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Additive Manufacturing in Supply Chains – The Future of Purchasing Processes

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Additive manufacturing is one of the leading production technologies when it comes to the efficient production of individual parts. This paper explains how additive manufacturing will influence purchasing processes and network structures of producing companies in future supply chain networks. Therefore, an exploratory research of relevant literature and recent studies in a systematic literature review is conducted, giving an overview of how additive manufacturing will change the processes of purchasing. Traditional purchasing and modern processes affected by the implementation of additive manufacturing are compared, in order to point out differences and new requirements. In the future purchasers have to extend their knowledge of additive manufacturing, to integrate this production technology into their sourcing strategy in an effective way. Technological knowledge and capabilities, supplier relations and internal integration of purchasers need to be improved, to make use of benefits e.g. reduced inventory. This exploration of the impact of additive manufacturing is focused on purchasing processes. Therefore, this paper investigates one special field of the supply chain layer, which is the unique characteristic of this submission. The findings are based on a literature review of studies and specialized literature, an analysis in collaboration with companies was not executed. Additive manufacturing has great advantages in many fields, but it cannot be integrated in supply chain processes with a significant leap forward. The sourcing strategy has to be changed; employees have to be trained, to interact with the new supply chain members and to learn which components can be manufactured additively.

Keywords: Additive Manufacturing; Purchasing; Supply Chains; Additive Manufacturing in Supply Chains

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1 Introduction

Additive Manufacturing is going its way from a pacemaker to a key-manufacturing technology. A lot of high technology companies spot the benefits of additive manufactured parts. At the moment, most of these parts are prototypes, spare parts or individualized consumer goods, but in the near future, taking the evolution of markets into consideration, more and more individual additive manufactured parts will be produced to enable individualized mass production (Zeyn, 2017). In this scenario, the decision to print additively or to produce a part conventionally has to be made during the purchasing process, preferably only in a matter of seconds. The velocity and the quality of this decision process will be a commercial advantage of companies acting on a globalized market. (Johannknecht and Lippert, 2015; Gress and Kalafsky, 2015)

A number of up-to-date studies and articles describe the trends and current developments in procurement. They do all point out digitalization as one of the main aspects influencing the future position of Purchasing & Supply Management (PSM) and the roles of purchasers (e.g. Kushner, 2015; Nowosel, Terrill and Timmermans, 2015; Pellengahr et al., 2016; PricewaterhouseCoopers, 2014). Digitalization, individualization and increasing autonomy as basic principles of Industry 4.0 also have an extensive impact on Purchasing and Supply Management (PSM) (Pellengahr, Schulte, Richard and Berg, 2016). Due to these facts and also because of the ongoing digitalization in production and administrative processes, the purchasing processes in companies will reach a new technological level.

On the one hand, digitalization is represented by new categories. Firms purchase digital products, services, and hybrid components. In order to acquire the demanded technical expertise, it is even more important to collaborate with other company functions. Purchasers have to be involved in product development processes on an early stage. New categories, e.g. related to additive manufacturing, will have to be procured with new sourcing strategies while others might lose importance or even disappear from the purchasing portfolio. (Arnolds, Heege, Röh and Tussing, 2016; Pellengahr et al., 2016; PricewaterhouseCoopers, 2014; Schuh, Aghassi, Bremer and Graw, 2014).

On the other hand, digital transformation causes not only technological advances and new requirements but also organizational and process-related changes. The administrative purchase-to-pay process will mostly be automated, as digital technologies help in the facilitation process. Further automation of transactional procurement decreases involvement of employees in purchase-to-pay and releases more personal resources for strategic tasks (Kushner, 2015; Pellengahr et al., 2016; Scharlach, Schuh and Strohmer, 2014; Drake, 2012). The purchasing staff members have to develop from former administrators to innovation managers, controlling data analysts and engineers in one person.

The network structures of future supply chains containing additive manufacturing as a production technology will refine and even different network partners will change their position and scope of duties. The value of data and their transfer through the supply chain network will be a new key performance indicator for effective supply chains. (Mellor et al., 2014; Zeyn, 2017)

Data for additive manufacturing processes will contain all information which is needed for an implementation in the production process. They will not only contain construction data but also parametric data and specialized settings for the building process in 3D-printers e.g. temperatures, feeding velocity and material advices. Taking this into consideration, one scenario could be that network partners that were not considered to produce goods can be enabled to execute additive manufacturing processes. (Zeyn, 2017)

A great example for this are forwarding companies that are able to become a producing network partner. The storing and distribution of goods will not be their main business area. The producing of parts on their 3D printers will become an important function for the supply chain network. All the parts that caused high storing costs for companies and that were no particular fast sellers can then be produced additively. As an example, these are parts that are only needed sporadically and were stored for the customer satisfaction, so that they have spare parts for a long period but also parts that had to be stored for legal regulation (e.g. aviation industry). (Mellor et al., 2014)

This paper will give an overview of how processes, especially in purchasing areas and network structures of supply chain, will change and develop because of additive manufacturing making its way to an important manufacturing technology. Based on that, recommended actions can be derived for companies, e.g. regarding know-how and competencies for procurement staff necessary for additive manufacturing, that is, amongst others, process knowledge and optimization, technical knowledge about the new products which need to be sourced.

2 Methodology

A literature review is a key method to overcome and manage the broad diversity of knowledge in management research. The main reason for conducting a literature review is to collect and assess already existing literature in order to specify a research question. With respect to the research question, the existing base of knowledge is about to be developed further. (Tranfield et al., 2003)

In addition to the advantages of literature review papers, such as giving a well-structured and up-to-date overview of a specific topic, it adds value by revealing knowledge gaps to the researcher. (Van Wee and Banister, 2016)

Newer technologies such as additive manufacturing that have not been adopted by a lot of companies yet, need a lot of guidance through its management. The difficulty is that there are only a few, if any, experienced employees or management staff because of the circumstances and challenges arising with such evolving technologies. Decision making can be really tough without any or only a little knowledge in this area. Literature reviews can provide the company with a broad base of information and knowledge. From this standpoint, it is easier for management and employees to handle decision making around additive manufacturing and develop its own experience and know-how.

The methodology for developing evidence-informed management knowledge provides three steps that have to be passed through for a systematic literature review. (Tranfield, et al., 2003) These steps are deployed in this paper to provide a desirable methodological approach: planning, conducting and evaluate the review.

2.1 Planning the review

The first step contains the systematic planning of the review. In this phase the guiding research question was developed, which is phrased as follows:

How does the implementation of additive manufacturing as a production technology influence future purchasing processes and the needed qualification of employees working in those processes?

The research question was developed upon the fact that an earlier literature review on the influence of additive manufacturing on company processes, in general,

showed that those examinations mostly focused on production processes, value processes or supply chain processes. Due to the fact that purchasing processes get more and more important for companies, because of a globalized market and a reduction of manufacturing depths, also the impact of additive manufacturing on those processes has to be evaluated.

The database, which was used for the review research, was ”google scholar”. In a second stage, the searching process was also conducted on the database of ”Scopus”, but in this case it did not provide further relevant papers, and so no additional paper could be added to the detailed review.

In this database, the keywords ”additive manufacturing”, ”3D-Printing”, ”procurement”, and ”supply chain management” were combined and in the following the most corresponding papers were selected.

The following combinations of keywords were entered, the number of results for every combination is specified behind:

”additive manufacturing” AND procurement (2.610 results), ”3D-printing” AND procurement (2.390 results), ”additive manufacturing” AND ”supply chain management” (1.630 results), ”3D-printing” AND ”supply chain management” (2.370 results)

Because of the two very similar keywords ”additive manufacturing” and ”3D-Printing” a lot of papers appeared in both searches and made the review process less elaborately.

Statistically, most of the publications on this set of issues were published in the years 2016 and 2017 and were classified as an Engineering or Business, Management and Accounting topic.

2.2 Conducting the review

From the first collection of papers, the relevant section was selected to execute the literature review.

For this, a selection of papers and studies was developed, based on a predetermined research strategy. The criteria for the selection was the conceptual link of the papers to both of the topics ”Additive manufacturing” AND ”Procurement”. Only those papers that had a connection to both of these fields and treated the

impacts in those fields were chosen for the literature review. This very restrictive search criterion has the advantage of avoiding issues that only mention the procurement process in additive manufacturing as an adjunct.

Beside this criteria, only papers which appeared in the period from 2006 to 2018, were collected in order to develop a current picture of the research field. The search yielded the 11 papers listed in table 1 and represent the final database for our analysis. A second search on the database Scopus was not able to identify additional papers concerning additive manufacturing and procurement.

The selection of papers is summarized in the following table.

Table 1: Selected Papers

Author	Title	Year	Key words
Baldinger M.	Supply Chain Management für Additive Manufacturing: Konzepte, Werkzeuge und Prozesse für die Zusammenarbeit mit Dienstleistern zur Reduktion der Risiken beim Einstieg in Additive Manufacturing	2016	Additive manufacturing cost, cost estimates, make-or-buy, service providers
Bogers M., Hadar R. Bilbergb A.	Additive manufacturing for consumer-centric business models: Implications for supply chains in consumer goods manufacturing	2015	3D printing, Additive manufacturing, Business models, Digital fabrication, Glocalized production, Rapid manufacturing, Rapid prototyping, Supply chains
Conner B.-P., Manogharan G.-P., Martof A.-N., Rodomsky L.-M., Rodomsky C.-M., Jordan D.-C., Limperos J.-W.	Making sense of 3-D printing: Creating a map of additive manufacturing products and services	2014	Additive manufacturing; 3D printing; Product development; Complexity; Customization; Volume; Complexity factor; STL; Surface area; Features; Part geometry; Product mapping; Strategy
Huang S.-H., Liu P., Mokasdar A., Hou L.	Additive manufacturing and its societal impact: a literature review	2012	Additive manufacturing. Environmental impact. Energy consumption. Supply chain. Health and wellbeing

Jiang R., Kleer R., Piller F.T.	Predicting the future of additive manufacturing: A Delphi study on economic and societal implications of 3D printing in 2030	2017	Additive manufacturing, 3D printing, Delphi, Forecasting, Scenario development
Liu P., Huang S.-H., Mokasdar A., Zhou H., Hou L.	The impact of additive manufacturing in the aircraft spare parts supply chain: supply chain operation reference (scor) model based analysis	2014	additive manufacturing; supply chain operations reference (SCOR) model; aircraft spare parts; safety inventory
Pellengahr K., Schulte K.-T., Richard J., Berg M.	Pilot Study Procurement 4.0 The Digitalisation of Procurement	2016	Procurement 4.0, Digitalization
Stucker B.	Additive Manufacturing Technologies: and Business Implications	2011	Additive manufacturing, Business Implications
Zhang Q., Vonderembse M.-A., Cao M.	Achieving flexible manufacturing competence: The role of advanced manufacturing technology and operations improvement practices	2006	Flexible manufacturing systems, Advanced manufacturing technologies, Operations management, Competences
Weller, C.; Kleer, R.; Piller, T.	Economic implications of 3D printing: Market structure models in light of additive manufacturing revisited	2015	3D printing, Additive manufacturing, Market structure, Flexible manufacturing, Economic modelling
Campbell, T.; Williams, C.; Ivanova, O.; Garret, B.	Could 3D Printing Change the World? Technologies, Potential, and Implications of Additive Manufacturing	2011	3D-Printing, Platform, Additive manufacturing, Potentials

For the actual review the following impact areas, which were developed in the planning process, were evaluated, Influence of additive manufacturing on the purchasing portfolio, Influence of additive manufacturing on procurement organization, Impact of additive manufacturing on procurement processes, Influence of additive manufacturing on buyer-supplier relationships and the Influence of additive manufacturing on competence requirements in procurement.

3 Findings

For a first brief dissemination of this review a diagram was developed, which illustrates the main findings of the literature review on a numerical basis. The number of references of the impact in context with the changes of additive manufacturing on the different areas of procurement were counted and applied to create a descriptive diagram. This diagram shows in which of the above mentioned categories the selected authors of the papers see the broadest number of changes, or rather which ones are most important for the future procurement processes and in this connection also for future supply chains. It also shows which category is yet not mentioned that often but can also be an important impact in the future.
The diagram points out that the changing in procurement organization caused by additive manufacturing is most mentioned in the selected papers. The need of new qualification for especially procurement employees is not yet mentioned in many papers
In the following section the most striking findings about the influence of additive manufacturing on procurement are summarized based on the information from the papers listed in (Table 1: Selected papers). The results are divided into the mentioned categories purchasing portfolio, organization, processes, buyer supplier relationships and competence requirements.

3.1 Influence of additive manufacturing on the purchasing portfolio

With the installation of additive manufacturing in a company, new products and services are included in the purchasing portfolio that are 3D printers, raw materials, construction data, additional devices and equipment for post processing, or even additive manufacturing services, like design or production services. (Pellengahr at al., 2016)

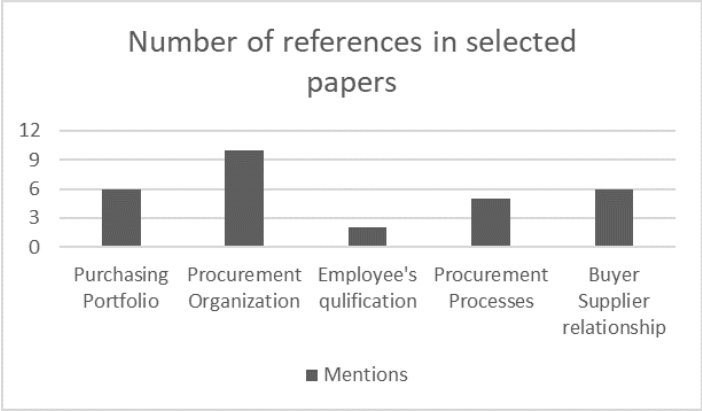

Figure 1: Number of references in papers

As the technological development progresses, innovative products must be sourced to stay competitive by keeping up with higher customer demands and changes in demand and price structures. (Pellengahr et al., 2016) To face the increasingly shorter product lifecycle Weller et al. point out that additive manufacturing is the appropriate manufacturing technology to produce initial prototypes. (Weller et al., 2005) That means the purchasing portfolio of industrial companies does not longer contain the prior number of tools or molds for conventional prototype production. This procurement of tools or molds is replaced by the purchasing of various raw material for the 3D-printers.
The increase of the integration of added manufacturing over different supply chains also influences the market prices that are volatile due to the current trends. It must be taken into account whether to make or buy additive manufacturing and which specific parts would be needed along the supply chain of additive manufactured goods. (Baldinger, 2016)
Conner discusses the nature of additive manufactured parts and necessary inputs like geometric complexity, customization, volumes, and implications for the interaction of product development, procurement and manufacturing further. (Conner, 2014)

3.2 Influence of additive manufacturing on the procurement organization

According to Bogers, due to a high customer focus and individualization, supply chains become more distributed on a decentralized basis. Production activities shift from manufacturer closer to customer. (Bogers, 2015)
In contrast, Liu describes two approaches for the organizational anchoring of additive manufacturing capacity: The capacity can either be centralized to replace inventories or distributed close to the customers. (Liu, 2014)
Additive manufacturing enables direct production of objects and enables the consumers to design own products. As an emerging market online databases offer product designs for additive manufacturing purposes (Jiang, 2017). Customer-centric focus on business models gives indications for operations along the supply chain. Flexibility and responsiveness need to be ensured by procurement organizations. (Bogers, 2015)
Also the integration of additive manufacturing platforms plays a significant role for the procurement organization. The option to use a network of companies as a supplier by using digital purchasing platforms can be one of the solutions for a not existing know-how of the production technology additive manufacturing. (Campbell et al., 2011)
Procurement along with other involved company functions faces the challenge that regulatory frameworks for additive manufacturing are still premature. That includes design and liability regulations, taking into consideration an outsourced additive manufacturing including digital platforms as service providers for data storage and print. (Gress and Kalafsky, 2015)

3.3 Influence of additive manufacturing on the procurement processes

Additive manufacturing influences supply chains and several enterprise processes. Additive manufacturing methods are used to reduce small batches. It has the potential to eliminate stocking activities for certain items and enable on-demand purchasing and production instead. Rapid prototyping becomes part of the strategic sourcing process. Supply logistics processes change as on-shoring is standard for additive manufacturing, different materials have to be procured and the procurement of spare part products decreases. (Stucker, 2011)
Simplified additive manufacturing increases efficiency and responsiveness in supply chains. (Huang, 2012) One advantage that takes effect in that case is that

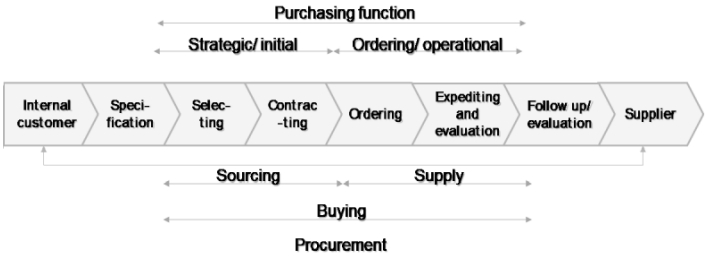

Figure 2: Effects on the PSM process phases. (Adapted from: Van Weele, 2014)

additive manufacturing enables the production of functionally integrated products. That means downstream production processes of several products can be eliminated using additive manufacturing. For example the assembly steps of different product parts can be reduced regarding the fact that with additive manufacturing these different parts can be integrated in just one component. For the procurement that means that the "scale-scope dilemma" of higher procurement costs links to a higher complexity of products can be solved by an supplier using additive manufacturing as one of his production technologies. (Weller et al., 2005; Campbell et al., 2011.)

Also the inclusion of the costumer into the product design process will play a big role for the changes in procurement processes. Additive manufacturing enables them to become a co-designer of their individual product. For procurement the sourcing of different modular parts for the individualization of products will decrease. (Weller et al., 2005)

With the procurement process structure by van Weele at hand, it becomes visible that all the following process steps are affected by changes through additive manufacturing:

In the process area of sourcing, the processes specification and selecting are most affected by additive manufacturing. The selecting process as a strategic procurement process contains the selection of a suitable supplier. Integrating additive manufacturing into the supply chain changes the supplier portfolio for this process. Now one service provider for additive manufacturing can take over the role of several modular materials suppliers.

In the process area of supply the ordering process can be simplified. Through functional integration, the complexity of products, which are produced additively,

can be reduced. That means that the supply risk along the supply chain decreases, as these products can be produced in a decentral manner at the point of use and by the lower number of suppliers involved in one product engineering process.

3.4 Influence of additive manufacturing on buyer supplier relationships

As additive manufacturing opportunities increase, procurement is more and more obliged to look at the costs and risks for make-or-buy-decisions and the choice of suppliers. (Baldinger, 2016)
Different and new suppliers are needed triggered by changes in purchasing portfolios. On the other hand, established suppliers might become obsolete. Procurement and manufacturing will be challenged to identify which items currently purchased from a third party can be developed internally. Companies can make use of offered additive manufacturing services or, with enough demand, buy their own printers. As material requirements continue to evolve, procurement continuously faces new challenges in identifying and developing strategically relevant suppliers and network partners. (Connor, 2014)
In the case of the special field of spare part supply, additive manufacturing can replace the buyer supplier process. With additive manufacturing it is now possible to produce spare parts for products or machines on demand at the point of use. In this case the supplier has to share the design file of the part only and the production takes place at the factory site. (Campbell et al., 2011)

3.5 Influence of additive manufacturing on competence requirements in procurement

PSM can stress its strategic role by gaining additional knowledge and networking as an equal partner within and outside the company. Besides technical expertise, which ensures that the correct new types of products can be bought, the networking as well as innovation scouting and sourcing role of the modern purchasers is fostered by further implementation of additive manufacturing. (Pellengahr et al., 2016)
Internal capacity for additive manufacturing projects is built up. This increases the knowledge about the technology and its potential applications for the focal firm. For successful implementation, personnel along the whole supply chain and network of which procurement is one of the essential functions connecting the involved companies need to be qualified accordingly.

Expertise is required for the procurement of the right products and technologies. Therefore, PSM needs to network with other departments, with suitable suppliers and stakeholders which calls for interdisciplinary know-how and interpersonal skills. In addition, entrepreneurial approaches and innovation abilities of the workforce are fostered. Buyers must have reliable product knowledge about their new digital procurement portfolio, e.g. about quality and pricing. As knowledge about current supply chain fundamentals and manufacturing techniques alters, procurement can benefit by remaining flexible and innovative in the face of 3D printing and other technologies. (Pellengahr et al., 2016)
Beyond explicitly PSM related new skills, technical infrastructure all over the networks needs to enhance regarding speed, security, availability of service and real-time efficiency. Curricula in practice as well academia should focus on increasing ICT skills in general. How these tasks can be embedded in the company depends on existing structures, process and know-how and will turn out clearer in the future. Procurement is one of the functions investigating intelligence solutions. Technological progress and related skills development can be pushed and controlled top down from management and strategic relevance. (Zhang, 2006)

4 Conclusion

One of the additional findings during the literature review is that the topic of additive manufacturing in connection with procurement processes or procurement organization was not often the main topic of the related papers. Most of them focused on technological or production issues. The changes in the area of procurement were only mentioned as a marginal note in the majority of the papers. Still, the systematic literature review has shown that a lot of advantages based on the production technology additive manufacturing can only be exploited by incorporating the specific features of additive manufacturing very early in the product lifecycle, right at the point of designing products in the supply chains and purchasing.
In addition to that, some of the main challenges procurement faces can be affected by progressing utilization of additive manufacturing in a positive way.
Certain risks can be minimized, e.g. by increasing own production of parts instead of relying on suppliers and by decentralization of production to locations close to the customer. Being a technology leader enhancing innovation potential can have positive influence on the company's reputation. The environmental impact decreases through the reduction of waste, transportation and inventory, and additive manufacturing can contribute to sustainability challenges and goals. It is

Figure 3: Challenges of procurement (Adapted from: Crawshaw, 2017)

important to demonstrate a partnership approach and develop a close network with the suppliers of new technology and data as well as with external and internal customers. These details are very important to exploit all advantages of additive manufacturing along the supply chain. Mentioned advantages have to be implemented already at the supplier stage to functionally integrate product parts at an early stage, so that the reduction of product complexity and a reduction of temporary storage can be spread as a monetary benefit alongside the complete supply chain. Centers of excellence can help establish the required know-how of new technologies and spread it throughout the organization as a support function. Procurement needs greater connections with stakeholders in the future to stay competitive, which is especially important for additive manufacturing net-works.

To point out the further research demands, based on the previous literature review, it can be summarized that past research concerning additive manufacturing and procurement is not broadly positioned in the research landscape. Most of the research focuses on additive manufacturing as a new technological production method and on the new products that can be realized with it. The changes in procurement as an early step in companies' processes have not been developed so far.

Additional to this finding, the competences of procurement employees as important decision-makers who affect the whole supply chain (e.g. if a part should

be bought or produced additively) are not yet explored scientifically in a strategic way. Nevertheless, it is obvious that especially at this point in the supply chain process a decision concerning additive manufactured parts is indispensable. That indicates that especially interdisciplinary research teams containing the disciplines of engineering and educational science should work together for the development of new education programs containing additive manufacturing topics.

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