Abstract

Firms are confronted with rising competitive pressure on both the manufacturing and innovation processes to meet the ever-increasing demand for customization and individualization. Despite this, only sparse research has combined literature from operations management and innovation management literature to investigate the interaction between innovation and manufacturing. Building on a survey of 2,333 Danish manufacturing firms this paper addresses this gap in literature and presents a novel perspective in exploring the role of additive manufacturing (AM) technologies in facilitating the integration of production, innovation, and market perspectives on the value creation processes. The survey data reveals a significant positive relation between the "used potential of AM technology" and the number of AM domains. The analysis show that technology ownership supports the development of incremental innovation, whereas it is integration between application domains that support the highest level of radical innovation.

The paper argues that the "used potential of AM technology" is an indicator of potential competitive advantage for a firm. Derived from the findings, an integrative AM application strategy will support the development of an innovative business as both the product and process innovation level will be affected, and consequently also the market innovation.

This paper contributes to the literature in technology management and to the relationship between the AM technologies and their associated competitive potentials. Furthermore, this paper specifically contributes to the much needed, but still scarce and fragmented literature, on decision models of AM, through an integrative perspective from innovation and operation management literature.
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**Keywords:** Additive Manufacturing, Integrative Innovation, Competitive Advantage, Technology management, Survey
1. Introduction

Globalization is pushing the boundaries of value chains for an increased focus on handling the growing competitive pressure arising from increased demand for customization and individualization (Tseng, 2003). The developed countries seek to preserve manufacturing in the home country, while focusing on increasing the innovative capabilities to push new solutions to the market (Gunday et al., 2011). The companies experience a pressure to reduce cost and increase productivity while meeting an increased demand for improved quality and product innovation. These pressures puts the manufacturing flexibility and speed at the front of the strategic agenda together with the demand for innovative competencies (Brettel, Klein, & Friederichsen, 2016; Colotla et al., 2016). Despite the rising competitive pressure on both the manufacturing and innovation process, there is little if any research evidence that combines operations management with innovation management literature.

Both academia and industry promote the importance of innovation, use of advanced technology (Colotla, 2016) and flexibility in manufacturing (Pérez, 2016) as sources to maintain or develop competitiveness, each field are however often addressed individually. Thus this article addresses this gap in literature and investigate the interaction between innovation and manufacturing, and especially the potential impact of innovative technologies. 3D printing technology, as an overall description of the different underlying technologies, has different fields of application, both within innovation and manufacturing. The research aim is the investigation of the integration of innovation and operation management, with focus on the potential competitiveness through the use of advanced technology; 3D printing (figure 0)
Figure 0. Research aim

Industry experts (Colotla et al., 2016; Küpper et al., 2017, Wohlers, 2015) and academics that additive manufacturing (AM) has the potential to improve companies’ ability to combine and utilize their capabilities for innovation, manufacturing, and business activities to improve their competitiveness (Baumers, Dickens, Tuck, & Hague, 2016; Berger, 2017; D’Aveni, 2013; Gambell et al., 2017).

Since the introduction in the 1980s, 3D printing technologies have mainly been used for rapid prototyping (RPT) as part of the innovation process (Oettmeier & Hofmann, 2016). The technology is well-known and mature, nevertheless, additive manufacturing technology is fast developing to become a key enabling technology of this century (Lipson & Kurman, 2013). Although often used interchangeably, AM utilize 3D printing technology. AM is anticipated to potentially disrupt barriers within, materials and product characteristics, business and value chains, and support tooling (Berman, 2012; Khorram Niaki & Nonino, 2017; Laplume, Petersen, & Pearce, 2016; Petrick & Simpson, 2013; Hannibal & Knight, 2018). However, to evaluate the potential impact on a firm’s competitive position and potential there is a need for developing an integrated framework combining innovation, operations, and competitive impact (Conner et al., 2014). This suggests that it has become paramount not just to study individual business activities. Instead there is a need of attaining insights on the linkages between individual business activities and the role of AM in this interplay. To address this
gap in research, this article theoretical model to analyze the influence of the firm’s AM maturity on the linkage between product development (innovation), market opportunities (customized part production), and the production setup (support for a flexible manufacturing system).

The contribution of this paper is the development of a theoretical model for assessing a firm’s maturity in use of AM technologies for multiple purposes (innovation, production and market development). This model guides the analysis of the results from a national screening of the Danish manufacturing industry. Based in this, the article presents a novel perspective on the integration of production, innovation, and market perspectives on the value creation processes and specifically the possible role of AM technologies in facilitating this integration.

2. Literature Review

2.1 The innovative process
Innovation has been argued to be the key competitive priority of firms for value creation. A large body of literature has demonstrated positive effects of innovation on economic performance (Camisón & Villar-López, 2014; Gunday et al, 2011). However, many firms struggle to successfully commercialize their technology (Simula & Valiauga, 2015). The innovation process is typically developed in phases, sketched out in a linear fashion, as illustrated in figure 1. This model shows that in the view of the innovation process, several stages may be outlined from the early idea to concept development and on to prototyping and validation. Commercialization is traditionally introduced at the point of market introduction. However, in many cases commercialization may extended into the actual purchase and subsequent (or not) use of the solution by the end-user. In figure 1 this is illustrated as the adoption process.
2.2 Manufacturing from a system perspective
A manufacturing system, consist of several sequential operations, including equipment, machines, people and procedures, that are able to carry out operations (Groover, 2016). In continuances of the illustrated innovation process, a manufacturing system can be conceptualized as system in which the product becomes transformed from design to a market ready product through a value creating process. The manufacturing system (MS) perform the manufacturing strategy, based on several competitive priorities, often described as cost, delivery, quality and flexibility (Hill, 2000; Miltenburg, 2008; Bellgran, 2010). To provide competitive priorities demanded by customers, the manufacturing system is further divided into production systems (PS), part production systems (PPS) and assembly systems (AS) (Bellgran & Säfsten, 2010). There are multiple ways of combining the production systems into a sufficient flexible setup, required to both support the market, and handle the innovation push, resulting in new product introduction, re-design and re-engineering of products. On the manufacturing system level; production planning and organizational structures are important levers to support the market, whereas the human resources and process technologies are integrated on the production system (Miltenburg, 2008), see figure 2.
2.3 Additive Manufacturing
As already stated in the introduction, 3D printing technology has been under development for more than two decades (Kruth et al. 1998)(Levy et al. 2003). Technology has developed within three different domains. First 3D printers have been used in Rapid protoptyping (RPT) linking towards the R&D and innovative processes. Secondly, printing technologies have been applied to tooling in manufacturing supporting a customized and flexible operations setup (Connor et al., 2014) and 3). Most recently, additive manufacturing has been used to manufacture components or product as finished items (Niaki & Nonino, 2017).

AM related research has dominantly been associated with specific and highly specialized industries, such as aerospace (Cesaretti, Dini, De Kestelier, Colla, & Pambaguian, 2014), pharmaceutical industries (Gelinsky, 2016), surgical (Goldstein, Smith, Zeltsman, Grande, & Smith, 2015), and dental applications (Conner et al., 2014; Gambell et al., 2017). In addition, much AM research has focused on either a specific technology (Gao et al., 2015; Rengier et al., 2010), product, or cost perspective (Pour, Zanardini, Bacchetti, & Zanoni, 2015). To further the dissemination of AM and the multitude of application potentials within each firms processes more broadly, there is a need for
bringing the fragmented literature on AM decisions and implementation together (Achillas, Aidonis, Iakovou, Thymianidis, & Tzetis, 2015) and substantiate these linkages with empirical research.

Both Additive Manufacturing (AM) and 3D printing adhere to the definition by ASTM as: “a process of joining materials to make objects from 3D model data usually layer upon layer, as opposed to subtractive manufacturing methodologies” (ASTM, 2012) (Mellor et al. 2014). The “layer upon layer”-technology, based on a digital model, can produce products and items based on different print technologies and in various materials. We therefore argue that it is important to separate the terminology by purpose. Rapid prototyping (RPT) utilize the 3D print technologies to speed up and value-add the design and development phase (Niaki & Nonino, 2017), whereas additive manufacturing has its focus on the manufacturing of parts or products (Gibson et al., 2015). Different technologies and materials are advantageous depending on how it is utilized. This is why RPT has its primary use in innovative processes and AM is directed at production. In addition, the use and implementation of various AM technologies (FDM, SLA, SLS or Metal Binder Jetting) or choice of materials (plastics, composites, metal) have significantly different demand for knowledge- and technology capabilities as well as financing. Many of these issues are only sparsely considered in the existing literature.

2.4 Additive Manufacturing Framework
As stated in the introduction, it has been suggested that additive manufacturing needs to be studied from an integrated perspective between the manufacturing system and innovation process (Bellgran & Säfsten, 2010) (Pour et al. 2015), to better understand the linkage between different applications of AM technologies, and the AM maturity of the manufacturing companies. In reviewing the AM literature, only a few theoretical frameworks emerge (Pour et al., 2015; Conner et al., 2014; Achillas et al. 2015). Each framework dealing with different elements and levels of AM.
Existing research on implementation of AM has identified the need of a three step approach; preliminary, technical and economical (Pour et al., 2015), and despite the holistic approach it has its unit of analysis on product level. Most authors agree on the importance of using key attributes for categorizing the product in an AM context. Most common are production volume, customization and complexity of the product (Conner et al., 2014).

Other frameworks also have a holistic approach, including, multi-criteria decision aid MCDA and data envelopment analysis (DEA), with focus on focused factory aiming for the optimal operations strategy (Achillas et al. 2015). Similar other conceptual frameworks propose an AM implementation process, which builds on assessing 5 factors; strategic, technological, organizational, operational and supply chain related, from a socio-technical viewpoint (Mellor et al. 2014). Another framework is based on four determinants; Technology-, Firm-, Market structure- and Supply Chain, to decide on the adoption of AM technologies for industrial part production, but consider only part production, and lack the capability perspective (Oettmeier & Hofmann, 2017).

The impact on the supply chain also draws the attention of various authors, e.g. business model conserving integrating AM based on either manufacture or customer focus, versus an either centralized or decentralized supply chain network (Borgers et al. 2016).

Many contributions within conceptualizing frameworks operate with evaluating and selecting AM technologies are very technical (either on technology or product level) (Fera et al. 2018), and cost driven (Achillas et al. 2015). Accordingly, there is a lack of research involving a competitive perspective from a manufacturing system point of view. In addition to this, none of the existing frameworks incorporate an integrative approach, integrating both AM maturity of the manufacturing company and the application of AM within the different domains (innovation, manufacturing and business development).
2.5 Integration of innovation process, manufacturing and AM
In contrast to additive manufacturing, subtractive manufacturing (Gibson et al. 2015) consists of more traditional manufacturing process as, drilling, grinding, milling, turning and cutting, processed by either single process machines or in advanced CNC machines (3-5-7 axis).

Both additive and subtractive processes are part of a manufacturing system (process level) that transforms and adds value to products (Slack et al. 2010). Productivity and cost are the drivers leading to technology decisions also within the domain of AM (Fera et al. 2017). The AM technology process is therefore only a sub-process of the production system and do therefore support the competitiveness of the overall manufacturing system.

In figure 3, a conceptual framework describes the integrative and innovative perspective including the manufacturing value creation system is proposed, addressing the multi-domain perspective on Additive Manufacturing.
Figure 3: Integrated innovation perspective from an Additive Manufacturing perspective, (Frederiksen & Knudsen, 2017, Bellgran & Säfsten, 2012)

Rapid prototyping (1) in the innovation chain will combined with digital development provide shorter time-to-market, higher potential for customization, customer integration in the development (concept and solution phase. Especially digital testing (FMEA/FEA), simulation and (advanced design modelling) will have cost reducing potential. Additive manufacturing (2) of products and components will support product complexity, use of advanced materials, less material waste and flexibility in terms of variation (customization). Additive manufacturing of support tooling (3) such as grippers,
molds, fixtures etc. increase the manufacturing flexibility and enable faster changeovers, small batch production and agility in the production setup. In this case AM is not the direct manufacturing process but provides shorter lead-time on tooling components, customized and low-cost tooling (relative depending on the initial printer investment). As additive manufacturing becomes an integrated manufacturing technology, a feedback loop (4) to the design and development chain appears, as new opportunities with in design, materials and changeability becomes available (maybe a change from design for manufacturing to manufacturing for design). Introduction of 3D printing in both the development phase (RPT) and the manufacturing (AM) will potentially support the current competitive level. There will be a potential of higher level of customization and customer integration and shorter leadtimes in both development and manufacturing which potential will change the overall business model (5).

2.6 AM maturity level
Through a narrative literature review on maturity or readiness level/index in relation to Additive manufacturing, no direct contributions have been identified. There are a few maturity or readiness models, that relates to either product technology or the manufacturing technology (Peters, 2015). These models steam from a maturity readiness level (1-10), based on related technology readiness level developed by the US department of defense. Indeed, this does provide a framework for assessing the current maturity of either a single product technology or manufacturing technology. However, these frameworks fail to include the maturity or the technology capability of the manufacturing setup. As there are no established maturity or readiness indexes available, inspiration has been found in the Moore’s “Chasm model” from 1991, which provide a company categorization in relation to adoption of new technology (Sroufe, R. et al. 2000). This proves to be an appropriate model, as the chasm of AM will be able to identify the threshold of fulfilling the full potential of the technology.
In the following section the elements from the AM domain section and the AM maturity section, are combined into a theoretical framework.

3. Theoretical framework development

In our theoretical framework, we propose that AM maturity is an important element to understand how well the firm is equipped to strategically unleash the potential for competitive strength. We argue that maturity can be seen as a combination of basic knowledge and information about the technology — *getting to know about the technology*. As a new technology is developed, the first information provides a basis for consideration into whether the technology is relevant for the firm or not. The second level of maturity describes a situation in which the firm has obtained some knowledge about the technology. However, at this stage the firm has yet to put the technology into use. The firm first engage in trial and error to learn about the specific opportunities offered by the technology — this is referred to as a process of *Getting acquainted with the technology*. At the subsequent next level, the firm has its first trial with the technology. Over time, as a consequence of use and collection of knowledge, the firm’s maturity level grows in relation the specific technology. We therefore argue that maturity is related to the single technology, here AM technology. Based on this knowledge and capability view, we therefore suggest the following levels.

The theoretical framework illustrated in figure 4 has been established by integrating AM maturity in terms of knowledge and utilization together with the potential usage domain within innovation (rapid prototyping), production support (direct tooling) and part production (direct manufacturing).

By adoption the “Chasm model” (Moore, 1991) we argue that; “The higher level of maturity a company achieve combined with activities in multiple usage domains will have a positive effect on the company competitiveness derived from AM technology”
4. Research design

The maturity framework can be applied to investigate the maturity level for use of AM technology. This tool was based on the comprehensive review of the literature combined leading to figure 4. Subsequently, this was operationalized into a survey. The aim of the tool was to assist a national screening of manufacturing companies in relation to their AM readiness and engagement and to provide insights on the role of AM maturity in relation to firm’s competitiveness. As a direct consequent of this, the screening tool categorizes responding firms into mature, pre-mature and infant in AM readiness in relation to three dimensions: product, production and market.

4.1 Survey administration

Pilots studies were carried out prior to administering of the full survey. Hence, survey tool was tested and comments were collected. This work led to revisions in terms of wording and small changes in use of terminology.
The survey was sent to the population of Danish manufacturing firms (NACE code 10-33) with more than 20 employees. In addition to this, firms with particular association to 3D print and additive manufacturing were invited to participate in the survey although they did not meet the initial criteria. In practice this resulted in the inclusion of 5 firms, which were smaller than the size criteria of 20+ employees. In the sample these firms were included in the group of small firms.

Data was drawn (18-04-18) from the databases Orbis and Bisnode. Bisnode produced 2,503 Danish manufacturing firms ((NACE 10-33) with 20+ employees registered at the Danish address. Based in the same search Orbis returned 2,017 firm meeting the same criteria. The two lists were merged to a gross list consisting of 2,957 firms. This list was subsequently cleaned for firms without a valid email and firms located in Greenland or the Faroe Islands. This resulted in a total population for the survey of 2,333 Danish manufacturing firms.

An invitation to participate was forwarded to the firms in the list in May 2018. In Mid-May non-responding firms were called. These calls were administered in acknowledging that firm without knowledge and use of AM technologies would be bias towards not completing the survey. Thus, to secure a representative dataset, responses from these firms were also needed. In extending this work two reminders were forwarded to all firms on the list that did not already complete their response. The last of these reminders was sent out in Mid-June with a notification that the collection of data would end 22-06-18.

4.2 Representativity of the data sample

In all, the survey resulted in 314 acceptable responses, equaling a response rate of 13.5%. The data set was tested in relation to representativity of the Danish population of firms with 20+ employees. The sample is representative in terms of size in relation to the Danish population of firms with 20+ employees. Table 1 illustrate the exact distribution of respondents in terms of size and indicate a
dominance of small to small-medium sized firms in the sample. Indeed, this is also the case for the entire population.

<table>
<thead>
<tr>
<th>Size</th>
<th>No. of employees</th>
<th>Total population</th>
<th>Total responses</th>
<th>Response rate in %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small</td>
<td>20-49</td>
<td>1.247</td>
<td>151</td>
<td>12.1</td>
</tr>
<tr>
<td>Small-medium</td>
<td>50-99</td>
<td>542</td>
<td>77</td>
<td>14.2</td>
</tr>
<tr>
<td>Medium</td>
<td>100-199</td>
<td>286</td>
<td>51</td>
<td>17.8</td>
</tr>
<tr>
<td>Large</td>
<td>200+</td>
<td>239</td>
<td>30</td>
<td>12.6</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>2.314</td>
<td>309</td>
<td>13.4</td>
</tr>
</tbody>
</table>

Table 1: Distribution of size in responses (representativity)

Some responses, that were not complete, were included in the sample if the missing was outside the investigated variables. Thus, the responses in different analyses can differ down to 286 (response rate 12.4%), which is still acceptable in relation to representativity.

To avoid misrepresentation in the findings due to regional differences, the data set was screened in relation the regional representativity. The regional distributions are representative of the general population of manufacturing firm with 20+ employees, with 15% of the respondents located in the Capitol area, 11% in the Zealand region, and 33%, 18% and 23% in the Mid-, North- and South-Jutland regions. In addition to these factors, the data set is also representative in relation to industry codes. The data cover 23 NACE codes in all. 20% of the respondents belongs to Manufacture of fabricated metal products, except machinery and equipment (NACE-gruppe 25). This represents the largest single group whereas the second biggest group of firms are Manufacture of machinery and equipment n.e.c. This group represents 18% of the total sample. Both groups represented in the data set match the distribution observed in the total population of Danish manufacturing firms. Finally, we checked for distribution in relation to level of technology intensiveness (EUROSTATs standard) in acknowledging that this will have an impact on the propensity to adopt new technology. The majority of the firms (approx. 63%) represented in the data set has a low to medium low technology intensiveness. This corresponds well to the entire population of Danish manufacturing firm.
5. Findings and discussion

5.1 Descriptive data
Observing on the survey responses, only 25% of the manufacturing companies in the data sample use AM or print technologies, either as an external service (8%), as an internal competence (6%) or as a combination (11%). This compounds to AM ownership in 17% of the responding firms in the survey. The data indicate that size does not have a significant impact on the propensity to use AM. However, there is a clear connection between the level of technology intensity and the use of print technologies. Hence, high technology intensiveness is positively associated with use of AM technology. The preferred print technologies are dominated by the relatively simple FDM (Fused deposition) technology, which are also used by hobbyists. There is also a share who apply SLA (light exposure of resin fluid) and SLS (laser sintering in powder), which are still easy manageable technologies. The main external incentives for adopting the AM technology is the “new potential market opportunities”, whereas “pressure from customers and competitors” are less significant. Internally the motivation for adopting AM technology is significant associated with “fast prototyping”, quick validation of prototypes” and “development purposes”. “Time to market” and “fast part production” has a less significant importance. This observed R&D driven motivation and the predominant use of relatively simple AM technologies focused on prototyping match falls in line with the trend described by Oettmeier and Hofmann (Oettmeier & Hofmann, 2016).

The further analysis of the surveyed data focuses on the relation between the different domains of usage of AM technology in combination with the AM maturity held by the company.

5.2 Analyzing AM maturity and usage domain
The responding manufacturing companies has been categorized into the four main categories based on the AM maturity framework proposed in figure 4. The categories are defined in relation to the ownership of 3D print technology competencies. Accordingly, the categories are as follow; 1) non-users with no AM awareness, neither competencies or knowledge, 2) outsourcing the AM
competencies to a services- or technology provider, possessing application knowledge, 3) in-housing the technology either through ownership or leasing, building both knowledge and competencies, and 4) Combining AM technology ownership and outsourcing specific tasks or services. This provides a gradually increasing maturity scale for categorization of the responding companies. As a second parameter, the actual usage of AM technology is also categorized in relation to the three main domains; 1) Product development (rapid prototyping), 2) Production support (direct tooling of molds, fixtures, supporting tools for production) and 3) Part production (Direct manufacturing). This creates a two-dimensional matrix to categories the sample firms in relation to AM maturity and domain use. Figure 5, represent the classification of the sample firms in relation to the two dimensions. All cases using AM (either owning, leasing or purchasing the service) have furthermore assessed the “used potential of the technology” in a “low-medium-high” scale, depending on the application area (usage domain). As argued earlier in the theoretical framework development extended usage, and output of the AM technology will increase the potential for competitive advantage. Thus, we argue that the “used potential of the technology” is an indicator of potential competitive advantage for the company case.
Figure 5: Findings from national AM screening – Distribution of usage domain

Of the 286 cases, 214 (75%) did not use AM print technology, 24 (8%) cases purchase services from technology or service providers, and 48 (17%) cases owned their own technology (including a subcategory which also purchased services from technology providers). 27 companies are only active in one usage domain (colored black), 25 companies are active in two domains (colored red) and 20 companies are active in all three domains (colored green). Each group of case companies has been organized and average scores (1 is low and 3 is high) been calculated based on their “used potential of the technology” and plotted into the maturity – domain matrix in figure 5. As an example, the group of firms active in the “product development” and “production support” domain, who has the AM technology in-house has been marked with a red color. The group of companies has been plotted
in the section between the “in-house” level, and the two relevant domains. In the “Product development”-domain the companies average score of “used potential of the technology” is 2.2 (maximum score 3). In the “Production support”-domain the average score in 1.2 for the same group of companies. In this case, it becomes clear that the companies possessing their own AM printer, being active in the two domains (Product development and Production support) have a higher used potential of their technology within Product development than in Production support.

Based on the collected data from the national screening there are some significant findings in relation to utilized potential of AM technology.

Firstly, in observing on figure 5 we see that the highest level of “used potential of the technology” among the usage domains is found in the product development domain. The lowest level of used level is found in connection to the parts production domain. This trend is evident for firms active in both one, two, and all usage domains. This indicate that “product development” domain currently has the lowest entry barrier. The “part production” domain has in general a lower “used potential of the technology” than the part production domain.

Secondly, figure 5 illustrate that the more domains a firm is active in, the higher level of “used potential of the technology”. Companies active in all the domains have a significant higher level of “used potential of the technology”, than those active in two. This tendency is particular apparent in relation firms active in only one domain. This indicates a knowledge building effect, resulting in an integrative effect across domains.

Thirdly, figure 5 also exhibits that the higher in the maturity level the company is, the higher the level of “used potential of the technology”. In other words, Companies that both own and source AM technology competencies, has an overall higher level of “used potential of the technology” than companies sourcing the AM services or only printing on in-house AM printers. This indicate that companies could maximize the benefit from AM technologies through engaging in a mixed approach
involving both own AM activities and collaborate with external partners. The complexity in different AM technologies could explain that the mixed approach has the highest potential, due to a two track (internal/external) knowledge and competence building.

In summary the data sample indicates a significant positive relation between the “used potential of the technology” and 1) the number of usage AM domains companies are active in and 2) a high AM maturity level.

5.3 AM technology impact on business model
In addition to tracking and classifying the sample firms in relation to AM maturity and domain use, the data sample also delves into how AM technology has impacted the firm’s business model and the product- and process innovation. The responding manufacturing companies has been asked if their interaction with AM technology have had influence on their business, eg. change in business model or development of such. The data points to more impact on business model the higher level of AM maturity the companies hold. In the group with companies only sourcing AM technology competencies 29% answer that there has been an impact on business model. In the group of companies that own their own AM technology 56% thinks their business has changed due to interaction with AM technology. At the highest level of AM maturity (companies that both insource and outsource the AM technology) 63% of the companies thinks their business have been influenced directly by their interaction with AM technology.

Change and influence on the company business model is comparable with innovation within market approach, equivalent with market innovation (Damanpour, 1991).

5.4 AM technology impact on innovation
In parallel with the survey questions regarding AM activities the responding manufacturing companies have also answered questions related to their innovation activities, respectively process and product innovation. Table 2 and 3 presents data of the relation between company activity in usage domains and AM maturity level versus and product innovation (incremental and radical) and process
innovation. The responding companies have answered concerning their introduction of new products or technologies within the last three years (2015-2017). In relation to new product introduction, respondents have answered to which degree the product were new to the company (incremental) or to the market (radical).

<table>
<thead>
<tr>
<th>Company AM activity within usage domains; product development, production support and part production</th>
<th>Product innovation</th>
<th>Process innovation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Use AM in all three domains</td>
<td>Incremental</td>
<td>Radical</td>
</tr>
<tr>
<td></td>
<td>85%</td>
<td>65%</td>
</tr>
<tr>
<td>Use AM in two domains*</td>
<td>88%</td>
<td>72%</td>
</tr>
<tr>
<td>Use AM in one domain*</td>
<td>66%</td>
<td>30%</td>
</tr>
<tr>
<td>No use of AM technology</td>
<td>52%</td>
<td>24%</td>
</tr>
</tbody>
</table>

*Usage domain is unspecified

Table 2 Company AM activity in domains compared with product and process innovation

Table 2 compares the company AM domain related activities in relation to product- and process innovation. It is evident that AM technology activities (in table 2) have significant impact on the innovative capabilities, both within product and process. It is however more significant that moving from activities in one domain into two or three will increase the innovative capabilities. Especially the radical innovation share increase from 30% to 72% which indicate that bridging between domains increase the innovative capabilities, particular radical innovation.

<table>
<thead>
<tr>
<th>Company AM maturity level</th>
<th>Product innovation</th>
<th>Process innovation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Incremental</td>
<td>Radical</td>
</tr>
<tr>
<td>Level 4: Inhouse + outsourcing</td>
<td>81%</td>
<td>56%</td>
</tr>
<tr>
<td>Level 3: Inhouse</td>
<td>81%</td>
<td>50%</td>
</tr>
<tr>
<td>Level 2: Outsourcing</td>
<td>75%</td>
<td>54%</td>
</tr>
<tr>
<td>Level 1: Non-user</td>
<td>52%</td>
<td>24%</td>
</tr>
</tbody>
</table>

Table 3 Company AM maturity level compared with product and process innovation

Table 3 compares the company AM maturity level in relation to product- and process innovation. Within product innovation, the most significant difference is in the transition from being non-user to user, either through service/technology provider, or technology owner. The process innovative has a different pattern, and the change in process innovation follows the change between in- and outsourcing the AM technology. 29% of the companies not owning AM technologies experience
process innovation, whereas companies who own their own AM technology has an increase to 63%. This indicates the importance of building knowledge and competencies through ownership.

The analysis of the relation between AM technology and innovation capabilities revealed some significant relations to support the increase of innovation, especially radical innovation. Technology ownership supports (based on maturity level) the development of incremental innovation, whereas it is integration between application domains that support the highest level of radical innovation. The level of process innovation is most sensitive towards the transfer.

6. Contribution

This paper contributes to the literature on technology management in the analysis of the relationship between the AM technologies and their associated competitive potentials. In this way, we present novel data and insights ready for theorizing on the role of enabling technologies for future competitiveness. This paper addresses the needed cross disciplinary approach to provide an appropriate level of abstraction in analyzing technology management in complex value chains. Emerging technologies can potentially impact various level and functions in the industrial value system, as conceptualized in “the coupling model of innovation” (Rothwell, 1994, p. 10, fig. 3).

Particularly, we notice other emerging technologies with similar properties like robotics, drones and InternetofThings (IoT), which may benefit from the insights on industrial dynamics obtained in this study.

Based on a unique data set, not collected before, it has been possible to get insights in the relations between technology, innovation and operations management, aiming for increase the company competitiveness. This paper does furthermore contribute with managerial implications in regard to the understanding of AM application domains and their relation to AM maturity. The AM technology management and its impact on radical innovation capabilities will potentially be a game changer for Danish manufacturing companies.
Based the findings figure 3, the conceptual framework has been updated, see figure 6.

We point to the potential for design for AM where new designs become possible, through introduction in the manufacturing system, opportunities become available in the innovation process, see 4). In the same way various combinations of 1), 2), 3) and 4) will result in market innovation and development of business model, aiming for competitiveness.

Furthermore, this paper specifically contributes to the much needed, but still scarce and fragmented literature, on decision models of AM (Oettmeier & Hofmann, 2016; Pour et al., 2015). We stress that this is only the first small step in assessing the potential of AM in specific manufacturing contexts.
1. References


Brettel, M., Klein, M., Friederichsen, N. 2016 The relevance of manufacturing flexibility in the context of Industrie 4.0, Procedia CIRP 41, p. 105 – 110


