Identifying Business Potentials of Additive Manufacturing as Part of Digital Value Creation in SMEs – An Explorative Case Study

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Abstract

Additive Manufacturing allows the production of parts based on layer by layer, three-dimensional printing. With a unique set of characteristics, Additive Manufacturing is an important technology regarding the digital transformation and digital value creation of the manufacturing domain. Particularly small and medium sized enterprises are challenged by digital transformation processes and decisions on where to invest their limited resources. This paper identifies business potentials of Additive Manufacturing based on a recent case study conducted during collaborative workshops with five small and medium sized enterprises. Considering the special capabilities of Additive Manufacturing technology, business potentials are examined alongside the entire product lifecycle. It was found that these potentials appear primarily on a digital level and are therefore not limited to the physical domain. The potentials may channel enterprise transformation and enable the purposive generation of digital value.

1. Introduction

Additive Manufacturing (AM) brings great change to the manufacturing sector. The US hearing-aid industry is one example which shows how AM can revolutionize an entire industry. Within a period of 500 days, all manufactures of hearing-aids in the US either manufactured with AM or went out of business [3]. AM is a collective term for a variance of industrial 3D-printing technologies. These technologies are based on an additive layer by layer manufacturing of parts, rather than subtractive like conventional manufacturing technologies [6]. With characteristics like freedom of design which enables light-weight products or an integration of functionality, AM offers benefits not only for the manufacturing sector [10]. With estimated yearly growth rates between 10-30% AM is an emerging technology [2, 20, 26]. Within the digital transformation and digital value creation of the manufacturing sector, discussed under terms like Industry 4.0 or Industrial Internet AM is seen as an game changing technology [24].

Digital transformation is particularly challenging for small and medium sized enterprises (SMEs). Lacking resources, know-how and well trained employees SMEs really have to be sure where to put their focus [23]. Seen from an economic viewpoint SMEs have a huge impact for Germany. SMEs employ about 17million workers which is around 60% of the total German workforce [5]. Throughout this paper, we want to address SMEs' needs to locate their resources for future business potential in the context of AM with a focus on digital value creation. Thus we will propose an answer for the following question: *How can small and medium enterprises create value with Additive Manufacturing?*

Our research provides an overview on the state of the art of Additive Manufacturing and answers the research question based on a case study analysis of five SMEs from South-Western Germany. The case study was part of a project funded by the ministry of economic affairs, labor and housing Baden-Wuerttemberg. In academia our research artefact serves as a base for further research in the field of digital business models and AM, as well as a first approach to structure business potentials for digital manufacturing based on capabilities. For society and our work shows possible steps to realize business potentials and create digital value. This work follows a qualitative, explorative research approach and is located in the field of information systems.

2. Background

The term Additive Manufacturing is used as an umbrella term for different additive technologies which are based on the building up of a part in layers. In that sense AM differs from convention manufacturing technologies like turning or milling which are

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subtractive technologies. The 3D-printing industry is seen as rather new but 3D-printer have existed since the late 1980s where the first systems entered the market [26].

2.1. Additive Manufacturing process

The generic AM process can be explained in five steps, shown in the upper part of Figure 1. Whereas the first phases design, pre-processing and processing are mostly digital and the later processing, post-processing and assembly are mostly seen as physical steps [2]. Following the five AM process phases are explained in detail.

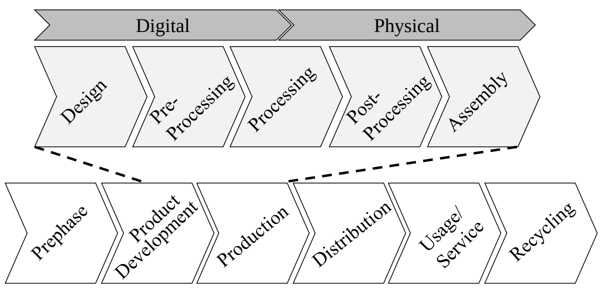

Figure 1: Additive Manufacturing process and product lifecycle adopted from [2, 7, 10, 19]

In the *design* phase a 3D-model of the part to be produced is being created. Usually it is done by a designer with a computer-aided design (CAD) software system. The input for the designer usually comes from parts requirements and the output is usually a description of the parts geometry generally in 3D. As there are almost no manufacturing restrictions in AM the designer has great possibilities to design parts. A shift from traditional design requirements to a creative thinking design is happening [7, 10, 17]. There are also other ways to generate designs for the production of AM parts. CAD-model based on the finite element method can be generated automatically as well as 3D-scanneres where existing parts can be digitalized in a reengineering way. 3D-scanners exist in a broad variance from handheld applications to computed tomography scanners. The quality of the resulting CAD-model depends on the accuracy of the scan.

In the next step, *pre-processing,* the build job is prepared for printing. The CAD-model is checked for the possibility to be printed. It is then digitally sliced into the layers which will be manufactured at a later stage. Often time machine specific software is used. Finally, the part is nested which means that all parts in one building job are being placed and orientated in the building chamber of the 3D-printer [10].

The building up of a part takes place during the *processing* phase. The machine starts generating layer-wise parts. In case of complex structures, depending on the AM technology supporting structures might be needed. After the build job is finished the part and the support structure is removed [10].

The *post-processing* starts with the finished build job. Depending on the required finish the treatments of the part can be very extensive manual labor. For example surface finishing, heat treatment or drilling of threads. For this phase conventional machinery is needed [10].

If the AM part is a component of a more complex product it has to be *assembled*. This phase might become irrelevant if the entire part is manufactured through AM [10].

To have a holistic view on AM the AM process is seen as part of the product lifecycle shown in Figure 1, The AM process as described in the literature often starts in the product development phase and ends with production. In the course of this paper we reference the whole product lifecycle. The prephase is the ideation phase, not more than an idea in the head of the people. In the product development the part to be produced is designed and specified, followed by the production phase where the part is manufactured. After the production the part is distributed via a logistic chain and put to use. During the usage a service of the product might come in place. At the end of the product lifecycle the product is recycled [19].

2.2. Additive Manufacturing characteristics

The underlying layer base technology of AM has a set of special characteristics [6].

- The basis of every AM produced part is a digital product model usually a 3D-CAD-model.
- No tool changing in the printing process is necessary
- The properties of the part are generated while the building process.
- Through the layer by layer manufacturing of parts there is a freedom of design, however some designs need support structures.
- The standard triangulation language (STL) and the additive manufacturing file format are commonly used data formats which eliminate most date exchange problems.

2.3. Additive Manufacturing technologies

There are a multitude of different AM technologies and machines with a still ongoing development for new once. As an overview three of the most often used technology-families are specified below [6].

Polymerization: The process of hardening of a liquid through a light, laser or heat source known as Laser Stereolithography or Polymer Printing/Jetting. *Sintering/Melting*: The process of sintering/melting powder based materials. Common technologies are Selective Laser Sintering, Selective Laser Melting (SLM), Selective Mask Sintering and Electron Beam Melting. *Extrusion Fused Layer Modeling*: The process of extruding a heated thermoplastic material, commonly known as Fused Deposition Modeling.

The variety of technologies enable a multitude of different materials which can be processed. The most common materials are polymers, metals and ceramics and its derivatives. For more details on the technologies and materials see [6, 7].

2.4. Additive Manufacturing in the field

AM applications can be found in different domains. Through the distinct features of AM it is primarily used for manufacturing individual parts, small batches of parts as well as parts with special requirements. These requirements can be light weight construction, a complex design or customized parts [1]. Figure 2 and Figure 3 show in an adapted and simplified illustration where AM can be used in a value adding way. Either for a small number of pieces where the costs per piece are cheaper than conventional manufacturing technologies, or for complex products where AM has close to no additional costs for more complex parts.

AM comes to use in the industrial sector in the form of rapid prototyping which is the ability to create physical prototypes in short period of time, as rapid tooling, the ability to create tools like casting molds with AM and as direct manufacturing the ability to produce final parts directly through AM [2]. A specific domain where the use of AM is particularly evident is aerospace. In this field, AM benefits from the freedom of design especially the ability to design light weight products, which engineers are often seeking in aerospace [2]. Another domain would be medicine. In the medical field the benefit of AM is especially the ability to create individualized products. For example, for dental purposes or hearing aid technology where products have to respond to the specific needs and circumstances of the patients [2, 3].

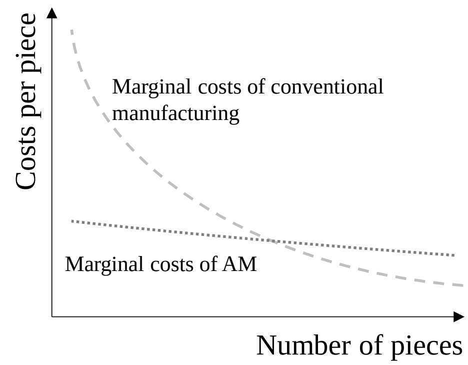

Figure 2: Marginal costs [22]

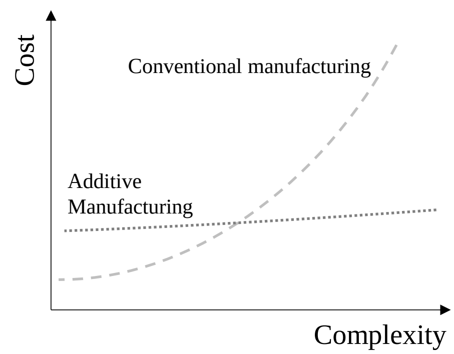

Figure 3: Cost over complexity [18]

2.5. Additive Manufacturing added value

As for AM added value and value potentials in companies there is some existing research. Kritzinger et al. describes in their research key potentials and key challenges from the perspective of the product, the technology, the process and the value chain which are amongst others limitations on materials and a short delivery time [11]. Hämämläinen and Ojala analyze value potential in groups and business networks and state that AM value in the context of business networks occur primarily in the relations to the customers, suppliers and employees [8]. Zanetti et al. present a framework for possible added value were they distinguish between product and solution as a output type, customer-oriented and community-oriented as the target, between assemble and make to order or engineer to order and lastly between a focal company or a p2p constellation regarding the network configuration [28]. Further research on AM, added value and value opportunities are presented amongst others by [12, 21, 25].

3. Research design and case study

This paper follows a design-oriented, qualitative approach in the field of information systems research [16]. This approach follows a four-step process from analysis, to design, to evaluation and lastly to diffusion [16]. In this paper the analysis has been provided in chapter one and two. Step two, the design, will be the focus of the following chapter in form of a case study analysis. The evaluation was excluded from this paper and presents room for further research. The diffusion starts with this research paper. A qualitative approach allows actors to articulate their perceptions of knowledge in the past and to evaluate the elements that influence their development for the future [14]. To answer the research question of our paper the qualitative research case study method was chosen. A case study is defined as: "… an empirical enquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident" [27]. A case study is suitable to answer 'how' or 'why' questions. Because of the research question and the contemporary phenomenon a single case study following the approach of Yin was chosen [27]. The aim of the case study was to identify business potentials enabled by AM in SMEs based on selected real-life parts. We see business potentials as a chance for SMEs to create future value. The case study was organized according to the following steps:

1. Partner selection
2. Get to know the enterprises
3. Part selection
4. Production of the selected parts
5. Identification of AM business potentials

To develop and discuss the intermediate results of the case study, three workshops were conducted between July 2018 and October 2018 with the goal to identify business potentials of AM for SMEs. Following Atteslander, the conducted workshops are unstructured group discussions which where protocoled [36]. The workshop participants were chief executive officers (CEOs) of the respective SMEs. Table 1 gives an overview of the participating SMEs and their number of employees. With less than 250 employees all participating enterprises fall under the definition of SMEs [4]. The participating SMEs were selected done by the AM expert who is the project manager prior to the first workshop. With his expertise as a former CEO, a researcher and an AM expert his selection was done based on domains where AM business potentials may have a big impact. One of the two manufacturing SMEs is an expert in plastics and metal 3D-printing, the other one in conventional milling and turning. The two restoring enterprises and the manufacturer of medical instruments have not produced or assembled final AM parts but represent two very relevant domains for AM use, as explained in Section 2.4.

Table 1. Participating enterprises of the case study

Enterprise domain	Number of employees
Manufacturing enterprise (AM)	6
Manufacturing enterprise (conventional)	< 25
Auto repair shop & restoring enterprise	40
Restoring enterprise	14
Manufacturer of medical instruments	50

It has to be noted that the CEOs of the manufacturing enterprises did not participate in all conducted workshops. In addition to the enterprises the mentioned AM expert and an additional scientific researcher were part of each workshop. Knowledge one AM was provided by the AM expert, the research and the manufacturing enterprise.

The aim of the first workshop was to introduce the participants to the basic principles of AM and to get to know the enterprises.

In the second workshop further knowledge of AM was transferred and the CEOs presented to be printed parts which they picked out of their real-live projects, between workshop one and two. It was discussed and agreed upon which parts should be pursued further. The time between the second and third workshops was used to digitalize the parts and manufacture first prototypes as well as to get quotations for the manufacturing process.

The third workshop was designed to finalize the decision on which parts would be manufactured on basis of the prototypes and the quotations. Five final parts where chosen from the domains of car spare parts and tools for the production of medical instruments. Possible future digital added value for the SMEs through AM was presented by the AM expert and the researcher. In the conducted workshops, the added value was discussed regarding a viewpoint of every single SME.

Out of the five final parts we chose one part, a door handle from a classic car, for the case study in this research paper. This part is easy to understand and a good representation of what was done in the workshops. The business potentials were identified by the interdisciplinary and collaborative exchange of the participating CEOs and shown on an abstract level.

4. Findings

As described above we focus on one real part from one of the participating enterprises. The chosen part is a door handle of a classic car. Originally this part is made of plastics and is a rare-to-get spare part. The findings are being discussed from the perspective of the auto repair shop & restoring enterprise along the generic product lifecycle phases shown in Figure 1.

The identification of the right spare part of a classic car took place in the *prephase*. Challenged by the large number of different parts of a classic car and the criteria rare-to-get, not safety reliant and printable by size and material the door handle was selected. This decision was supported by the participants of the workshops. The final idea and decision was made by the auto repair shop & restoring enterprise. Taking a closer look back at Figure 2 and Figure 3, the door handle is a low volume number of pieces part and fairly complex.

As the part was already developed, the steps of the *product development* phase differ from the lifecycle of a new product. In this case there was neither an existing 3D-model of the door handle nor technical sketches. One way to get a CAD file of the door handle was to reengineer the existing original part. We did this via a 3D-scanner by an external provider. The part was scanned via x-ray beams in a computed tomography scan. The result is show in Figure 4 a STL file of the door handle of a classic car. Detailed features like threads and small drillings were digital edited. More details are described in the production phase.

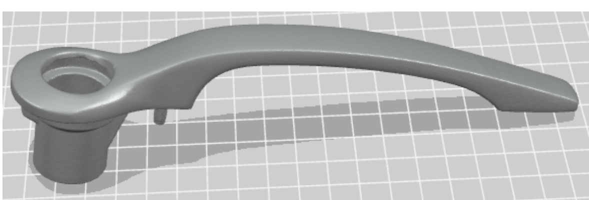

Figure 4. Door handle CAD-model

The part was *produced* with the powder based SLM process. This was done by the AM manufacturing SME of the case study. All the pre-processing steps as well as a great part of the post-processing steps as described in section 2 where done by this manufacturer, not the auto repair shop & restoring enterprise. Beforehand, the CAD-model was digitally edited to the end that a conventional manufacturing step in the pre-processing was possible. Where threads were located, more material was printed so that the threads could later be cut conventionally. The finishing and the paint job of the part was done by the auto repair shop & restoring enterprise, as they were most experienced in that field.

As the door handle was primarily for the auto repair shop & restoring enterprise's own needs and customers no emphasizes was put on the *distribution* phase. However there is a market for spare parts especially rare or very expensive ones.

The digital model of the door handle provides an on-demand printability in a *service* case of the car. No physical stock keeping has to be made, which makes it independent from a location. However the validation of the printed door handle in the usage is still pending.

As the printed part is made of one kind of plastics, *recycling* can be pure grade. For this case study recycling was out of scope.

On an abstract level we have derived several capabilities from the realization of the door handle. As a capability is defined as an ability a business may have to reach their corporate goal [15]. The capabilities where needed to produce the AM door handle like described in the case study but are not limited to the door handle and apply to other parts chosen from the participating enterprises as well. In Table 2, these capabilities are categorized according to the different phases of the product lifecycle. The specific capabilities provide the basis for the abstract business potential of AM. These potentials are being discussed in section 5. The identified capabilities show that although AM is a manufacturing technology it affects the entire product lifecycle not only the production phase is affected. We make no claim to be complete and to have considered the complete allocation of capabilities due to case study's limiting factors as described in section 7.

Table 2. Identified capabilities

Product lifecycle phases	**Identified capabilities**
Prephase	• Know-how about printability (size, material, etc.)
Product development	• Access to 3D-models • Data handling • 3D-model reengineering
Production	• Manufacturing know-how • Material know-how • Digital preparation of the 3D-models
Distribution	• End-user access • Trusted partner
Usage/Service	• Storage of 3D-models • Data handling • Print on demand • 3D-model retailer
Recycling	Not part of the case study

5. Identified Additive Manufacturing business potentials

In this section we address the identified business potentials based on the previously shown capabilities. Although the potentials are derived from the capabilities used to produce the door handle, on an abstract level they are relevant outside the restoring business. The potentials are classified on a physical level regarding the physical part and on a digital level regarding digital services and digital platforms. Table 3 shows the potentials with their related capabilities.

The identification of the business potentials were achieved by bundling the capabilities alongside the product lifecycle and thus reveal possible potentials of future value creation for SMEs. Yet, the distinction between the digital layer and the physical layer which is not always clear as depicted. The allocation was made on the primarily share which lies on one layer. There might be further potentials that have not been considered. The limiting factors will be discussed in more detail in section 7.

Table 3. Additive Manufacturing business potentials

Identified capabilities	Business potential
• Know-how about printability (size, material, etc.)	Part identification
• Access to 3D-models • Data handling	Part scanning
• 3D-model reengineering	Digital editing
• Manufacturing know-how • Material know-how • Digital preparation of the 3D-models	Part printing
• Manufacturing know-how • Material know-how • Digital preparation of the 3D-models • Trusted partner • 3D-model retailer	Digital platform for production
• End-user access • Trusted partner • Storage of 3D-models	Digital platform for distribution
• Storage of 3D-models • Data handling • Print on demand • 3D-model retailer	Digital warehousing

5.1. Business potential on a physical layer

In the prephase the business potential *part identification* was detected. Having the know-how to choose which parts are possible to print and which have the general conditions to be valid is a great asset. For not digitalized parts the know-how is bound to the physical world, knowing all parts and its requirements is necessary. In our case study this potential was mainly tapped by the auto repair shop & restoring enterprise, however AM know-how is mandatory which the enterprise lacked at the beginning of the case study.

Following the product lifecycle, the next identified potential is the *scanning of a part*. This potential occurs mainly in reengineering projects like our case study, particularly in cases where no digital models of a part exist. There are different technologies available to scan an object. This potential primarily concerns external service providers as in our case study. The reason for it being the necessary know-how and the machinery plus periphery.

The third identified potential on the physical layer is the *printing*. Seen as a typical printing service provider this potential can either be tapped by an external service provider or by the auto repair shop & restoring enterprise themselves. Requirements to make use of this potential are printing know-how and machinery as well as the necessary periphery. More scenarios and strategies of how to enter a market as a printing service were described amongst others by Hiller et al. [10] and Mellor et al. [13].

5.2. Business potential on a digital layer

The first identified business potential on the digital layer is the *digital editing* of scanned parts. To achieve a good quality CAD-model the output of the scanning might not be good enough. In the restoring business some parts might be damaged and have to be fixed digitally. Digital editing also comes in place when a post-processing is done by conventional machinery.

The threads of the door handle where digitally edited by thickening the material so the threads could later be cut. The potential is seen for external enterprises because of the needed software know-how which the auto repair shop & restoring enterprise can not offer.

One highly discussed potential in the case study was *digital platforms for production*. Other than the typical service provider for printed parts, platforms stand out by making a quick estimation of production time and costs resulting in an offering within minutes. Price comparisons done in our case study are led by digital platforms. Testing in quality of manufacturing of one digital platform which was done outside of the scope of this case study shows a deficiency. The potential of these digital platforms and the corresponding ecosystems however is seen as great to the extent that SMEs have to decide if they want to build up their own digital platform or become part of an existing ecosystems. The participating SMEs have preferred the latter.

As the door handle as the chosen part for this research paper is primary used by the restoring enterprise the identified potential *digital platform for distribution* was not highlighted throughout the case study but is valid nonetheless. As described in section 4 there is a market for rare spare parts. Having the possibility to distribute the needed spare parts digitally and then printed on demand on site bares a significant potential.

The last identified potential *digital warehousing* is seen in close combination with the digital platform for distribution. Having a digital model of a part and the ability of AM to print on demand and on site the need of conventional warehousing of parts ceases. Figure 5 summarizes the findings with the potential on the respective layer. A comparison to Figure 1 illustrates that although the process is digital the business potentials can be physical as well and vice versa.

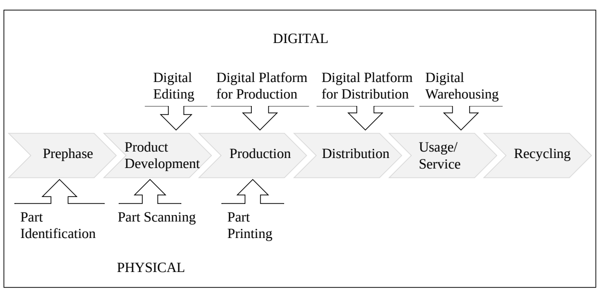

Figure 5. Additive Manufacturing business potential

6. Conclusion

The identified AM business potentials are shown on an abstract level. Some of the potentials are being tapped by the auto repair shop & restoring enterprise, but most of them are provided by other stakeholders. The majority of these stakeholders have not been part of the restoring business value creation so far. Thereby AM offers new opportunities for digital value creation in previously unknown markets. Compared to other research results shown in chapter two, the identified business potentials for SMEs are novel and give a concrete indication for SMEs where they can find future value through AM.

The results of the case study show, that in the future SMEs have to find their place by tapping digital business potentials and make sure to either have the corresponding capabilities or develop them. These findings complement existing research and give a bases for die implementation among others presented by [9, 10]. To make use of these digital potentials digital open platforms are a key enabler. On the basis of digital open platforms, processes can be fragmented. The process fragments can be provided by stakeholders from different domains. That means that the value chain as part of the product lifecycle will be fragmented into a digital value network, as illustrated in Figure 6. In our case study the auto repair shop & restoring enterprise is slowly transforming from a regional restoring enterprise to an international retailer of digital 3D-models of spare parts, or in individual cases even to an international manufacturer of spare parts.

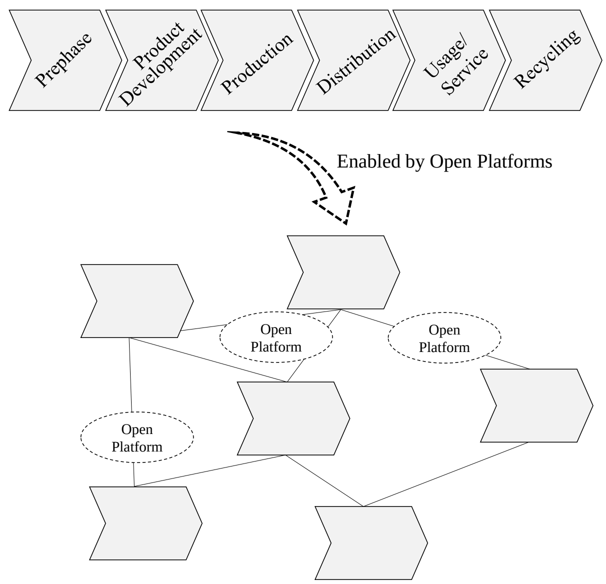

Figure 6. Fragmentation of the product lifecycle to a value network

For this transformation, SMEs need to have a framework of digital added value specifically for AM. This framework works as a guidance for the digital transformation in terms of which strategy concerning digital platforms and networks SMEs should adopt and what other options they have. The AM business potentials that have been identified on the basis of capabilities are a foundation for future research on such a framework. To give a broader perspective, this framework also needs to be based on existing frameworks of the industrial internet of things and should be seen alongside all phases of the product lifecycle.

7. Limitations and outlook

Our research results are based on one case study and one example part. The identified capabilities and the business potential have a strong focus on the business of spare parts for cars. To broaden the scope other domains, as well as the design of new parts have to be considered. Another limiting factor is that the case study only consists of five SMEs which are located in South-Western Germany. To give a more detailed view the number of SMEs has to be increased as well as SMEs from different location and domains have to be considered to ensure a saturation in the data collection.

Due to these limiting factors, we make no claim to be complete in terms of the capabilities and the identified business potentials. As most of the times in case of research on real enterprises, all proposed capabilities and business potentials have to be seen enterprise-specific and have to be adapted where necessary. As proposed, our paper provides a basis for further research. In a next step the derived business potentials should be evaluated in a broader context. We see potential in the development of a holistic approach or a framework to capture added value with Additive Manufacturing and in the provision of examples of concrete design-patterns for the implementation. Especially, the digital component of AM is seen as a great potential calling for further research. The enablement of added value through capabilities and a comprehensive description of AM capabilities has to be examined. Capabilities could on the one hand side be seen as independent of an AM technology and on the other hand as dependent on specific technology-family capabilities. Two further links to for future research activities are seen in the deeper connection of AM and the industrial internet of things as well as the detailed description of the AM value network and the interaction of different stakeholders.

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