Guest editorial

1. Exploring the impact of additive manufacturing in different industries: introduction to the special issue

1.1 Introduction

Additive manufacturing is an upcoming technology that has been identified as one of the potentially most disruptive technologies for society in general (Hyman, 2011; Sung-Won, 2013) and for manufacturing in particular (Merrill, 2014). This manufacturing technology deserves a proper analysis of historical developments, technical developments and their consequences for production, distribution, supply and marketing of industrial goods. Ultimately the structure of our entire economy might change because of the large-scale use of additive manufacturing. We created two special issues that explore a variety of topics with the aim to create a vision on the impact of this technology in specific industries. The first issue is published now, another will be published in 2017 in the same journal. These special issues aim to understand the history of the emergence of additive manufacturing, to analyze current technical and market developments and to explore future consequences of this technology for the structure of industries and the economy at large. Before summarizing the contents of the papers in this first special issue, we would like to define additive manufacturing and describe some of the machines that emerged.

The terms "3D-printing" and "additive manufacturing" are often used interchangeably and both refer to a process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies (ASTM, 2012). Subtractive technologies, such as drilling and milling, remove material when making an object whereas additive manufacturing technologies build up an object layer by layer and are therefore more efficient in using material. Furthermore, additive manufacturing technologies, because of the process of adding subsequent layers, enables the creation of more complex objects compared to subtractive technologies (ASTM, 2012). Ford *et al.* (2016) describe additive manufacturing as a range of technologies, each at different levels of technological maturity, offering the option of using a variety of materials, with different quality outputs. Oettmeier and Hofmann (2016) in this special issue refer to additive manufacturing as a set of different technologies, which all work according to the same principle: based on a digital blueprint, materials are joined to form 3D objects. The ASTM proposes seven categories depending on how the layers are created: vat photopolymerization; material jetting; binder jetting; material extrusion; powder bed fusion; sheet; and directed energy deposition (see also Wohlers and Caffrey, 2013).

Rylands *et al.* (2016) in this special issue describe the different printers that emerged over time. These printers range from hobbyist printers, such as those by MakerBot, or the printer created in the RepRap project to industrial scale printers, such as systems that have the ability to produce solid items by using lasers to sinter powders layer by layer to create a finished object (Griffey, 2014). There are also food printers, such as ChefJet (Sun *et al.*, 2015) and bio-printing technologies, such as bioplotters (Soel *et al.*, 2014) able to create organic structures for tissue and bone engineering (Richards *et al.*, 2013; Bose *et al.*, 2013).

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2. Method and summary of the papers

The special issue contains six papers, all of which explore the impact of additive manufacturing. Although additive manufacturing technologies are around for about three decades, it is important to notice that the study of additive manufacturing is an emerging scientific field. The emerging nature of this field is reflected in the approaches that the papers in this issue adopt. These approaches are more explorative and practical rather than theoretical. Some papers provide practical advice, such as advice about the type of additive manufacturing technology that should be adopted in particular use contexts (see Meisel *et al.*, 2016) or advice about the type of machine spare parts that can be produced cost-efficiently using additive manufacturing (see Knofius *et al.*, 2016). The other papers explore the consequences of the implementation of additive manufacturing in various industries using a case-study methodology or adopting a practical experimental approach (see Steenhuis and Pretorius (2016) who report their own experiences of using a 3D-printer). Below is a short description of the six papers in this issue.

Meisel *et al.* (2016) in their paper "Decision support for additive manufacturing deployment in remote or austere environments" focus on particular kinds of niche applications for additive manufacturing, niche applications in remote or austere environments. Contemporary examples are military applications to provide parts near to the battlefield or near to the operation of the military forces. Another example is the application of additive manufacturing to provide parts required in a mobile military hospital. In these environments traditional large-scale manufacturing approaches are not possible or are not cost-efficient. There are many civilian niche applications possible also. Meisel *et al.* (2016) describe that many different types of additive manufacturing technologies can be distinguished and that these technologies can be applied in a variety of use contexts and with many different materials. The resulting amount of possible combinations of additive manufacturing technology and materials in each use context make decision support highly valuable. This decision support tool is built after interviewing potential users, and it is illustrated using an example. The contribution of the paper is that it includes process, logistics and environmental needs in the selection process of a good additive manufacturing technology and material.

Knofius *et al.* (2016) in their paper "Selecting parts for additive manufacturing in service logistics" also focus on a particular niche application: after sales service logistics in high-tech industries. For advanced capital goods, in high-tech industries such as the aerospace industry or healthcare industry, many different spare parts are required during the lifetime of these goods, a life time that typically spans decades. This paper, like the previous one, also offers decision support. Knofius *et al.* (2016) describe a model that allows companies that produce and maintain capital goods, to select the type of spare parts for which additive manufacturing represents a viable business case. After sales services is a company function that involves maintenance and repair and as a result of these services parts are required at the customer's site. In some cases the number of parts that are demanded is large enough to enable cost-efficient production using contemporary large-scale manufacturing technologies such as injection moulding (for plastics) or milling (for metal parts). In other cases, however, the number of parts is small, and as a result additive manufacturing becomes a viable production technology. To facilitate the choice between manufacturing technologies a model is created.

Kothman and Faber (2016) in their paper with the title "How 3D printing technology changes the rules of the game: insights from the construction sector" describe the disruptive changes that may come along with the implementation of additive manufacturing in the current construction industry. Disruptions, changing both the way in which we produce and in which complete value chains are structured, are required for significant improvements in ecological performance of the construction industry. Kothman and Faber (2016) describe how potential performance improvements and efficiency gains in production using additive manufacturing technology may entail a redesign of the structure of value chains. The authors adopt a case-study approach to study disruptive effects in the construction industry. The case study reveals that additive manufacturing entails several potential performance improvements such as a shortening of lead times, integration of functions and allowing for reduced material usage. These improvements entail a restructuring of the value chain when turning production steps within the construction supply chain obsolete while also reducing logistical and production efforts.

Oettmeier and Hofmann (2016) present a paper with the title "Impact of additive manufacturing technology adoption on supply chain management processes and components." This paper, like the previous one (Kothman and Faber, 2016), also addresses consequences of additive manufacturing. Additive manufacturing is described to affect manufacturing and order fulfillment processes of manufacturing companies and also affects the arrangement of actors on the supply and demand-side of these companies. Additive manufacturing thus requires a significant redesign of the external supply chain structure around a company and the internal processes such as manufacturing, order fulfillment and logistics within a company. Oettmeier and Hofmann (2016) focus on the effect of additive manufacturing in an engineer-to-order environment, in particular the hearing aid industry. The paper has adopted a multiple case-study approach to explore the impact of additive manufacturing.

Rylands *et al.* (2016) in their paper "The adoption process and impact of additive manufacturing on manufacturing systems" explore the adoption process of additive manufacturing technology in companies. The paper adopts a multiple case-study approach focusing on two manufacturing companies, a metal manufacturing company and a company manufacturing wallpaper. The paper describes the old and the new value stream for these companies after adopting additive manufacturing. The value stream refers to the combination of the external value chain and the internal manufacturing and logistics processes in a company. Rylands *et al.* (2016) describe that additive manufacturing is complimenting and strengthening traditional manufacturing value streams rather than replacing them.

In the last paper with the title "Consumer additive manufacturing or 3D printing adoption: an exploratory study." Steenhuis and Pretorius (2016) explore the potentially disruptive effect of additive manufacturing in the consumer market on existing manufacturing industry. The authors adopt an exploratory mixed method approach combining their own experiences with a 3D-printer, discussions with actors in the domain of additive manufacturing, a survey, and a preliminary bibliometric study. In contrast with the authors of the previous papers, Steenhuis and Pretorius (2016) claim that the cost of consumer 3D printing is lower than for traditional manufacturing. That might represent an important sign that large-scale adoption and diffusion of additive manufacturing is about to start. However, the current adoption rate is low and the user-friendliness and technological capabilities need to improve to enable large-scale adoption and disruption of the current manufacturing industry.

3. Meta-analysis and comparison of the papers.

An overview of the six papers in the special issue is provided in Table I. The table summarizes for each paper the type of industry and application (rows 1-3). The methodology for each paper is in row 4, while rows 5 and 6 summarize the main advantages and disadvantages of additive manufacturing according to the papers. The main result of the papers, their managerial and theoretical relevance are summarized in the last three rows (rows 7-9).

The overview shows that papers represent a variety of industries. Most of the papers still observe that additive manufacturing is operational in niche applications at the side of, or complementary to, traditional large-scale manufacturing technologies. Kothman and Faber (2016) and Steenhuis and Pretorius (2016) envision more large-scale applications of additive manufacturing in the future of industries that they explore, the construction industry and market for consumer households, respectively. It is interesting to see how the authors' visions on niche vs mass market application can be explained in terms of the advantages and disadvantages that they discuss in their papers. Several articles observe that the cost of production for large batches of products is higher for additive manufacturing than for contemporary manufacturing technologies. In contrast, Steenhuis and Pretorius (2016) claim that the cost-level of additive manufacturing has become lower. But, particularly for the consumer market, the three printers still fall short in the user-friendliness that is required for laymen in consumer households. This disadvantage is claimed to limit diffusion of additive manufacturing.

Additive manufacturing is an important process innovation. An interesting observation made by all authors is the fundamental restructuring of both internal company processes and external value chains that come along with the adoption of additive manufacturing. The value chain comprises of the network of companies that supply parts for additive manufacturing, manufacture additive manufacturing machines, supply materials used in these machines, provide 3D designs of products that can be created by these machines, the companies that install the additive manufacturing machines and the ones that distribute and adopt the products made by additive manufacturing. This entire value chain will have a fundamentally different structure than the contemporary value chains. The fundamental restructuring will require some time. For the moment many niche applications pave the way.

4. Conclusion and future research

This special issue has addressed several issues regarding additive manufacturing. The papers explore the topic and tend to focus on practical issues. Decision support is provided by two papers (Meisel *et al.*, 2016; Knofius *et al.*, 2016), while three papers (Kothman and Faber, 2016; Oettmeier and Hofmann, 2016; Rylands *et al.*, 2016) explore the impact of additive manufacturing on internal company processes and external value chain structures. The last paper (Steenhuis and Pretorius, 2016) addresses how consumer households can adopt additive manufacturing to manufacture goods locally and what that means for traditional consumer goods manufacturers. The papers discuss additive manufacturing in the context of several industrial sectors and in the consumer market. It is fascinating to observe that most papers in this issue conclude that additive manufacturing is still adopted in niche applications and thereby complements contemporary manufacturing technologies rather than substitutes them. Kothman and Faber (2016) envision that the construction industry as a whole will change due to additive manufacturing and

Table I. Overview of the papers in the special issue

Paper 1 Meisel *et al.* (2016)	Paper 2 Knofius *et al.* (2016)	Paper 3 Kothman and Faber (2016)	Paper 4 Oettmeier and Hofmann (2016)	Paper 5 Rylands *et al.* (2016)	Paper 6 Steenhuis and Pretorius (2016)
Industry					
Manufacturing for military operations	Manufacturing in advanced capital goods industries	Manufacturing in construction industry	Manufacturing in hearing aid industry	Manufacturing of metal parts and wall paper	Manufacturing in consumer households
Application					
Remote or austere environments Military applications. Civilian applications are explored	After sales service logistics (typically in industries like aerospace, healthcare, military)	Additive manufacturing in the construction industry	Engineer-to-order system in the hearing system industry	Metal part production and wall paper production	Application of consumer 3D printing
Type of application					
Niche	Niche	Mass application (in the future)	Niche	Niche	Mass application (in the future)
Methodology					
Practical: interviewing potential users to build decision support, example to illustrate tool	Practical: field study to demonstrate and validate model. Sensitivity analysis to test robustness of outcomes	Case-study approach	Multiple case-study approach	Multiple case-study approach	Mixed method: first-hand experience, discussions, survey, bibliometric study
Criteria: advantages of AM					
Possible and cost-effective in these niches compared to other manufacturing technologies (see below)	Positive business model for subsets of spare parts. (AM enables lower costs for low volume parts)	Potential performance improvements and efficiency gains (reduced material usage, reduce production and logistics efforts)	AM affects internal manufacturing and order fulfillment processes of companies and external arrangement of actors on the supply and demand-side	AM compliments strengthen traditional manufacturing value streams rather than replacing them	Cost of AM is lower than traditional manufacturing technologies and thus can substitute these technologies soon

(*continued*)

Table I.

Paper 1 Meisel *et al.* (2016)	Paper 2 Knofius *et al.* (2016)	Paper 3 Kothman and Faber (2016)	Paper 4 Oettmeier and Hofmann (2016)	Paper 5 Rylands *et al.* (2016)	Paper 6 Steenhuis and Pretorius (2016)
Criteria: disadvantages of AM					
Cost is higher for large numbers	AM cost is higher for large numbers	Redesign of value chain required	AM requires fundamental transition in company and its value chain	AM caused a shift in value propositions and the creation of additional value streams	User-friendly-ness is low
Result					
Tool to advice the best combination of AM-technology and material after analyzing the context	A scoring method is developed to identify eligible spare parts for the application of AM technology	Vision on future changes in value chain when implementing AM	Vision on future changes in company and value chain when implementing AM	Vision on future changes in company and value chain when implementing AM	Vision on future changes in value chain when implementing AM
Managerial relevance					
Decision support	Decision support to select spare parts for which AM is good business case	Preview of future changes in industry	Shows the consequences of implementing AM both internally and externally	Explores the adoption process of AM and its consequences	Explores the potentially disruptive effect of AM in the consumer market on existing manufacturing industry
Theoretical contribution					
Adds to the existing decision support literature	Adds to the existing decision support literature	Assesses the effect of AM on ecological performance	Addresses how AM deals with the dilemma between product variety and scale economics	Addresses the adoption process and its consequences	Addresses the consumer market

Note: AM, additive manufacturing

Steenhuis and Pretorius (2016) claim that the cost of additive manufacturing has now decreased to the point where substitution of complete manufacturing systems become a serious scenario. Are we observing the shift of additive manufacturing from complementary and specialized niches in manufacturing to large-scale substitution of manufacturing technology in several industries?

The results of this first special issue also indicate research gaps that might be explored in the future. In all of the papers either practical decision support is provided (Meisel *et al.*, 2016; Knofius *et al.*, 2016) or exploratory research is reported (in the remaining papers). A research gap that might be addressed is to compare more systematically across sectors how additive manufacturing is adopted and implemented and what the consequences of additive manufacturing in companies and value chains in these sectors are. More systematic and large-scale empirical studies can be planned once we have explored the consequences of additive manufacturing enough to proceed. Several issues in the call for papers were not, or hardly, addressed by the current papers. This leads to additional future research opportunities. A research gap is the lack of a proper historical account of developments of additive manufacturing. The fifth paper in the special issue by Rylands *et al.* (2016) addresses the history to some extent, but a full account of this history is still lacking. Another gap is an analysis of the impact of additive manufacturing on the economy and society as a whole, not just in specific industries. Steenhuis and Pretorius (2016) present some preliminary ideas for such an analysis. A final gap is the lack of a systematic literature analysis on the topic of additive manufacturing. Some of the gaps will be addressed in the second special issue (2017). We feel that we have just started to explore the impact of additive manufacturing.

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