3D PRINTING AND SUPPLY CHAIN MANAGEMENT: A LITERATURE REVIEW AND RESEARCH AGENDA

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ABSTRACT

The main objective of this study is to assess the current level of research on 3D printing in the supply chain context using Scopus, which is the largest abstract and citation database of peer-reviewed literature. Our search identified 67 relevant journal articles, the distribution of which are being analysed and discussed in this study. Such paper distribution is being established by year of publication, subject area, country, and top authors with at least two publications. Finally, based on the limitations and shortcomings of the retrieved literature, we have set out a research agenda for future research.

KEYWORDS

3D printing, additive manufacturing, supply chain, supply chain management, literature review

1. INTRODUCTION

Three-dimensional (3D) printing, also called additive manufacturing, has recently emerged as a new wave of technological innovation with the capability to transform a great deal of business areas, spanning manufacturing, building, healthcare, education, automotive, aerospace, defense and supply chain, inter alia. Transforming digital "3D models into various objects by building them up in layers" features among the possibilities offered by 3D printing, which increases on-demand manufacturing of any given product or parts of the product at various stages of the supply chain [1]. No wonder that [2] could see in 3D printing the "potential to revolutionize supply chains, because experts and novices alike can design, customize, and manufacture products locally for their own use" (p. 315). Analysts actually estimate that 3D printing can turn "global supply chain" into "local supply chain"; thus playing a key role in promoting local content and technology transfer. Therefore, mega factories, ships, and malls could easily become mini-factories, ships, and malls. The same authors argued that 3D printing have the tremendous potential to shrink all long supply chains, broaden many jobs in order to "combine design, consulting, sales, and production roles", and finally transform many large organizations into a range of small organizations (p.5) [3]. The direct effect is that small organizations integrating the use of such technology boost their level of transparency, while developing more motivation among their employees. As a result, such organizations visibly appear "faster, nimbler, and more adaptive than larger ones" in their daily operations (p. 7) [3].

Even if 3D printing technology has been around over the past 30 years, its adoption and use by the wide business community have been exacerbated thanks to a combination of

two major events: not only did the 3D printing come out of patent (giving rise to a massive interest in it), but also it benefited from an accelerated sophistication. In 2015, analysts estimated that more than 30% of the top 300 largest global brands were using or evaluating 3D printing tools (p. 2) [4]. They also estimated that potential revenues generated from the secondary and primary 3D printing market (e.g., 3D printer, system upgrades, materials) could reach $8.8 billion worldwide in 2017 [5].

In the manufacturing context, 3D printing can help reduce substantially subtractive manufacturing processes and fixed costs related to the customization process of products; while triggering a significant increase in production speed, thereby reducing the time-to-market [6]. The potential for 3D printing can spread over many other purposes, as it can be used to ease on-demand manufacturing of spare parts, produce prosthetics and human organs [7] and work out replacement skin for burned victims and airway splints for kids with tracheobronchomalacia (p. 3) [8], but also to reduce supply chain complexity by allowing for example the consolidation of components into a single product, facilitate the rationalization of warehousing and logistics [9], and reduce production cycles [10].

Despite the huge potential of 3D printing, very few empirical studies have been directed to the assessment of its real business value. A study showed that "although many people are aware of 3D printing, only few recognize the extent to which this technology may impact the world" (p. 5) [3]. Therefore, the main objective of the paper is to fill the knowledge gap identified in the literature by assessing the current level of research on 3D printing in the context of supply chain and supply chain management. More specifically, this study aims at examining the following research questions:

1. What is the current level of research on 3D printing in the context of supply chain and supply chain management?

2. Where should future efforts be directed to accelerate the adoption and use of 3D printing in the context of supply chain and supply chain management?

To address our research questions, we drew on the literature on 3D printing and supply chain through a literature review conducted on these topics within the database called SCOPUS.

The rest of this paper is structured as follows: Section 2 is concerned with the description of our research methodology; Section 3 presents and discusses the results; and Section 4 provides the conclusion as well as future research directions.

2. METHODOLOGY

This study follows a research method derived from previous studies [11] and involves the following steps: (a) conducting a search using a combination of the following keywords: "3D printing" or "additive manufacturing" AND "supply chain management" OR "supply chain" within the SCOPUS database. SCOPUS is a major database compiling abstracts and citations from peer-reviewed scientific journals, books and conference proceedings. The database delivers a comprehensive overview of the world's research output in the fields of science, technology, medicine, social sciences, arts and humanities. It provides a set of tools to pursue, analyze and visualize research [12]. In our study, we

mainly focus on peer-reviewed journal articles from SCOPUS.

Our search was carried on in August 21, 2017. It resulted in 67 relevant journal articles [6, 13-78], discussing a range of topics. For example, [13] argued that modern AM technologies allow efficient manufacturing solutions for small production volumes, and that they could enhance supply chain responsiveness through make-to-order strategy and customization possibilities. In addition, AM is able to contribute to traditional mass production systems by significantly improve the productivity of injection molds (p. 328). [14] identified AM implementation challenge and advantages over traditional manufacturing and explored the impact of this technology on the supply chain and various industries. For [15], 3D printing could improve the production rate at different scales and levels. However, there will be an important lag time between 3D printing investments and the benefits derived from these investments. [16] proposed that AM could lead to sustainability improvements through the minimization of process energy consumption. On their part, [18] argued that digital fabrication such as AM could transform radically the way firms develop and bring products to the final customers, notably by allowing for example the design of new business models (e.g., moving from centralized to decentralized supply chains). [19] suggested that AM could lead to various benefits including "reduced manufacturing lead times, streamlined supply chains, part consolidation, structural optimization and improved buy-to-fly ratios" (p. 276). However, the adoption and use of AM could face many challenges including "high material and processing costs, low build rates, isotropic material properties, and variable processing conditions" (p. 276).

3. RESULTS AND DISCUSSION

This section discusses and presents the important findings of available studies on 3D printing and supply chain.

Table 1 presents the distribution of publications by year. From the table, we can notice that the first article on the topic appeared in 2009, followed by another publication in 2010. Then, there was a gap till 2013, with only 3 articles (4%) published in that period. Later, there is a continuous increase in the number of papers published on the topic from 2014 (8 articles, 12%). In 2015, 2016 and 2017 (August 21), 13 articles (19%), 27 articles (40%) and 14 articles were published respectively

Table 2 presents the distribution of articles by subject area. The most important subject area discussed is 'Engineering' with 43 papers (29%), followed by 'Business, Management and Accounting' with 29 papers (20%), 'Computer Science' with 18 papers (12%), 'Decision Sciences' with 12 papers (8%), and 'Social Sciences' with only 9 papers (6%).

Table 1. Distribution of publications by year

Year	# of papers	%
2017	14	21%
2016	27	40%
2015	13	19%
2014	8	12%
2013	3	4%
2012	0	0%
2011	0	0%
2010	1	1%
2009	1	1%
Total	**67**	**100%**

Table 2. Distribution of publications by subject area

Subject area	#of papers	%
Engineering	43	29%
Business, Management and Accounting	29	20%
Computer Science	18	12%
Decision Sciences	12	8%
Social Sciences	9	6%
Environmental Science	8	5%
Materials Science	8	5%
Economics, Econometrics and Finance	7	5%
Chemical Engineering	3	2%
Energy	3	2%
Chemistry	2	1%
Psychology	2	1%
Agricultural and Biological Sciences	1	1%
Arts and Humanities	1	1%
Biochemistry, Genetics and Molecular Biology	1	1%
Total*	**147**	**100%**

*Some articles are counted more than once because they cover more than one subject area.

The distribution of articles by country is presented in Table 3. Surprisingly, 9 articles (11%) were found not to be related to any country. The table clearly indicates that the United States is leading the research on 3D printing and supply chain, as19 articles are being published (23%) in that country, followed by The United Kingdom with 8 articles (10%), China and the Netherlands with 6 articles (7%) each, and Germany and Italy with 4 papers each (5%).

Our results indicate that 160 scholars have published a paper on the topics under study. However, only 11 of them have published at least two articles. Table 4 provides the list of authors with at least two journal articles. Baumers, M., Fawcett, S.E., Holmström, J. and Waller, M.A. have registered 3 articles for each of them, while the other authors have registered 2 published articles: Bills, P., Hofmann, E., Khajavi, S.H., Oettmeier, K., Partanen, J., Racasan, R. and Shah, P.

Table 3. Distribution of publications by country

Country	**# of papers**	**%**
United States	19	23%
Undefined	9	11%
United Kingdom	8	10%
China	6	7%
Netherlands	6	7%
Germany	4	5%
Italy	4	5%
Switzerland	3	4%
Australia	2	2%
Canada	2	2%
Denmark	2	2%
Finland	2	2%
Singapore	2	2%
Taiwan	2	2%
Chile	1	1%
Estonia	1	1%
Greece	1	1%
India	1	1%
Ireland	1	1%
Norway	1	1%
Romania	1	1%
Spain	1	1%
Sweden	1	1%
United Arab Emirates	1	1%
Total*	**81**	**100%**

*Some articles are counted more than once as their authors come from more than one country.

Table 4. List of authors with at least two journal articles

Author	**# of papers**
Baumers, M.	3
Fawcett, S.E.	3
Holmström, J.	3
Waller, M.A.	3
Bills, P.	2
Hofmann, E.	2
Khajavi, S.H.	2
Oettmeier, K.	2
Partanen, J.	2
Racasan, R.	2
Shah, P.	2

4. CONCLUSION

The main objective of this study was to assess, by means of the SCOPUS database, the current level of research on 3D printing in the context of supply chain. Our study identified 67 journal articles from such a database, the distribution of which—by year of publication, subject area, country, and top authors with at least two published articles—is being presented and discussed. Future studies could expand our study by looking for more datasets including ABI/Inform Complete, Taylor & Francis, Business Source Complete, IEEE Xplore, Emerald, Science Direct, Academic Search Complete, and the Association of Information Systems (AIS) basket of top journals.

Our results showed that the most important subject area discussed is 'Engineering', followed by 'Business, Management and Accounting', 'Computer Science', 'Decision Sciences', and 'Social Sciences'. It would be interesting to find out more papers on the topic from 'Social Sciences', 'Environmental Science', 'Materials Science', 'Economics, Econometrics and Finance', 'Chemical Engineering' and 'Energy', since the 3D could also have significant impacts on these fields.

Our study also found that the United States is leading the research on 3D printing and supply chain, followed by The United Kingdom, China and the Netherlands, and finally Germany and Italy. It would be interesting to examine the impact of 3D printing on the renewal of manufacturing in many western countries. Also, exploring the impact of 3D printing on the development of the manufacturing sector in developing countries is an interesting future research avenue. Other angles of research include: investigating the disruptive effect of 3D on the supply chain in both developed and developing countries; and the contribution of 3D printing to the democratisation of manufacturing.

[6] argued that "3D-printers consumer 50–100 times more electrical energy than injection molding". Therefore, it is important to explore means and ways of streamlining high electrical energy consumption by 3D appliances on the one hand, and to find out alternative sources of energy for such apparatus on the other hand

As [2] noted that "an important way that 3D printing technology is being diffused to consumers is through reuse of previously created designs. 3D printing communities are a lot like open source software communities: there is a culture of sharing and modifying designs through the editing of digital files" (p. 315). So it would be important to assess the robustness of this culture when it comes to extending the use of 3D printing to the wider business community, where the main objective is not always to share but to realize benefits.

For [79], "one of the obstacles that 3D printing has to overcome to gain wider adoption in the supply chain and logistics industries is 3D printer and material costs". Therefore, such a gap should be filled, especially by examining various mechanisms enabling a cost-effective production of 3D printing, but also by exploring different strategies for the creation of 3D printing hubs and for their strategic localization across a given supply chain, in order to facilitate resource sharing.

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