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Analysis of Requirements, Potentials and Risks Caused by Using Additive Manufacturing

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Abstract

Nowadays many companies are thinking about using additive manufacturing in their production processes. Mostly a substitution of an existing subtractive production process is what comes to their mind at first. To give companies a clearer idea of the benefits by using additive manufacturing the presented approach results in portfolios, visualizing the impacts and therefore help companies in the orientation phase. On top of that, correlations between corresponding requirements, potentials and risks are shown, by means of dependencies. To structure requirements, potentials and risks the MITO model is adopted and presented. This approach to holistic process-oriented organizational development and output-oriented corporate management divides processes into the four sub-segments "Management, Input, Transformation and Output". Lastly an overview of currently available standards and guidelines is given, because the absence of appropriate documents is often an obstacle to use additive manufacturing. The availability of standards and guidelines differs strikingly from one industry sector to another. Therefore, the overview is structured in general valid documents and only specifically applicable documents.

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Keywords: Additive manufacturing, Portfolio analysis Introduction

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1. Introduction

1.1. Motivation

In the context of Additive Manufacturing (AM) there is a multitude of scientific publications and different research fields. These mainly deal with questions in the field of technology or process optimization. Holistic considerations of the use in industrial enterprises are only rudimentary so far. In the course of the symposium "Production engineering aspects in the environment of additive manufacturing" professors of the Scientific Society for Production Engineering (WGP) come to the following conclusion, which confirms the indispensable need for action on this topic:

"Only production systems that cover the entire value chain from material delivery and the actual additive process through to post-processing and automatic quality control can help generative technology achieve a lasting breakthrough in series production". [12]

Product-related modifications such as increasing individualization of products, lightweight construction and function integration as well as potentials in the extended product life cycle make the use of additive processes very interesting for companies. The first step is to put companies in a position to assess the effects and their occurrence.

1.2. Current Research

The state of the art in science comprises a selection of studies and approaches that deal with the effects of the use of AM. Most of the studies on the effects of the use of AM deal with potential product modifications (e.g. functional integration, complexity reduction, materials etc.). Furthermore, there are studies that deal with the effects on the environment. There are also studies that examine the effects, e.g., on society and the economy from Huang et al. and Kumke et al. [1,2]. More holistic approaches in the literature are mainly available when considering the effects on the supply chain.

The scientists Mohr and Khan from the Technical University of Denmark deal with the effects on the supply chain through the use of AM [3]. The scientists identify seven core areas that are strongly influenced by the use of AM:
mass Customization, resource efficiency, decentralization of production, complexity reduction, rationalization of stock and warehousing, product design and prototype construction and legal and security issues.

Mashhadi et al. [4] divide the design of the supply chain into five levels: product design, device setup, design of the production line, plant design and the last level referring to the design of the supply chain itself.

Kellens et al. show in their paper "Environmental Impact of Additive Manufacturing Processes: Does AM contribute to a more sustainable way of part manufacturing?" [5], the economic impacts of various AM technologies (LS, LBM, EBM, FLM, SL). The researchers draw the following conclusion: Most approaches to the analysis of environmental impacts by AM focus on energy consumption. Data on resource consumption and direct and indirect process emissions are usually not available. There is a lack of documentation regarding the environmental impacts of AM production processes. The researchers stated that the specific energy values documented for AM processes are one to two orders of magnitude higher than for conventional production processes. The higher environmental impact during the additive manufacturing process can be compensated by functional improvements during use (e.g. weight reduction in the aerospace industry).

A concrete calculation on the sustainability of AM was carried out by scientists from the Institute for Product Development and Equipment Engineering (IPeG) at the University of Hanover [6]. For this purpose, the manufacturing process of a demonstrator component, a reflector from the automotive industry, was investigated using two different manufacturing processes. Cost efficiency was also included in this analysis, as each use of energy causes monetary expenses.

Moreover, there are approaches for introducing AM in a company. For example the company KPMG supports companies in identifying "levers" and thus successfully implementing AM in the company. In order to effectively implement AM, KPMG offers a three-step procedure [7]. The Fraunhofer IGCV offers a method box that supports companies in the evaluation and implementation of AM [8]. This is based on experience gained from industrial projects in various industries. The roadmap developed for implementation is based on three main steps: methodical analysis (finding potentials), innovative business models (assessment of potentials) and implementation of AM (exploitation of potentials).

The AMLab with its partners Fraunhofer IGCV and the Institute for Machine Tools and Industrial Management of the Technical University of Munich (IWB) deals comprehensively with AM. One of the services offered is the potential analysis [9]. The first step is to pre-select components from the company's product portfolio. For this purpose, individual key figures such as component complexity or cost structure are analysed. This is followed by an exact analysis of the preselected components. In the third step, a comparison of the existing conventional with the new additive production chain is made on the basis of technological criteria (e.g. mass reduction of components, increase in component performance, etc.) and economic aspects (costs, time, etc.).

2. Analysis of requirements, potentials and risks caused by using AM

2.1. Basis of the analysis

In order to determine the requirements, potentials and risks of the integration of AM, it is first necessary to gain an overview of the conventional product life cycle and the environment of a company. In order not to go beyond the scope of this paper, this is only done by using an overview diagram. There is no claim to completeness, as only the most important phases are illustrated. Figure 1 schematically shows the conventional product lifecycle embedded in the environment of the company.

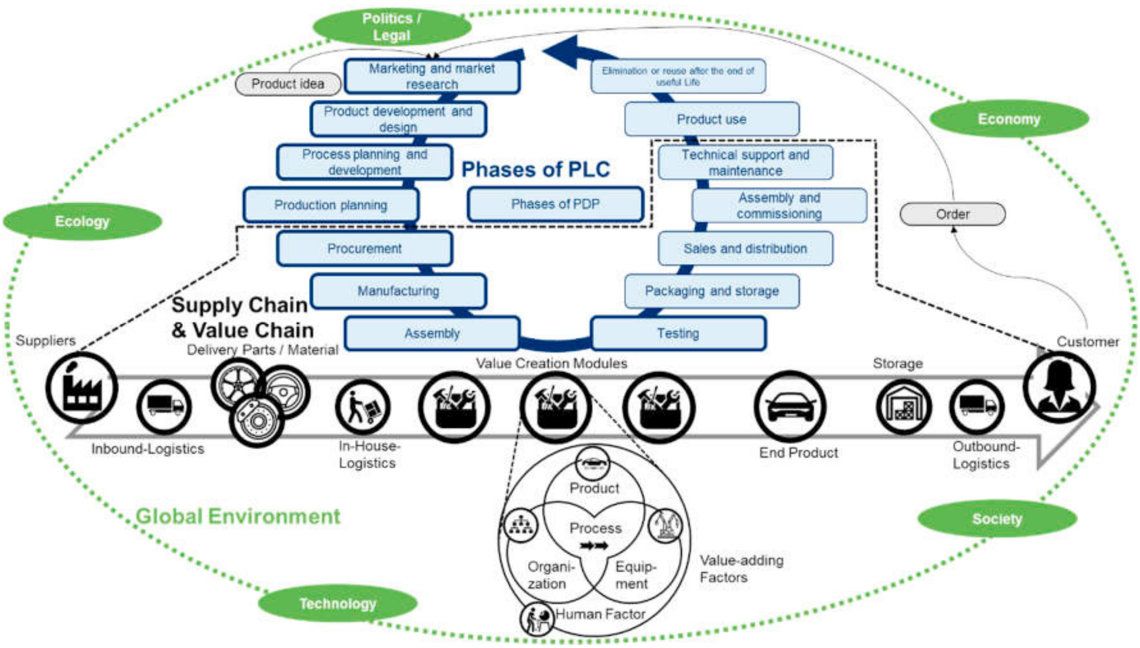


Fig. 1. Process landscape of companies (depiction based on [10,11]

2.2. Approach for structuring requirements, potentials and risks

The "MITO" model is used for the holistic analysis and structuring. This theoretical approach to holistic process-oriented organizational development and output-oriented corporate management is divided into the four sub-segments "Management, Input, Transformation and Output" in order to structure and classify business processes [13].

The approach of a company with the help of the MITO model makes it possible to depict a company with its different sub-segments, relationships to partners and its environment in a simplified but nevertheless holistic way [13]. Figure 2 shows the MITO model with clusters relevant for the use of AM for each of the four segments. In the following, these clusters are used to structure the effects to be identified. The MITO model was extended to include the product segment, as this plays a central role with regard to AM.

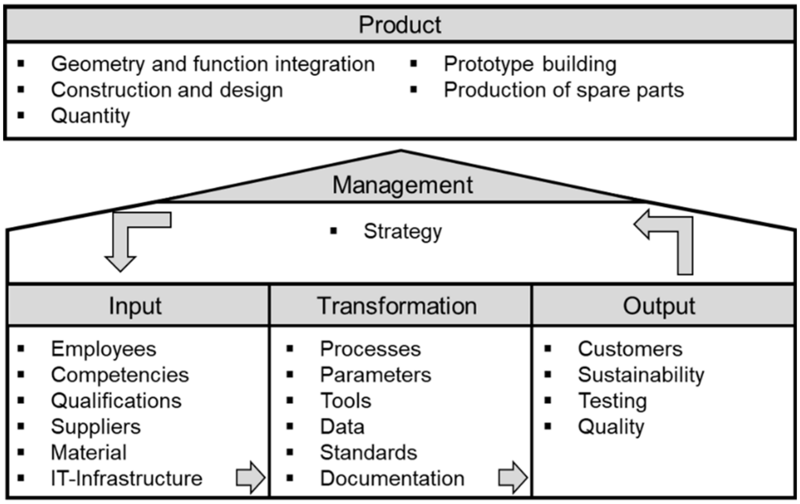


Fig. 2. Adopted MITO model based on [13]

2.3. Identification of requirements, potentials and risks

The identified and classified impacts are subdivided into requirements, potentials and risks. For this purpose, clear boundaries between requirements, potentials and risks are defined, as requirements and risks are often blurred in the literature. Cause-effect relationships are explicitly examined for potentials. This enables a subdivision into direct and indirect potentials. Direct potentials result from the integration of AM. Indirect potentials describe possibilities that are at least facilitated by the usage of AM. This was done for all segments and prepared as tables. The following table shows an excerpt of the results from the Input segment (the whole table would exceed the scope of this paper).

Input				
Cluster	Requirements	Direct potentials	Indirect potentials	Risks
Compe-tencies 	▪ Manual activities for the preparation and post-processing of models ▪ Use of support services for the technical and artistic design of 3D print objects			▪ Error susceptibility of manual work ▪ Progressive obsolescence of conventional know-how
Quali-fication 	▪ Necessity of the organizational implementation of a certified laser safety officer when using high-power lasers ▪ Use of Internet services via digital design plans, training in the use of design software or provision of unused 3D	▪ Increasing the motivation of employees through additional AM qualificatio n	▪ Advance ment opportunit ies for employee s	▪ Lack or inadequacy of training provision

Suppliers 	▪ Production organization from order entry to delivery of the component ▪ Specification of the cycle by incoming orders ▪ Increasing price pressure in additive series production (customer orients himself on series conditions, e.g. plastic injection molding) ▪ Supply chain only handles "individual parts" No containers or other collective packaging for further assembly, but individual parts	▪ Flexibilisation of logistics ▪ Loss of suppliers (from the point of view of the company)		▪ Loss of customers (from the suppliers' point of view)
IT-infra-structure 	▪ Influencing the customer-supplier relationship and thus the classic organizational structures through Internet-based cross-border communication, e.g. exchange of digital design data via the Internet			▪ IPR ▪ Data Protection ▪ Secure connections

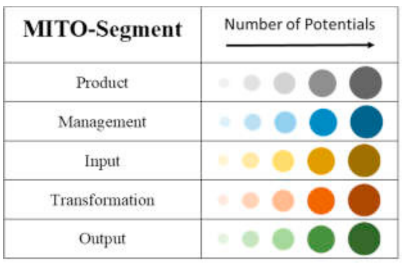
2.4. Assessment of the degree of efficiency

For an initial assessment of the degree of efficiency, the number of identified requirements, potentials and risks per cluster is determined. This should provide a first picture of how many effects occur in which areas. In addition, the effects on the phases of the product lifecycle and the global environment are applied. In the evaluation, no weighting of the identified impacts and their possible dependencies was carried out. This would distort the result due to industry, company and product specific differences. For example, depending on the application, indirect potentials or dependencies can play a greater role than direct potentials. Therefore, the number of dependencies and the indirect potentials are equally important in the evaluation.

In total identified:

- 63 requirements with additional 47 requirement dependencies,
- 48 direct and 31 indirect potentials with an additional 34 potential dependencies, and
- 55 risks with an additional 44 risk dependencies.

The portfolios in figure 3 and 4 visualize the number of identified requirements, potentials and risks. The number of cumulative requirements and requirement dependencies per cluster is plotted on the x-axis. The y-axis describes the cumulative risks and risk dependencies per cluster. The aggregate of direct and indirect potentials and potential dependencies per cluster is represented by the size of the bubble. In the portfolio in Figure 3, the clusters of the product segment are combined to form a product in order to generate uniform granularity. In addition, as already indicated, this segment is very important with respect to AM. In addition, the clusters within a MITO segment were sorted according to the color saturation at the left side (no different colors are shown in figures 4 and 5).



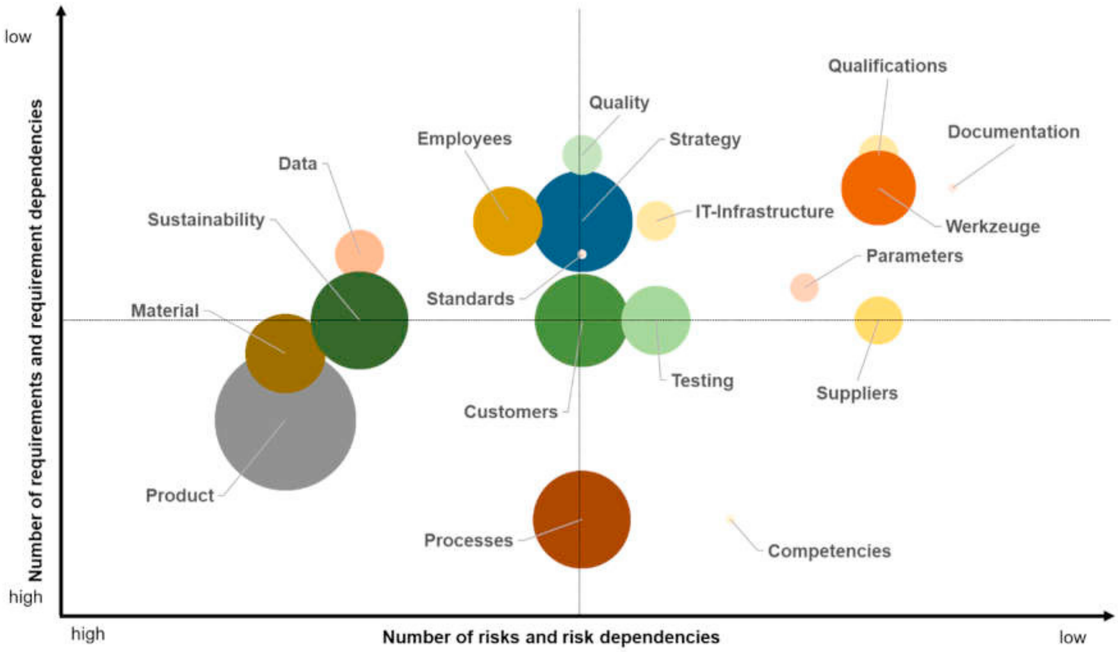


Fig. 3. Portfolio for identified changes with regard to the MITO clusters

Relatively far in the upper right field (few risks or risk dependencies and few requirements or requirement dependencies) of the portfolio in figure 3 are the clusters of qualifications, documentation and tools. Tools have the most potential or potential dependencies. In the lower left field (many risks or risk dependencies and many requirements or requirement dependencies) are the Material and Product clusters. As mentioned above, a product is the entire segment consisting of several clusters. This has the most potential dependencies in this portfolio, followed by strategy.

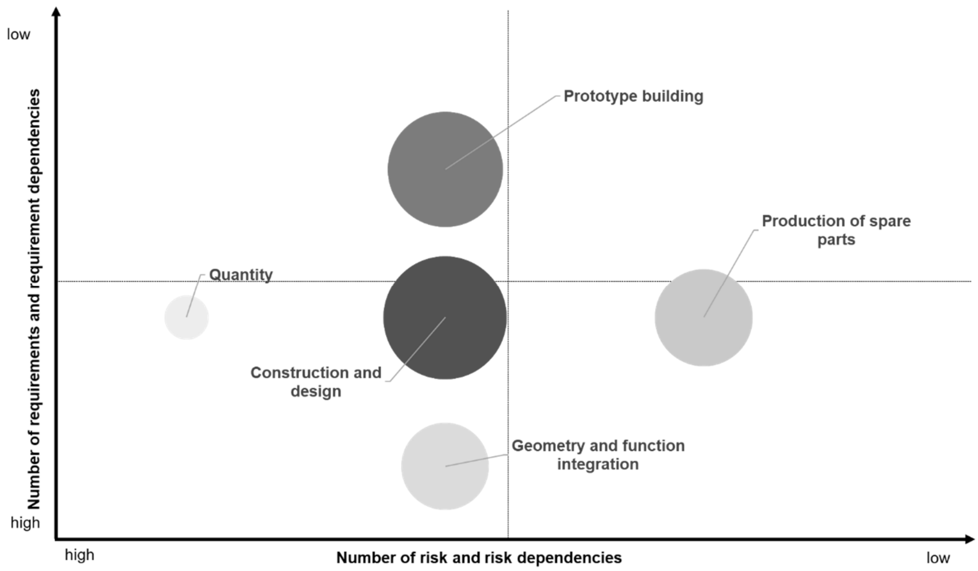


Fig. 4. Portfolio for the cluster product

There is no cluster in the upper right field in the broken-down portfolio of the product segment. All clusters therefore have relatively many requirements and risks. In this portfolio, the number of potentials and potential dependencies is the most important factor in construction and design. The number of units goes hand in hand with the fewest potentials or potential dependencies.

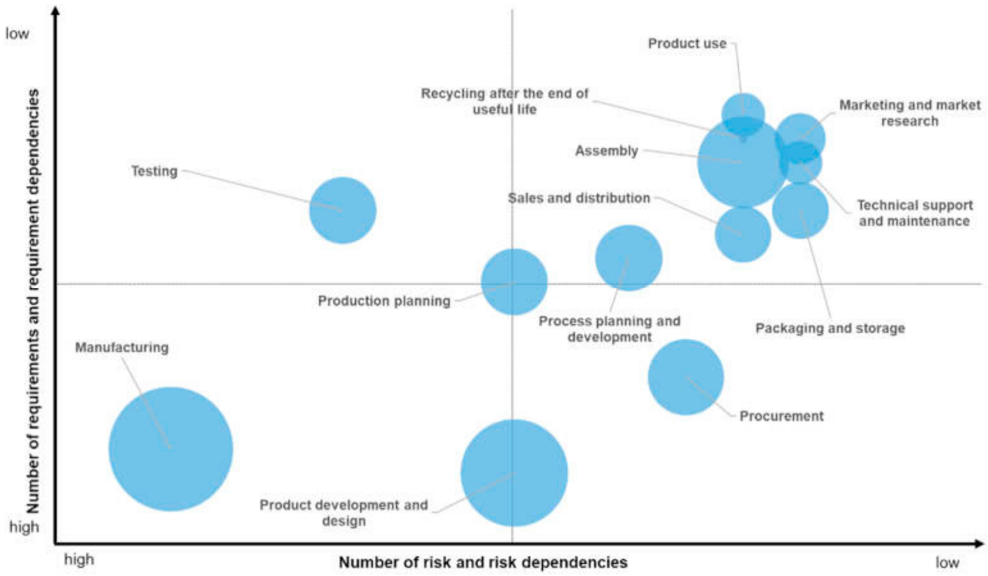


Fig. 5. Portfolio of the dependencies in the lifecycle phases

The upper right field of the portfolio in Figure 5 contains many phases in relation to each other. In this field, the assembly has the most potentials or potential dependencies. In the portfolio as a whole, the number of potentials or potential dependencies of recycling at the end of the useful life is the lowest, that of production the highest. Production is located in the lower left field.

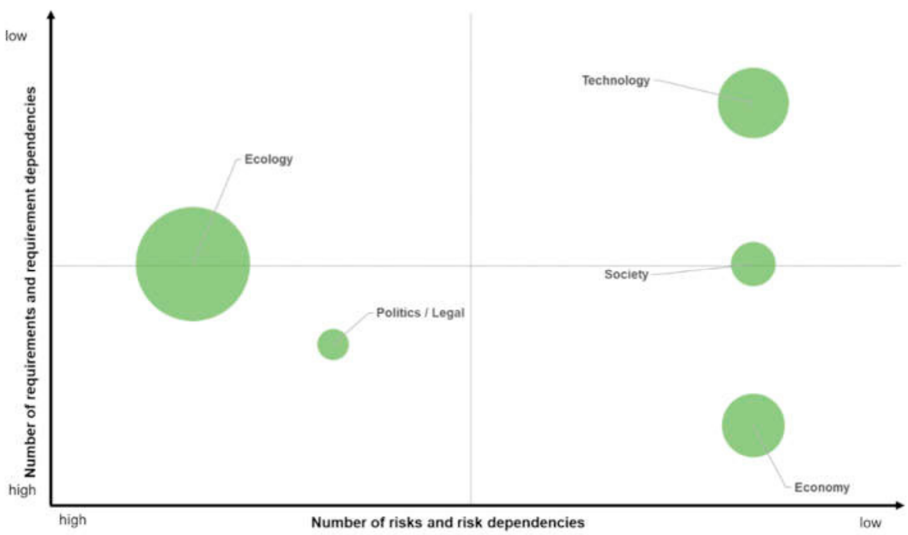


Fig. 6. Portfolio of the dependencies regarding the company surrounding

The Technology cluster is free-standing in the upper right field with a relatively high number of potentials and potential dependencies. In this portfolio, ecology has the most potentials and potential dependencies. Politics / law goes hand in hand with relatively few potentials or potential dependencies.

3. Overview of specifications and normative regulations

As shown in figure 3, potentials in the area of standards for additive manufacturing are almost non-existent, this is explained by the fact that AM is a relatively new technology compared to conventional manufacturing methods like turning or milling. This lack of regulations also implies a couple of risks, this why an overview of currently available documents is presented in this paper.

When analyzing the different normative regulations and guidelines it is striking that more than one fifth of them is applicable for the aerospace sector while the others address a general point of view. This can be explained by the fact that the aerospace sector is one of the industrial sectors where the potentials of e.g. weight reduction or function integration, as well as the production of spare parts through additive manufacturing come to bear most strongly, which makes it very attractive for the aerospace sector to engage in additive manufacturing. This engagement in return calls for normative regulations so that additive processes and standards are comparable. Another noticeable thing is the fact that powder bed fusion of metal is the most mentioned manufacturing process, probably because it is at this time the most advanced additive manufacturing process generating solid metal parts whose strength properties come closest to those of conventional manufactured metal parts. The following table shows an overview of the norms and regulations, documents that are available but in draft status are not listed.

Name	Branch	Topic	Technique
DIN 35224: Welding for aerospace applications – Acceptance inspection of powder bed based laser beam machines for AM	Aerospace	Machines	PBF – Metal
DIN 35225: Welding for aerospace applications – Qualification testing of operators for powder bed laser beam machines for AM	Aerospace	Operators	PBF – Metal
DIN 65122: Aerospace series – Powder for additive manufacturing with powder bed process – Technical delivery specification	Aerospace	Material	PBF – Metal
DIN 65123: Aerospace series – Methods for inspection of metallic components, produced with additive powderbed fusion processes	Aerospace	Post process, Inspection	not clear
DIN 65124: Aerospace series – Technical specifications for additive manufacturing of metallic materials with the powder bed process	Aerospace	Material	PBF – Metal
DIN EN ISO 17296-2: Additive manufacturing – General principles – Part 2: Overview of process categories and feedstock	General	Process, Material	-
DIN EN ISO 17296-3: Additive manufacturing – General principles – Part 3: Main characteristics and corresponding test methods	General	Postprocess, Inspection	-
DIN EN ISO 17296-4: Additive manufacturing – General principles – Part 4: Overview of data processing	General	Data Handling	-
DIN EN ISO / ASTM 52900: Additive manufacturing – General principles –Terminology	General	Terminology	-
DIN EN ISO / ASTM 52901: Additive Manufacturing – General principles –Requirements for purchased AM parts	General		-
DIN EN ISO / ASTM 52907: Additive manufacturing – Technical specifications on metal powders	General	Material	PBF – Metal
DIN EN ISO / ASTM 52915: Specification for additive manufacturing file format (AMF) Version 1.2	General	Data Handling	-
DIN EN ISO / ASTM 52921: Standard terminology for additive manufacturing – Coordinate systems and test methodologies	General		-
VDI 3405: Additive manufacturing processes, rapid manufacturing -	General	Terminology	-

Basics, definitions, processes			
VDI 3405 Part 1: Additive manufacturing processes, rapid manufacturing - Laser sintering of polymer parts - Quality control	General	Quality	LS – Polymer
VDI 3405 Part 1.1: Additive manufacturing processes - Laser sintering of polymer parts - Qualification of materials	General	Material	LS – Polymer
VDI 3405 Part 2: Additive manufacturing processes, rapid manufacturing - Beam melting of metallic parts - Qualification, quality assurance and post processing	General	Quality	PBF – Metal
VDI 3405 Part 2.1 (including correction): Additive manufacturing processes, rapid manufacturing - Laser beam melting of metallic parts - Material data sheet aluminum alloy AlSi10Mg	General	Material	PBF – Metal
VDI 3405 Part 2.2: AM processes - Laser beam melting of metallic parts - Material data sheet nickel alloy material number 2.4668	General	Material	PBF – Metal
VDI 3405 Part 2.3: Additive manufacturing processes, rapid manufacturing - Beam melting of metallic parts - Characterization of powder feedstock	General	Material	PBF – Metal
VDI 3405 Part 3: Additive manufacturing processes, rapid manufacturing - Design rules for part production using laser sintering and laser beam melting	General	Design	PBF – Metal
VDI 3405 Part 3.5: Additive manufacturing processes, rapid manufacturing - Design rules for part production using electron beam melting	General	Design	PBF – Metal

4. Conclusion

The analysis of the impacts of AM on the product lifecycle coincides with some suspected correlations, but also holds some surprises. As expected, the "coarsest" cluster “product” has the greatest changes and risks, but also the greatest potential. Prototype construction, where AM is most likely to be used so far, offers many potentials, modern risk and a low degree of change. The three main advantages of AM - temporal, production-specific and constructive flexibility - are clearly reflected in the size of the clusters "Construction and Design", "Geometry and Function Integration" and "Production of Spare Parts". However, "construction and design" as well as "geometry and function integration" in particular are associated with increased requirements and risks. It is also not really surprising that a decline from machining specific tools to a centralistic tool for all applications is associated with few risks and comparatively low requirements and brings moderate advantages.

In particular, the evaluation of the identified impacts requires further research. In this work, no weighting of the individual impacts was undertaken, as this would be too sector-, company- and product-dependent. For this purpose, evaluation methods must be developed in follow-up work.

References

[1] Huang, S. H.; Liu, P.; Mokasdar, A.; Hou, L.: Additive manufacturing and its societal impact: a literature review. In: The International Journal of Advanced Manufacturing Technology 67 (2013), Nr. 170, London: Springer-Verlag 2012, S. 1191–1203.

[2] Kumke, M.; Watschke, H.; Hartogh, P.; Bavendiek, A.; Vietor, T: Methods and tools for identifying and leveraging additive manufacturing design potentials. In: International Journal on Interactive Design and Manufacturing (IJIDeM) (2018) Nr. 12, S. 481-493.

[3] Mohr, S., & Khan, O.: 3D Printing and Its Disruptive Impacts on Supply Chains of the Future. In: Technology Innovation Management Review 5 (2015), Nr. 11, S. 20–25. http://timreview.ca/article/942.

[4] Mashhadi, A. R.; Esmaeilian, B.; Behdad, S.: Impact of Additive Manufac-turing adoption in future of Supply Chain. Proceedings of the ASME 2015 International Manufacturing Science and Engineering Conference MSEC2015-9392, Charlotte, North Carolina, 8.-12. Juni 2015.

[5] Kellens, K.; Mertens, R.; Paraskevas, D; Dewulf, W.; Duflou, J. R.: Envi-ronmental Impact of Additive Manufacturing Processes: Does AM con-tribute to a more sustainable way of part manufacturing?. The 24th CIRP Conference on Life Cycle Engineering, Kamakura, Japan, 8.-10. März 2017. Amsterdam: Elsevier, 2017. S. 582-587.

[6] Lachmayer, R., Lippert, R. B., Fahlbusch, T.: 3D-Druck beleuchtet, Ber-lin, Heidelberg, Springer Verlag, 2016.
[7] KPMG Wirtschaftprüfungsgesellschaft: Die Potenzial von Additive Manu-facturing effektiv nutzen: Richtig auf Veränderungen und Auswirkungen in Geschäftsmodell, Supply Chain und Recht reagieren. München. 2015.
[8] Illgner, M.; Seidel, C.: Finden Sie die Vorteile für Ihre Unternehmen: Ein-stieg in den 3D-Druck In: MM Maschinenmarkt Vogel: Das Industrieportal. Additive Fertigung (2017). https://www.maschinenmarkt.vogel.de/finden-sie-die-vorteile-fuer-ihr-unternehmen-a-616322/.
[9] AMLab: Homepage. © 2019, http://www.amlab.de/, date of the information collection: 2019-03-10
[10] *VDI-Richtlinie 2247: Qualitätsmanagement in der Produktentwicklung. Berlin: Beuth, 1994*
[11] Stock, T.; Seliger, G.: Opportunities of Sustainable Manufacturing in In-dustry 4.0. 13th Global Conference on Sustainable Manufacturing - De-coupling Growth from Resource Use, Ho Chi Minh City / Binh Duong, Vi-etnam, 16.-18. September 2015. Amsterdam: Elsevier, 2015. S. 536-541.
[12] Wissenschaftliche Gesellschaft für Produktionstechnik (WGP): Homepa-ge. © 2019, https://wgp.de/de/additive-fertigung-auf-dem-weg-zum-produktionssystem, date of the information collection: 2019-03-10
[13] Binner, H.F., Methoden-Baukasten für ganzheitliches Prozessmanagement, Wiesbaden, Springer Gabler-Verlag, 2016. S. 9-10