WHAT IS THE POTENTIAL OF ADDITIVE MANUFACTURING IN SUPPLY CHAINS? A NARRATIVE LITERATURE REVIEW APPROACH

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ABSTRACT:

The study of additive manufacturing (AM) has grown rapidly during the last decade as it is perceived that the technology has the potential to revolutionize the way in which products are produced and delivered to the customer. Additionally, AM is able to create new business opportunities, as well as introduce new rules of competition to the business world. Despite experiencing immense growth in the study of AM, the knowledge of interdependencies across forms of technology deployment and different sectors involved in supply chains is widely dispersed. The initial consequence of this situation is to proliferate fragmented studies duplicating identical efforts, while neglecting certain aspects. Therefore, this article attempts to synthesize the existing research on AM regarding its impact on business and supply chain management with the goal of shedding light on the current situation and open up avenues for further research. This paper applies a narrative approach to conducting a literature review and summarizes the findings in relation to three main categories of the supply chain: supply side, firm side and demand side. Additionally, it offers recent examples of AM deployment in industry and the real world to highlight the trend and potential in the area of AM. Given this trend and potential of AM in business, decision makers (based on their positions in the entire supply chain) are able to make better choices when deploying this technology as a disruptive technology. Being on time and making the right choice of new technology deployments not only prevent firms from losing their competitive advantage (and from bankruptcy in ultimate situations), but also support them to enhance their advantage over their competitors. In particular, they can receive high-level benefits as early or first adopters. This article is a step towards reaching this goal.

Keywords: additive manufacturing, direct digital manufacturing, rapid prototyping, 3D printing, product and process innovation, supply chain.

INTRODUCTION

AM technologies (also known as direct digital manufacturing or 3D printing) are all technologies automatically producing components by setting up or joining volume elements preferably in layers. This technology enables firms to directly manufacture parts from an original digital design (or physical scan) without tooling and setting up, similar to laser printers that do not need type setting to print (Hopkinson et al., 2006) (Gibson et al., 2010, pp. 363-384). This technique, which has its origins in rapid prototyping, is becoming popular in various industries, such as the aerospace, automotive and medical device industries. Considering that the growth rate of AM is estimated to increase to 11 billion euros in 2020, compared with 3.7 billion euros in 2013, this technology is one of the most increasingly popular manufacturing technologies, which has a total market potential of about 130 billion euros (European-Commission, 2014).

Given the expanding number of successful applications of AM, the technology has attracted the attention of the academic community in evaluating its effect as a disruptive technology in various parts of the supply chain with the goal of reinforcing competitive advantages, which is indeed the goal behind the deployment of any technology (Porter, 1985). It is undoubtedly true that scientific publications about AM, particularly its impact on supply chain configuration, has grown rapidly during the last five years; yet, existing knowledge is widely dispersed because of AM's varied nature within the supply chain. Therefore, this paper tries to fill this gap by presenting a comprehensive narrative literature review about the potential of AM in the main parts of supply chains, namely, the supply, demand and firm sides. It also presents the most recent applications of 3D printing in industry to highlight the trend and scope of future research.

The rest of the paper is organized as follows. In the first section, the methodology of gathering materials is presented, followed by a general description of AM technologies and determinative attributes when choosing this technology for a particular industry. Next is a discussion on the new application of 3D printing in industry. In the subsequent section, how products and production are affected by AM technologies is explored. Then, the potential of AM within supply chain configuration is described with regard to four scenarios: 1. simple supply chain (absence of AM), 2. benefits to the supply side, 3. benefits to firms, and 4. benefits to the demand side. The paper closes with a discussion and conclusion.

METHODOLOGY

There are two main approaches to conducting a literature review: systematic and narrative approaches. Systematic literature reviews are employ detailed, rigorous and explicit methods. As systematic literature reviews are based on the selected research questions, the procedure and methods of selecting material are defined explicitly in advance. This approach is most common in the field of health science. On the other hand, narrative literature reviews, which are the most common form of literature reviews, provide a broad overview of a topic, rather than addressing a specific research question (Onwuegbuzie & Frels, 2016, p. 25).

This literature review is based upon the guidelines for performing narrative literature reviews produced by Green et al. (2006). Therefore, the results comprise the author's findings on a given topic (in this case, AM) and synthesize the available resources in order to shed light on the potential of AM within business sectors by summarizing its effect within supply chain management (Green et al., 2006).

Since there are no guidelines for the threshold number of databases (to the best of the author's knowledge), and due to the interdisciplinary nature of the AM literature, this review has been made comprehensive through the use of Scopus and Google Scholar, which are reputable among scholars of technology management, business strategy and supply chain management. We only selected academic articles in English, including articles from conference, scientific reports and information from companies' websites prior to October 2017. We searched using the following keywords: additive manufacturing, 3D printing, rapid prototyping, digital manufacturing and direct digital manufacturing, in combination with the Boolean operators "AND" and "OR" and the terms supply chain management and configuration.

Technology selection

AM (direct digital manufacturing, 3D printing and rapid prototyping) is the process of joining materials to make objects from 3D model data, usually layer by layer. It was originally applied, for the most part, in the fabrication of conceptual and functional prototypes in the late 1980s (Hopkinson et al., 2006). Nowadays, it is applied in many other areas, such as customer-driven medical devices (e.g., dental crowns and hearing aids), the aerospace industry (to decrease weight), the automotive industry, the jewelry industry, architecture and defense (Pérès & Noyes, 2006), (NASA, 2013) (Fitzgerald, 2013). Although the application of 3D printing is growing, there are critical voices asserting the associated challenges of AM in terms of cost and printing time (Times, 2014).

There are various AM processes, which differ in the way that layers are deposited to create parts, as well as the materials that can be used in relation to operation principles. There are two main methods in AM technology: one is based on melting or softening materials to produce the layers, while the other is based on curing liquid materials (Bikas et al., 2016). At present, in general terms, there are seven different options in AM technology: 1. material extrusion, i.e., fused deposition modeling (FDM), 2. material jetting, 3. binder jetting, 4. sheet lamination, 5. vat photopolymerization, i.e., stereolithography (SLA), 6. powder-bed fusion, i.e., SLS or selective laser modelling (SLM), and 7. direct energy deposition. FDM, SLM and SLS belong to the category of melting or softening materials, while the others belong to the second category. The cost of equipment in each process varies from 30,000 to 500,000 US dollars (Holmström et al., 2016). While each method and process have their own advantages and disadvantages, the main criteria that a company applies when choose the best solution are the speed of the machine, the cost of the printed prototype, the cost and range of materials, and color capabilities (Pham & Dimov, 2012, p. 6).

Technology application

While the original application of AM was in rapid prototyping, nowadays, this technology has applications in tool-making and low-volume manufacturing across various industry sectors. The aerospace industry is one of the pioneer industries in terms of adopting AM technology, for example, 3D printing parts for the F-18 Super Hornets and the 787 commercial jetliners, where weight reduction of the final products is important (Hopkinson et al., 2006). Another pioneer industry is the medical industry in terms of producing customized orthopedic implants and braces, hearing aid shells, and dental crowns (Wohlers, 2015).

The technology has a huge potential in the automotive industry as well. For example, Volkswagen Autoeuropa, which is responsible for manufacturing Volkswagen cars, now deploys 3D printing on its production line for printing manufacturing tools, jigs and fixtures. Using 3D printing in Volkswagen has revolutionized the workflow by reducing the number of suppliers the company deals with, lead times, increasing the productivity of personnel, and improving their work conditions ergonomically. For instance, a wheel protection jig was previously sourced for 800 euros from an external supplier with a production time of 56 days. But it can now be printed inside the company's facilities for just 21 euros in 10 days. Compared to conventional methods, 3D printing in this company has resulted in a cost reduction of 91% and time saving of 95%, with a return on investment in less than two months (De Vries, 2017).

3D printing technology also has major potential in domestic appliance manufacturing, especially spare parts and aftersales. For instance, in order to improve aftersales service, Electrolux conducted research to address the source of problems affecting both manufacturers and customers. This revealed that the manufacturer stopped producing certain spare parts once production of the actual appliances that used them stopped. While this was due to high production levels, high inventory levels and repair costs, these parts were still used by customers. From a customer point of view, the cost and time needed to repair and replace increased after the product was no longer sold. Therefore, Electrolux decided to deploy on-demand 3D printing of spare parts to overcome the problem identified in its aftersales service (Haria, 2017).

Traditional 3D printers mainly involve size constraints when printing objects. But the combination of 3D printers with robots make it possible to overcome this constraint and print almost everything. For example, a new hybrid manufacturing process combining AM and industrial robotics capabilities is used to make ship propellers in the Netherlands' Port of Rotterdam (the largest port in Europe and one of the most important cargo destinations). The Port of Rotterdam's AM laboratory, which is a pioneer in the deployment of AM in the maritime industry, is trying to develop an 'on-demand' hybrid manufacturing capability for the replacement of different large-scale metal parts of a vessel. This will have a major impact on reducing wasted time and the cost of maintenance across the maritime industry around the world (Autodesk, 2017).

The combination of 3D printing with robots makes it possible to produce "endless" different structures, regardless of size, since robots are able to move across the object as they print. For instance, MX3D, a startup company in the Netherlands, used industrial robots to print a small pedestrian bridge over an Amsterdam canal in 2017. This is a small example, but shows how the combination of 3D printers and robots offers huge potential in construction (Hobson, 2015).

Table 1: Some recent applications of 3D printing

Industry	Example	Main objective
Aerospace	Air duct of F-18 Super Hornets and 787 commercial jetliners (Khajavi et al., 2014)	Reduces inventory, Decreases down time, increases system reliability
Medical and dental	Customized orthopedic implants (Shinal, 2013) and braced, hearing aid shells (Sharma, 2013), dental crowns (Murray, 2012), deployment of AM in Philips' healthcare spare parts (Wullms, 2016)	Promotes customization, improves aftersales services
Automotive	Manufacturing tools, jigs and fixtures are printed on Volkswagen Autoeuropa's manufacturing line (De Vries, 2017)	Reduces lead time and cost
Domestic appliance manufacture r	On-demand 3D printing of spare parts for aftersales service at Electrolux (Haria, 2017)	Improves aftersales services
Maritime	AM in combination with industrial robotics is used to make ship propellers at the Netherlands' Port of Rotterdam (Autodesk, 2017)	Reduces down time and cost, increases parts availability, improves maintenance service
Construction	Printing a small pedestrian bridge over an Amsterdam canal in 2017 (Hobson, 2015)	Combination of 3D printers with robots removes the constrain of size and makes it possible to produce almost everything.
Food	3D chocolate printing machine pioneered by Choc Edge especially for custom-shaped chocolate (Jia, et al., 2016)	Supports customization and provide higher profit for manufacturers.

A percentage breakdown of the use of AM in industrial sectors is presented in the next figure:

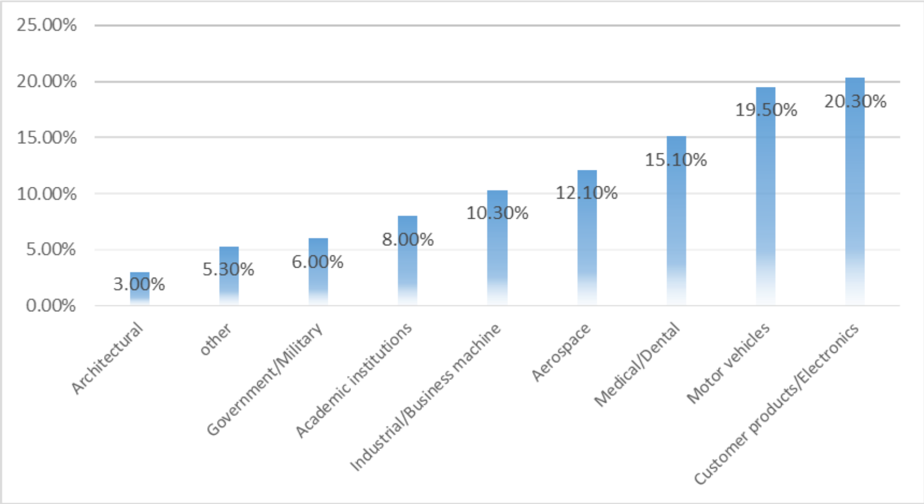


Figure 1: *Percentage breakdown of AM use in industrial sectors using AM (Wohlers, 2012)*

Although AM is a growing method of producing objects, its technology and market are quite new. Initially, it was believed that, given there was no need for tools, AM was economically suitable for low and medium production volumes involving highly customized products (economy of one) (Wohlers, 2015) (Weller et al., 2015). But recent studies on the commercialization of AM systems have revealed that the technology is adaptable to economies of scale in different ways, for example, through increased machine throughput or physical scaling-up (Baumers et al., 2016) (Jia et al., 2016). The general perception is that AM will not completely replace conventional methods, apart from in some specialized markets and industries. For example, a survey by the consultancy firm PricewaterhouseCoopers of the Swedish domestic appliance manufacturer Electrolux showed that 3D printing would play a "dominant role" in the production of spare parts within the next five years (Geissbauer et al., 2017).

In deploying AM as a new technology, the comparison with conventional manufacturing models, essentially in terms of cost, is crucial and decision makers need to conduct a thorough cost-benefit analysis to determine the level of profitability that a firm can achieve with the deployment of AM (Schniederjans, 2017). Cost models for conventional tool-based manufacturing processes often consist of labor and machines (tools), which are amortized over production runs; meanwhile, in AM, other factors, such as the high impact of investments and overheads, should be considered (Ruffo et al., 2006) (Tuck et al., 2008).

AM impact on product(ion):

A typical AM process should consist of seven main stages: 1. design, 2. STL conversion, 3. positioning, 4. 2D slicing, 5. machine warm-up, 6. construction, 7. part removal, 8. support removal, and 9. Final part (Khajavi, et al., 2015).

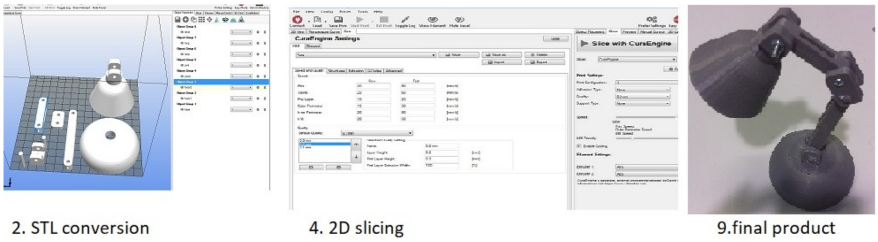


Figure 2: AM process stages

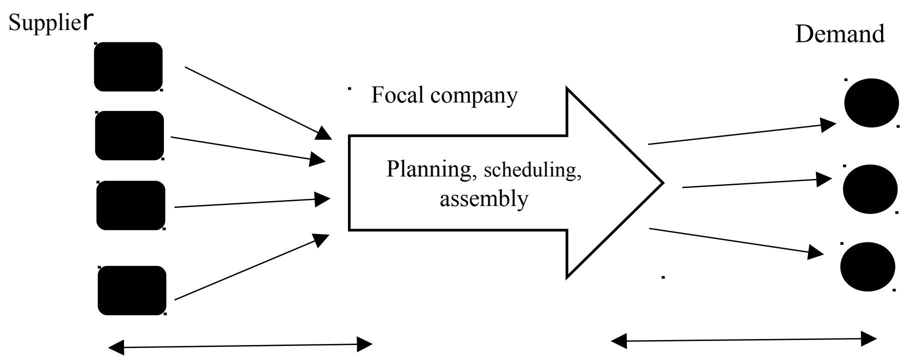
With the application of AM as a tool where manufacturing is not on a large scale, manufacturers can make most shape parts without typical manufacturing limitations. Additionally, the cost of changing and customizing products is reduced significantly. These fundamental features lead to the following benefits for AM types of production (Holmström et al., 2010): design customization, shorter lead times, lower inventories, reduce waste, small production batches are feasible and producing batches of one becomes economical, production of products that are functionally optimized, quick change design, no tool is needed (this characteristic leads to shorter ramp-up times and expenses).

Generally, the deployment of AM has an impact in two main directions: 1. products and 2. supply chain management and configuration. AM make it possible to produce economically innovative customized products with high value added and facilitates mass customization (Mellor et al., 2014) (Zawadzki & Żywicki, 2016) (Chen et al., 2015). In detail, compared with conventional methods, AM offers many advantages, particularly in design flexibility, the low cost of geometric complexity, dimensional accuracy, assembly not being required, and time and cost efficiency in production runs (Gao et al., 2015). All these capabilities help manufacturers to increase their performance outputs, manage risk, promote innovation and make greater profits (Cotteleer & Joyce, 2014).

AM impact on the supply chain

In terms of the impact of AM within supply chain management, we need to consider four scenarios:

Simple supply chain (starting situation without AM)



Supply side Demand Side

Figure 3: A schematic depiction of a simple tool-based manufacturing system

In the traditional supply chain, a focal firm receives raw materials from several suppliers to produce and deliver standard products to the end customers. The standard activities inside the firm comprise storing raw materials, planning, scheduling and assembly, storing the final products and delivering then to the end customers. The conventional continuous supply line has many drawbacks, from storage to handling. The problem is amplified by increasing product variety. Changing products according to customer requirements can be time-consuming and costly because various suppliers have to be involved and tool changes are necessary (Oettmeier & Hofmann, 2017). Therefore, it is predicted that the application of AM in a business should generally lead to reducing complexity and the better management of the risk of disruption by simplifying the supply chain (Holmström & Gutowski, 2017).

Potential of AM on the supply side

Basically, there are two different options of AM deployment on the supply side: 1. contract manufacturing, when a firm sources ready-made AM parts, and 2. when a company purchases the required materials and capital goods in order to engage in AM itself (Oettmeier & Hofmann, 2016). The first option enables firms to be vertically integrated and probably supports them in dealing with a smaller number of suppliers. It is estimated that it leads to improvements in supplier relationship management for firms, while the focal company needs to rethink its supplier relationship management in terms of procurement processes, quality management in procurement, and quality management by suppliers (Oettmeier & Hofmann, 2017). AM also facilitates outsourcing because product design and production can easily be separated (Berman, 2012) (Oettmeier & Hofmann, 2016).

Another benefit of AM for the supply side is that it could shift the production of small lot sizes to high salary countries, since AM reduces the need for manual labors. This potential of AM has been emphasized in several studies examining the many driving forces behind the rise in manufacturing jobs in Western countries, such as the emergence of AM as a new process of innovation in those countries, rising wage levels in emerging economies and falling business quality in emerging economies (Kianian et al., 2015). Additionally, recent studies have shown that the demand for products from US and other Western counties is increasing around the world; and, even more surprisingly, over 60% of Chinese customers prefer to pay more for products labeled as made in a Western country that those labeled a “Made in China” (Boston Consulting Group, 2012) (Kianian et al., 2015). Therefore, we believe that AM could be one way of meeting this demand and creating new business opportunities and profits. The deployment of AM not only leads to job creation in Western countries, but also supports their manufacturing sectors by reducing the risk of innovative Western companies' intellectual property being "leaked" to emerging economies, thus damaging competitive advantages of the former (Wang, 2004).

AM should also influence the relationship between the focal firm and its suppliers in terms of their mutual contact, as well as support the focal firm in enjoying a binding (more profitable) contract. In particular, the possibility of manufacturing products within an AM process should influence companies when making "last-time buy" and "final order quantity" decisions, along with preventing high levels of safety stock and saving costs on all selected parts when AM is included in the "last-time buy" process (Wullms, 2016).

Potential of AM for manufacturers

The decision about AM deployment for a firm is very much related to its production and market. It is estimated that 3D printers will at least be applied in some particular industries, thus changing the dynamic of competitive advantage from traditional economies of scales (mass productions) to economies of one (customized products) (Petrick & Simpson, 2013). Generally, AM has been applied economically to produce single units in some industries at a very low rate of volume demand (Economist, 2012). For example, in terms of spare parts and aftersales services, the deployment of AM can improve the quality of such services by decreasing the stock-out probability and saving costs by reducing safety stock levels. Additionally, AM deployment in the spare parts industry supports localized and on-demand production, which results in delivery that is fast and low cost (Holmström et al., 2010), (Khajavi et al., 2014). In Germany alone, AM deployment in the spare parts industry will save three billion euros annually over 10 years (Geissbauer et al., 2017).

There are several studies that show how AM deployment affects a focal firm and its network (Barz & Haasis, 2016) (Holmström & Partanen, 2014) (D'aveni, 2013). Generally, the deployment of AM affects focal firms in terms of manufacturing flow management, product development and customization, and return managements (Eyers & Dotchev, 2010) (Oettmeier & Hofmann, 2016). Additionally, AM affects firms' business strategy and increases their performance by promoting product and process innovation (Khorram Niaki & Fabio, 2017). Besides, it improves other performance measurement factors, such as lead times, order fulfilment and waste rates (Chiu & Lin, 2016). Furthermore, AM deployment supports firms in managing the risk of launching new products by rapid prototyping and innovation process (Khajavi et al., 2015) (Lipson & Kurman, 2013, p. 59). Finally, the deployment of AM promotes e-commerce and introduces new business models (Eyers & Potter, 2015) (Bogers & Bilberg, 2016). For example, the deployment of AM in the 3D printing of chocolate has shifted the dominant business model from retailers to manufacturers, with the latter gaining more profits while the former's profits tend to stagnate (Jia et al., 2016).

Studies also show that the deployment of AM affects the supply chain strategy of the focal firm and supports it in the implementation of a lean and agile supply chain by reducing waste and increasing manufacturing flexibility (Nyman & Sarlin, 2014, pp. 4190-4199) (Thomas & Gilbert, 2014). Since AM changes the operation point to a single-stage manufacturing process (Olhager, 2003), it eliminates all uncertainty about throughput times, production schedules and delivery dates. Thus, it makes managing the work in process easier and reduces inventory levels in the warehouse (Rönkkö et al., 2007) (Holmström et al., 2011) (Arnäs et al., 2013).

Benefits of AM on the demand side

There are several studies that shows how AM can prompt changes on the demand side of a supply chain (Oettmeier & Hofmann, 2017). One of the main effects is the democratization of design/customization processes, which can help customers to be co-producers of products and play an active role in product design; ultimately, AM makes it possible for customers to design and print parts by themselves (Waller & Fawcett, 2013) .

The deployment of AM makes the role of demand stronger in a supply chains by moving it less about stock strategy and more about engineering to order, which is a more demand-driven model (Shah et al., 2017). Additionally, it is able to consolidate demand (Holmström & Partanen, 2014). The adoption of AM also makes production geographically closer to the customer’s location, which in practice leads to a quicker response to customer changes and needs, while improving the quality of demand forecasting and order fulfilment (Oettmeier & Hofmann, 2016) (Christopher & Ryals, 2014) (Ford, 2014). The results of this literature review are summarized in Table 2:

Table 2: the impact of AM deployment according to the literature

Authors	Year	Area	Main results of the paper	Typology	Method
Hopkinson & Dickens	2001	Firm	Presents how AM can be applied in the manufacture of parts in thousands by comparing the cost of injection molding with SLA. In particular, it considers five sources of cost for each model: direct machine cost, indirect machine cost, machine operation costs, material costs and tolling costs. Additionally, it considers production details and limitations. Considering all costs, the paper concludes that using AM to manufacture parts in medium and high volumes is a credible idea.	Empirical research	Quantitative case research
Tuomi & Karjalainen	2006	Firm	Presents AM as a solution to overcome the uncertainty and challenges of the product development phase of a product life cycle. It analyses the economics of new rapid manufacturing applications, base-case cost modeling methodology. In detail, it compares the costs of manufacturing an electronic industry product using conventional and AM methods. Results show AM deployment leads to a 13% decrease in net present value (NPV).	Empirical research	Case study by calculating the NPV under different scenarios
Holmström, Partanen, Tuomi & Walter	2010	Firm	Introduces the potential benefits of AM in the spare parts and aircraft industries. Generally, the paper reveals that the supply chain benefits from AM deployment in the spare parts industry in terms of improving service and reducing inventory levels. Considering the supply chain of the F18 air-ducting system, the paper concludes that the on-demand and centralized production of spare parts is the most likely approach to succeed.	Conceptual study	
Eyers & Dotchev	2010	Firm	Examines the potential of rapid prototyping in mass customization, and presents case studies demonstrating the use of rapid processing in mass customization, such as customized hearing aids and customized lamps.	General review	
Berman	2012	Firms	Examines the characteristics and applications of 3D printing and compares it with mass customization.	Review	
Mellor, Hao & Zhang	2013	Firm	Proposes a guideline for the manufacturing sector in order to adopt and implement AM technology by constructing and testing a normative structural model of implementation factors related to AM technology, supply chains, organization operations and strategy.	Empirical research	Qualitative case research
Petrick & Simpson	2013	Firm	Compares the main drivers of economies of scale (mass production) with economies of one (mass customization) in terms of source of competitive advantage, supply chain, distribution, economic model, design and completion. The paper shows that AM supports the economies of one philosophy and can change the competitive dynamics of business by impacting the design, build and deliver stages.	Conceptual study	
Nyman & Sarlin	2014	Firm	Examines in detail how AM deployment can influence supply chain strategies by supporting lean and agile philosophy.	Conceptual study	

Authors	Year	Area	Main results of the paper	Typology	Method
Khajavi, Partanene & Holmström	2014	Firm	Examines the deployment of AM in the manufacturing spare parts for F/A-18E/F Super Hornet fighter jets. Using scenario planning, the paper shows when centralized manufacturing is cost-effective and under which conditions decentralized manufacturing implementation is economical.	Empirical research	Quantitative case research
Holmström & Partanen	2014	Demand, firm, logistics service provider (LSP)	Examines how AM can affect the relationship between LSPs, users and manufacturers of equipment. In detail, it shows how AM offers significant and direct benefits to manufacturers of complex and high-value equipment in particularly challenging settings. Additionally, it can consolidate the demand and bring about new business opportunities for LSPs.	Conceptual study	Brian Arthur's theory of combinatorial technological evolution
Ford	2014	Firm, manufacturer	The US is already a leader in the production and use of AM. For US manufacturers, AM mainly offers potential to the following sectors: motor vehicles, aerospace, business machines, medical and dental, government and military, architecture and consumer products. Challenges when developing and adopting AM in US manufacturing are standards development, material selection and cost, equipment and process. Drivers to develop AM in industry are mass customization, new and improved processes and products, incorporating energy and electronics, creating new structures, 3D scanning, bioprinting, government initiatives and public-private partnerships	Review	
Eyers & Potter	2014	Supply, firm, demand	The paper proposes four e-commerce AM models: B2B/B2C outsourced manufacturing, B2B closed marketplace, B2B regional manufacturing, and C2C network manufacturing. The paper also sets out the required action and intended outcomes for each model.	Systematic literature review	
Huang, Liu, Mokasdar & Hou	2014	Supply, firm, demand	AM improves supply chains in terms of: 1. Customization 2. Increased manufacturing sustainability 3. Simplified supply chains and increased responsiveness	Conceptual study	
Ituarte, Salmi, Partanen & Tuomi	2015	Firm	Shows that Finland is not currently in the position to compete on a global scale in primary sectors of AM value chains, such as AM industrial machine manufacturing and raw material supply. The paper sets out the challenges in the deployment AM in Finland as follows: insufficient awareness of benefits, lack of willingness to share knowledge, weak internal 'cluster' structures, especially after Nokia's collapse in 2000. The paper also presents proposals for action, such as promoting funding strategies for AM, developing a future skilled workforce, and linking funding to technology advisory services.	Conceptual study	Non-structured interviews with industry experts
Rüßmann, Lorenz, Gerbert, Waldner, Justus,	2015	Supplier, firm	Explores AM as one of the components of Industry 4.0. To quantify the impact of Industry 4.0, the paper uses Germany as an example and	Conceptual study	

Authors	Year	Area	Main results of the paper	Typology	Method
Engel & Harnisch			presents the results of Industry 4.0 deployment in terms of productivity, revenue growth, employment and investment. The paper also states that the next wave of manufacturing will affect producers' entire value chain, from design to aftersales service. It also examines the automobile industry in terms of the next wave of automation.		
Thomas	2015	Firm	Discusses a supply chain approach to examining costs from a monetary (Hopkinson & Dickens) perspective and a resource consumption (Ruffo et al) perspective. It examines AM adoption and diffusion regarding firms' resources, processes and capabilities. The paper illustrates that AM deployment leads to higher flexibility of firms, while lower unit costs are not always promising.	Conceptual study	Mathematical modeling
Khajavi, Partanene, Holmström & Tuomi	2015	Firm	AM supports manufacturers in new product development and risk management. In detail, the paper proposes a hybrid production method consisting of conventional and AM approaches to new product development. Using scenario modeling, results show that, while the implementation of conventional production methods is not, in the beginning, significantly costly compared to hybrid methods in terms of the success of products on the market, conventional methods are much costlier when products do not succeed at the first attempt.	Empirical research	Quantitative case research via calculating NPV of multiple scenarios
Jia, Wang, Mustafee & Hao	2015	Firm, demand, retailers	3D printing of chocolate supports customization. It also shifts the dominant profit opportunities in the chocolate industry from retailers to manufacturers.	Empirical research	Agent-based simulation
Ming-Chuan Chiu & Yi-Hsuan Lin	2015	Firm	AM deployment improves supply chain performance in terms of lead time and total cost.	Empirical research	Case research, optimization-based simulation
Christopher & Ryals	2015	Demand, supply	AM shifts the dominant logic of business from production push towards demand pull.	Conceptual study	
Ming-Chuan Chiu & Yi-Hsuan Lin	2015	Firms	AM processes improve the supply chain performance in terms of lead time, total cost, order fulfilment and waste rates.	Empirical research	Case simulation
Kianiana, Tavassoli & Larsson	2015	Supply, firm	Investigates the role of AM in job creation in Sweden. It considers technical factors related to AM and non-technical factors in emerging economies. Results show that AM technology contributes to job creation in both the manufacturing sector and the service sector, mainly in product development stages and in production stages of low-volume batches of complex products. That said, it cannot "bring back" mass production jobs	Empirical research	Case study via semi-structured interviews in Swedish companies

Authors	Year	Area	Main results of the paper	Typology	Method
			from emerging economies to Sweden.		
Holmström, Holweg, Khajavi & Partanen	2016	Firm	Examines the potential of AM and proposes a research agenda for manufacturing on three levels: factory level, supply chain management level and strategy level.	Conceptual study	
Oettmeier & Hofman	2016	Supply, firm, customer	Shows that AM has a major impact on manufacturing flow management, supplier relationship management, product development, order fulfilment, demand, customer relationships and customer service management, and returns management.	Empirical research	Two explorative case studies
Zawadzki, Żywicki	2016	Firm	Examines the potential of AM with virtual reality in smart design approaches. The author proposes that smart designs and production controls will be necessary for the smart factories of the future in order to be able to realize mass customization strategies.	Conceptual study	
Wullms	2016	Supply, supplier relationship	AM deployment for suppliers will influence the mutual contract between the focal firm and other suppliers in terms of “last-time order quantity”. The focal firm is able to bind more effectively and become more profitable.	Empirical research	Quantitative case research on Philips healthcare products
Li, Jia, Cheng & Hu	2016	Firm	AM deployment in firms reduces total costs and carbon emissions in the manufacturing process.	Empirical research	System dynamic simulation
Khorram Niaki & Nonino	2016	Firm	Provides empirical insights regarding the effects and drivers of AM in industry. It also reveals how the implementation of AM in metal manufacturing has boosted productivity.	Empirical research	Exploratory study using a sample of 16 heterogeneos companies
Oettmeier & Hofman	2017	Supply, firm, demand, technology adoption	Proposes a conceptual guideline to identify the determinants of AM technology adoption for production. In detail, the paper examines the impact of four factors in the adoption of AM technologies for industrial parts production. These factors are: technology-related, firm-related, market structure-related and supply chain-related factors. The results show that ease of use (complexity), absorptive capacity, compatibility, perceived outside support, and supply- and demand-side benefits have a significant impact on the adoption of AM technology by the manufacturing sector.	Empirical research	Online survey of 934 Swiss companies

Authors	Year	Area	Main results of the paper	Typology	Method
Schniederjans	2017	Firms	Applies the diffusion of innovation theory to evaluate the main drives of AM deployment in firms. Results shows that the attitude of top management plays the main role in the potential speed of adoption.	Empirical research	Survey with 270 top management personnel from manufacturing firms across the US
Shah, Mattiuzza, Ganji & Coutroubis	2017	Firms	Investigates AM adoption in the supply chain of small and medium-sized enterprises (SMEs). Results show that SMEs' challenges when adopting AM are: machinery and raw material costs, the uncertainty of the market and this new environment, and the lack of liquidity.	Conceptual study	
Holmström & Gutowski	2017	Firms	Evaluates AM in term of environmental sustainability.	Conceptual study	

DISCUSSION

Reviewing the current body of knowledge in the area of AM reveals that the main focus of study is on manufacturers (firms) with cost as the main performance measurement, while there are only a few studies evaluating the impact of this technology on the supply and demand sides in creating (or changing) demand. Although there is limited research on how AM separately impacts supply and demand, there is a need for more studies examining the potential of AM on demand and supply simultaneously in a particular industry.

Existing studies also show that, while the adoption of AM is becoming more and more popular, it is likely to be a gradual expansion. While some efforts have been made to evaluate the impact of AM on the manufacturing sector, exploring how this technology changes business models and shifts the profit domain of supply chains is a rare occurrence. For example, Holmström and Partanen (2014) show that the deployment of AM creates new business opportunities for third-party logistics providers and gives them a more important role compared to manufacturers or customers. That said, more research is needed in this area in order to investigate the potential of AM in creating new business opportunities.

Based on the results of this review, the main studies in the area of AM are presented in terms of conceptual papers and only in relation to traditional 3D printing techniques. As the combination of robots with AM is increasingly popular in industry, especially because it removes the size constraints, academic studies are required to examine the potential of such new capabilities for the entire supply chain. Additionally, in terms of traditional printing techniques themselves, more empirical research is needed to evaluate the impact of this technology on supply chains, given that existing studies are mainly conceptual.

Without any doubt, AM is replacing tool-based manufacturing in some specialized industries. Thus, there is a need for more research that can determine the variable that defines the trade-off between conventional methods and AM. Existing studies mainly consider “unit cost”, while intangible factors, such as risk, flexibility and sustainability, should be also included.

Finally, existing studies, including this one, mainly consider the positive impact of the deployment of AM on business, while there is limited number of studies about negative effects. For example, while AM deployment supports the creation of innovative jobs, especially in Western counties, it is also eliminating some tool-based jobs, not only in emerging economies but also in the West (Samuel et al., 2013). The main question, then, concerns the social impact of such a phenomenon.

CONCLUSION

The aim of our study was to conduct a comprehensive narrative literature review on the subject of AM regarding its potential for supply chain configuration. In detail, this paper has sought to synthesize current knowledge in the area of AM with the goal of summarizing its impact on different parts of supply chains.

In summary, it seems that AM is an emerging class among manufacturing methods, which has already offered diverse and rich opportunities to the business world. It has also changed the role of value added in the supply chain by creating new possibilities and eliminating existing opportunities. Awareness of the full potential offered by AM, which this article seeks to raise, will support decision makers in business to make the right decisions about technology deployment.

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