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REQUIREMENTS OF INFORMATION SYSTEMS IN PRODUCT DEVELOPMENT AND PRODUCTION REGARDING ADDITIVE MANUFACTURING – A QUANTITATIVE EXPLORATION

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Research

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Abstract

Additive Manufacturing differs in some characteristics from conventional manufacturing techniques. The core of additive techniques is a manufacturing process building up parts layer by layer. Furthermore, it is possible to include functionality into monolithic parts, which are built up within one process without the need of assembly. The research objective of this paper is the identification of requirements that are induced by Additive Manufacturing, for Information Systems in the product development and the production phase. This interdisciplinary research field is less considered by Information Systems researchers yet. Therefore, an explorative quantitative study, based on assumptions, is chosen as an adequate research method to reach that objective. As a result, a conceptual approach for an improved exchange of product data is presented. This concept mainly addresses the request of enterprises to satisfy the information demand in different industrial business processes. The following main requirements could be identified: improvement of Information Systems for customer participation in industrial Additive Manufacturing fields; determination of all product defining data into Additive Manufacturing product development phase; standardized, bidirectional data exchange between production and product development in context of Additive Manufacturing enterprises.

Keywords: Additive Manufacturing; 3D Printing; Information Systems; Requirements; Quantitative; Product Development; Production; Customer Integration; Product Lifecycle.

1 Introduction

Additive Manufacturing (AM) as new technology for the industrial production induces opportunities for industrial enterprises (Beyer, 2014). The main principle of AM is to build up parts layer upon layer. AM used to be a prototyping technique, but this technology generates other fields of application (Gebhardt, 2011, Gibson et al., 2010). While the amount of usable materials increases and the quality of end products improves, the industrial application range extends rapidly (Wohlers Associates, 2015, Gausemeier et al., 2012).

From an Information Systems (IS) research view, AM is perceived as an enabler in terms of mass customization, decentralized production, and new product development principles (Thiesse et al., 2015, Bateman and Cheng, 2006, Hague et al., 2003). Therefore, a high grade in digitalized processes is needed. For instance, in order to (re-)produce a part in an economical way, everywhere with the same part quality, all information for product definition is needed digitally and needs to be accessible. In fact, industrial AM application still has a long way to go, but slowly approximates to this vision (Khajavi et al., 2014). In addition to that, AM could have a disruptive character to some business models (Berman, 2012). In consequence, the development of IS has to face those challenges.

In terms of IS, AM could be seen as an enabler for digitalization of processes (Lasi et al., 2014a). Direct fabrication from 3D CAD models without complexity in production process planning, as mentioned above, leads to a lean seamless digitalized process (Gibson et al., 2010, Hopkinson et al., 2006). Furthermore, the integration of customers into product development and production in combination with AM promises new business values. Thus, AM affects business strategy and will lead to changes in organisation, operation and supply chains (Thiesse et al., 2015, Mellor et al., 2014). In conclusion, IS could contribute to further realize the potentials of AM in enterprises. Currently, there often are technological challenges that are examined, but soon there will be an increasing demand for IS that enables efficiency in AM processes in enterprises, because industrial AM applications increase (Venekamp and Le Fever, 2015). In order to gain a suitable research design to this emerging and fast developing technology, this survey follows an exploratory approach (see section 3).

2 Research Background

The following sections describe the AM background concerning technology and product development processes (section 2.1), as well as related IS research, which leads to the objectives of this research and the research question (section 2.2). Both sections are the foundation for the research framework, which is depicted in Figure 1.

2.1 Additive Manufacturing

AM enables a direct fabrication of complex 3D CAD models without a production process planning in a conventional sense. There are various AM techniques that have been developed during the last decades. The common characteristic of every AM technique is that parts are built up layer by layer. In this publication, only AM techniques are considered that are used in an industrial context. Thus, relevant AM techniques for this use case mainly utilize metal powder or polymers (powder or filament). For example, Fused Deposition Modeling (FDM) is an AM technique which forms parts out of polymer filament. An extrusion nozzle builds up each layer by "printing" polymer in lines. When one layer is completed, the built platform is lowered a layer. This technique is also known from consumer printers like 'MakerBot' (MakerBot Industries, 2015). In contrast, Selective Laser Sintering (SLS) or Selective Laser Melting (SLM) are powder bed fusion processes. The powder is deposited in layers and the powder of each layer is fused together by a laser at the specified areas. Once a layer is completed, a new layer of powder is deposited and the laser starts over again (Gebhardt, 2011, Gibson et al., 2010).

Subsequently, there are manual post-processing tasks, e.g. supporting features or remaining powder have to be removed.

In general, the product development phase starts with a specification that determines product functionality and ends with a definite layout as well as production and operating instructions (Pahl et al., 2007). In AM production, just the geometry of a part is transferred to the production machine, but product functionality still matters (Gibson et al., 2010). For instance, surface quality depends on the orientation of the part in the machine – a diagonal orientation causes a so-called 'staircase effect' on the surface of the part (Wenbin et al., 2005). Relevant operating instructions for AM machines are mainly parameters of production machines, for example, layer thickness, extrusion speed or laser power (Vandenbroucke and Kruth, 2007). Therefore, geometry, functionality, and production parameters of an AM part are considered to be the relevant properties in an AM digital product model.

2.2 Related Information Systems Research

Currently, there are some research activities in the field of IS and AM, although there could not be any hits identified for "Additive Manufacturing" out of the eight Senior Scholars' Basket of Journals, yet (AIS, 2011). A qualitative study identifies value potential of AM of different stakeholders in enterprises (Hämäläinen and Ojala, 2015). They are concluding that IS research has to develop concepts for value creation and value networks in the context of AM. Furthermore, there are research activities in order to discuss IS contributions to product innovation, design and marketplace issues of AM (Wirth et al., 2015, Wirth and Thiesse, 2014). In addition, there are some publications that cover business process aspects, dealing with web service systems for networked manufacturing and price quotation workflows for AM (Wu et al., 2009a, Wu et al., 2009b), and knowledge modelling (Liu and Rosen, 2010).

Prototyping, the origin of AM, is a very technical subject. That is reflected by the higher frequency of publications that focus on information technological aspects and on developing concrete applications: 264 hits can be found for "Additive Manufacturing" on 'IEEE Xplore' by April 2016. Out of these, relevant publications could be divided into applications that address aspects of customer integration in the product design process (Buckner and Love, Zhou et al., 2010), and aspects of production process concerning Computer Aided Manufacturing (Xiaoshu and Xinchen, 2010, Chen et al., 2008, Munguia and Riba, 2008).

According to the IS literature listed above, AM affects product development and customer participation. It should be added that only few IS publications could be identified which are addressing AM, especially the application of AM in manufacturing enterprises. Furthermore, IS literature lacks empirical founded requirements of manufacturing enterprises in our point of view. Hence, the identification of requirements and recommendations for the design of IS is the objective of this paper. Therefore, the following question needs to be answered: How should Information Systems be designed so as to be applied in terms of product development, production, and customer integration of industrial AM products?

In order to answer this question, we chose a quantitative approach based on assumptions. Finally, the revised assumptions are discussed and IS requirements are derived. Therefore, IS in product development and production, especially IS of Product Lifecycle Management (PLM), are affected by this results (Stark, 2015, Sääksvuori and Immonen, 2008). This research focuses on customer participation, product development, and production issues of PLM.

3 Research Design and Methodology

In order to answer to the research question, general requirements for IS in context of AM in enterprises should be determined. According to the research background above, the environment of this conceptual research framework are IS in AM product development and AM production in enterprises. Therefore, it considers roles (e.g. customer, product developer), business processes (product development, production), and technology (e.g. applications in product development and production, communication architecture) (Hevner et al., 2004). Furthermore, the digital product model could be seen as an information artefact, which is a central part in this research framework. Hence, this research is a contribution to the early phases of IS development, while it identifies, and refines requirements of the design object – IS for AM applications – and recommends objectives for solutions (Hevner et al., 2004). Furthermore this is an evaluation step in order to check theoretical assumptions against general business needs of AM enterprises. Figure 1 depicts the specified research framework.

Based on this framework, assumptions for each object and relation of interest are derived. Assumptions are adequate utilities in order to derive system requirements, defining this as an exploratory approach (Nunamaker Jr and Chen, 1990). The assumptions, which are motivated and explained in the following sub-section (see Table 1), are based on discussions with AM experts and literature (see section 2). Therefore, results of five semi-structured interviews with AM experts from enterprises were discussed with three IS researchers in order to conceptualize a quantitative study – some results of the preliminary research are published (Lasi et al., 2014b). When referencing those results in further context, there is a clear denotation as given from “interview experts”. Furthermore, there was experimental previous research in terms of simulation data exchange between product development (CAD) and production, and 3D printer specific software, in order to determine first assumptions.

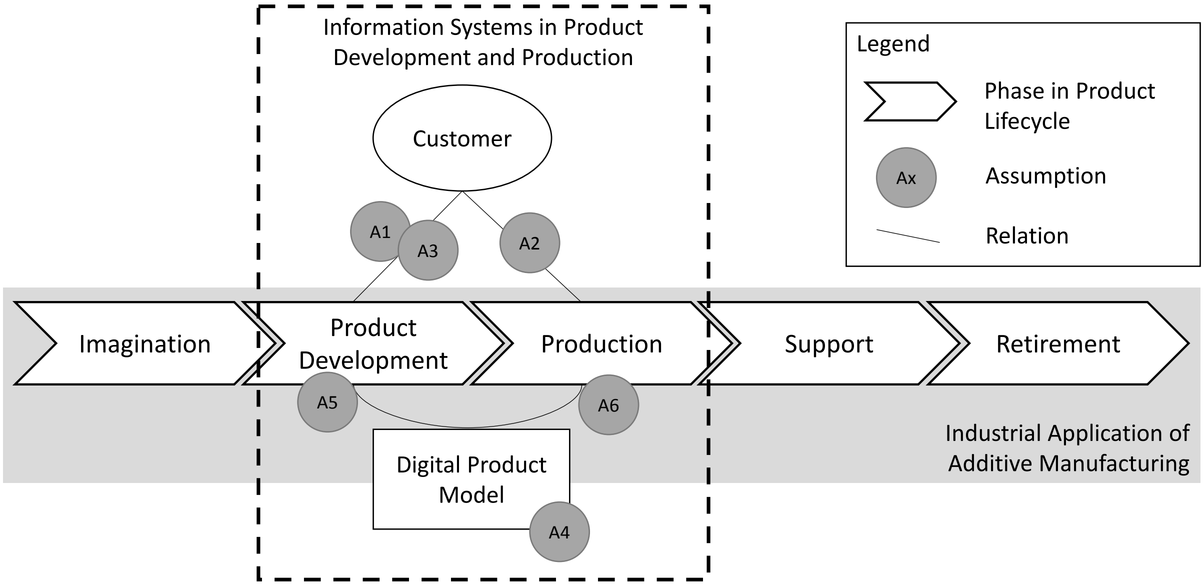

Figure 1. Research framework

The assumptions should be evaluated and advanced by results of this study and deliver requirements for further IS research activities in terms of AM (Venkatesh et al., 2013). This study was realized by an online questionnaire, which is an appropriate tool to contact specific groups of participants (Wright, 2005, Schonlau et al., 2002). The questionnaire was in German and structured as follows: Firstly, the participants had to answer questions about their enterprise (e.g. industry, size) and function (e.g. department, business processes they are involved in). Secondly, there were questions concerning their experience with AM (e.g. used AM techniques, application grade of AM technique). Thirdly, they had to approve/disapprove statements (Likert-Typed, see Table 3, Table 4, and Table 5 for English translations of the original statements).

3.1 Assumptions

The results from preliminary research are six main assumptions, as depicted in Figure 1 and further broken down in Table 1. AM claims to be an enabler in terms of mass customization and digitalization of processes (Thiesse et al., 2015, Tuck and Hague, 2006). Thus, AM is seen as an enabler of allowing customers to participate in product development and production (see A1 and A2 in Table 1). Moreover, AM is seen as an enabler in seamless communication between customer and product developer, mainly in business-to-customer relations (Wirth et al., 2015). However, the interviewed experts drew a picture of a very inhomogeneous process. Mostly, customers (Business-to-Business) separately delivers geometry and textual descriptions to AM service providers. This often leads to manual editing and consultations. In order to proof if this issue could be transferred into a more industrial background the third assumption is derived: *In AM industries there are interfaces to integrate customer design data into product development IS* (A3).

In addition to that, AM is often described as a technique that allows to simply print a CAD model into an end-use part (Gibson et al., 2010, Hague et al., 2003). In contrast, the interviewed experts described AM as a highly complex and know-how dependant manufacturing technology. On top of that, experimental research at our laboratory proves a loss of information regarding existing interfaces between applications of product development and production. A digital product model (Digital Mock Up, DMU) that contains all necessary information would improve the situation. Therefore, the next general assumption claims that *In AM industries production parameters, product functionality, and product geometry must be determined in the product development phase in order to provide a digital product model for an automatic, decentralized production* (A4) (see section 2.1). In order to affirm this assumption, it is divided into two falsified sub-assumptions, which are proved by results of the survey (see Table 1): *A standardized information exchange between product development and manufacturing in AM industries primarily includes geometrical data* (A4-1) and *AM product quality is mainly determined by part geometry* (A4-2). Both sub-assumptions need to be proven faulty in order to apply A4. Furthermore, there are three sub-assumptions (positive) to ensure that product design and functionality are determined in the product development phase and managed together (see A4-3, A4-4 & A4-5 in Table 1).

In favour of instantiating this digital product model with all data, it has to be checked if *All relevant production parameters are determined in the product development phase* (A5). Therefore, the falsified assumption *AM production parameters are determined within the production process* is built (A5-1).

Finally, it would be helpful to make conclusions about the characteristics of bidirectional information exchange between AM product development and AM production. A result of preliminary research is that members of AM production do need insights into part functionality in order to guarantee a certain part quality, e.g. the stability of a hinge depends on its build direction (see section 2.1). Hence, it has to be evaluated whether *involved persons in the manufacturing phase of AM enterprises are able to access relevant information from product development supported by Information Systems* (A6). Therefore, the ability of retrieving construction data in production – as well as product geometry and product functionality data – as a conditional assumption seems to be an adequate indication: *Construction data (product design, product functionality) could be retrieved in the manufacturing process by Information Systems* (A6-1).

According to the interviewed experts and Wirth and Thiesse (2014), knowledge building in design for AM design is a challenge. Therefore, industrial product developers need experience from AM production. In order to evaluate the possibility of information exchange between AM product development and AM production, the following assumption must be evaluated: *Involved persons in the product development phase of AM enterprises are able to access relevant information from manufacturing supported by Information Systems* (A7). Therefore, two conditional assumptions must be tested: First of all, it might be helpful if *Production parameters of produced parts are recorded by IT systems* (A7-1). Secondly, there should be the ability to assign those parameters to parts in product development: *Production parameters could be assigned to parts supported by Information Systems in the phase of product development* (A7-2). Both assumptions have to be seen as indications for information access to AM manufacturing information by AM product development.

	Assumption
A1	**AM enables customers to participate in product development.**
A2	**AM enables customers to participate in production.**
A3	**In AM industries there are interfaces to integrate customer design data into product development IS.**
A4	**In AM industries production parameters, product functionality, and product geometry must be determined in the product development phase in order to provide a digital product model for an automatic production.**
A4-1	A standardized information exchange between product development and manufacturing in AM industries primarily includes geometrical data. *(Falsified!)*
A4-2	AM product quality is mainly determined by part geometry. *(Falsified!)*
A4-3	Product design of AM products is determined within the product development process.
A4-4	Product functionality of AM products is determined within the product development process.
A4-5	Construction data and information of product functionality are managed together.
A5	**All relevant production parameters are determined in the product development phase.**
A5-1	AM production parameters are determined within the production process. *(Falsified!)*
A6	**Involved persons in the manufacturing phase of AM enterprises are able to access relevant information from product development supported by Information Systems.**
A6-1	Construction data (product design, product functionality) could be retrieved in the manufacturing process by Information Systems.
A7	**Involved persons in the product development phase of AM enterprises are able to access relevant information from manufacturing supported by Information Systems.**
A7-1	Production parameters of produced parts are recorded by IT systems.
A7-2	Production parameters could be assigned to parts supported by Information Systems in the phase of product development.

Table 1. Starting assumptions

3.2 Description of the Sample

The study was conducted between October 2014 and April 2015 in German-speaking countries. Furthermore, there is a narrow focus on participants that have experience with AM in industrial applications. In order to reach as many participants of this kind as possible several contact channels were used: First of all, mailing lists, and AM user groups in online business networks were mainly used to recruit participants. In attendance, announcements on specific websites that are dealing with AM topics, and information flyers at business events with AM topics were used. Out of 625 reactions to our contacting, 120 replied to the obligatory question (including 6 partial responses). Therefore, the return rate is 19.2%, which documents a high relevance to this topic. A preliminary overview of the study (other sample of participants, evaluation of few questions on a high level of abstraction) was published in (Moisa and Morar, 2015).

As depicted by Figure 1, more than half of the participants are from Micro, Small, and Medium Enterprises (SME) as defined by the EU (EC, 2003). The top five industries the participants come from are mechanical engineering (32%), services (24%), automotive (21%), plant engineering and construction (12%), and aviation (11%, n=120, multiple choice). Most of them have practical experience with AM technology in at least one AM application area. Regarding to those participants that specified their AM application, 56% (44 of the participants) are using AM technology for producing end-use parts or subparts (see Figure 2). Obviously, SLS and SLM are wide spread for applications in production.

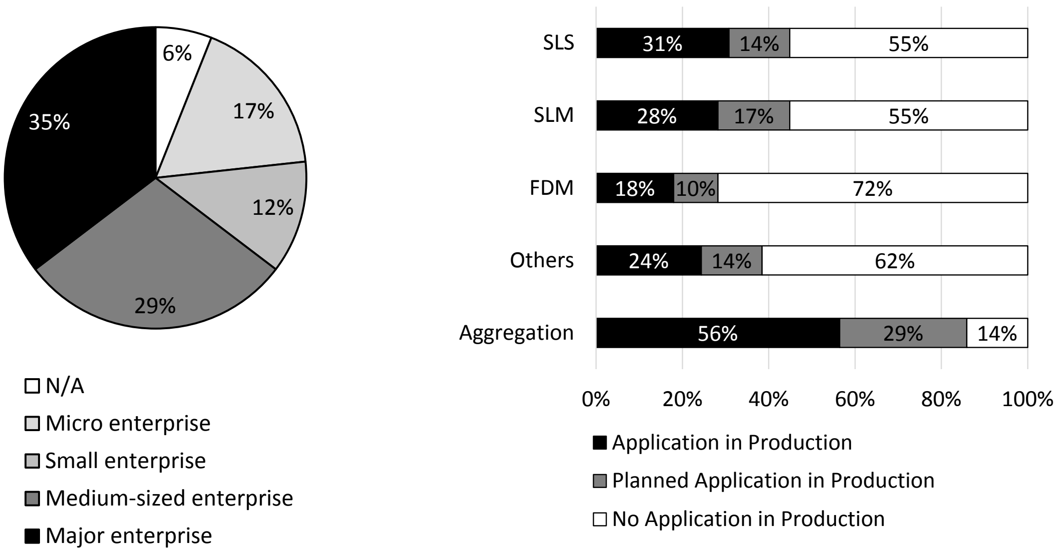

Figure 2. Sample characteristics in enterprise size (left side, n=116) and application of Additive Manufacturing for end-use parts (right side, n=78)

4 Results of Data Analysis

In this section, the results of data analysis are presented. The following analyses are based on statements with Likert-Type answers aggregated into three categories: approve (1), undecided (2), disapprove (3). Therefore, the analyses mainly include frequencies (approve/disapprove), mode, and median. Other analyses like an association test (Kendall Tau c, T_c) and a Chi-Square (X^2) test are conducted. (Boone and Boone, 2012, Clason and Dormody, 1994).

In order to clearly point out results that are in conjunction with AM in an industrial application, as a production technology, data has been segmented (see Table 2). There is a segmentation that differentiates participants that actually are using AM in their enterprises – not necessarily for production. Hence, it could be supposed that they have practical knowledge with AM. In addition to that, there is a segmentation that only includes participants that are producing end-use parts with AM techniques. We assume that practical AM expertise increases over the clusters, especially in terms of issues in production with AM.

Segment	**Description**	**Abbr. (Coding)**	**Size (max) / freq.**
All	Participants from enterprises that have practical or theoretical know-how in AM technologies.	-	n=120 / 100%
AM Application	Participants that confirmed the application of AM for at least one use case (e.g. manufacturing, prototyping, and tooling).	AM-A (1)	n=81 / 67%
	Participants that do not use AM yet.	!AM-A (0)	n=39 / 33%
AM Production	Participants that confirmed the application of AM for manufacturing end-use parts.	AM-P (1)	n=44 / 37%
	Participants that do not use AM for manufacturing.	!AM-P (0)	n=76 / 63%

Table 2. Segmentation of the sample

4.1 Analysis in the Field of Customers

#	Statement (Sample size / segment)		App. (1) / Disapp. (3)	Mode / Median
1	AM enables customers to fulfil product development tasks	n = 28 / AM-P (1)	50% / 39%	1 / 1.5
		n = 49 / !AM-P (0)	29% / 47%	3 / 2
		T_c= -.156, p_{exact}=.189; X^2: 4.222, df. 2, p_{exact}=.148		
2	Constructional changes of product design could be done by the customer.	n=30 / AM-P (1)	63% / 33%	1 / 1
		n=51 /!AM-P (0)	28 % / 60%	3 / 3
		T_c= -.304, p_{exact}=.007; X^2: 10.736, df. 2, p_{exact}=.004		
3	Constructional changes of product functionality could be done by the customer.	n=30 / AM-P (1)	67% / 20%	1 / 1
		n=54 /!AM-P (0)	35 % / 59%	3 / 3
		T_c= -.351, p_{exact}=.001; X^2: 12.088, df. 2, p_{exact}=.002		
4	AM enables customers to fulfil production tasks	n=27 / AM-P (1)	33% / 59%	3 / 3
		n=49 /!AM-P (0)	20 % / 67%	3 / 3
		T_c= -.098, p_{exact}=.374; X^2: 1.727, df. 2, p_{exact}=.417		
5	Product development could integrate product design data from customers by an interface.	n=28 / AM-P (1)	46% / 25%	1 / 2
		n=47 /!AM-P (0)	60% / 32%	1 / 1
		T_c= .058, p_{exact}=.604; X^2: 5.254, df. 2, p_{exact}=.074		

Table 3. Results for customer relations

According to the results 1-3 in Table 3, there is a higher rate of approval in the AM production segment concerning the view that AM enables customers to fulfil product development tasks but it is not significant. Though, there are significant higher approvals in AM producing industries that customers could do constructional changes in product design and functionality. Therefore, we claim the first assumption, *AM enables customers to participate in product development* (A1), as approved. Further, there is a considerable rate of disapproval concerning the statement *AM enables customers to fulfil production tasks* by all experts (see Table 3, #4). Also, there is no significant difference between participants form AM industries and the rest of the sample. Caused by the rates of disapproval assumption A2, has to be revised, as we suggest:

AM does not enable customers to participate in production. (A2)*

Result 5 shows that there is no significant difference in approval between experts with AM production background and the rest of the participants to have the ability of integrating customer's product design by an interface (p_{exact}=.604 for T_c). In fact, there is a lower tendency of approval from AM production experts. In this case, assumption A3 has to be revised. We presume the following revision as adequate:

There is a lack of IS support in customer participation in AM product development. (A3)*

4.2 Analysis Concerning Digital Product Model for AM Products

#	Statement (Sample size / segment)		App. (1) / Disapp. (3)	Mode / Median
1	Only the geometry of a part is transferred to manufacturing in a standardized way.	n = 51 / AM-A (1)	71% / 18%	1 / 1
		n = 25 / !AM-A (0)	44% / 36%	1 / 2
		T_c= -.241, p_{exact}=.032; X^2: 5.090, df. 2, p_{exact}=.101		

2	Only the geometry of a part affects its quality.	n = 57 / AM-A (1)	26% / 54%	3 / 3
		n = 27 / !AM-A (0)	19% / 70%	3 / 3
		T_c= -.134, p_{exact}=.215; X^2: 1.991, df. 2, p_{exact}=.435		
3	Only the production parameters of a part affect its quality. (n = 83)		46% / 45%	1 / 2
4	Only the IT process affects a parts quality. (n = 83)		6% / 77%	3 / 3
5	All production parameters are defined by members of production	n = 50 / AM-A (1)	70% / 16%	1 / 1
		n = 22 / !AM-A (0)	36% / 46%	3 / 2
		T_c= -.315, p_{exact}=.005; X^2: 8.371, df. 2, p_{exact}=.012		
		n = 28 / AM-P (1)	75% / 14%	1 / 1
		n = 44 / !AM-P (0)	50% / 32%	1 / 1.5
		T_c= -.245, p_{exact}=.036; X^2: 4.519, df. 2, p_{exact}=.117		
6	The final design of a product must be released by product development.	n = 31 / AM-P (1)	65% / 26%	1 / 1
		n = 52 / !AM-P (0)	90% / 8%	1 / 1
		T_c=.240, p_{exact}=.005; X^2: 8.441, df. 2, p_{exact}=.014		
7	Constructional changes of product functionality solely could be done by product development.	n = 31 / AM-P (1)	58% / 29%	1 / 1
		n = 52 / !AM-P (0)	71% / 17%	1 / 1
		T_c=.133, p_{exact}=.216; X^2: 1.763, df. 2, p_{exact}=.404		
8	Constructional changes of product design solely could be done by product development.	n = 31 / AM-P (1)	45% / 48%	3 / 2
		n = 52 / !AM-P (0)	72% / 15%	1 / 1
		T_c=.298, p_{exact}=.005; X^2: 10.976, df. 2, p_{exact}=.004		
9	Construction data and information of product functionality are managed together.	n = 28 / AM-P (1)	43% / 25%	1 / 2
		n = 51 / !AM-P (0)	61% / 29%	1 / 1
		T_c= .100, p_{exact}=.377; X^2: 6.284, df. 2, p_{exact}=.048		

Table 4. Results for digital product model

Especially experts of enterprises that are using AM more often approve the statement *Just the geometry of a part is transferred to manufacturing in a standardized way* (see Table 4, #1). In this case there is a significant (p = .032) medium negative association, which means that AM application correlates with approval. According to the experts, a standardized information exchange between product development and manufacturing in AM industries primarily includes geometrical data. Hence, we consider assumption A4-1 as approved. Concerning product quality there is no significant association between quality and part geometry. Rather, production parameters have a higher influence on quality of a part (see Table 4, #2-3). In conclusion to that A4-2 has to be revised.

Experts of enterprises that are using AM for fabrication of end-use parts clearly approve the statement *All production parameters are defined by members of production* compared to those experts that do not have an AM production background (see Table 4, #5). In this case, there is a significant (p=.005/p=.036) medium negative association, which means that AM application correlates with approval. In conclusion to that, A4-3 is approved.

Whereas the final design of an AM product is not necessarily determined in product development. There certainly is an approval rate around 65% in AM industries, but it is significantly lower than in the rest of the sample (see Table 4, #6). Moreover, product development in AM production enterprises are less often solely accountable for construction changes – in terms of product design, there is a high significance (see Table 4, #6-8). Hence, assumptions A4-3 and A4-4 have to be revised. Furthermore, there is neither a remarkable approval nor a significant association which denotes that product geometry data and product functionality information are managed together (see Table 4, #9). In consequence, A4-5 has to be revised.

Finally, caused by the approval of A4-1 and the disapproval of A4-3, A4-4, and A4-5 the assumption *In AM industries production parameters, product functionality and product geometry must be determined in the product development phase in order to provide a digital product model for an automatic production* (A4) has to be revised. We suppose the following revision as adequate:

> *In AM industries production parameters and product functionality mostly are determined in the product development phase in order to provide a digital product model for an automatic production. (A4*)*

According to the last result in Table 4 there is a medium weighted association between approval of the statement that *AM production parameters are determined within the production process* (A5-1) and usage of AM as a production technique for end-use parts. Therefore, the falsified sub-assumption A5-1 has to be approved and, in consequence, the assumption *All relevant production parameters are determined in the product development phase* (A5) must be revised:

> *Relevant production parameters are determined in the production phase. (A5*)*

4.3 Analysis Concerning Information Exchange between Product Development and Production

#	Statement (Sample size / segment)		App. (1) / Disapp. (3)	Mode / Median
1	Construction data could be retrieved in the manufacturing process by Information Systems.	n = 26 / AM-P (1)	73% / 15%	1 / 1
		n = 44 / !AM-P (0)	66% / 23%	1 / 1
		T_c= -.075, p_{exact}=.519; X^2: .563, df. 2, p_{exact}=.863		
2	Information of product design could be retrieved in the manufacturing process by Information Systems.	n = 26 / AM-P (1)	64% / 12%	1 / 1
		n = 46 / !AM-P (0)	61% / 24%	1 / 1
		T_c= -.076, p_{exact}=.509; X^2: 1.931, df. 2, p_{exact}=.417		
3	Information of product functionality could be retrieved in the manufacturing process by Information Systems.	n = 24 / AM-P (1)	63% / 13%	1 / 1
		n = 45 / !AM-P (0)	60% / 20%	1 / 1
		T_c= -.045, p_{exact}=.760; X^2: .702, df. 2, p_{exact}=.776		
4	Product development has access to production parameters.	n = 26 / AM-P (1)	42% / 35%	1 / 2
		n = 45 / !AM-P (0)	53% / 29%	1 / 1
		T_c=.098, p_{exact}=.444; X^2: .815, df. 2, p_{exact}=.682		
5	Production parameters could be assigned to parts supported by Information Systems in the phase of product development.	n = 25 / AM-P (1)	56% / 28%	1 / 1
		n = 46 / !AM-P (0)	52% / 30%	1 / 1
		T_c= -.035, p_{exact}=.784; X^2: .095, df. 2, p_{exact}=1.000		

Table 5. Results for IS in product development and manufacturing

Evaluating the results 1-3 in Table 5, there are high frequencies (73%) in approval that construction data and data of product design could be retrieved in AM manufacturing by Information Systems. Although, there are no significant associations to AM background. In addition, the product functionality information is not accessible at the same frequency. Therefore, we need to carefully deal with this result and revise assumption A6 as follows:

> *Involved persons in the manufacturing phase of AM enterprises often seem to be able to access construction data from product development supported by Information Systems. (A6*)*

The other way around, it seems that members of product development have access to production parameters in lower frequencies (42%), but also without significant associations to AM background (see Table 5 result 4). The results for *Production parameters could be assigned to parts supported by Information Systems in the phase of product development* show some higher rates of approval of AM production experts (56%), but also without significance. These lead to the following revision of A7:

> *Involved persons in the product development phase of AM enterprises partly are able to access production parameters from manufacturing supported by Information Systems. (A7*)*

	Revised assumptions
A1*	AM enables customers to participate in product development.
A2*	AM does not enable customers to participate in production.
A3*	There is a lack of IS support in customer participation in AM product development.
A4*	In AM industries production parameters and product functionality mostly are determined in the product development phase in order to provide a digital product model for an automatic production.
A5*	Relevant production parameters are determined in the production phase.
A6*	Involved persons in the manufacturing phase of AM enterprises often seem to be able to access construction data from product development supported by Information Systems.
A7*	Involved persons in the product development phase of AM enterprises partly are able to access production parameters from manufacturing supported by Information Systems.

Table 6. Revised assumptions

At least, some restrictions have to be noticed in terms of interpretation or transfer of this results. This sample is biased in various ways: Firstly, the participants are from German-speaking industrial enterprises that are using or planning to use AM and most of the enterprises are SMEs. Secondly, the main part of the participants has a background of pre-production and production. Third, the number of participants is comfortable but not very high. Therefore, there might be unknown specific characteristics of this sample that might influence the results of this study. This leads to some grade of uncertainty concerning the results.

5 Interpretation and Discussion of the Results

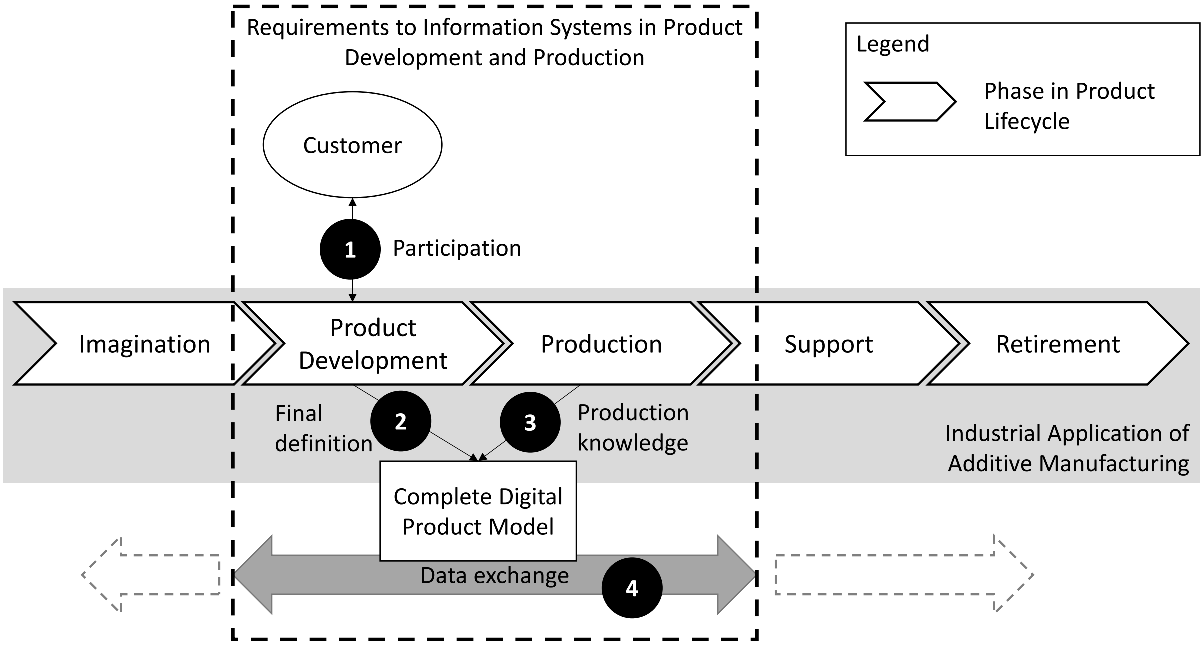

Figure 3. Visualization of the requirements

In this section, the revised assumptions of the fourth section are interpreted, discussed, and finally phrased into IS requirements. The results indicate that AM as a technology is already used for real production cases, but there are some improvements that could be realized by supporting IS. Currently, engineering issues often are the main challenges for AM enterprises. By increasing grades of application of AM in production efficiency is demanded through optimization in processes, management, and information infrastructure.

AM definitely is seen as an enabler in terms of customer participation in product development phases (see Table 6, A1*). Actually, there is a need for enabling customers to do constructional changes, a classical product development domain. Although, there is a lack of IS support in doing so (see Table 6, A3*). Especially the integration of customer design, a relevant feature for mass customization, often seems not to be supported by industrial IS solutions in an adequate way. Therefore, an essential requirement is to *develop or improve IS solutions for customer participation in industrial AM fields* (see Figure 3, #1). A first step could be the development of IS to support product design exchange. Based on this first approach, extensive approaches like construction and knowledge platforms could be developed. Currently, there is some research activity on this topic concerning development of concrete applications (Wu et al., 2012, Zhou et al., 2010).

On the other hand, participation in production is not enabled by AM, according to the results (see Table 6, A2*). This might be motivated by the understanding of AM as an industrial application. The sample is biased in this case, because exclusively participants with industrial background were contacted. Mostly, AM enterprises generate value by manufacture and service tasks, which they will not externalize to customers. Hence, this result should carefully be transferred to other AM domains, because in so-called "Consumer 3D Printing", production by customers is a central aspect. Nevertheless, customer production might become an industrial AM topic, because there are use cases in which it seems to be valuable to have a customer producing parts on his own, e.g. non-valuable expandable parts (Thiesse et al., 2015, Tanenbaum et al., 2013).

Currently, the way of standardized data exchange of part geometry does not reflect its relevance for quality of (end-use) parts. An adequate way of data exchange between product development and production depends on standards that allow more than the exchange of geometrical data (see Table 6, A4*). If the vision of direct printing of CAD data is to be true, a *shift of determination for all product defining data – digital product model – into the AM product development phase* is necessary (see Figure 3, #2). In particular, production parameters have to be defined by product development. Subsequently, business cases like decentralized production would become more likely.

In our view, a central requirement is a *standardized, bidirectional data exchange between AM production and AM product development*. Our results suggest that components of a digital AM product model currently are determined in production – production parameters – and product development – product design and functionality (see Table 6, A4* & A5*). There are promising developments like a new file format (3MF), but it seems not to be common in AM industries yet (3MF Consortium, 2015). Furthermore, AM production knowledge has to be accessible to product development (see Table 6, A7* and Figure 3, #3). Especially in terms of a decentralized production, externalized information exchange could be an adequate solution. Although, a standardized data exchange could mark a first step – further *holistic approaches in AM information management* are needed. Those approaches must consider new requirements in information exchange between product development and production as well as requirements in customer participation. Furthermore, other product lifecycle phases, for instance the usage/support phase, have to be included (see Figure 3, #4). Therefore, these are mainly requirements of IS in terms of PLM, and there seems to be a lack in PLM concepts for AM enterprises. There are indeed various results to AM specific characteristics with influence on business value, like high grade of digitalization, high grade of decentralized production, high grade of product individualization, high grade of customer integration, and special design knowledge (Khajavi et al., 2014, Mellor et al., 2014, Hague et al., 2003).

6 Conclusion

In conclusion, Additive Manufacturing (AM) industries could be a pioneer in cases of digitalization in the product lifecycle. However, the depicted results indicate a need for improvement in IS concerning the information exchange between customer and product development, as well as between product development and production. In the production of the future, these topics will increasingly become relevant. As described, current IS literature lacks holistic approaches that address needs of enterprises that use AM for production. Therefore, the presented, refined general requirements of IS in context of AM are relevant contributions to the development of IS that adequately support AM enterprises. Especially the phases of AM product development, considering customer participation, and AM production, could benefit from improvements in information management. According to the requirements, this has to be based on more product defining information than geometry. Therefore, the digital AM product model as an information artefact should contain product functionality and production parameters, besides geometry. This information is determined in both AM product development and AM production. In fact, this information is necessary in order to continuously guarantee the quality of same parts. Furthermore, IS architectures for information management could be developed, based on the requirements by using qualitative methods in order to specify them.

However, IS exceedingly have to consider changes in technology, like AM, in order to develop new or evolve existing IS concepts. In order to conceptualize IS solutions, further research has to complement the assumptions by other product lifecycle phases – especially the phase of usage and service. De facto, there are other fields of AM which could be researched in order to expand these results, like intellectual property questions or product liability (Thiesse et al., 2015).

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