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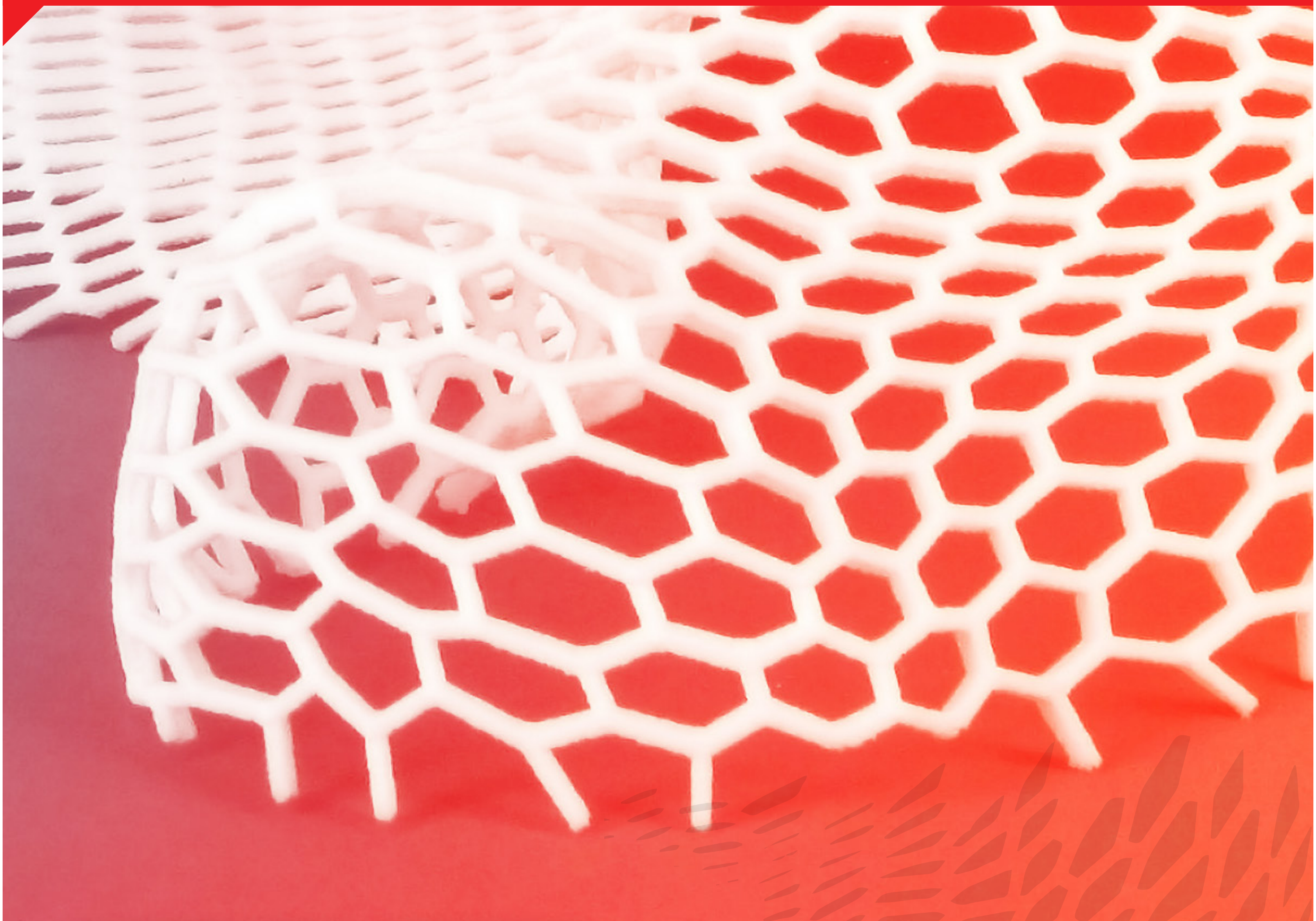

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8. MEDICAL APPLICATIONS OF ADDITIVE MANUFACTURING

Systematic approach for the identification of new industrial application fields for AMT

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***Abstract*— Additive manufacturing technologies have the potential to revolutionize entire value creation chains and systems. Companies are facing several challenges by using AMT in industrial application fields without straying too far from their own core competences. Often companies tend to apply AMT as a substitute technology for the same products produced by conventional manufacturing technologies. This is based on a lack of knowledge and the high complexity of the multi-dimensional impact of AMT on value creation chains. Frequently, the identification of a new AMT product is based on product-, material- or manufacturing factors. Thereby, further potential of applying AMT remain concealed based by a missing extension of the scope to the entire value creation chain. This paper presents a systematic approach to identify new application field for additive technologies in companies' industrial environment. An essential aspect is the identification of the products function and the property of the product. Not only product- or material specific factors will be taken into consideration. Moreover, from new opportunities and potentials in the entire value-added chain through to the development of new business models will be identified and explained.**

Keywords-additive manufacturing technologies, 3d-printing, industrial application, value creation system, systematic identification, holistic approach, application fields

1. INTRODUCTION

Additive Manufacturing Technologies (AMT) becomes more and more relevant as manufacturing technologies in industrial environment (small series or series production of products for end-users, production of tools and shapes). Beyond that, they have the potential to significantly change complete value creation systems [1, 2]. This is one reason why AMT is a part of the new industrial revolution [3–7]. Currently the industrial implementation of this technology is limited due to lacks in the process stability and quality issues, often also regarding economic issues [8–10]. The main area of applications for AMT is where conventional manufacturing technologies can´t be used due to technological restrictions [11]. The use of AMT aims at an additional customer value due to e.g. functional integration, individualization, personalization, organic structures, optimized or material efficient products, light-weight structures or production without the use of tools. In general, to substitute conventional manufacturing technologies is neither effective nor efficient. Moreover, factories of the future which rely on Additive Manufacturing Technologies shall be enabled to switch from manufacturing-oriented design towards design-oriented manufacturing. This will partially cause radical effects to the whole value creation system and requires a holistic view beyond product development.

To minimize this hurdles, a stepwise and systematically identification from use cases on the base of standardized selection criteria with regard to material, quality, design and value chain specific requirements have to be executed [12]. Significant is the comprehensive consideration from the idea generation to requirements of new business models in consideration of the value chain and all production-supporting processes like administration- and logistic-processes [13].

This paper aims at a broader view on AMT, especially in context to the value added system. As a further important point for a successful implementation of AMT, two approaches for the systematic identification of new application fields will be discussed. This approaches will allow an identification and prioritization of company specific application cases due to selection criteria and the potentials of AMT in the whole value creation system.

2. APPLICATION OF ADDITIVE MANUFACTURING TECHNOLOGIES

One of the big advantages of additive manufacturing technologies is the ability to "generate" a physical product in a short time slot, based on a virtual model. Therefore, AMT became more and more importance in the last decades, especially in prototype building, where AMT today is seen of State-of-the-Art. A further important step is the advancement of AMT for broad industrial application. Specifically, this means that AMT-produced parts are directly used by customers respectively additive manufactured tools are directly used for the production of end-user products [14]. Basically, AMT can be divided in prototyping, direct manufacturing and the cross-sectional field with Rapid Tooling (see Figure 1). The rapid tooling is grouped into direct tooling for producing tools for serial production and prototype tooling for pre-series production.

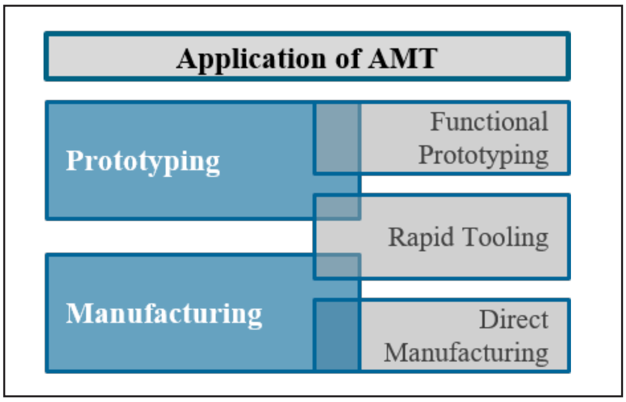

Figure 1: Application of AMT

The application of AMT in the field of producing prototypes necessitates know-how regarding material requirements and technology settings to get usable prototypes. The significant distinction between AMT-application in prototyping and manufacturing is reflected in the higher effort of technology implementation and the effects to the value creation system.

2.1. Industrial application

The implementation of AMT in the technology portfolio of companies passes through different stages. As shown in Figure 2 in a first step it can be started by substitution of the conventional technology due to the potentials of AMT that allow a more efficient production of the considered product. But the success of holistic implementing AMT in companies is strongly depending on the companies' innovation and technology strategy. A short-sighted approach by „only substituting" a conventional manufacturing technology in the most cases is not expedient. This first step allows companies to gain more know-how in the field of additive manufacturing and the resulting value.

For industrial application of the disruptive AMT there is the need of an comprehensive perspective of various aspects in value chains [12]. Furthermore, new potentials and business models (see chapter 4) can be developed by initiating a rethinking process leading to innovative approaches which are getting enabled by using the advantages of AMT [10, 15].

An additional benefit of AMT is the functional integration. Another essential aspect is the product life cycle. If you're able to decrease the life cycle costs of a product by the manufacturing with AMT, possible higher production costs can be equalized in short time. When analyzing the production costs solely, AMT has advantages compared to traditional manufacturing technologies also at the break-even point when producing small quantities and when the investment costs of traditional technologies (like injection molding) are higher compared to AMT.

Nevertheless, it is recommended to extend the analysis of the production costs to a holistic approach ranging from the inbound logistic to the final inspection of the product. AMT causes changes in traditional structures of companies and combines multistage processes to a single-stage process which leads to huge challenges for companies. Especially due these challenges it is a necessity of the innovation process to analyze the technical and the financial feasibility of components produced by AMT [16].

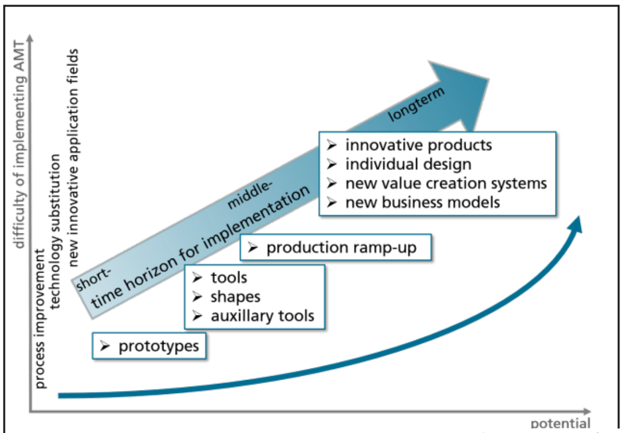

Figure 2: 3D-printing-maturity-Kurve (own graphic according to [14])

Summarized, the following aspects support the application of AMT [11]:

- high geometric complexity of the products
- individual/customized products
- High number of variants
- Relatively small size to fit the installation space specifications of plants

As shown in Figure 2 the comprehensive and holistic view to the additive value creation system enables substantial product innovations. Due to AMT, in the context of digitalization and digital production new business models are created with high degrees of individualization and automation at the same time.

2.2. Definition of AMT application strategy

As described above, a comprehensive successful implementation of AMT is strongly depending on the company's strategic management. A substantial fact in the identification and selection of AMT application fields therefore is a strategic risk minimization, based on company specific core competences, comprising different characteristics. From the perspective of implementing AMT in the first step a new application field serves the same market of the existing product-portfolio (see Figure 3). Therefore, based on a function-oriented approach, the task is to identify applications who will be more efficient,

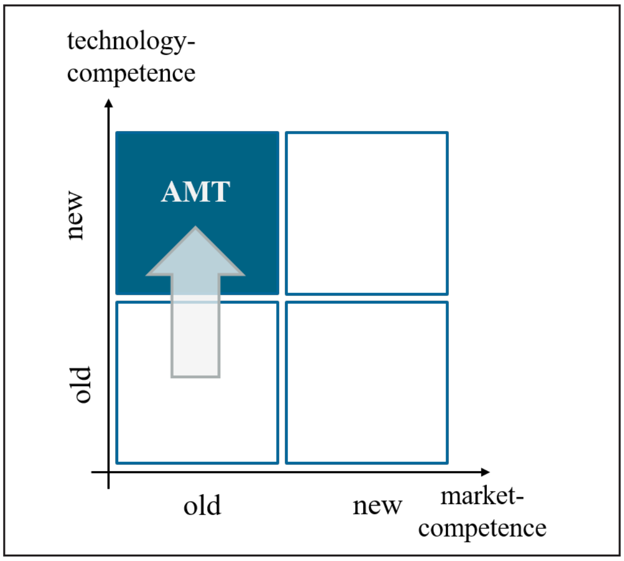

Figure 3: portfolio techniques for determination of application fields

more sustainable or better to produce in the view of production and logistic through AMT – in short, a company's application field for AMT has to create an added value for the customer or the company itself.

3. FIELD OF OBSERVATION REGARDING THE VALUE ADDED SYSTEM

The high interdisciplinarity and complexity of additive manufacturing processes necessitates a wide knowledge base, which is already important in early stages of the whole innovation process [15]. Another significant requirement is the understanding of interactions between different processes, based on varying manufacturing technologies, materials and product specific boundary conditions. A specific application is resulting in a large set of solution of different manufacturing processes. Their complexity can be controlled subsequently only through the integration of sub-processes in the innovation process (conception, process planning and production) and existing knowledge and experience (additionally based on external knowledge with e.g. cross-industry-business or open-innovation approaches).

For the identification of AMT effects and interdependencies to the whole value creation system, it is divided up into a "horizontal" and a "vertical" observation field (see Figure 4). The horizontal observation area includes all processes along the material flow with impact to the manufacturing process chain, starting at the raw material supplier and ending at the customer of the AMT product. With the specific AM-Technology as a central starting point, pre- and post-processes (production and logistics) have a significant impact to the flow of material and product. The difference between classic value creation chains and additive value creation chains can be described as follows:

- Changes (or complete elimination) of tool manufacturing
- Post-processes like assembly or technology caused post-processing (e.g. sintering, surface finish etc.)
- Internal and external logistic processes
- etc.

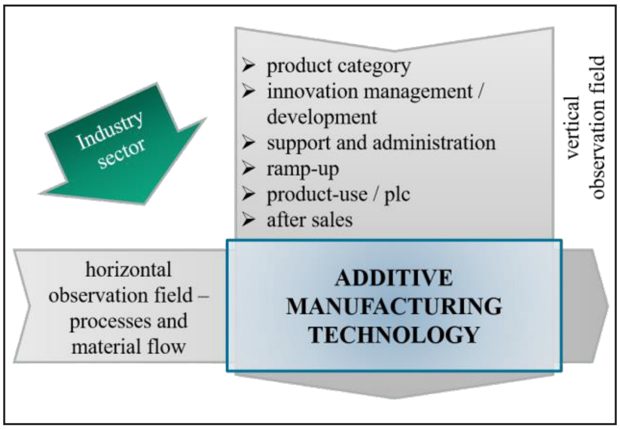

Figure 4: The horizontal and vertical observation fields in the value creation system

In addition to the additive manufacturing flow of material further thematic areas are strongly influenced by

AMT, in the current approach defined as vertical observation field. As essential areas administrative-, support-, innovation- and product development-processes may be mentioned here. Further relevant aspects are product categories, market and sales incl. aftersales, product life cycle, new business models and other strategic application field.

Every industry sector has its own requirements to AMT application, especially product characteristics are depending on the application sector. Therefore, initially it is necessary to define the requirements based on the different sectors, divided up into the main categories:

- consumer, fabber/maker sector
- architecture, design, jewelry
- textile and shoes sector
- mechanical engineering and plant manufacturing
- medical and dental
- aerospace

Based on this 2-dimensional approach emerging potential and impacts can be determined and assigned to the different observation field more easily. This step forms an important basis for the evaluation of relevant applications of AMT.

4. AMT IMPACTS TO THE VALUE CHAIN AND POTENTIALS

The selection process of parts getting produced by AMT is often based on substitutive approaches compared to the advantages of traditional manufacturing technologies. Pre- and post-processes along the value chain are rarely part of these analysis [9, 17], which are having great influence on the potentials/advantages of the AMT.

4.1. Impacts to the value creation chain

Different details among the value added chain regarding implementation and integration of AMT have to be taken into account [18], like e.g.:

- material- and quality properties
- process-stability
- productivity
- degree of automation
- post-processing
- transition to flexible production systems
- decentralization of the production

For the industrial application [19], Campbell and Ivanova [12] identify the necessity of a comprehensive analysis of different factors for the, in some areas disruptive, AMT. Furthermore, additional potentials based on changes in the manufacturing process chain and business models (production on demand, production on customer-site, customer individualized production, ergonomic personalization, wide product variety with lot-size 1, short set up times and innovative after sales concepts etc.) can be created through innovative approaches by initiating a radical rethinking process [20] and enabling an “additive thinking”. All these business models have in common that they are getting enabled by making use of the holistic advantages of AMT [10, 15].

The recommended approach analyses the impacts of an AMT on the complete value chain, analyzing pre- and post-processes in multiple dimensions like:

- time
- cost
- quality
- functionality
- sustainability
- etc.

which are able to offer an increased benefit for the customers.

4.2. Potentials of AMT

Often, only technical aspects and benchmarks like surface qualities, material properties etc. are considered in the technology selection process. Due to these reasons AMT can’t be solely seen as substitutive technologies to traditional manufacturing technologies (milling, injection molding etc.) but have to be analyzed in a holistic approach on the specific application. An implementation of an “additive thinking” [15, 21] offers a chance to identify comprehensive potentials enabled by AMT. The frequently mentioned potentials are high geometric complexity of components, functional integration and a high level of (customer-oriented) individualization. As further substantial potentials can be cited e.g. resource efficiency along the product life cycle, reduction of lead times, organizational potentials, new support-, sales- and business models etc. (see Figure 5), which are potentials based on the extended view to the value creation system.

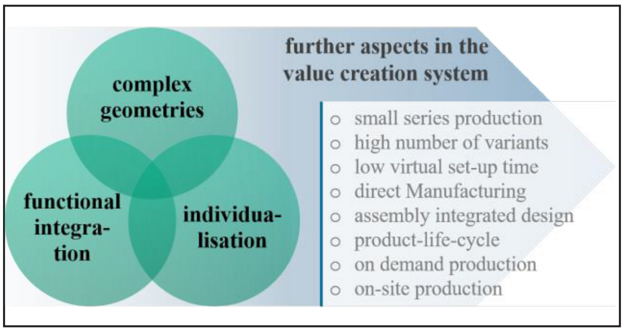

Figure 5: Potential of AMT in industrial application

Strategically, companies can gain competitive advantages by implementing new manufacturing technologies before their competitors do [22]. Beside the changes due to more complex connections of product and function, customer requirements and customer needs the future value chain will be controlled by the customer. These future state value chains will require stronger alliances between companies and their stakeholders, a new perspective for production technical and logistic influential factors and a strategic approach which are enabling new areas of activity and business models for AMT [23–25].

5. SYSTEMATIC APPROACH FOR THE IDENTIFICATION OF NEW INDUSTRIAL APPLICATION FIELDS

In most instances, the applicability of AMT is checked by confronting conventional and additive manufacturing based on material and quality characteristics. Often, the common advantages of AMT are not taken under consideration with the effect, that AMT is not able to compete.

Therefore, in the Austrian lead project "AddManu", funded by the Austrian Funding Agency FFG, two different approaches to identify new industrial application fields were developed (see Figure 6).

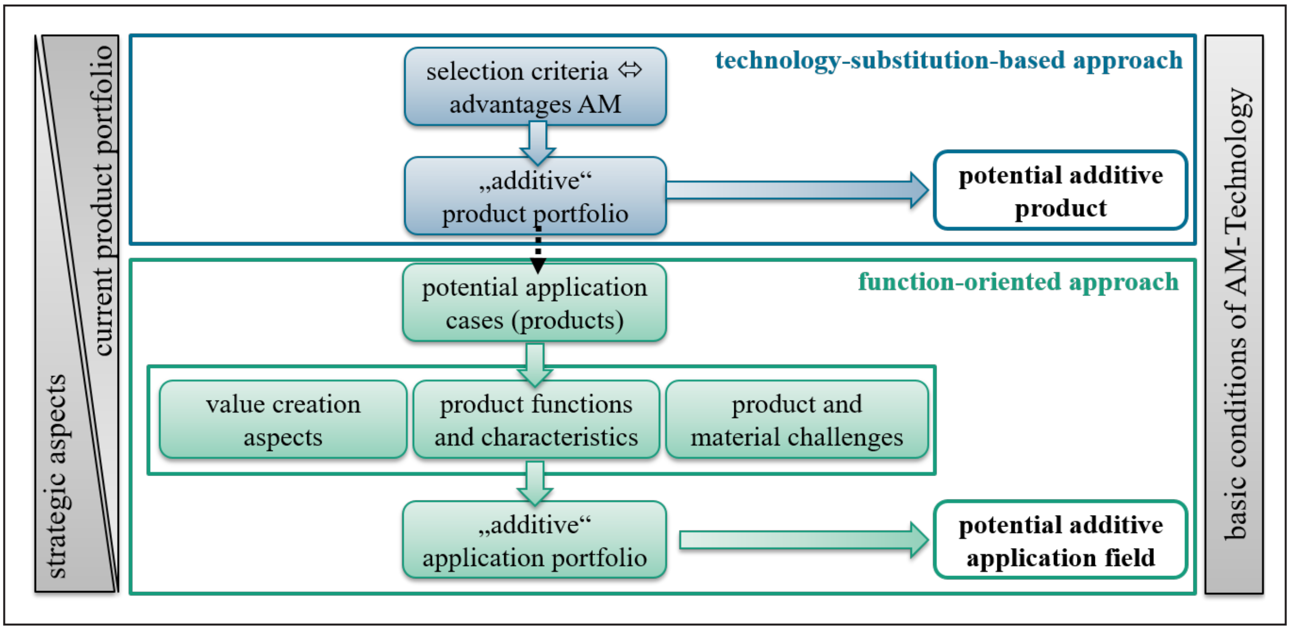

Figure 6: Overview systematic approach for identification of potential additive application fields

5.1. Technology-substitution-based approach

The first approach attempt to identify a potential "additive product portfolio" based on the current portfolio matching with defined criteria with respect to the classic advantages of AMT, technology restrictions and general requirements. This approach is called the technology-substitution-based approach, because of the selection based only on product and technology specific advantages of AMT aligned to the basic mechanical properties and challenges of each product in the product-portfolio. The big advantage of this approach is the missing of complex dependencies in the entire value creation system. The result is a potential additive product portfolio with an analysis about product and technology based potentials regarding implementation AMT. The identified products can also be seen as a solid starting point and input source for the second approach as follows.

5.2. Function-oriented approach

The more complex approach is the so called function-oriented approach where, in addition to the product specific aspects, production, logistic aspects as well as needs of the main and side functions in regard to the technology are taken into scope.

Potential application fields can be identified by abstraction of product- or production functions or analysis of challenges regarding actual products, materials, production-, logistics- of further supporting processes. These identified facts, matched to basic conditions and the actual TRL of the considered AM-technology offer not only a new "additive product portfolio", but also a potential "additive application portfolio" regarding potential over the entire value creation system.

A further aspect of the function-oriented approach is the consideration of the future strategic orientation of the company. This aspect contains the company's potentials and competences regarding to the broad potentials in industrial application of AMT.

6. CONCLUSION

AMT becomes more and more relevant as manufacturing technologies in industrial environment (small series or series production of products for end-users, production of tools and shapes). In general, to substitute conventional manufacturing technologies is neither effective nor efficient. Moreover, factories of the future which rely on Additive Manufacturing Technologies shall be enabled to switch from manufacturing-oriented design towards design-oriented manufacturing. This will partially cause radical effects to the whole value creation system and requires a holistic view beyond product development.

The application of AMT has essential advantages regarding product design, such as structures or geometries which are complex, light, topologically optimized or material efficiently designed. Additionally, AMT, as partially disruptive manufacturing technologies, will change value added chains, enterprise structures, business models and whole (logistic-) processes in the worldwide economic. Dynamic customer requirements (client-driven supply chains) are becoming increasingly important, needing a changed view to production and logistics and a strategic approach.

To fully utilize available potential of AMT, a comprehensive view of the impact compared to conventional manufacturing technologies is unavoidable. Currently, these impacts could only be handled with great efforts, due to the complex interdependency.

Due to these facts, the actual research in this field shows the necessity of systematic approaches to handle this complexity regarding the identification of AMT application fields in the industrial environment and further on for a comprehensive implementation of these future-oriented innovation manufacturing technologies.

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