Successful approaches for implementing additive manufacturing

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Received 28 December 2019
Revised 29 February 2020
Accepted 9 March 2020

Abstract

Purpose – The purpose of this qualitative, multiple-case study was to explore the successful strategies that managers of light and high-tech small and medium-sized manufacturing companies in the Netherlands, use to adopt additive manufacturing (AM) technology into their business models.

Design/methodology/approach – A qualitative, multiple-case study approach was used. The participants for this study consisted of executive-level managers of light and high-tech manufacturing companies in the Netherlands. Company documents were studied, and individual interviews were undertaken with participants to gain an understanding of the strategies they used to adopt AM technology into their business models.

Findings – Three significant themes emerged from the data analysis: identify business opportunities for AM technology, experiment with AM technology and embed AM technology.

Research limitations/implications – The findings of this study could be of advantage to industry leaders and manufacturing managers who are contemplating to adopt AM in their business models.

Originality/value – This study may contribute to the further proliferation of AM technology. Industry leaders may also gain a clearer understanding of the effects of 3DP on local employment. The results of the study may also work as a catalyst for increased awareness for manufacturing firm leaders who have not yet considered the opportunities and threats AM technology presents to their organizations.

Keywords Additive manufacturing, 3D printing, Innovation adoption, Disruptive innovation, Supply chain management

Paper type Research paper

Introduction

Hull (2015) invented additive manufacturing (AM) in 1983. In the United States, the automotive and aviation industries were early adopters of this innovative technology. After essential patents expired in the 2000s, new companies selling AM equipment emerged rapidly (Yeh, 2014). AM technology builds items layer by layer, thereby enabling design freedom and supporting the production of customized products in small series (Gibson *et al.*, 2015). Uncoupling design and production enable local production that may lead to the rise of advanced business models and supply chains. Products made using AM may be lighter or even stronger than products created with traditional manufacturing processes (Thomas and Gilbert, 2014). Moreover, items produced with AM enhance sustainability (Mani *et al.*, 2014; Thiesse *et al.*, 2015) as they can be designed lighter, produced locally and require fewer natural resources (Despeisse and Ford, 2015). These phenomena have the characteristics of a disruptive innovation that may affect existing marketplaces but also may offer new opportunities through innovative business models (Amshoff *et al.*, 2015).

The authors would like to thank Dr Robert Martens for providing the seminal research, which significantly contributed to development of the paper.

World Journal of Entrepreneurship, Management and Sustainable Development
Vol. 16 No. 2, 2020
pp. 131-148

2042-5961
DOI 10.1108/WJEMSD-12-2019-0100

Research methodology/design

A research design outlines the framework for the main components of a study: what to ask, which data to collect, and how to evaluate this data (Yin, 2018). With the qualitative research approach, the most common designs are case studies, phenomenology or narrative inquiry (Collis and Hussey, 2014; Dixon, 2015; McNulty *et al.*, 2013). An exploratory multiple-case study is a suitable research design to explore a phenomenon (Dixon, 2015; Houghton *et al.*, 2013; Yin, 2018). In this study, the researcher attempted to answer how or what questions on a complex contemporary phenomenon. Cronin (2014) argued that using case studies generates a wealth of experience and allows readers to view the study through the eyes of the researcher, thereby creating more acceptance of the research conducted. A method to increase the validity of a study is methodological triangulation by data saturation. Data saturation originates from grounded theory, but it also applies to case studies (Cleary *et al.*, 2014). When researchers obtain sufficient information for their study to be replicated and no additional information can be acquired, they achieve data saturation (Fusch and Ness, 2015; Houghton *et al.*, 2013; Robinson, 2014). Saturated data consist of information that is both rich, meaning high quality and thick, meaning large quantity (Fusch and Ness, 2015).

Purposeful sampling was used for this study. Elo *et al.* (2014) and Kaczynski *et al.* (2014) indicated that no set rules exist to decide the sample size for a case study. Ishak and Abu Bakar (2014) argued that purposeful sampling is appropriate when researchers: (1) wish to select particularly interesting cases, (2) want to include members of specialist groups and (3) wish to select specific case types to study more intensely.

Based on the principles of purposeful sampling, a sample size of four participants was used, each one from four different companies. Yin (2018) argued that sample sizes of two or three are adequate for multiple-case studies where no utmost certainty is required. By interviewing four participants and reviewing documents such as business plans, reports, meeting minutes, memos, e-mails, organizational charts or market surveys, data saturation was expected to be achieved. However, interviewing more participants and reviewing more documents continued until no new information emerged. In case studies, obtaining quality data through rich description is more important than acquiring thick data through larger size populations (Morse, 2015; Palinkas *et al.*, 2015).

The target population consisted of senior-level executives with comprehensive expertise in the subject area within different light and high-tech manufacturing companies in the Netherlands. In addition, methodological triangulation was used to ameliorate the validity of the research findings from various sources, which included semistructured interviews, company documents, a review of publicly available data and internal and external websites. Atlas.ti was used as QDAS to assist in the organization, assessment, querying, matching and explanation of the collected data to develop themes.

Conceptual framework

In 1997, Christensen introduced the disruptive technology theory, later relabeled the disruptive innovation theory (Christensen, 2006). In this theory, Christensen (2016) described a process where at first, people use innovative products or services in uncomplicated situations outside the mainstream application. Next, the disruptive innovators take over the existing market and, in the end, force incumbent companies out (Christensen, 2016). Often, disruptive technologies initially perform less well than current technologies (Christensen, 2016). Novel technologies attract first users because of their distinctive features, such as more natural use or convenience, cost, smaller or more flexible than existing technologies (Christensen, 2016). Usually, incumbent firms' most profitable clients are initially not interested in these innovations, so, as a result, disrupters can test their innovative technologies in smaller markets that existing companies tend to ignore (Christensen, 2016). Slowly, the novel technology improves, in performance or price, until demands of the mainstream marketplace are met; this is the moment the disruptive technology supplants the most prevalent technology, and new firms replace nonadapting companies (Christensen, 2016). The emergence of AM technology shows a similar pattern to that covered in the theory of disruptive innovation (Bogers *et al.*, 2016). Therefore, this theory was a lens for understanding the findings of this study.

Literature review

The term disruption has an alarming connotation among business leaders (Gans, 2016). King and Baatartogtokh (2015) argued that Christensen's (2016) theory of disruptive innovation has value but should be applied sparingly and in the right situation. When faced with an industry disruption, managers need to know how to react, but the theory of disruptive innovation is not a lens that managers use to determine how to respond to disruptions. Instead, the concept supports making strategic choices between investing in sustaining or disruptive innovations (Christensen *et al.*, 2015). Gans (2016) warned executives who have identified potential disruption to their companies to act, since having too much self-confidence is an evil advisor in circumstances of disruptive innovations.

Additive manufacturing

Arising out of the many patents and their owners' fierce protection, companies first mostly used 3DP for rapidly creating prototypes. Upon the expiration of some essential patents in 2004 and 2009, more competitors entered the market resulting in substantial growth of AM equipment sold (Gibson *et al.*, 2015). The first application of AM was with the do-it-yourself and maker movement platforms (Gao *et al.*, 2015). Mashhadi *et al.* (2015) argued that AM had undergone a dramatic transformation, which still has not ended. Gao *et al.* (2015) expected the scale and quality of the AM technology would soon improve sufficiently to enter mainstream markets.

Building items layer by layer brings design freedom and generates less waste. As a result, products made by AM can be lighter (Huang *et al.*, 2017; Lindemann *et al.*, 2015), or stronger than products made by traditional manufacturing processes (Duchêne *et al.*, 2016; Liu *et al.*, 2014). Moreover, Thiesse *et al.* (2015) mentioned that the adoption of AM enables creating products that companies cannot create with any other manufacturing process. Also, the total amount of energy required using AM is lower compared to conventional production methods (Gebler *et al.*, 2014; Huang *et al.*, 2015) and it requires less raw materials to produce items (Burkhart and Aurich, 2015; Lindemann *et al.*, 2015). The freedom of design enables manufacturing of complex (Mashhadi *et al.*, 2015; Slotwinski, 2014; Weller *et al.*, 2015) customized (Fawcett and Waller, 2014; Weller *et al.*, 2015), or even personalized products (Bogers *et al.*, 2016; Gress and Kalafsky, 2015). Those items could be made in small series (Ford, 2014; Sasson and Johnson, 2016), up to single objects (Thomas and Gilbert, 2014). Before the rise of AM technology, only artisans could produce small series, unique products or customizatize at excessive cost (Chen *et al.*, 2015); though consistent reliability and controllability of the product was difficult to achieve (Sandström, 2016). During the manufacturing process, in combination with the possibility to optimize product design, companies have achieved remarkable results in improving parts used to build their products. To illustrate: engineers at Airbus used AM to create parts that were 67% lighter, and General Electric redesigned fuel nozzles as one unit, originally consisting of 18 parts (Knofius *et al.*, 2016), as well, product weight was reduced by 84% (Camisa *et al.*, 2014). Other examples are Lockheed Martin's joint strike fighter brackets and Airbus' aircraft components, using 90% less energy and weighing 30–55% less (Camisa *et al.*, 2014). Assertive customers are demanding faster delivery and more personalized items. Lindemann *et al.* (2015) postulated that the modern manufacturing industry is a highly competitive, global sourcing environment encountering increased customer demands for innovative and customized or individualized products. Furthermore, because the lifetime of goods is reducing, a faster time-to-market is required; AM can support these needs (Khorram Niaki and Nonino, 2017a; Lindemann *et al.*, 2015).

AM has not yet reached the same level of adoption as traditional production methods, but indications exist 3DP has ignited the third industrial revolution (Andrews, 2015). Amshoff *et al.* (2015), Bogers *et al.* (2016), Gibson *et al.* (2015) and Hahn *et al.* (2014) considered AM to be a disruptive innovation. D'Aveni (2015) expected AM to upturn businesses in the short term. The success of disruptive innovations is interlinked with the business models in which managers apply them. Amshoff *et al.* (2015) posited that disruptive technologies, such as AM, both pose a threat and offer opportunities to incumbent companies as they affect established value chains and initiate new business models. Bogers *et al.* (2016) expected AM to revolutionize the production processes of the consumer goods industry. Therefore, 3DP poses a significant problem to, but also opportunities for, companies' existing and contemporary business models (Bogers *et al.*, 2016). However, Steenhuis and Pretorius (2016) argued that when consumers use AM on a larger scale, this will affect actual business models, but not in the way Christensen defined disruptive innovations. Ortt (2017) confirmed that AM is a disruptive innovation that currently only affects niche markets. Amshoff *et al.* (2015) argued that extant business models are often not suitable for disruptive technologies as the market for their products is just opening.

Local production of goods will affect existing supply chains. As Mohr and Khan (2015) posited, 3DP technology is one of the most disruptive innovations impacting global supply chains. Holmström and Partanen (2014) concluded that AM has the potential to transform the supply chains of sophisticated, high-value equipment, mainly in the areas of after-sales service. Moving manufacturing closer to the end-user, reducing inventory (cost) and demand consolidation all are opportunities for the supply chain (Khorram Niaki and Nonino, 2017b). Holmström and Partanen believed that logistics service providers would be the catalyst for this transformation, but they emphasized that product re-engineering will be required to establish the critical mass needed for AM to utilize the potential for change entirely. Therefore, AM could exist side-by-side with and in addition to traditional manufacturing (Rogers *et al.*, 2016; Sasson and Johnson, 2016). However, Durach *et al.* (2017) concluded that prosumers, lower inventory requirements, and mass customization would have insignificant effects on existing supply chains. AM technology minimizes the number of nodes in a supply network. This reduced complexity decreases the risk of supply chain disruption (Thomas and Gilbert, 2014). Additionally, deploying AM enables localized production in small factories, which further reduces the risk of supply disruption (Thomas and Gilbert, 2014).

Using AM has a broad impact on society, but the effects are not well understood (Ford *et al.*, 2016). Gebler *et al.* (2014) found that AM technology has the potential to sustainably lower energy consumption and CO_2 emissions. The European Commission (2014) argued that AM could disconcert existing value chains, but it could also substantially support the European economy because of the potential to create new employment positions. AM technology has the potential to positively affect the European economy by bringing back high-tech manufacturing jobs to Europe (European Commission, 2014) and America (Schniederjans, 2017). Notwithstanding this anticipated shift of labor, Garrett (2014) recognized opportunities for governments in developing countries to support local production, utilizing 3DP. Besides the safety, security and military challenges AM brings, Garrett expected 3DP to cause substantial social and geopolitical impact. Using AM may also improve emergency responses. Tatham *et al.* (2015) argued that 3DP technology has a positive social impact as it mitigates logistical challenges during rescue activities, such as out-of-stock, long lead times or hold-ups during customs clearance. Despite this potential for positive social change, governments and academics need to understand and acknowledge this potential and remove roadblocks for it to come to fruition (Gebler *et al.*, 2014).

Faludi *et al.* considered preceding claims that 3DP is more environmentally friendly than traditional manufacturing depends on the equipment utilization rate, which has a substantial effect on energy usage. Nevertheless, at maximum use, material usage and waste creation of AM equipment compared to CNC machines are substantially lower (Faludi *et al.*, 2015). Resulting from simpler and shorter supply chains, goods produced by AM require less transportation. Gebler *et al.* (2014) argued that the industrial sector needs substantial changes to become more sustainable as this area uses 22% of the world's total final energy consumption and produces 20% of global CO_2 emissions. Huang *et al.* (2015) estimated that 33–50% energy reduction during manufacturing is possible with 3DP compared to conventional methods. Furthermore, as AM enables producing goods closer to their area of use, shorter and more straightforward supply chains will emerge, requiring less amount of transportation (Barz *et al.*, 2016), thereby reducing CO_2 emissions (Garrett, 2014). Despeisse *et al.* (2017) posited that 3DP could support circular economies. Nevertheless, Brennan *et al.* (2015) warned for over-optimism as increased amounts of consumerism could lead to increased waste production.

Moving production activities back to Western countries will positively affect local employment there. Brennan *et al.* (2015) investigated the increase or decrease of offshoring of manufacturing related to contemporary trends, such as lean or AM, and argued that the trend of reshoring is visible but not (yet) significant, but they considered AM has the characteristics to accelerate this process. Labor cost in developed nations is higher than in developing countries, but this does not necessarily result in cost increases for products made with AM. Achillas *et al.* (2015) argued that AM is suitable for producing low-volume products, or items requiring multiple molds, which is the source of longer lead times. The effect of 3DP on global value chains mainly lies in the relocation of labor from centralized manufacturing locations, such as China, closer to consumers (Garrett, 2014; Laplume *et al.*, 2016). Moreover, Lehmhus *et al.* (2015) posited that AM will disrupt global supply chains and will move manufacturing back to higher-wage regions that have lost their making industry.

Brennan *et al.* (2015) indicated the lack of skilled labor in areas where traditional manufacturing has disappeared, thereby creating barriers for reshoring production. Furthermore, Simpson *et al.* (2017) highlighted the lack of skilled labor to operate AM equipment. Conversely, Tatham *et al.* (2015) argued that 3DP technology has a positive social impact as it mitigates logistical challenges during emergency responses; longer-term, 3DP could lead to new industries in remote locations, giving a source of income to the poor, a situation Gress and Kalafsky (2015) called spatial leapfrogging. Moreover, Dumitrescu and Tănase (2016) argued that countries with trade deficits could exploit 3DP to offset this problem.

Disruptive technologies, such as AM, pose both a threat and offer opportunities to existing companies. Established value chains are affected, and new business models initiated (Amshoff *et al.*, 2015; Ortt, 2016; Rylands *et al.*, 2016). With AM, managers now can develop innovative business models (Rylands *et al.*, 2016; Thiesse *et al.*, 2015) and change, or even disrupt current models (Bogers *et al.*, 2016). Kianian *et al.* (2016) revealed another benefit for companies deploying 3DP: the possibility to create end-products using substantially less material and time. These advantages enable firms to bring products to the market faster than before (Kianian *et al.*, 2016). Moreover, Soomro *et al.* (2016) argued that AM enables value chains based on push instead of pull mechanisms.

Ford and Despeisse (2016) referred to Christensen's (2016) disruptive innovation theory and emphasized the importance of entrepreneurs to investigate different business opportunities that 3DP offers. Furthermore, incumbent firms need to examine AM's potential for their organization and develop and test new business models (Bogers *et al.*, 2016). Whereas, other scholars pointed at the legacy of the use of AM for RP may create a psychological barrier to management when contemplating to utilize AM technology (Mellor et al., 2014) or warned companies to investigate what business model they would like to deploy 3DP in before implementing this technology (Rayna and Striukova, 2016). AM reduces the number of assembly activities, requiring re-engineering of business processes (Thomas and Gilbert, 2014). Hence, Thomas and Gilbert posited that companies adopting 3DP are taking considerable risks, which impedes this technology's level of diffusion. Every company, industry or government must take a strategic position on what AM means to them (Beyer, 2014), but having a business strategy, whether to wait-and-see or to adopt actively innovative technologies, both have their merits (Sandström, 2016).

Nevertheless, Holmström *et al.* (2016) warned practitioners and researchers to be alert. Although Holmström *et al.* did not expect DDM to replace mass and batch production shortly, they argued that many operations management activities, such as production planning and inventory management, are likely to be affected or even become redundant. Notably, it took the internet, a disruptive technology, almost 20 years to achieve maximum potential, yet 3DP has already started a revolution that will change our lives, similar to the proliferation of information on the internet, AM technology will require only half this time (Dumitrescu and Tănase, 2016).

Discussion of findings

The three major themes that emerged from the data were: (1) identify business opportunities for AM technology, (2) experiment with AM technology and (3) embed AM technology.

Theme 1: identify business opportunities for AM technology

Demil *et al.* (2015) pointed at the importance of understanding customers' latent requirements, whereas Christensen and Raynor (2003) emphasized that companies formulating strategies should endeavor to understand how and under what circumstances customers use items, not focus on the customers themselves. Triggered by the substantial attention that 3DP received in the media, participant companies all considered using AM, as they believed that this technology could give them a competitive advantage. In line with previous research, the first theme to emerge, identify business opportunities for AM technology, had two subthemes: (1) understanding the market that valued such advantages and (2) conducting market research to identify competitive advantages, such as technical opportunities, cost-saving opportunities, and lead time reduction.

All participant companies identified markets where customers would value some of the unique characteristics of AM: low volume, high complexity, customization or short production time. Furthermore, as Ortt (2017) and Weller *et al.* (2015) predicted, all those customers operate in or supply to niche markets: the medical implants and tools sector, Formula One race cars, spare parts, racing yachts and aerospace parts. Besides the medical sector, which is willing to pay higher prices for low volume items made with traditional subtractive manufacturing techniques, such niche markets are often ignored as traditional equipment setup costs would be too high (Rayna and Striukova, 2016). In such markets, adopting AM might offer a competitive advantage (Piller *et al.*, 2015).

Firms operating in more traditional markets experienced limited customer interest in products made with AM. P3 noticed that clients often do not understand what to do with 3DP; their engineers do not have the right mindset to consider the benefits of AM and often dismiss the technology as they see it as a threat to their position, whereas buyers just expect a lower price. P4 blamed this inertia mostly on the reluctance of senior engineers: "The speed of adoption is the speed by which engineers are prepared to consider applying AM . . . no client was pushing us to start with 3D printing." Consequently, C3 mostly has new customers for their AM equipment as they believed that there is not much that they can offer existing clients; although this was their original intent. Slowly, their AM capabilities generated more business from new customers. P2 argued that it is a misconception that you can buy a 3D printer, and then the new business will come automatically. Metal 3DP is complex. P3 confirmed this stance when explaining that C3 decided to acquire AM equipment as a new technical competence but later discovered that their existing customer base was hardly interested in this technology.

To establish a sustainable competitive advantage, manufacturing firms need to develop capabilities that competitors cannot easily replicate (Slack and Lewis, 2015). Contrary to 3DP hubs, whose core capability is to produce a plethora of items using specific AM equipment, existing firms adopting AM into their business models can offer a blend of flexible manufacturing together with their existing competencies, thereby offering a unique selling proposition. To attract clients' attention in 3D printed products, firms implementing AM need to emphasize to customers the benefits of using this technology. As most participant companies are machining shops, they can also offer surface finishing of products made by AM as a one-stop-shop; a competitive advantage over a 3D-printing hub. As a value-added logistics service provider, C1 can offer a combination of supply chain management and AM services. In such hybrid manufacturing models, the advantages and disadvantages of the existing and new technologies are more balanced (Newman *et al.*, 2015). A traditional process for manufacturing complex shapes is molding, sand casting and lost-wax casting, processes not designed for fast delivery, small quantities, shape modifications or customization (Conner *et al.*, 2014). AM is an alternative technology that solves these constraints. P1 stated, "I think 3D printing should be seen as a replacement for casting rather than milling or machining." P3 echoed this stance "Small series with faster delivery times . . . you can design differently or can design hollow or easier, for example, to create a kind of sloping surface. Sometimes it is . . . about the small runs or faster delivery times."

Another opportunity that the use of 3DP enables is the possibility for high levels of customization. Eggenberger *et al.* (2018) mentioned the plans some car makers have for customization of their vehicles. P1 recognized the potential role that the company could facilitate in such a future supply chain. P1 explained:

> Our customers in this exploration say, "Our future thought is to build a basic car, with fifty to sixty parts, which are 3D designed, which are replaceable. In color, shape, material, etcetera." So, they sell a car, once, but they can sell the fifty to sixty spare parts thousands of times every year. . . . Because you have new shapes, new dashboards you can- if you have a midlife crisis- you can change your basic car into a sports car because it is possible. C1 demonstrated its aptitude for providing a solution to customer's problems, even problems their clients had not yet thought of.

To optimally benefit from the geometric freedom of AM, products need to be designed for use with this technology. Therefore, existing components often require redesign (Klahn *et al.*, 2014). However, design engineers need to have a thorough understanding of the aspects of AM (Klahn *et al.*, 2015). When existing parts are redesigned for AM, they may be sold at higher prices, outweighing the higher production cost (Eggenberger *et al.*, 2018). Current design methods are mostly based on subtractive manufacturing methods, limiting engineers' creativity (Salonitis and Al Zarban, 2015). P4 lamented that "80% of the applications they receive are not designed for 3D printing." P2 echoed this issue by pointing out that C2 often received customers' requests for proposal for reproducing existing items with AM at a lower cost. Such requests never led to success because the benefits of AM mostly lie in producing items with designs optimized for 3DP. A change in the education of engineers to equip them with the skills to functionally design items is an essential factor for the successful diffusion of AM technology (Gausemeier *et al.*, 2012). P2 said that it should really be part of the technical curriculum: the possibilities and impossibilities of 3D printing before expanding to mainstream.

Theme 2: experiment with additive manufacturing technology

Although the European Union funded comparable initiatives, currently no AM collaborative experimentation program exists in the Netherlands. Therefore, the participant firms, Dutch small to medium-sized enterprises (SME) that made a strategic choice to implement AM, had to develop a trial-and-error approach themselves. All firms participating in this study conducted extended experimenting with 3DP technology. The experimenting either took place internally, individually, or jointly with customers, suppliers, partners, or government agencies or externally in the form of a joint experimentation laboratory. Three subthemes are buttressing theme 2: internal piloting, joint internal piloting, and joint external piloting. These subthemes represent a crucial step in these firms' implementation of 3DP.

Contrary to a collaborative process of knowledge transfer, C1 and C3 followed an individual experimenting approach with AM technology. C1 purposely decided to establish an exploration lab. Through this lab, C1 explored the opportunities that 3DP could bring, attracted potential customers' attention to the possibilities of using AM for solving their supply chain challenges and produced some spare parts. C3 took a different approach: following its management's decision to buy a metal printing machine to complement the existing manufacturing capabilities, they had to test the new equipment themselves in a production environment. This experimenting took place in the form of heuristics. In hindsight, P3 would have preferred to conduct a pilot project before selecting a specific AM equipment brand and learning by trial-and-error during operations: "I think it would have been better for us if we had a pilot phase because … I do not know if we have had a pilot phase, we would have chosen the same equipment." Next to single firm experimentation with 3DP technology, the participants also joined forces with partners in trial-and-error the new technology.

Other than the internal experimenting that C1 and C3 conducted, C2 joined an initiative for a joint pilot program, called AddLab. Eight firms formed AddLab, consisting of machining companies, a 3DP hub, networking, and financing organizations. In this lab, C2 could experiment with different AM equipment and materials to identify the most suitable 3DP solution for their needs and learned how to utilize 3D technology. The main benefit of joint piloting in AddLab was, as P2 said, "The possibility to test various types of [AM] technology and transfer knowledge between the participants at limited financial investment. It was a responsible playground to test the state of the technology regarding hardware and software." Furthermore, following the piloting phase and understanding the severity of requirements for medical implants, P2 collaborated closely with its clients to develop AM capability; "unless if you decide to operate in the prototype market only, you have to cooperate with your customers closely."

One of the main benefits of AM is the freedom of design. Chiu and Lin (2016) emphasized the importance of early customer involvement with AM product design. However, because the participating firms either are contract manufacturers or value-added logistics service providers, product design lies outside their area of responsibility. Notwithstanding, early customer involvement often is used by firms to attach clients to a firm (Van der Zee *et al.*, 2015).Two participant firms involved their clients in the newly adopted technology. The phase when those customers participated and the depth of their role varied across the participants. Upon customers' positive reactions, P2, together with its clients, tested 3D printed medical implants to establish the right parameter setting and printing positions. In hindsight, P3 lamented, "It seems that you can only do this successfully together with your customer unless you elect to work in the prototype market where finished product properties are less important." When implementing new technology, supplier support often is critical. Van Dijk (2015) identified vendor support as one of the factors influencing AM adoption. All participant organizations involved their suppliers during the AM implementation process.

Theme 3: embed additive manufacturing technology

Embedding AM in the organization by adopting the technology and adjusting the firm's business model emerged as the third theme, supported by two subthemes: business model innovation and technology adoption. Embedding this novel technology requires new employee skills. Integrating an immature technology such as AM is a substantial challenge for SMEs (Zanetti *et al.*, 2016). Furthermore, those firms need to adapt their existing business model to adjust for the different opportunities that AM offers or should establish a separate business unit or legal entity to nurture the new technology. According to the University of Paderborn in Germany, adopting AM mostly does not radically alter companies' business models (University of Paderborn, n.d.). Building on Cotteleer and Joyce (2014), Steenhuis and Pretorius (2017) argued that companies adopting AM either improve their existing products by using their existing business model, create a new model or do both. Accordingly, four types of AM adoption could be distinguished: (1) stasis or equilibrium, (2) supply chain evolution, (3) product evolution and (4) business model evolution, which are noted in Table 1.

In the equilibrium phase, firms adopt AM to create more complex or customized products, either following customer demand or as a first step toward an enhanced business model or the creation of unique products (Cotteleer and Joyce, 2014). C2 and C3 operate in this phase. C1 is an example of a firm adopting AM to create a new supply chain for low volume or customized products, parallel but separate from their existing one. An example of a firm adopting AM in the product evolution phase is General Electric, making the complex fuel nozzles for their LEAP jet engines with 3DP equipment, thereby reducing the number of parts from 20 to one, also reducing weight with 20% (Conner *et al.*, 2014). Type 4 AM adoption currently is not widespread. Rare examples are: 3D printed five-story concrete buildings made by Chinese company Winsun (Kothman and Faber, 2016), the 3D printed, highly customized, chocolate products made by Miam Factory, a spin-off from the Belgium University of Leuven (Schofield and Colville, 2017). When C4 took a strategic decision to implement AM, they quickly discovered that no suitable AM technology existed for printing ceramic materials. Hence, they decided to develop this technology themselves. When their prototype machine became more mature, C4 started selling this equipment, parallel to using it for producing 3D printed ceramic products. Later, C4 also developed metal 3D printers, based on the same technological concept as used for the ceramic printers. By morphing from a ceramic products contract manufacturer to a 3DP equipment manufacturer, C4 can be considered a type IV AM adoption company.

All participating firms occupied a similar position in their supply chains: that of a contract manufacturer. This position did not change after implementing AM (except for the 3DP equipment that C4 developed and sells, next to their contract manufacturing activities). Nevertheless, when zooming into their manufacturing activities, business model differences between these organizations can be noticed. C1 accepts all 3DP activities, subcontracts design, metal printing and finishing activities in addition to its core logistics activities. C2, C3

Type	I	II	III	IV
Characteristic	Equilibrium	Supply chain evolution	Product evolution	Business model evolution
Product change	Low	Low	High	High
Supply chain change	Low	High	Low	High
Goal	Profit and cost reduction	Creating a profitable new market	Profit through higher performance and growth	Growth and innovation
Company	C2, C3, C4	C1		C4

Table 1. Types of additive Manufacturing adoption

and C4 all offer finishing and inspection/testing activities but avert taking responsibility for design activities, as they did before AM implementation.

Contrary to Amshoff *et al.* (2015), the participant firms demonstrated a non-transformational approach to business model innovation. It could be argued that C1 ignited a non-market disruption, competing against nonconsumption (Christensen and Raynor, 2003). Possibly, this risk-averse approach is caused by the significant cost business model innovation requires (Rayna and Striukova, 2016). For incumbent firms often no other choice than trial-and-error exist when it comes to business model innovation, and this heuristic process comes at a significant cost, particularly in case a new business model is developed in parallel (Rayna and Striukova, 2016). P2 confirmed, "additive manufacturing was added as an additional competence." In a hybrid model, traditional manufacturing is combined with AM capability, offering advantages like faster production, high finish quality or less assembly (Ford and Despeisse, 2016) and minimizing disadvantages (Newman *et al.*, 2015). The participants' choice for such a model seems prudent. Notwithstanding, P2 also warned that AM could "cannibalize existing products" by eventually replacing the conventional manufacturing methods. P3 noticed the new 3DP activities attracted new customers who subsequently also showed interest in their traditional machining activities.

Christensen and Raynor (2003) advised organizations fighting or creating disruptive innovations to establish an autonomous business unit. Such an organization does not have to be physically located elsewhere or have different shareholders. Merely, the idea is to establish a unit free of corporate culture, overhead, processes and cost structure. Sometimes, the choice where to establish the new technology does not result from deliberate strategic decisions but out of practical circumstances. C1 did not create a separate business unit but decided to establish the 3DP exploration lab in their value-added logistics and not in their logistics solutions organization as the leadership wanted P1, a senior manager of this organization, to lead this initiative. C2 did not set up a separate business unit either but embedded the AM capabilities in their medical division. However, resulting from the fast growth of AM-related orders, C2 procured more AM equipment, and C2's shareholders have decided to set up a separate organization for 3DP only, serving all companies in their holding. Sometimes, the separate unit eventually becomes or overflows the primary organization (Christensen and Raynor, 2003). P4 believed that this feeder firm could benefit more from its parent company, especially their knowledge of traditional machining. Therefore, P4 forecasted that C4 would eventually merge back into its parent organization. Markides (2006) described such an approach as creating feeder companies to colonize new markets that the central group later may take over.

Following the acquisition of 3DP equipment and the initial pilot phase, firms need to integrate these new resources into their organizations (Cremona *et al.*, 2016). AM production know-how is a source of competitive advantage (Cremona *et al.*, 2016; Holzmann *et al.*, 2017). Production know-how can be obtained from suppliers or established in-house. Wolff (2016) highlighted the different skillset AM engineers need, compared to traditional metal workers: computer literacy, metallurgy, gas flow, laser melting, mechanics or coordinate-measuring systems. Following the further adoption of 3DP technology, increasing demand for a competent industrial workforce emerged (Simpson *et al.*, 2017). When implementing AM into an existing manufacturing organization, companies require employees with different expertise (Oettmeier and Hofmann, 2016). Kothman and Faber (2016) argued that more automation of traditional manufacturing activities leads to a reduced need for lower-skilled workers, whereas a disruptive technology as AM requires highly skilled employees. P2 explained the effect on their workforce: "The team handling 3D printing here did not exist three years ago. They are all new people. They all have master's degrees. People who were involved with the development of 3D printers. Previously, we had workers educated at the vocational level, but are now they are all university-educated people."

The General Electric Corporation that already adopted 3DP on a large scale published a report on how advanced manufacturing technology affects the workforce of the future (Soltesz *et al.*, 2016). Soltesz *et al.* posited that the disruptions by innovations, such as AM, have resulted in workers having outdated competencies that will become redundant. Notwithstanding, these disruptive innovations also create new job opportunities at a more strategic or creative job level (Soltesz *et al.*, 2016). However, a scarcity of qualified AM engineers is expected (Van der Zee *et al.*, 2015). P1 even believed that "there is going to be a trade war . . . over people who are good at 3D modeling and engineering because that is the new gold."

During the piloting phase of the new technology, the participant firms accumulated knowledge about the particulars of work preparation and manufacturing parameter settings for 3D printed products. Additionally, some of the participant firms emphasized the importance of understanding general customer requirements that remain unchanged despite the new manufacturing technique: avoiding cross-contamination of materials, the oxygen content of final products, using anti-static floors, or product and process certification. Cremona *et al.* (2016) argued that such know-how is one of the most valuable intangible assets that a company may possess. As early adopters of AM technology, the participant firms have established a substantial competitive advantage that will be difficult to replicate by later entrants.

Conclusion

AM or 3DP, emerged as a disruptive technology affecting multiple organizations' business models and supply chains. Some first-mover companies have already implemented AM. From this multiple-case study, three major themes emerged: identify business opportunities for AM technology, experiment with AM technology, and embed AM technology. The findings showed that manufacturing firm managers adopted 3DP as a result of the potential competitive advantage that the technology offers instead of an attempt to disrupt the marketplace. All participant companies identified markets where customers would value some of the unique characteristics of AM: either low volume, high complexity, customized products or items requiring short delivery times. Mostly, those customers operated in niche markets. The participants in this study conducted extended periods of probing 3DP, either individually or jointly, with customers, suppliers, partners or government agencies. The findings of this study revealed the importance of managers first to understand the opportunities of 3DP and second, to conduct thorough market research to identify potential customers and marketplaces interested in products made with AM technology. Next, managers should plan for an extensive experimentation period required to learn how to operate this technology and to understand the products for which the use of AM could be attractive. Finally, managers need to select the appropriate business model for adoption of the new technology and recruit operators and engineers with the right skills and education, different from their existing workforce.

Recommendations for action and further research

Because AM impacts existing supply chains, manufacturing locations will move, consumers will become producers, production activities will be reshored, different workforce competencies will be required and traditional designs will change. The impact of this technology should not be underestimated. Therefore, managers and policymakers need to start considering the disruptive effects of 3DP to their business and society. A research limitation was the relatively small sample size, the type of participating firms and limiting the geographic boundaries to three provinces of a small country like the Netherlands. Therefore, further research is recommended on a larger participant size. Furthermore, as the diffusion of

AM technology is spreading, conducting a similar study using quantitative or mixed research methods could reveal more insights into strategies used for adopting 3DP. Further research could also include AM service organizations or manufacturing firms in other provinces or countries.

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