

Additive Manufacturing and Business Models: Current Knowledge and Missing Perspectives

Christina Öberg, Tawfiq Shams, and Nader Asnafi

“With 3D printing, complexity is free. The printer doesn’t care if it makes the most rudimentary shape or the most complex shape, and this is completely turning design and manufacturing on its head as we know it.”

Avi Reichental
CEO, 3D Systems

Additive manufacturing, that is 3D printing technology, may change the way companies operate their businesses. This article adopts a business model perspective to create an understanding of what we know about these changes. It summarizes current knowledge on additive manufacturing within management and business research, and it discusses future research directions in relation to business models for additive manufacturing. Using the scientific database Web of Science, 116 journal articles were identified. The literature review reveals that most research concerns manufacturing optimization. A more holistic view of the changes that additive manufacturing may bring about for firms is needed, as is more research on changed value propositions, and customer/sales-related issues. The article contributes to previous research by systematically summarizing additive manufacturing research in the business and management literature, and by highlighting areas for further investigation related to the business models of individual firms.

Introduction

In recent years, interest has risen in additive manufacturing, that is, layer-based 3D printing of goods (Conner et al., 2014; Go & Hart, 2016). Although concerns are still placed on the challenges of getting the technology to work (Gardan, 2016), several industry actors have started to explore the business potential of additive manufacturing. Research largely remains focused on the technological advancement, although voices have recently been raised about how additive manufacturing research needs to be integrated with industry (Simpson et al., 2017), and thereby affecting business practices. In short, additive manufacturing is expected to change the ways in which business is run (Brennan et al., 2015; MacCarthy et al., 2016).

This article focuses on the meaning of additive manufacturing for individual firms by adopting a business model perspective (Osterwalder & Pigneur, 2010; Zott et al., 2011) on additive manufacturing. Business models refer to conceptual descriptions of a company and its business logic (Osterwalder et al., 2005; Zott et al., 2011),

that is, how the company is organized and earns its income. Business *modelling* describes change processes related to how business is pursued (Zott & Amit, 2010). For additive manufacturing, such changes would follow from the perspective for local manufacturing (e.g., Rogers et al., 2016), but also from completely new designs and materials (Sharma et al., 2017), and companies may try to reposition themselves along the supply chain as their current positions are challenged by local manufacturing and home-based production, for instance (Shams & Öberg, 2017), in turn affecting the business models.

This article addresses whether companies’ business models and changes to them are considered in the present literature on additive manufacturing, and how changes to individual companies’ operations can be understood from present research. The article presents a literature review on additive manufacturing with the underlying question of whether and how the research indicates new business models of companies, the transformation of current business models, or the development of completely new ones. The purpose of the

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article is to summarize current knowledge on additive manufacturing within management and business research, and to discuss future research directions in relation to business models for additive manufacturing.

The article contributes to previous research by examining how the emergence of additive manufacturing affects existing business models. It further points out research gaps in the intersection of additive manufacturing and business models. The contributions are important due to the emerging practical interest in additive manufacturing (Simpson et al., 2017) and because the literature specifically focusing on business models and their changes related to additive manufacturing has not previously been systematically summarized and analyzed.

The rest of the article is structured as follows. After this introduction, the theoretical building block of business models is presented, followed by the research design. Findings from the literature review are described and analyzed by looking into business model traces in the literature. The article ends with conclusions and a description of a future research agenda on additive manufacturing linked to business models.

Business Models

Business models describe a company's business logic: what it does, how it is organized, how it earns its income, and how it reaches those resources needed (Osterwalder & Pigneur, 2010). They thereby adopt a holistic perspective on the company's business (Bolton & Hannon, 2016) and link various activities together (Zott & Amit, 2010) at the centre of what is offered to customers (Margretta, 2002; Teece, 2010). In the general description of business models, one key aspect is the border between activities of the company and those of external parties. Research has here referred to how business models may be open or include border-spanning activities (Vanhaverbeke & Chesbrough, 2014), thus emphasizing the business model's connection to supply-chain decisions (Lambert et al., 1998; Nordin et al., 2010) in how the business model includes make-or-buy decisions related to core and strategic competences of the firm.

The literature provides several ways to describe business models, often reflected as canvas and non-canvas models. The canvas models refer to illustrative descriptions of a company's different processes (such as resource provision, value creation, and customer offering, as in Osterwalder et al., 2005), whereas the non-canvas models refer to textual descriptions of, for instance, activities

(such as the description of content, structure, and governance of activities, as in Zott & Amit, 2010). The business model canvas (Osterwalder & Pigneur, 2010) describes key resources, activities, and partners on the providing side; the value proposition (the offering); customer relationships, segments, and channels on the sales side; along with revenue streams and cost structures. Key resources, activities, and partners describe what is needed to produce the company's services or products, and what part of these are made by the company or other companies. The value proposition reflects how the company puts forth its products or services to customers that are then to decide their value. It includes the product, price, extended product, etc., and is what creates the competitive edge of the company's offering. How the customers are reached is understood through descriptions of channels (such as through independent retailers, the Internet, etc.), whereas segments describe what portion of the market the company aims to reach. Customer relationships, lastly, reflect the relational or transactional characteristic of exchanges along with how resale is created. Cost structures define the types of costs (fixed, variable, etc.) that the company's operations create, whereas revenue streams reflect structures of payments and financial deals with customers.

Business *modelling* puts focus on the development of new business models or changes to current ones, resulting from opportunities in the market as well as challenges manifested in awareness of contextual change (Johnson et al., 2008). In the case of additive manufacturing, new technologies may constitute challenges as well as opportunities for companies linked to rapid prototyping, rapid tooling, direct manufacturing, and home fabrication (Rayna & Striukova, 2016), for instance, which would affect and require changes to the company's business model.

As a means to analyze previous additive manufacturing literature in the business and management research, this article juxtaposes the ideas of Osterwalder and Pigneur (2010) with those of Zott and Amit (2010), so as to capture business models (Osterwalder & Pigneur, 2010) and changes to them (Zott & Amit, 2010). Figure 1 outlines this framework. Osterwalder and Pigneur's (2010) framework consists of the following: key resources, key partners, key activities, the value proposition, customer relationships, customer segments, channels, revenue streams, and cost structures. Zott and Amit's (2010) description of content, structure, and governance refers to what activities are pursued (content), how they are linked (structure), and who performs the activities (governance), so as to capture their changes.

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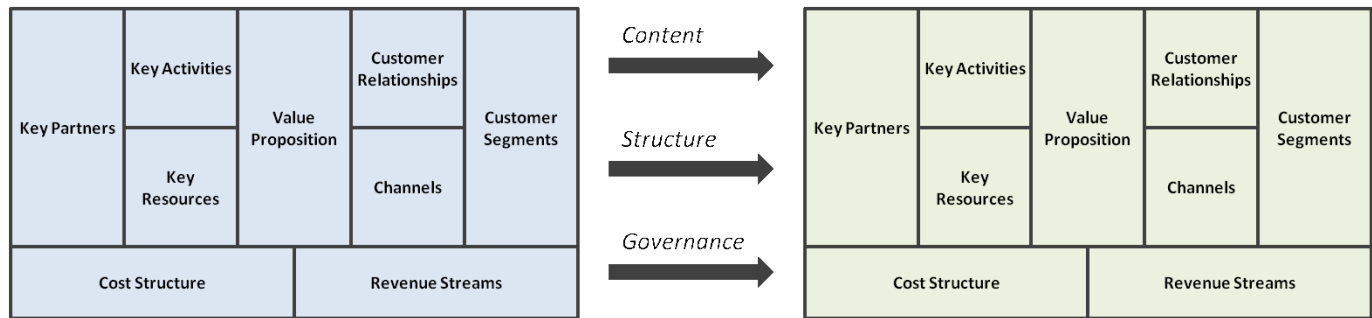


Figure 1. Analytical framework

Research Design

The article is based on a systematic literature review (cf. Tranfield et al., 2003) conducted as two separate searches so as to capture business models and business model changes in the additive manufacturing and 3D printing literature. The first search provided a very limited number of articles, therefore a second search focused more broadly on additive manufacturing and 3D printing in the business, management, and operational management literature to see whether any traces of business model parts (Osterwalder & Pigneur, 2010) were described in that literature. Both searches used the academic database Web of Science. The literature reviews were delimited to journal articles (thus excluding conference proceedings, etc.). The reason for using the search terms “additive manufacturing” and “3D printing”, respectively, was how an initial search only including additive manufacturing failed to capture some of the predefined relevant articles connecting related methods to business models.

The first search, which focused on “additive manufacturing” or “3D printing” in combinations with “business model” or “business logic” resulted in a total of seven journal articles for the years 2014–2017 (starting date set by occurrence in the database, end date defined to capture entire years):

1. Bogers, Hadar, and Bilberg (2016)
2. Flammini, Arcese, Lucchetti, and Mortara (2017)
3. Holzmann, Breitenacker, Soomro, and Schwarz (2017)
4. Kurman (2014)
5. Laplume, Anzalone, and Pearce (2016a)
6. Pisano, Pironti, and Rieple (2015)
7. Rayna and Striukova (2016)

Among these articles, the one by Flammini and co-authors (2017) does not describe additive manufacturing beyond exemplifying it as one of several technologies, leaving only six articles for further inclusion.

Based on the limited number of articles resulting from the initial search, the second search was conducted, this time focusing on the description of any of the parts of the business model canvas (Osterwalder & Pigneur, 2010) or changes thereto as means to code articles in the business and management area. Rather than searching for each of these terms and variations thereof, this second search focused on business research on additive manufacturing and 3D printing and then analyzed the articles through the business model canvas. The search focused on the following research areas: operations research management science, management, and business (research areas defined by the database).

The second search resulted in 82 journal articles referring to additive manufacturing and 66 journal articles describing 3D printing. Among these, 34 journal articles overlapped, leading to 114 unique publications. In the analysis, these journal articles were combined with the result of the initial search meaning that a total of 116 journal articles were analyzed (thus representing an overlap of four articles between the searches). To verify the search result, complementary searches were performed in the databases Scopus and Business Source Premier. Although these searches captured additional publications, the publications were excluded based on the low ranking of the journals or were news items, and similar (and not journal articles).

The 116 articles were analyzed to figure out what assumptions were made about additive manufacturing/3D printing in relation to companies and their management, how the business/management scholars linked to the technological side of additive manufacturing/3D printing, and whether and how the scholars described a process of change, current business models (or parts of business models), or completely new actors and business models entering into a business sector, thus implying a remodelling also on the industry level. More specifically, the journal articles were classified into whether they concerned key resources, key partners,

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key activities, the value proposition, customer relationships, customer segments, channels, revenue streams, or cost structures. The changes to these were then discussed in terms of changes to content, structures and governance mechanisms as extracted from the different parts of the business models (Zott & Amit, 2010). Appendices 1, 2 and 3 present the articles reviewed and their classifications and content specifications.

Findings

Frequencies

Figure 2 illustrates the frequencies of journal articles per search term (additive manufacturing, 3D printing, or both combined) and by year. As indicated by the figure, there has been a steep rise in the number of journal articles on additive manufacturing and 3D printing during the past few years. Although the data includes few articles published before 2014, it nonetheless suggests that the frequent use of 3D printing as a keyword is a recent trend.

In terms of the types of journals, most of them have a strong technology/innovation or operations management orientation, with *Journal of Manufacturing Systems* (17 publications), *Journal of Manufacturing Technology Management* (14 publications), *International Journal of Production Research* (10 publications), and *Technological Forecasting and Social Change* (10 publications) dominating. The type of journals is partly reflected in the key research areas, which focus on the way a company's offering is produced (key resources and key activities) rather than the value proposition or sales/customer side of the business model, as discussed below.

Business models in additive manufacturing

As Table 1 reveals, most of the journal articles concern the providing side (key partners, resources, and activities) of the business models (77 journal articles in total), with the main emphasis on key activities (42 articles), seconded by key resources (29 articles). These articles concern such issues as how manufacturing is or should be organized with additive manufacturing, the comparison between traditional and additive manufacturing (Achillas et al., 2015), or descriptions of a specific manufacturing process (Zhao et al., 2017). Additionally, several of these articles only refer to additive manufacturing as one of several technologies affecting the future development of producing firms (Hoover & Lee, 2015; Mortara & Parisot, 2016; Pisano et al., 2015).

As for changes, it is mainly the key activities that are expected to change due to the introduction of additive manufacturing. Mavri (2015), for instance, describes how the production chain changes due to additive manufacturing. Ben-Ner and Siemsen (2017) and Laplume, Petersen, and Pearce (2016b) include the change of supply chains in this regard, describing the shift from global to local, and from long to short supply chains. While not being very specific about the changes of “who does what”, articles by Ben-Ner and Siemsen's (2017) and Laplume and colleagues (2016b) indicate a change of governance (cf. Zott & Amit, 2010), whereas Mavri (2015) and most other articles focusing on changes to production concern the change of content (activities pursued; cf. Zott & Amit, 2010). This also means that additive manufacturing would foremost be seen changing internal processes of the firm, also indicated by the quite limited number of articles (six) focusing on key partners. The articles concerning key partners mainly

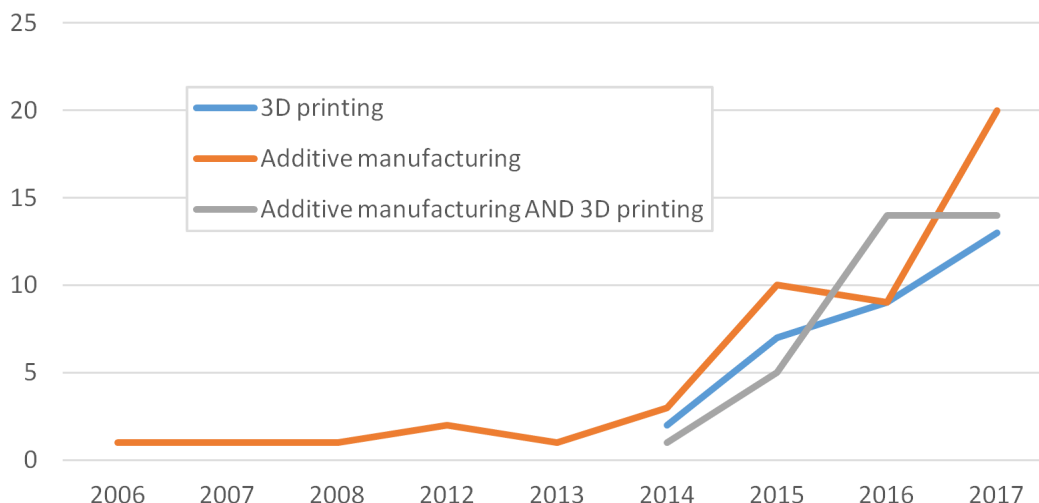


Figure 2. Frequency of results for each search term by year

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Table 1. Key themes by year

Theme	2006	2007	2008	2012	2013	2014	2015	2016	2017	Total
Key partners							1	1	4	6
Key activities	1		1			4	9	13	14	42
Key resources		1		1		2	6	7	12	29
Value proposition				1	1		1	4	6	13
Customer relationships						1	2			3
Cost structure								2	2	4
Revenue stream							1			1
Policy/societal level							1		3	4
Not in focus				1			1	6	6	14
Total	1	1	1	3	1	7	22	33	47	116

describe platforms or communities for design, examine technology transfers from universities, or emphasize the difficulties for small firms to adopt the technology (Birtchnell et al., 2017; Flath et al., 2017; Samford et al., 2017; West & Kuk, 2016). The limited attention paid to key partners implies that additive manufacturing would not require any major changes to core competences of firms or the companies would be equipped to change their current competences to fit with future needs. Related to this, is an acknowledgement of how additive manufacturing could expect to create disruption for certain companies along the supply chain (Mohr & Khan, 2015).

As for key resources, the discussion in the literature focuses on such issues as intellectual property rights (Gardan & Schneider, 2015; Kurman, 2014; Steenhuis & Pretorius, 2017), manufacturing issues and printer choices (Dwivedi et al., 2018; Elango et al., 2016; Paul & Anand, 2015), skills and (financial) support systems, and how new structures may be produced using additive manufacturing (Gardan & Schneider, 2015; Vongbunyong & Kara, 2017; Zhao et al., 2017). While partly concerning changes to resources (such as new skills or changes to intellectual property rules), most articles on

key resources describe quite a static view, also not indicating any changes to content, structures, or governance (Zott & Amit, 2010).

As for the offering, 13 journal articles concern value propositions (cf. Osterwalder & Pigneur, 2010). These include the type of products produced through additive manufacturing: rapid prototyping and innovations, for instance (Berman, 2012; Maric et al., 2016; Rayna & Striukova, 2016; Salles & Gyi, 2013). Rayna and Striukova (2016) make an overview of various offerings and the incremental or radical change they describe, and Laplume and co-authors (2016a) illustrate how small firms use 3D technology in their offerings. Others link additive manufacturing to business performance or business impact more generally (Niaki & Nonino, 2017; Rylands et al., 2016), or describe how incumbent firms would react to the entrance of 3D technology or 3D-printer firms (Hartl & Kort, 2017; Kietzmann et al., 2015). The articles concerning the value propositions broadly defined partly point at changed governance (Zott & Amit, 2010) as new players may enter, but mostly indicate an increased number of practices and thereby offerings enabled through additive manufacturing.

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As for the sales side, only three journal articles could be seen to concern customer-related issues, then focusing on customer relationships or changes to them. Rayna, Striukova, and Darlington (2015) discuss co-creation with customers in relation to 3D printing. Christopher and Ryals (2014) introduce the idea of demand chains to emphasize how additive manufacturing means customization and how ideas are pulled by customers rather than created by manufacturers and pushed onto customers. Appleyard (2015), lastly, reflects on piracy music as a means to understand 3D as a process owned by consumers. Thus, the limited literature on the sales side indicates how customers increase their influence and activity on what is produced, thus implying a change in governance of ideas (Zott & Amit, 2010), or “who does what”.

The cost structure is discussed in four articles focusing on the analysis of total costs of production or a change in the cost structure with printers being expensive, while the cost of producing low series is less so (Baumers et al., 2016; Baumers et al., 2017; Manogharan et al., 2016; Tsai, 2017). As for revenue streams, Weller, Kleer, and Piller (2015) discuss revenues related to entry barriers and point at how additive manufacturing may lower entrance barriers, thereby impacting competition and revenues.

In addition to those articles that could be linked to any part of the business model, there are a few journal articles focusing on the societal and policy level, along with a total of 14 articles having 3D printing as one of several empirical examples, while not giving the technology or its business impact any focus.

Summary of results

To summarize the findings, most journal articles thus concern the providing side of the business model, often with an internal manufacturing focus. Optimization is discussed either including changes to activities or meaning that 3D printing is a technology used in processes similar to those of traditional manufacturing. Little suggests knowing about changes to structures (cf. Zott & Amit, 2010), whereas key activities are linked to potential activity changes, and key resources are linked more to static descriptions. The discussion on key partners is limited, where supply chain discussions are quite general while not describing partnerships. Notably, the literature seems to imply that the companies in their internal processes are expected to adjust their core competences to new production methods, rather than link these to partnerships. Value propositions de-

scribe various offerings enabled through additive manufacturing, focusing on innovations and prototyping mostly, whereas the literature on the sales side/customer-related issues concerns the increased involvement of customers, implying a possible shift in power (cf. Öberg, 2018) to the customers' advantage. Discussions on change in business models or their parts focus on some changes to content (activities) related to production, and some few examples of changes in governance (who does what) in supply-chain structures and the shift to customers' activities, whereas the structures (the links among activities), and thereby the holistic business model influence of additive manufacturing does not seem to be described in previous research. Early articles seemed to be more prescriptive about what would happen, while more recent ones are more questioning to 3D printing/additive manufacturing.

Conclusions

This article summarizes current knowledge on additive manufacturing within management and business research, which leads us now to a discussion of future research directions in relation to business models for additive manufacturing. The literature review indicates a continuous focus on production issues also in the business and management literature. There is an indicated shift from positive connotations to increased questioning of the entrance and meaning of additive manufacturing in the production systems of tomorrow. There is also, when describing how business may change, the tendency to relate to parallel developments in business: the co-production and increased fuzziness between producers and consumers as crowds and communities affect design and production procedures (Ebner et al., 2009; Gulati et al., 2012; von Krogh et al., 2003) that would not be the direct consequence of additive manufacturing.

In terms of business models, what is rarely considered are changes in key partners, entirely new type of offerings, or revenue streams. What is also not considered is how individual companies, given their supply chain position, change or need to change their positions but also competences to meet those challenges and opportunities that additive manufacturing may bring about (Shams & Öberg, 2017). Changes to how various activities are linked are seldom described, which could imply that additive manufacturing is viewed from the lens of traditional manufacturing. And, empirical data beyond measurement in calculations of internal company optimization of manufacturing is rare.

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A research agenda for additive manufacturing and business models

Studies on additive manufacturing and its impact on business models are thus scarce, and there is a need to further explore the area and its many different aspects. Specifically, more empirical work is needed, moving knowledge away from scenarios and into how 3D printing in fact affects current businesses on the company level. The following research streams are suggested:

- *Research on value propositions and customer-related issues.* This would include how offerings are presented, decisions on channels and segments, and their consequences for firm performance. The holistic view including all parts of the business model and how various business models affect the performance of the firm in relation to additive manufacturing would also be important to study, as would the focus on structures (links among activities, cf. Zott & Amit, 2010).
- *Research focusing on how individual firms based on their present roles as manufacturers/suppliers, logistics providers, and business customers would change or need to change their roles so as to fit with additive manufacturing.* Such research would include the study of various companies as units of analysis and how additive manufacturing would lead to new business opportunities, or constrain current ones. Depending on the company's position in the supply chain, the vulnerability to additive manufacturing would differ, and the studies could compare companies based on their various supply-chain positions, while thus focusing on the company level.
- *Research on the effects of parts, tooling, and prototyping.* This would include how companies at various supply chain position would be affected by, take on, and also potentially try to move into more lucrative positions as, for instance, part manufacturing would be insourced by other companies. Comparisons could here be made among companies at each position for the effects of parts, tooling, and prototyping, respectively.
- *Research on what competences are needed as companies adapt to additive manufacturing and depending on the company's current role.* Competences would not only include those of additive manufacturing, but also competences on how offerings could be created, and they may well mean that a company manages to keep its position based on specific competences, while it would otherwise be challenged by the additive manufacturing. Competences should ideally be studied over

time to see how requirements of them change, and how companies develop and adjust them. The role of key partners and thereby structures and governance would be important to study in relation to competences.

- *Research into how payment models should be designed to minimize financial risks, while also taking into account the high investments of additive manufacturing.* The payment systems and price strategies of today traditionally focus on how a customer pays the supplier for products delivered. In multiple-party systems, and if competences become a key concern, the way and for what payments are made could expect to change and create new and more creative business models.
- *Research taking a deeper look into customer interaction from the perspective of home-based production.* While it is important to contextualize any development, it is also important to study the customer interaction as an isolated activity (that is, not in conjunction with, for instance, community trends) so as to understand how roles and powers are changed for parts, tooling, and prototyping, respectively.
- *Research into additive manufacturing/3D printing using different materials.* Most studies concern plastic materials, and it would be important to compare how various materials change the business models of companies in similar or different ways. This would include comparing plastics with metal printing, for instance, in how they would cause changes to business models of companies.

Managerial implications

Related to the findings from this article and also the research gaps indicated above, it would be important for any manager introducing additive manufacturing, or challenged by competitors doing so, to grasp how the interaction with customers could expect to change, what additive manufacturing means for cost structures – and thereby risk – but also what competences would be required to successfully operate the new technology. The literature indicates some changes to manufacturing as additive manufacturing is introduced, but in addition to these, it would be important to carefully analyze what activities may be excluded, how this affects the current business and connections to key partners, along with the business performance of the company. Hence, there are several issues to consider, where the present literature gives a good overview of effects on production, but less often links this to the entirety of the company. Through adopting a holistic

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business model perspective on the introduction of additive manufacturing and its consequences, it is easier to also grasp the coordination of activities (the structures, Zott & Amit, 2010). Furthermore, specific attention should be directed at how additive manufacturing may provide opportunities in terms of new offerings, customer involvement, and customization, along with production-to-order, and how these affect the business model from a provision, offering, sales, and cost/revenue side.

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Christina Öberg is Professor/Chair in Marketing at Örebro University in Sweden, and she is also associated with The Ratio Institute, the University of Exeter, and Leeds University. She has a background from Linköping University and Lund University and has also been a visiting scholar at Stanford University, the University of Bath, and Manchester University. Her research interests concern mergers and acquisitions, customer relationships, innovations, and new ways to pursue business including the sharing economy and effects of additive manufacturing. She has previously published in such journals as the *Journal of Business Research*, *Industrial Marketing Management*, *International Marketing Review*, the *European Journal of Marketing*, and *Production Planning & Control*.

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Appendix 1. Reviewed articles found using the search term “additive manufacturing”. Articles are ordered by publication date from newest to oldest. None of the articles included business model as a topic.

Article	Journal	Main Theme	Business Model
Hartl & Kort (2017)	<i>International Journal of Production Economics</i>	How incumbent firms react to new market entries of 3D-printing firms	Value proposition
Ambriz et al. (2017)	<i>Journal of Manufacturing Systems</i>	Material handling related to 3D	Key activities
Smith & Kerbach (2017)	<i>Journal of Manufacturing Systems</i>	Supply chain network design. Additive manufacturing (AM) as deconstructing supply chains	Not in focus
Samford et al. (2017)	<i>Business and Politics</i>	High costs of AM leading to difficulties for small firms to adopt the technology; how can they be supported	Key partners
Attaran (2017)	<i>Business Horizons</i>	AM implementation challenges and opportunities; changes to production	Key activities; offering
Roca et al. (2017)	<i>Research Policy</i>	Regulation of emerging technologies	Not in focus
Jin et al. (2017)	<i>Journal of Manufacturing Systems</i>	Process planning of AM	Key activities
Sturm et al. (2017)	<i>Journal of Manufacturing Systems</i>	Cyberattacks to AM processes	Key resources
Le et al. (2017)	<i>Journal of Manufacturing Systems</i>	The combined use of additive and subtractive manufacturing	Key resources
Ransikarbum et al. (2017)	<i>Journal of Manufacturing Systems</i>	A decision-aiding model to coordinate multiple printers. Parts. How different printers are needed and should be coordinated for optimization (operations).	Key resources
Giberti et al. (2017)	<i>Journal of Manufacturing Systems</i>	Original path planning algorithm including AM. Production processes (operations).	Key activities
Zhao & Rosen (2017)	<i>Journal of Manufacturing Systems</i>	Approach of interferometric curing monitoring and measuring data mining to intelligently decipher part height. Parts. Focus on production processes (operations).	Key activities
Roca et al. (2017)	<i>MIT Sloan Management Review</i>	Over-optimism in 3D printing. View on 3D and its potential influences.	Policy/societal level
Baumers et al. (2017)	<i>International Journal of Production Research</i>	Comparison of costs between AM and traditional manufacturing, also including changes to production processes	Cost structure
Strange & Zucchella (2017)	<i>Multinational Business Review</i>	New technologies (web 4.0) affecting location of firms	Not in focus
Jin et al. (2017)	<i>International Journal of Computer Integrated Manufacturing</i>	Extrusion-based layered deposition as an AM technology	Key resources
Vongbunyong & Kara (2017)	<i>International Journal of Computer Integrated Manufacturing</i>	Cellular structure enabled through AM. Focus on the manufacturing.	Key resources
Niaki & Nonino (2017)	<i>Journal of Manufacturing Technology Management</i>	Impact of AM on business performance	Value proposition
Aboutaleb et al. (2017)	<i>IIE Transactions</i>	Optimizing processes from a cost and time perspective. Parts. Manufacturing (operations).	Key activities
Li et al. (2017)	<i>International Journal of Production Research</i>	The impact of AM on spare parts supply chain. Simulations. Parts. Supply chain.	Key activities
Popescu et al. (2016)	<i>Studies in Informatics and Control</i>	Communities/platforms in orthopedic applications	Not in focus
Portoles et al. (2016)	<i>Journal of Manufacturing Systems</i>	Quality assurance in AM for aero industry. Parts, metallic. Manufacturing.	Key activities
Chen & Xiao (2016)	<i>Systems & Control Letters</i>	Disturbances in production	Not in focus

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Appendix 1. (continued) Reviewed articles found using the search term “additive manufacturing”. Articles are ordered by publication date from newest to oldest. None of the articles included business model as a topic.

Article	Journal	Main Theme	Business Model
Manogharan et al. (2016)	<i>International Journal of Computer Integrated Manufacturing</i>	Economic models (cost side) of additive and subtractive methods. Manufacturing and cost-side.	Cost structure
Paz et al. (2016)	<i>International Journal of Computer Integrated Manufacturing</i>	Optimized design of parts (e.g., different structures of material). Parts. Manufacturing.	Key activities
Featherston et al. (2016)	<i>Technovation</i>	New technologies	Not in focus
Wagner & Walton (2016)	<i>Production Planning & Control</i>	The current and future states of AM in the aviation industry. Supply chain. Parts.	Key resources
Bastani et al. (2016)	<i>IIE Transactions</i>	AM as an empirical example to test online sparse estimation-based classification.	Not in focus
Caputo et al. (2016)	<i>Business Process Management Journal</i>	Internet of Things framework tested on AM.	Not in focus
Xu et al. (2015)	<i>International Journal of Production Research</i>	A method to build an energy consumption model for printing stage of binder-jetting processes	Key activities
Gartner et al. (2015)	<i>Creativity and Innovation Management</i>	The need for policies about AM	Policy/societal level
Kim et al. (2015)	<i>Concurrent Engineering-Research and Applications</i>	AM process example to illustrate processes in smart manufacturing environments	Key activities
Mohr & Khan (2015)	<i>Technology Innovation Management Review</i>	The areas of the supply chain most likely to be disrupted by 3D printing technology	Key activities
Ali & Rehman (2015)	<i>Journal of Manufacturing Systems</i>	Novel manufacturing methods in medicine	Key activities
Gardan & Schneider (2015)	<i>Journal of Manufacturing Systems</i>	How what is manufactured is allowed to change (complex geometries) by means of AM	Key resources
Paul & Anand (2015)	<i>Journal of Manufacturing Systems</i>	Analysis of form errors	Key resources
Eyers & Potter (2015)	<i>Journal of Manufacturing Technology Management</i>	The use of e-channels for files between designer and manufacturer in AM	Key resources
Appleyard (2015)	<i>Business Horizons</i>	The development of the music industry (piracy) as example to understand AM as a production process owned by consumers	Customer relationships
Toth et al. (2015)	<i>Quality Innovation Prosperity</i>	The use of 3D for customized implant manufacturing	Key resources
Liu et al. (2014)	<i>Production Planning & Control</i>	The impact of AM in the aircraft spare parts supply chain. Scenarios including distributed and centralized supply chains.	Key activities
Christopher & Ryals (2014)	<i>Journal of Business Logistics</i>	From supply chain to demand chain. AM as one of the clues for this.	Customer relationships
Mellor et al. (2014)	<i>International Journal of Production Economics</i>	Implementation framework for AM	Key activities
Salles & Gyi (2013)	<i>International Journal of Computer Integrated Manufacturing</i>	The production of personalized footwear through AM	Value proposition
Paul & Anand (2012)	<i>Journal of Manufacturing Systems</i>	Energy calculations for laser sintering	Key resources
Berman (2012)	<i>Business Horizons</i>	3D as a revolution. Current practices mostly prototyping though	Value proposition
Ren et al. (2008)	<i>Journal of Manufacturing Systems</i>	Process planning of AM of metals testing various techniques	Key activities
Bingham et al. (2007)	<i>International Journal of Computer Integrated Manufacturing</i>	Rapid manufacturing in textile through AM. Technological focus.	Key resources
Ram et al. (2006)	<i>Journal of Manufacturing Systems</i>	Layer-based 3D printing in metals. Technology in focus.	Key activities

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Appendix 2. Reviewed articles found using the search term “3D printing”. Articles are ordered by publication date from newest to oldest. Articles in bold include business model as a topic.

Article	Journal	Main Theme	Business Model
Flath et al. (2017)	<i>Journal of Information Technology</i>	Platforms for 3D design	Key partners
Rindfleisch et al. (2017)	<i>Journal of Product Innovation Management</i>	Innovation as data, 3D as example	Not in focus
Dotsika & Watkins (2017)	<i>Technological Forecasting and Social Change</i>	3D as one of several disruptive technologies. Focus on methods to discover disruptive technologies.	Not in focus
Hartmann & Vanpoucke (2017)	<i>Journal of Organizational and End User Computing</i>	Customer acceptance with 3D as an example (intention to use)	Value proposition
Zhang et al. (2017)	<i>Journal of Manufacturing Systems</i>	Manufacturability optimization in processes including 3D and traditional manufacturing. Production processes (operations).	Key activities
Kyriakou et al. (2017)	<i>MIS Quarterly</i>	The reuse of 3D models. Customization and supply-side in communities.	Key partners; customer relationships
Walsh et al. (2017)	<i>Small Enterprise Research</i>	How 3D platforms support small firms in their innovation and commercialization processes	Key resources
Tsai (2017)	<i>International Journal of Production Research</i>	The impact of cost structure on cash flow risk; AM as one example	Cost structure
Wu et al. (2017)	<i>Journal of Manufacturing Technology Management</i>	Risks in projects	Not in focus
Zhao et al. (2017)	<i>International Journal of Computer Integrated Manufacturing</i>	Truss structures enabled through 3D printing	Key resources
Bai et al. (2017)	<i>Journal of Manufacturing Technology Management</i>	Comparative advantage of 3D printing among countries	Value proposition
Long et al. (2017)	<i>International Journal of Production Research</i>	The impact of 3D on Chinese manufacturing	Key activities
Schniederjans (2017)	<i>International Journal of Production Economics</i>	Adoption of 3D technology among top managers.	Key activities
Stanko (2016)	<i>Information Systems Research</i>	Online communities	Not in focus
Kannattukunnel (2016)	<i>International Journal of Innovation and Technology Management</i>	Patents and investments in 3D. Technology/manufacturing.	Key activities
Laplume et al. (2016a)	<i>International Journal of Advanced Manufacturing Technology</i>	The use of 3D printing for small manufacturing firms in their offerings	Value proposition
Kothman & Faber (2016)	<i>Journal of Manufacturing Technology Management</i>	Impact of AM on performance: efficient manufacturing and changed supply chain structure	Key activities
Maric et al. (2016)	<i>Journal of Innovation Economics & Management</i>	Frugal innovation	Value proposition

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Appendix 2. (continued) Reviewed articles found using the search term “3D printing”. Articles are ordered by publication date from newest to oldest. Articles in bold include business model as a topic.

Article	Journal	Main Theme	Business Model
Elango et al. (2016)	<i>International Journal of Production Research</i>	Technology of 3D printers. Technology (manufacturing).	Key resources
Wang et al. (2016)	<i>International Journal of Production Research</i>	Chinese consumers' adaption of 3D for home-based manufacturing.	Key resources
Sasson & Johnson (2016)	<i>International Journal of Physical Distribution & Logistics Management</i>	Direct digital manufacturing coexisting with traditional manufacturing methods. (Supply chain changes).	Key activities
West & Kuk (2016)	<i>Technological Forecasting and Social Change</i>	Openness in 3D printing. Manufacturing (community-based, that is, its organizing)	Key partners
Rayna & Striukova (2016)	<i>Technological Forecasting and Social Change</i>	3D printing affecting business models	Value proposition
Hull (2015)	<i>Research-Technology Management</i>	Development, descriptive	Key resources
Han & Sohn (2015)	<i>Journal of Technology Transfer</i>	Patents. 3D as empirics.	Not in focus
Pisano et al. (2015)	<i>Entrepreneurship Research Journal</i>	Business models as a means to better react to new trends. 3D as one example.	Key activities
Rayna et al. (2015)	<i>Journal of Engineering and Technology Management</i>	Online 3D printing and its effect for co-creation	Customer relationships
Huang et al. (2015)	<i>IIE Transactions</i>	Shape shrinkage in manufacturing with 3D	Key resources
Rayna & Striukova (2015)	<i>International Journal of Technology Management</i>	Challenges of co-creation. 3D as one example.	Key partners
Mavri (2015)	<i>Knowledge and Process Management</i>	Change in production chain due to AM	Key activities
Potstada & Zyburia (2014)	<i>Technological Forecasting and Social Change</i>	Home printing for consumers	Key activities
Fawcett & Waller (2014)	<i>Journal of Business Logistics</i>	Adaptation and proactiveness	Key activities
Zeleny (2012)	<i>International Journal of Information Technology & Decision Making</i>	Barriers to innovation. 3D mentioned as one technology affecting innovation and changing customers' role.	Not in focus

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Appendix 3. Reviewed articles found using the search terms “additive manufacturing” AND “3D printing”. Articles are ordered by publication date from newest to oldest. Articles in bold include business model as a topic.

Article	Journal	Main Theme	Business Model
Ben-Ner & Siemsen (2017)	<i>California Management Review</i>	Changes to production: from global to local; from mega to mini; from long to short supply chains	Key activities
Birtchnell et al. (2017)	<i>Technological Forecasting and Social Change</i>	The role of universities in the development of 3D printing knowledge	Key partners
Li et al. (2017)	<i>Computers & Operations Research</i>	Cost functions of AM. Very different cost structures to traditional manufacturing.	Key resources
Jiang et al. (2017)	<i>Technological Forecasting and Social Change</i>	Scenarios on future development (2030) through Delphi methods	Policy/societal level
Trappey et al. (2017)	<i>Technology Analysis & Strategic Management</i>	Patent analysis approach to explore biomedical 3D printing technology trends. Technology.	Key resources
Despeisse et al. (2017)	<i>Technological Forecasting and Social Change</i>	Whether or not 3D will lead to sustainability, and how it need to function to do so. How 3D affects – positively and negatively – the development of a circular economy.	Policy/societal level
Durach et al. (2017)	<i>International Journal of Physical Distribution & Logistics Management</i>	AM processes, their barriers and impact on supply chains	Key activities (supply chain)
Dwivedi et al. (2017)	<i>International Journal of Physical Distribution & Logistics Management</i>	Barriers to AM in Indian car industry; technological skills and governmental support as main issues	Key resources
Ryan et al. (2017)	<i>International Journal of Physical Distribution & Logistics Management</i>	Scenarios for 3D printing. Supply chain.	Key activities
Achillas et al. (2017)	<i>International Journal of Production Research</i>	Different AM technologies are compared in terms of lead time and total production cost with injection molding	Key activities
Gibson (2017)	<i>Journal of Manufacturing Technology Management</i>	State of the art in 3D printing related to business. Changed applications over time.	Value proposition
Holzmann et al. (2017)	<i>Journal of Manufacturing Technology Management</i>	User entrepreneur business models in 3D printing	Value proposition
Deradjat & Minshall (2017)	<i>Journal of Manufacturing Technology Management</i>	Dental sector; implementation of 3D for mass customization. Focus on technology.	Key resources
Steenhuis & Pretorius (2017)	<i>Journal of Manufacturing Technology Management</i>	AM innovations. Focus on issue of IP among others.	Key resources
Laplume et al. (2016b)	<i>Journal of International Business Studies</i>	Ideas (about the future) and how 3D may impact global supply chains. Increased geographically dispersion and production closer to the end users (localization). Changes to supply chain. Future oriented.	Key activities
Holmstrom et al. (2016)	<i>Operations Management Research</i>	Discussion of current over-optimism for 3D and how it in the future may change supply chains, etc., but not yet indicates the major shift and advantage to current production methods. Supply chain.	Key activities
Gardan (2016)	<i>International Journal of Production Research</i>	Review of the different AM technologies and the new trends. Focus on technology and manufacturing. Technology/manufacturing process	Key activities
Meisel et al. (2016)	<i>Journal of Manufacturing Technology Management</i>	Decision support for AM; focus on resources	Key resources

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Appendix 3. (continued) Reviewed articles found using the search terms “additive manufacturing” AND “3D printing”. Articles are ordered by publication date from newest to oldest. Articles in bold include business model as a topic.

Article	Journal	Main Theme	Business Model
Knofius et al. (2016)	<i>Journal of Manufacturing Technology Management</i>	Spare parts through AM in logistics	Key resources
Oettmeier & Hofmann (2016)	<i>Journal of Manufacturing Technology Management</i>	Impact of AM on supply chain components and processes. Hearing industry.	Key activities
Rylands et al. (2016)	<i>Journal of Manufacturing Technology Management</i>	Adaptation of AM in manufacturing and its business impact	Value proposition
Steenhuis & Pretorius (2016)	<i>Journal of Manufacturing Technology Management</i>	Consumer AM impact on future manufacturing industry	Key resources
Rogers et al. (2016)	<i>International Journal of Physical Distribution & Logistics Management</i>	3D services and their impact on supply chains. Literature review and research agenda. Services (external parties' provision). Supply chain.	Key activities
Mortara & Parisot (2016)	<i>International Journal of Production Research</i>	AM as one of several production techniques at fab-spaces (not key focus). Manufacturing. Organizing of manufacturing.	Key activities
Salvador & de Menendez (2016)	<i>Journal of Intelligence Studies in Business,</i>	The potential effect of bio-additive manufacturing on healthcare	Key activities
Sandstrom (2016)	<i>Technological Forecasting and Social Change</i>	How AM has been adopted for manufacturing and its potential impact competition in different industries. Hearing aid case study. Technology and new manufacturing possibilities.	Key resources
Baumers et al. (2016)	<i>Technological Forecasting and Social Change</i>	Cost performance using two different techniques	Cost structure
Bogers et al. (2016)	<i>Technological Forecasting and Social Change</i>	The implications of AM on production systems in new business models. Focus on consumer goods and open business models implying a consumer-centric logic and changes to supply chains.	Key activities
Hoover & Lee (2015)	<i>Research-Technology Management</i>	3D as one force of change in the current business landscape (in parallel with, e.g., sharing)	Key activities
Achillas et al. (2015)	<i>Journal of Manufacturing Systems</i>	A decision-making framework for selecting an effective portfolio of production strategies, including alternative additive and traditional manufacturing technologies. AM effective for small series and high customization (increased supply chain responsiveness). Injection molds to traditional manufacturing also in larger series.	Key activities
Weller et al. (2015)	<i>International Journal of Production Economics</i>	The impact of AM on firm and industry level from an operational management perspective. In monopoly situation, firms may increase their revenues, while in competitive markets, AM lowers entrance barriers	Revenue stream
Kietzmann et al. (2015)	<i>Business Horizons</i>	The impact of AM on firms and consumers	Value proposition
Tatham et al. (2015)	<i>Journal of Humanitarian Logistics and Supply Chain Management</i>	The use of 3D in disaster and development activities	Key activities
Kurfess & Cass (2014)	<i>Research-Technology Management</i>	Intellectual property changes as a result of AM	Key resources
Kurman (2014)	<i>3D Printing and Additive Manufacturing</i>	Intellectual property as inefficient in AM	Key resources

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