
- Quick and easy implementation of design optimizations
- Close-to-production-tests with fully functional prototypes
- Protection of product ideas through in-house-development.

Especially in the early phases of product development, when the design has not been fully finalized, AM is a very attractive realization method for prototypes. Robert Bosch GmbH/DE produced prototypes of a contact holder of a tribological sensor using the LCM-technology to make first functional tests and to optimize the design (Fig. 3). Once the design is fixed, the parts will be produced in large quantities by ceramic injection moulding.

Customization and mass customization of products

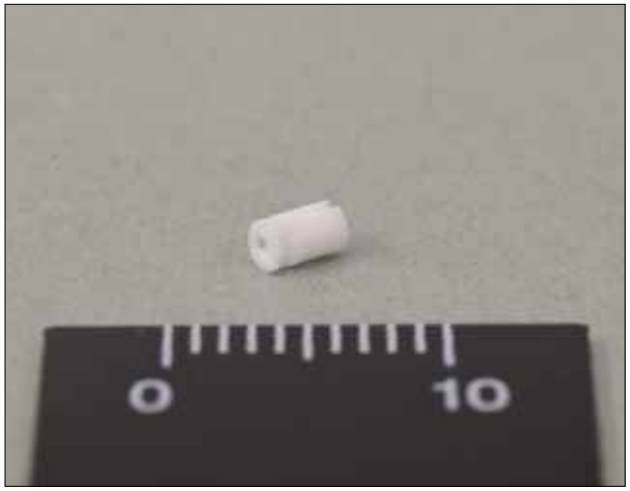
The tool-less production method can achieve a mass customization and an individualization of ceramic products. The batch-oriented manufacturing approach offers the opportunity of combining individualized products with the simultaneous benefits of mass production. Specifically, this means:

- Simple and cost-effective individualization of products
- Product changes already during the life cycle
- Cost-effective production of high-performance ceramics from batch size 1
- On-demand-production – more efficiency in production planning and supply chain.

Mass customization is already applied in the hearing aid industry, where currently 95 % of the hearing aids are produced by AM. In the ceramic industry, the medical applications seem to be a high potential market for mass customizations too. Personalized implants (permanent and resorbable) are promising candidates and are already a matter of intense research.

Function-oriented design

While generations of designers have always been educated to design their parts



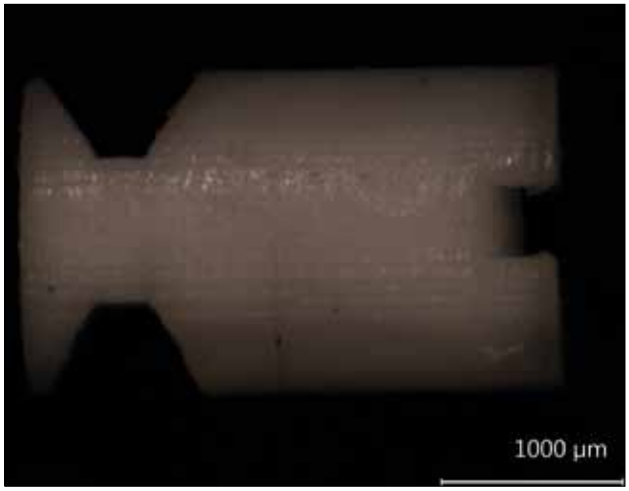


Fig. 3
Prototype of a contact holder of a tribological sensor (Courtesy of Robert Bosch GmbH)

in accordance with the limitations of conventional production technologies, the use of AM opens up unimaginable opportunities in terms of design and geometrical freedom. The internalization of new design rules allows the creation of entirely new designs that would not be possible with conventional manufacturing methods. Thus, a change is taking place from production- towards function-oriented designs. This transformation is based to a large extent on the characteristics of the further potential of AM:

- No demoulding-problems due to a tool-less production method
- Feasibility of bionic designs, defined pore structures, undercuts and cavities
- Realisation of fine channels (<200 µm) and thin-walled structures (<150 µm).

The mixer shown in Fig. 4 provides not only a component of high complexity, which could not be manufactured with other methods, but indicates a paradigm shift in the design of ceramics. The design of this mixer is based on the results from fluid dynamics simulation and mechanical engineering. Functional-oriented design requires a focus on the needs and the ability to think out of the box.

The traditional ways were abandoned and new ideas have been followed. The mixer with changing cross-sections and openings in the walls leads to changing velocities of the fluid fluxes inside the channels. This results in a faster and more intense mixing of two fluids and hence, the reaction way can be shortened [4]. Finally, this leads to a much smaller version of the mixer and furthermore to a weight reduction. This could specifically be used in aerospace applications, where a reduction in weight is very valuable.

Fig. 4
Mixer with changing cross-sections and openings in the walls (Courtesy of Fraunhofer IKTS, Dresden/DE)

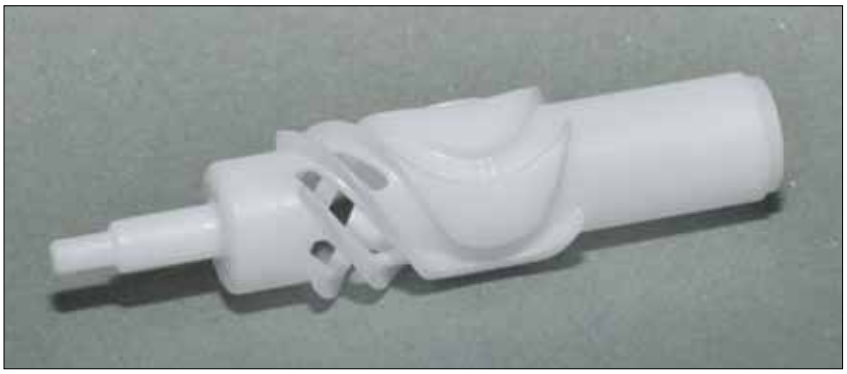


Fig. 5
Functional integration in a blood pump (Courtesy of Vienna University of Technology/AT)

Functional integration to reduce assembly costs

AM is particularly suitable for a comprehensive integration of functions by combining different parts into one. The aim of functional integration is to combine as many technical functions with the least possible number of components.

Often, the functional integration leads to highly complex geometries, which cannot be realized with conventional manufacturing processes or only with great effort. With this functional integration high assembly costs can be saved and more functional products can be produced.

A first good example of functional integration in AM is General Electric's/US fuel nozzle of the LEAP-engine, where seven parts were combined to one. Furthermore, the fuel efficiency was also increased by the new design. Examples in the ceramic industry are rather rare, but the following example of a blood pump gives a first indication of the future opportunities.

The power turbine of the blood pump shown in Fig. 5 highlights the functional integration. In the beginning the main objective was the integration of as many functions as possible without limiting oneself to a certain material or manufacturing technology. The primary function of the power turbine is to convert the gas flow into a rotational movement. Furthermore, the hollow structure of the turbine enables a back-flow of the gas through the turbine. Two consecutive bearing points at the end of the turbine lead to a higher rotational stability.

An important reason, why the LCM-technology was chosen for this project, was the ability of using fully functional ceramics parts without the limitations known from traditional forming technologies.

AM of ceramics and its potential for innovation

Due to their excellent material properties ceramics are often referred to as the material of the future and are used for a wide variety of industrial, medical and technical applications [5]. If the ceramic knowledge is combined with AM, new expertise can be established which could be the key for the company to create new markets.

The identification and development of new markets is already on the agenda of many companies. Decision makers use a wide

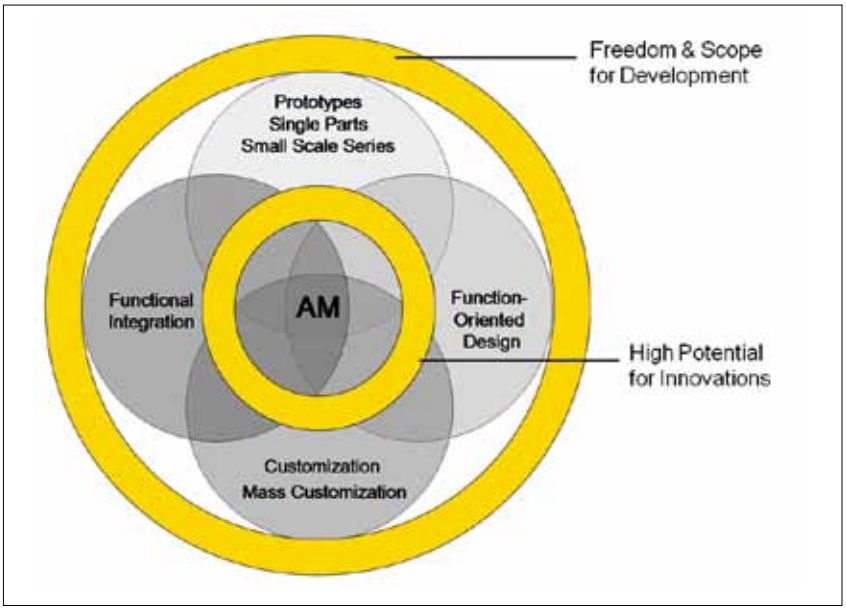


Fig. 6
Freedom and scope of development are basis for innovations in all fields of application

variety of tools to identify new potential customers and markets.

Environmental analysis (e.g. Porter's five forces, PESTLE [Political, Economic, Social, Technological and Legal] analysis) is used in order to observe indicators to recognize and understand correlations of environmental factors and make predictions for the changes in the market. These tools are very important for the business activities, if the task is "doing things right".

Hence, decision makers try to identify new opportunities to open up markets for their existing products, where they know the needs of the customers or where they try to adapt their products. As a consequence companies often start innovation processes with a specific problem caused by a particular situation on the market, or with a tangible idea.

So the results are usually incremental innovations. The applied tools don't allow companies to question common market mechanisms. Often, they do not lead to the great and radical innovations.

However, AM in combination with high-performance ceramics has the potential for radical innovations.

But why should decision makers deal with radical innovations and why is the creation of radical innovations of particular importance for the ceramics industry? The irony we see today in the quote by Ken Olsen, founder and president of Digital Equipment Corp. from 1977 answers this question: "There's no reason anyone would want a computer in their home."

Radical innovation will arise independently of one's own will. If they are not invented in-house, a competitor or even more likely a new market intruder will come up with these market changing developments. The only constants of our time are progress and the constant development of markets. Radical innovations revolutionize or open up new or so far non-existing markets, because they break the usual market mechanisms (e.g. iTunes, Airbnb). The manufacturing of hearing devices by AM has lead to a complete technology switch in a whole industry. Existing business models became obsolete overnight.

Two questions arise if one thinks about the future of the ceramic industry. How can the ceramic industry ensure that their company will still be successful in the future and where from comes the innovation idea for the ceramics industry?

Freedom and scope of development

Tomorrow's success is based on today's actions. Hence, it is necessary that companies are starting today to deal with the opportunities and potentials of a new technology. The acquiring of professional expertise requires time, courage but also freedom and scope for development. Only by the means of these attributes competence is gained to be able to leave common thought patterns and to innovate. With the ability to gain experience and to experiment it is possible to establish an adequate expertise and to discover the potential and limits of a technology.

All examples shown in the beginning had a scope for development and freedom to think out of the box. It does not matter, whether AM is used to produce prototypes, individualized parts, parts with a higher functionality or function-integrated parts; it always starts with the basic freedom and the scope for development as schematically shown in Fig. 6.

Freedom and the scope for development put high demands on the employees as well as on the company. On the one hand employees need a lot of self-determination and personal responsibility to take action and claim freedom for discovering the opportunities of new technologies. On the other hand companies need to invest into new technologies in order to give their employees the freedom to acquire the necessary competence for a prosperous future of the company.

Today companies already realize the value of scope for development to reveal the creative potential in the company. However, this is often a luxury which companies give their employees only in theory, because in the end only the financial results count. It takes courage to demand scope for development. If employees ask for it in companies they are often seen as egoistic, elbow-types or outsiders. But these attributes are more than concepts, which mark the boundaries between public interest and egoism.

Freedom and scope for development stand for the openness of results. Friedrich August von Hayek, the Austrian Nobel laureate, said: "Since the value of freedom rests on the opportunities it provides for unforeseen and unpredictable actions, we will rarely know what we lose through a particular restriction of freedom" [6].

Conclusion

Innovators and pioneers have understood that the inclusion of a new technology in a company's portfolio is not only done with the purchase of an equivalent system, but

that the advantages of such decisive edge technology are only achieved through the acquisition of new design rules and the redesign of existing geometries.
It requires an in-depth discussion of these technologies in order to exploit the full potential of AM in the company. Although it is said that AM has no design limitations, every AM technology is subject to certain design rules as well as other manufacturing technologies.

Once these design rules have been fully understood, a completely new range of design freedom can be reached. It requires a so-called "learning and playing time" with the technology, to utilize the full potential of technology. Therefore only an intense discussion and engagement will lead to a paradigm shift in the design of ceramic products.
Conventional technologies have a long history which allowed a lot of time for the accumulation of experience and the development of special expertise. But even in its early days, there were courageous pioneers who recognized and supported the potential of new technologies and new production methods. Especially, in a traditional and very demanding industry like ceramics, it is important to give AM some scope for development and the appropriate freedom to reach its full potential.

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