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The intersection between additive manufacturing and management: a bibliometric study

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1. INTRODUCTION

Nowadays the society is living in an industrial revolution. The scale and speed of this revolution is higher than other revolutions we faced in the past, this phenomenon was called "The fourth Industrial revolution" (Schwab 2017). Deep changes are taking place on physical, digital and biological aspects, and this changes can have disruptive effects (Schwab 2017). The main objective of this revolution. The main objective of this revolution is to meet the futuristic demands of the industry and, for this, new technologies are the central engine (Haleem and Javaid 2019). These technologies aim to eliminate the existing barrier between the physical and digital world, performing an integration between these two dimensions (Xu et al. 2020).

Some of the most prominent technologies under this revolution are: internet of things (IOT), wireless sensor networks (WSN), cloud computing and cyber physical systems (CPS), additive manufacturing (AM), intelligent machines, autonomous robots, intelligent materials, artificial intelligence, augmented reality and virtual reality (Haleem and Javaid 2019; Xu, Xu, and Li 2018). Within the diverse range of technologies present in this revolution, the present article focuses on one of these technologies, additive manufacturing, also called 3D printer, which transforms digital objects made in CAD (Computer aided design) into physical objects. Printing is performed layer by layer in a similar technique to a common printer, but instead of using ink, a variety of materials are used to print an object (Berman 2012; Campbell, Bourell, and Gibson 2012).

Additive manufacturing is a technology that can give companies a great competitive advantage, however, managers are required to have a good understanding of the phenomenon and its impacts (Martens, Fan, and Dwyer 2020; Sonar, Khanzode, and Akarte 2020). Although at an early stage, the theme has been increasingly arousing the interest of researchers due to its great potential impact on organizations (Khorram Niaki and Nonino 2017). Additive manufacturing is not yet widely used in organizations, being only applied in some specific areas where it is possible to take advantage of its unique characteristics (Mittal et al. 2019).

There's a crescent need to understand the disruptive impacts of additive manufacturing on organizations and society (Martens et al. 2020), in addition to being a first step towards understanding the role of additive manufacturing in future production systems (Öberg, Shams, and Asnafi 2018). The literature that aims to understand the insertion of additive manufacturing within organizations began to develop in recent years, however, a large part of the literature still focuses on technical aspects of technology (Öberg et al. 2018).

Given the general lack of knowledge about technology and how it relates to the theme of management, this research aims to better understand the structure and evolution of the literature on the intersection between AM and Management. This main objective was divided in two: the first is to understand the general evolution of scientific production at the intersection between management and additive manufacturing. With this it will be possible to obtain a macro view of the topic and how it is developing. Second, after identifying the literature on the topic, each of the articles will be classified into emerging topics in the area of Administration. This process will give rise to the main areas of Administration that are impacted by the adoption of additive manufacturing.

The rest of the article is organized as follows: the next section will bring the theoretical framework for understanding the additive manufacturing technology; the third section aims to explain the procedures used to select and analyze articles; subsequent to the methodology is the presentation and discussion of results section; finally, the final considerations indicate the contributions of the article and possibilities for future research development.

2. THEORETICAL BASIS

So far, society has gone through three industrial revolutions, in recent years "The fourth industrial revolution" has begun (Schwab 2017). It brings the power of technology into almost every area of science, and now the scope and scale of change is faster than ever (Schwab 2017). Haleem and Javaid (2019) made a description of the fourth revolution by comparing it with the others, and concluded that the main objectives of the fourth revolution is to meet the futuristic needs of the industry and involve the importance of disruptive technologies (artificial intelligence, internet of things, etc.), the possibilities that will be created in relation to creativity, design, business model, supply chain and the change that manufacturing processes will undergo with the addition of these new technologies (Haleem and Javaid 2019).

Xu, Xu and Li (2018) conducted a literature review making it possible to understand the impact of new enabling technologies, such as the internet of things (IOT), wireless sensor networks (WSN), cloud computing and cyber-physical systems (CPS), on the integration of the digital world to the physical world within of the organizations (Xu et al. 2018). Haleem e Javaid (2019) added other technologies to this discussion: additive manufacturing, intelligent machines, autonomous robots, intelligent materials, artificial intelligence, augmented reality, and virtual reality. As highlighted in the introduction, the focus of the present work is on additive manufacturing technology.

Additive manufacturing is the layered printing of a model made in digital software (Computer aided design - 3D CAD) where it is possible to observe a great simplification of the product production process (Gibson 2017). In the early stages the technology was known and used as rapid prototyping, but due to advances in technology, which made a number of other applications possible, the term was changed to additive manufacturing (Campbell et al. 2012).

As some of the spectrum technologies of Industry 4.0, additive manufacturing has a great disruptive potential with the ability to affect companies in general and the supply chain (Amshoff et al. 2015; Bongomin et al. 2020; Majumdar, Banerji, and Chakrabarti 2018; Martens et al. 2020). Of course not all industries will be affected in all ways, in some cases AM will be an incremental innovation and in other cases a disruptive innovation, but most importantly, organizations that do not invest in this technology may face difficulties when it actually becomes a mainstream technology (Steenhuis and Pretorius 2017).

As discussed by Christensen, Raynor and McDonald (2015), disruption arises in market niches not served by incumbent companies and in the creation of new markets. In addition, the product supplied is of lower quality than that supplied by the incumbent company, but as technology evolves there is a significant improvement in quality overtaking previously established companies in the market. (Christensen et al. 2015, 2018). The disruption caused generates numerous opportunities and challenges for managers, requiring the adaptation of current business models to capture and generate value (Amshoff et al. 2015).

These impacts on manufacturing enable companies to organize around new business models to explore the potential of additive manufacturing. According to D'Aveni (2018) the 3D printer allows business models that were not possible before in conventional manufacturing. These business models take advantage of product variation, making complex products and the efficiencies that technology enables (D'Aveni 2018) . In this way, organizations are able to strategically position themselves, aiming to compete in unexplored and specific niches, block market entrants and reduce dependence on a large supply chain (D'Aveni 2018).

Additive manufacturing is still under development (Gibson 2017; Haleem and Javaid 2019), but some researches have already started to appear in the field of management, bringing to the discussion the impact of these new technologies in the present time and, mainly, for the future (Khorram Niaki and Nonino 2017). Based on the discussed literature, it is possible to observe that there was a great advance in the technical part of additive manufacturing, but discussions regarding its insertion in management are still at an early stage. Given this context, we intend to answer the following questions:

> RQ1: what is the overview of the evolution of the literature in the intersection of additive manufacturing and management?
> RQ2: which are the emerging topics on the intersection between management and additive manufacturing?

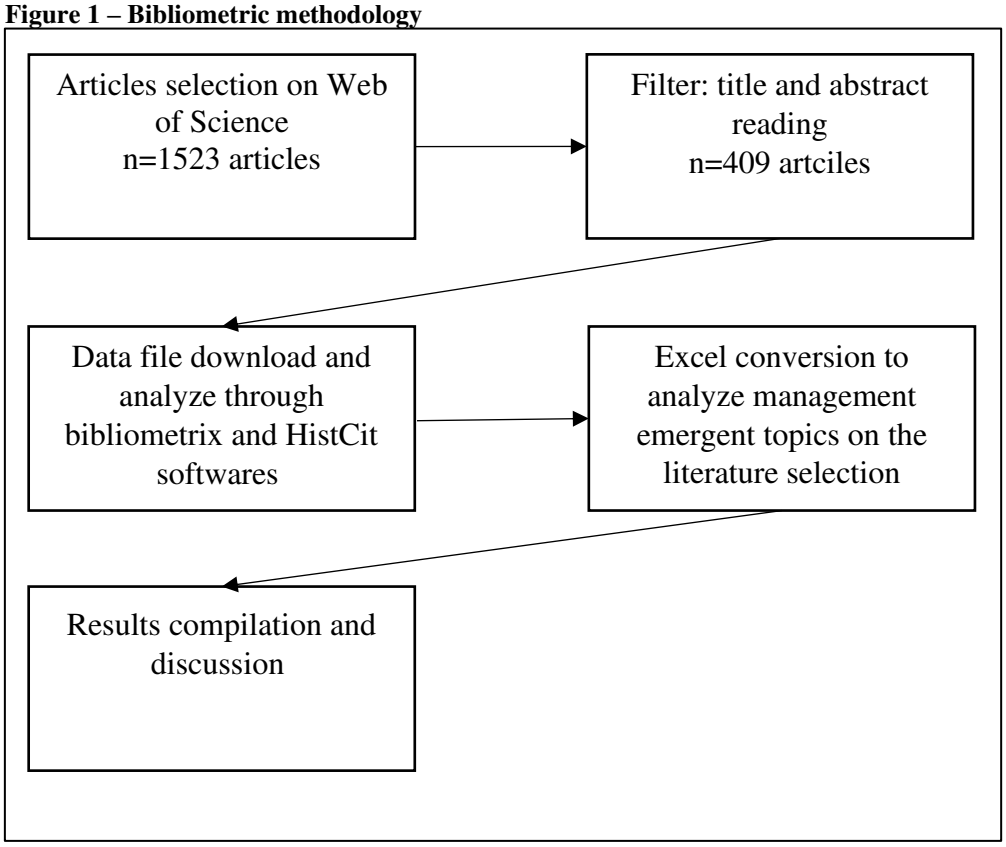
3. METHODOLOGY

To achieve the proposed objective, a literature analysis methodology was used through the use of bibliometric techniques and tools. Articles for analysis were collected from the Web of Science (WOS). The time window considered for selection of articles was opened, that is, the lower limit was not defined and the upper limit was defined as the year 2021. This window aims to select all articles produced regardless of the publication date.

The search carried out in the databases sought to identify the overlap between the theme of 3D printing and management (InTopic: "additive manufacturing" AND InTopic: "management"). Initially 1523 articles were found. A first filter was applied to eliminate articles that did not address the topic of interest, and after this process, 409 articles remained, which were used for the final analysis.

After the database refinement, the Histcite software was used to identify the citation between authors, identify the main authors and most relevant articles. This analysis supported by the software allowed the graphic visualization of the structure of the relationships present in the selected literature. Another relevant process was the reading and classification of each of the articles regarding the area of Administration that was being discussed in the context of adopting additive manufacturing. The processes described are represented in Figure 1. After this process, the results were presented and discussed in the subsequent section.

Figure 1 – Bibliometric methodology



Source: the authors (2021)

4. RESULTS AND DISCUSSION

On table 1 the descriptive data about the articles are presented. Despite leaving an open timespan it's possible to observe that the literature taking into account management and additive manufacturing started to emerge around 2007. The 409 articles selected was published on varied sources, demonstrating how pulverized the theme is. A critical aspect demonstrated on the table is the nature of papers, a great majority of the production are theoretical papers (64%). In this theme, there is a possibility of developing empirical articles that bring theoretical developments to the field.

Table 1 - Descriptive of articles selection

Main information about data	**Results**
Timespan	2007:2021
Sources (Journals, Books, etc)	216
Documents	409
Average years from publication	2,87
Average citations per documents	20,66
Empirical articles	36%
Theorical articles	64%

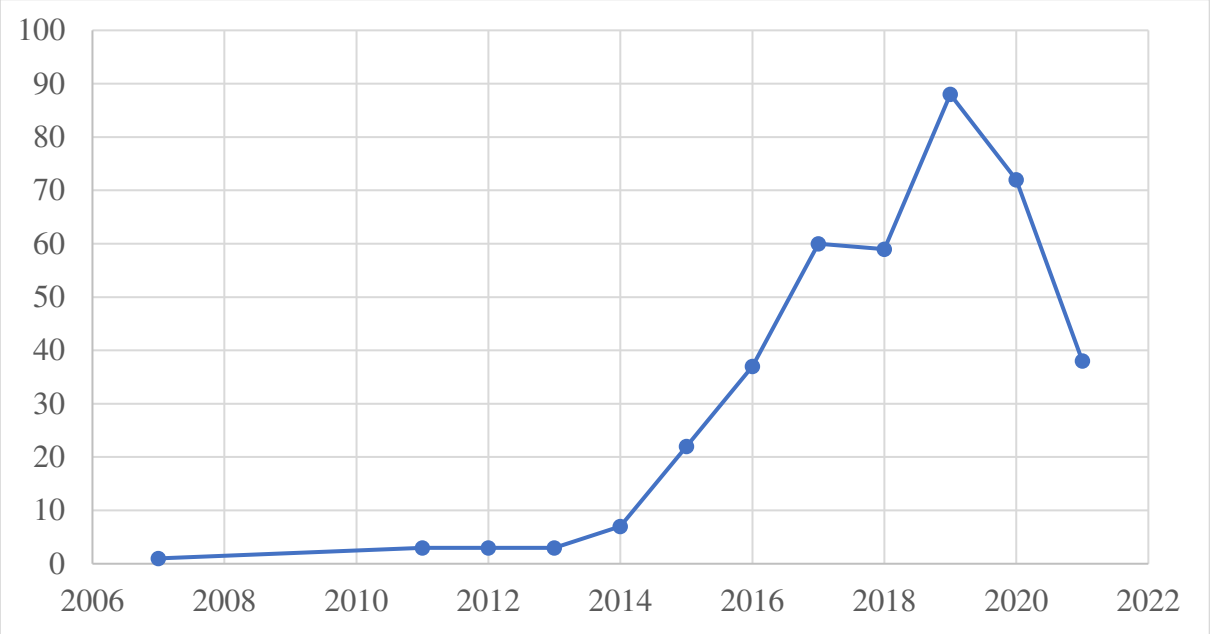
Source: the authors (2021)

The first outstanding aspect is the annual scientific production. Observing figure 1, it is possible to infer that the productions at the intersection between additive manufacturing and management started to growth around 2012 and from 2014 onwards they had a great evolution.

Added to this, it is possible to observe in each year an increase in the average citations per document.

Together these initial findings demonstrate two aspects: novelty and interest in research on the subject. First, the topic is considered new, as research began to emerge more consistently after the year 2012. The literature on additive manufacturing is not new, however, its insertion in organizations and its impacts have started to be studied recently because of the technological advances that allowed the technology to be used widely. The interest in research can be seen in the increase in the volume of publications, especially from the year 2014. These data confirm a fertile and recent field of research that tends to become increasingly larger as technology reaches greater maturity and finds more applications on the organizational context.

Figure 2 – Additive manufacturing and management annual article production



Source: the authors (2021)

The second analysis consisted of preparing table 2 with the articles publishes by each journal, their total citations and the Scimago Journal Ranking (SJR). The first journal with the highest number of publications don't have the highest number of citations, neither the highest SJR among all the selected journals in the sample. The citations are distributed for important papers on a high diversity of journals. Some important journals, like Technological Forecasting and Social Change and Journal of Operations Management, published articles on the theme indicating the relevance of the discussion. Overall, excluding a few publication sources, most journals have a JCR greater than 1.20.

Table 2 – Journals with higher number of publications

Journals	**Articles**	**Total citations**	**SJR**
Journal of Manufacturing Technology Management	34	483	1.29
International Journal of Production Economics	16	543	2.40
International Journal of Production Research	16	469	1.90
Technological Forecasting and Social Change	15	459	2.22
Production Planning & Control	12	164	1.33

Ifac Papersonline	9	154	0.30
Journal Of Manufacturing Systems	9	171	2.31
Rapid Prototyping Journal	7	503	0.82
International Journal of Advanced Manufacturing Technology	6	430	0.94
Journal Of Cleaner Production	6	340	1.93
Computers In Industry	5	255	1.43
International Journal of Physical Distribution & Logistics Management	5	182	1.74
Journal of Operations Management	5	188	3.64
Ieee Access	4	232	0.58
International Journal of Operations & Production Management	4	147	2.15

Source: the authors (2021)

The most important countries were also analyzed according to the number of citations. USA occupies the first position with the highest total citations closely followed by United Kingdom. It's possible to observe a high presence of European countries and some Asian countries like China, Malaysia and Iran. The presence of the European majority may be linked to strong investments in industry 4.0 and the attempt to reduce dependence on extensive supply chains with the use of additive manufacturing. It's also important to highlight the lack of presence of underdeveloped and developing countries. This issue may draw attention to the fact that investments in technology may only be taking place in developed countries.

Table 3 - Most important countries by number of citations

Country	**Total Citations**
USA	2123
United Kingdom	1846
Germany	711
Italy	689
Finland	555
Switzerland	305
China	281
France	211
India	192
Denmark	184
Canada	180
Netherlands	137
Australia	136
Greece	132
Sweden	127
Portugal	106
New zealand	88
Malaysia	73
Austria	72
Iran	68

Source: the authors (2021)

It was also identified the most cited articles in the sample. On table 4 it's possible to infer that Berman (2012) was the most cited paper, and the journal Business Horizons don't appear on

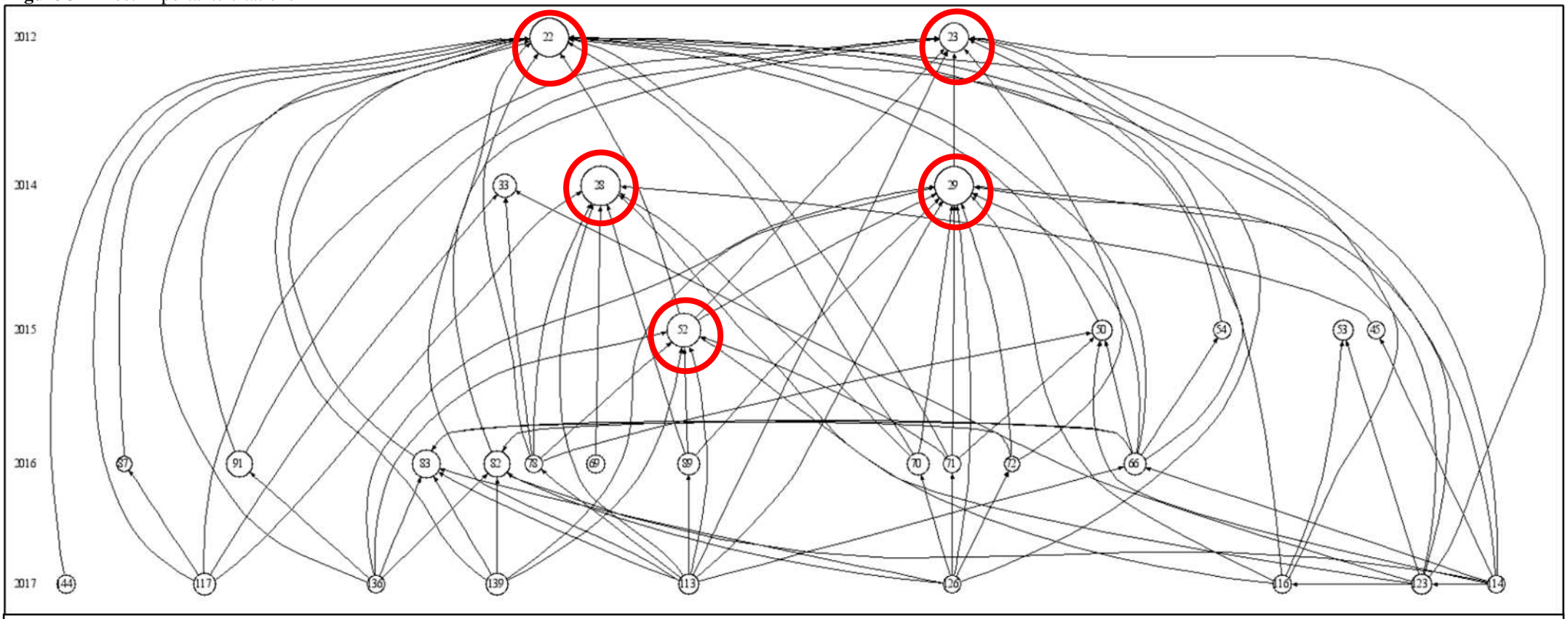
the most important journals. This is an example of how literature is spread across journals. The article made by Berman (2012) is a seminal article discussing some general topics about the future of insertion of additive manufacturing in firms. On figure 3 it's possible to see the structure of citations of the most important articles on the theme including Berman (2012).

Table 4 – Most cited articles

Article	**Total Citations**
Berman (2012) -Business Horizons	964
Ford (2016) - Journal of Cleaner Production	420
Mellor (2014) - International Journal of Production Economics	302
Atzeni (2012) - International Journal of Additive Manufacturing Technology	285
Khajavi, (2014) - Computer Industry	284
Weller (2015) - International Journal of Production Economics	277
Attaran, (2017) - Business Horizons	272
Baumers, (2016) - Technology Forecast and Social Change	241
Jiang, (2017) -Technology Forecast and Social Change	166
Gardan, (2016) - International Journal of Prodction Research	153
Kietzmann, (2015) - Business Horizons	147
Bogers, (2016) - Technology Forecast and Social Change	140
Despeisse, (2017) - Technology Forecast and Social Change	127
Laplume, (2016) - Journal of International Business Studies	96
Liu, (2014) - Production, Planning and Control	85

Source: the authors (2021)

Figure 3 – Most importante citations



22-Berman (2012); 23-Atzeni (2012); 28-Khajavi (2014); 29-Mellor (2014); 52-Weller et al. (2015)

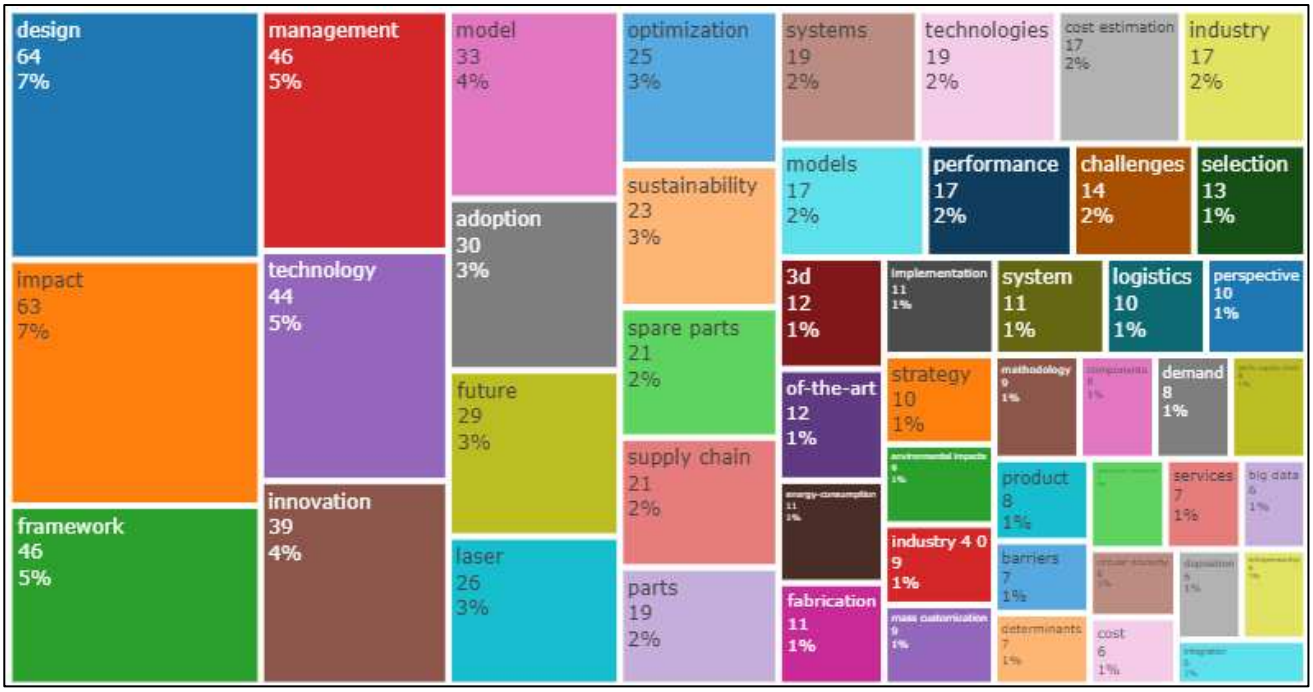
Source: the authors (2021)

Atzeni and Salmi (2012), and Weller, Kleer and Piller (2015) make a discussion in the same thematic area that refers to the economic aspects of additive manufacturing. Both articles analyze the cost models of additive manufacturing compared to traditional manufacturing (Atzeni and Salmi 2012; Weller, Kleer, and Piller 2015). The question that guides these articles is to identify the contexts in which additive manufacturing becomes more advantageous, for example, Weller concludes that stable and uniform demand does not bring advantages for the application of additive manufacturing, however, in cases of variable and uncertain, or manufacturing processes that require flexibility, additive manufacturing has a great advantage over conventional manufacturing (Weller et al. 2015).

Mellor, Hao and Zhang (2014), just like Khajavi, Partanen and Holmström (2014), have a discussion much more focused on the impacts of additive manufacturing on the organization, assuming the economic feasibility discussed above. The first authors will build a framework for implementing additive manufacturing in organizations, going through the construction of an AM strategy, the supply chain, the operations system, organizational changes and the technology that will be adopted (Mellor, Hao, and Zhang 2014). All these aspects are guided by external forces that are fundamental both for the success of the adoption of additive manufacturing in the industry, or for its failure (Dwivedi, Srivastava, and Srivastava 2017). The second authors carry out a discussion focused on the impacts of additive manufacturing on the supply chain, taking into account the repair parts supply chain (Khajavi, Partanen, and Holmström 2014). Repair parts are a focus of discussion in several articles as they are a class of products that can take great advantage of additive manufacturing due to their varied demand. Through a case study, they have created supply chain configurations that can be useful in the process of decentralizing supply chains in order to increase flexibility (Khajavi et al. 2014).

The final analysis consisted of identifying emergent topics in the sample. In figure 4 it is possible to identify some of these topics according to their frequency.

Figure 4 – Emergent topics on the literature



Source: the authors (2021)

Figure 4 shows the main topics that emerged from the selected sample. It is worth highlighting the topics that emerged: innovation, adoption, sustainability, supply chain, implementation and strategy. All these topics that have emerged are challenges for management and research areas that have started to emerge and that tend to grow as the area evolves. In addition to the topics that emerged in the analysis, security and intellectual property is also an important topic that has been gaining more and more relevance in the field of additive manufacturing

5. CONCLUSION

As previously proposed, this work aimed to investigate the state of the art in the literature on the intersection between additive manufacturing and management. A total of 409 articles extracted from WoS that discussed the proposed theme were analyzed. Through bibliometric analysis, it was possible to identify the evolution of the literature in the area, the most important journals, the countries with the highest productivity and the most important articles. Based on this initial analysis, future researchers can identify critical articles for reading and authors who have contributed most significantly to the field.

In addition to general analyses, a deeper investigation was carried out seeking to identify emerging topics. In conjunction with additive manufacturing, topics such as innovation, adoption, barriers, sustainability, supply chain, business models and strategy were addressed. To different degrees, it is possible to observe that the theories that already exist in the field of management are beginning to intertwine with additive manufacturing.

As highlighted in the theoretical discussion, AM technology is still in an evolution stage and is only applied in some specific sectors where it is possible to take advantage of the technology and be economically viable. Despite this, technology is gaining more space and attention from researchers due to its great potential for several companies and also for society in general. From this bibliometrics, future authors can focus their efforts on the major highlighted areas, or invest their efforts in areas that are beginning to emerge, for example, safety and patents of products made in AM. In the present study, an effort was made to include as much literature as possible at the intersection between the two themes, but it is considered that some literature was not included in the analyses.

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