VIII SINGEP
Simpósio Internacional de Gestão de Projetos, Inovação e Sustentabilidade
International Symposium on Project Management, Innovation and Sustainability
ISSN: 2317-8302
8TH INTERNATIONAL CONFERENCE
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INDÚSTRIA 4.0 - UMA ANÁLISE BIBLIOMÉTRICA DO PANORAMA CIENTÍFICO NA ÁREA DE NEGÓCIOS E GESTÃO

INDUSTRY 4.0 - A BIBLIOMETRIC ANALYSIS OF THE SCIENTIFIC OVERVIEW IN BUSINESS AND MANAGEMENT AREA

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Nota de esclarecimento:
Comunicamos que devido à pandemia do Coronavírus (COVID 19), o VIII SINGEP e a 8ª Conferência Internacional do CIK (CYRUS Institute of Knowledge) foram realizados de forma remota, nos dias **01, 02 e 03 de outubro de 2020.**

Agradecimento à orgão de fomento:
This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) - Finance Code 001

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Objetivo do estudo
O objetivo do nosso estudo é, além de mapear o cenário científico geral da indústria 4.0 e dos autores mais citados, identificar com mais detalhes o cenário científico na área de negócios e gestão.

Relevância/originalidade
Após uma leitura mais detalhada de 29 artigos bibliométricos sobre Indústria 4.0, apresentados na seção dois deste estudo, identificamos que apenas três deles abordam especificamente a Indústria 4.0 no contexto da área de Negócios e Gerenciamento quando se trata. Desses três, um focado especificamente nos aspectos robóticos da Indústria 4.0 (Klincewicz, 2019), o segundo realiza uma revisão dos estudos bibliométricos, fornecendo informações de uma revisão sistemática (Ozdagoglu et al., 2019), e um terceiro se concentra em a estrutura intelectual da Indústria 4.0 no cenário de negócios e gerenciamento (Mariani & Borghi, 2019). Nesse sentido, a relevância do estudo se deve à abordagem do tema na área específica de gestão e negócios, servindo como base de pesquisa da indústria 4.0 nessa área do estudo.

Metodologia/abordagem
Para analisar o cenário científico, utilizamos o método de pesquisa bibliométrica.

Principais resultados
O estudo identificou como resultado em todos os campos de pesquisa, podemos verificar entre 2015 e 2019, o percentual relativo de produção de artigos e realização de conferências diminuiu de 120,2% para 54,7%. Essa conversão mostra um aumento na maturidade do campo de pesquisa pela consolidação da pesquisa através da publicação de artigos em periódicos especializados.

Contribuições teóricas/metodológicas
O presente trabalho buscou contribuir para o mapeamento dos estudos acadêmicos que tratam da Indústria 4.0 na área de negócios e gestão, servindo de base para futuras pesquisas sobre o tema, demonstrando os principais autores, palavras-chave, países e trabalhos relacionados ao tema.

Contribuições sociais/para a gestão
Com relação às contribuições práticas, este estudo apresenta uma compilação de artigos científicos que tratam da Indústria 4.0 de maneira sistemática e objetiva.

Palavras-chave: Indústria 4.0, Negócios, Gestão, Bibliométrico

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Study purpose
The objective of our study is, beside mapping the general scientific scenery of industry 4.0 and the most cited authors, identify in more detail the scientific landscape at the business and management area.

Relevance / originality
After a more detailed read of 29 bibliometric articles in Industry 4.0, which is presented in section two of the this study, we identify that only three of them specifically address Industry 4.0 in the context of the Business and Management area when it comes to. Of those three, one focused specifically on Robotic aspects of Industry 4.0 (Klincewicz, 2019), a second performs a review of bibliometric studies, thus providing insights from a systematic review (Ozdagoglu et al., 2019), and a third one focuses on the intellectual structure of the Industry 4.0 at the Business and Management Landscape (Mariani & Borghi, 2019). In this sense, the relevance of the study is due to the approach of the theme in the specific area of ??management and business, serving as the research base of industry 4.0 in this area of ??the study.

Methodology / approach
In order to analyze the scientific landscape, we use the bibliometric research method.

Main results
The study identified as a result in all research fields, we can verify between 2015 and 2019, the relative percentage of articles production and conference proceedering decreased from 120.2% to 54.7%. This conversion shows an increase in the maturity of the research field by the consolidation of the research through the publication of articles in specialized journals.

Theoretical / methodological contributions
The present work sought as a contribution to map the academic studies that deal with Industry 4.0 in the area of business and management, serving as a basis for future research on the theme, demonstrating the main authors, keywords, countries and works related to the theme.

Social / management contributions
With regard to practical contributions, this study presents a compilation of scientific articles that deal with Industry 4.0 in a systematic and objective way.

Keywords: Industry 4.0, Business, Management, Bibliometric

1. Introduction

Ever since the introduction of the "Industry 4.0", by the German Government in 2011, and later with the "Final report of the Industry 4.0 Working Group", in 2013 (Kagerman *et al*, 2013), the concept related to Industry 4.0 attracted a lot of academic attention over the past years (Liao *et al*., 2017). The academic literature, ranges from the development of maturity models (Jufer *et al*., 2012; Veza *et al*., 2015), to studies where dynamic capabilities are explored (Orlandi, 2016; Zeng *et al*., 2017), encompassing also business models approaches (Arnold *et al*., 2017; Kiel *et al*., 2017), as well as value aspects (Müller *et al*., 2018). Furthermore, a wide range of academic areas is currently addressing Industry 4.0. Liao *et al*., (2017), for example, identify 15 different areas where Industry 4.0 studies were published. Nevertheless, there's an emphasis on the Engineering and Computer science streams, since according to Kagerman *et al*., (2013) and Kiel (2017) those are the two areas where this discussion emerged.Nevertheless, some studies such as Kiel (2017) demonstrate that Business and Management are gaining more prominence when it comes to Industry 4.0, with a crescent number of studies being published.

Systematic reviews (Kiel, 2017; Machado *et al*., 2019; Novais *et al*., 2019), and also bibliometric studies (Ciano, 2019; Da Costa *et al*., 2019; Muhuri *et al*., 2019), were conducted aiming to better understand the scientific landscape related to the industry 4.0. A research using the string ("Industry 4.0" and bibliometric*), at the Web of Science (WOS) and at the Scopus databases, reveals 29 studies exploring this scenario (after removal of duplicated entries). After reading their abstracts, we identified that the objective of those bibliometric studies and their research areas were sparse, ranging from industrial engineering, where 'lean manufacturing' (Ciano *et al*., 2019) and also 'Smart Factory' (Strozzi *et al*., 2017) aspects are addressed, to telecommunications, were Big Data (Ahmi *et al*., 2019) and, Robots (Klincewicz, 2019) and also a review of bibliometric studies (Ozdagoglu *et al*., 2019) are explored.

After a more detailed read of those 29 studies, which is presented in section two, we identify that only three of them specifically address Industry 4.0 in the context of the Business and Management area when it comes to. Of those three, one focused specifically on Robotic aspects of Industry 4.0 (Klincewicz, 2019), a second performs a review of bibliometric studies, thus providing insights from a systematic review (Ozdagoglu *et al*., 2019), and a third one focuses on the intellectual structure of the Industry 4.0 at the Business and Management Landscape (Mariani & Borghi, 2019).

The objective of our study is, beside mapping the general scientific landscape of industry 4.0 and the most cited authors, identify in more detail the scientific landscape of industry 4.0 within the business and management area and also the keywords relationships that are more frequent used in the area, which can provide novel insights about what is currently being researched and also about future research directions regarding Industry 4.0.

A bibliometric research method (Zupic & Čater (2015), was used, in which a single keyword ("Industry 4.0") was used to search at the title, abstract, and keywords of the Scopus database. A sample of 7,057 studies was retrieved and analyzed with the software package *bibliometrix* (Aria and Cuccurullo, 2017) for the statistical software R, along with the software VOSviewer (Van Eck & Waltman, 2010) for the creation of the scientific maps of the literature.

Our study is structured as follows: Section two explores the theoretical background related to Industry 4.0, together with a review of bibliometric studies related to Industry 4.0 that were identified in the Scopus and WOS database. Section three contains the methodological procedures of our study, explaining how the research was conducted. Section four then presents

the results, while section five presents the discussion, conclusion, and also future research directions.

2. Theoretical Background

Industry 4.0

Being Industry 4.0 can be summarized as an integration of technologies such as Internet of Things (IoT), machine learning, 3D printers, big data, data analytics, among others (Khaitan & McCalley, 2015), The concept was first introduced by the German Government in 2011, aiming to demonstrate the ambition of this government for their manufacturing sector (Kagerman *et al*., 2013). A commonly discussed concept in Industry 4.0 is Cyber-Physical-Space (CPS) (Spath *et al*., 2013), which according to Shrouf *et al*., (2014) characterize an organization as being a 'Smart Factory'., Industry 4.0 is more related to an integration of technologies (Liao *et al*., 2017), which according to Kagerman *et al*., (2013), will have impacts for a large number of organizational aspects, such as Business Models (Arnold *et al*., 2017; Müller *et al*., 2018), and also Dynamic Capabilities (Zeng *et al*., 2017; Teece, 2018). Kagerman *et al*., (2013) define Industry 4.0 as being the integration of the CPS to the logistic and manufacturing process, besides the use of IoT at the industrial processes (Kagerman *et al*., 2013, p.14). They also point that the CPS can expand itself to outside the Smart Factory, thus encompassing other 'Smart' aspects of the digital world, such as Smart Products (Porter & Heppelman, 2014) and also Smart Buildings (Lilis & Kayal, 2017).

Industry 4.0 originated at the engineering and computer science streams. Liao *et al*., (2017) for example, demonstrate at their study that from a sample of 224 studies, 69% were related to those two research streams.Nevertheless, the impacts that industry 4.0 causes on the business and management aspects of the organization resulted in an increasing number of studies exploring this stream (Arnold *et al*., 2017; Kiel *et al*., 2017; Müller *et al*., 2018). Porter and Heppelman (2014) for example, point out that the integration of Information Technology (IT) to the product itself generates a new wave of innovation at the organizations. Teece (2018) points to the digitalization as something that can generate novel organizational processes and business models, and some studies also point to changes at collaborative practices, which tends to become more open and dynamic (Nambisan *et al*., 2017).

The systematic review performed by Kiel (2017) also demonstrates that scenario, identifying that human resources management and Industry 4.0 implementation accounts for the largest amount of studies at the business and management area. Those two streams are then followed by supply chain management and business model studies. However, a bibliometric study performed by Cortes-Shancez (2019), demonstrates that at Latin America, themes such as Industry 4.0 remain unnoticed, which we can also see in other studies such as Liao *et al*., (2017) and also Ahmi *et al*., (2019), where the scientific production at developed countries and more specifically at Europe (with emphasis at Germany) become evident.

3. Methodology

In order to analyze the scientific landscape of Industry 4.0 in Business Administration, Management, and Accounting (hereinafter BMA), we use the bibliometric research method. This method enables the analysis of bibliographical data using quantitative methodologies, improving reflections on the research field and showing opportunities for future academic studies.

The bibliometric method is the use of aggregate data to analyze the works of scientists from a specific field (Zupic & Čater, 2015). This method uses technics such as analysis of citation, co-citation, and bibliographic coupling to enhance the quantitative analysis of the collections composed by academic works (Osareh, 1996).

The use of such bibliometric techniques enables two types to evaluate scientific production (Gutiérrez-Salcedo *et al*., 2018). The first is the performance analysis, which evaluates the citation impact using the production indicator, impact indicators (based on received citations), and also indications based on the journal impact. The second one is the science mapping, which shows aspects related to the dynamics and evolution of a scientific field. It uses network structures to demonstrate the relationships between scientific actors (e.g., authors, journals, keywords, and institutions).

However, despite the possibility of analyzing data related to the field structure (e.g., countries, universities, and journals), bibliometric studies do not intend to replace traditional academic review methods. In this sense, bibliometric is a complementary method, and not a substitute, to the traditional academic review methods (Zupic & Čater, 2015). Thus, this method is a useful starting point when the researcher begins an extensive literature review, as it provides a broad knowledge of the research field and the most influential works related to the subject being researched.

This type of knowledge regarding the research field is made up of the research front and also from its intellectual base (Persson, 1994). The knowledge of the research front uses bibliographic coupling and the grouping of citing articles according to their shared references. Then, the more references two studies share, the higher are the similarities with the research front they represent.

The second option, assessment of the intellectual base, uses the co-citation analysis. This technique allows clustering works according to their co-occurrences in reference lists. In this sense, the higher is the number of two (or more) authors cited in the same work, the higher the chances of them shaping an intellectual base.

Furthermore, Zupic and Čater (2015) expose five bibliometric methods to demonstrate the relationships among studies, authors, journals, and keywords. Those five methods are described in Table 1.

Table 1.
Summary of bibliometric methods

Method	Description
Citation	Estimates influence of documents, authors, or journals through citation
Co-citation	Connects documents, authors, or journals on the basis of joint appearances
Bibliographic	Connects documents, authors, or journals on the basis of the number of
Co-author	Connects authors when they co-author the paper
Co-word	Connects keywords when they appear in the same title, abstract or keyword

Source: Zupic and Čater (2015)

It is essential to emphasize the differences between the results of two of the cited methods in Table 1, where the co-citation analysis map the intellectual base of the field, and the bibliographic coupling shows the research front of the field (Persson, 1994). In this sense, and also to avoid comprehension mistakes, we need to point out the differences between reference and citation. While a reference is the mention that one document gives to another, citation is the mention that one document receives from another.

Research Steps

The present article uses Zupic and Čater (2015) five steps model to perform the research, as detailed in Table 2.

Table 2.
Bibliometric research stages

Step	Activities
Research Design	Definition of research questionChoice of the most suitable bibliographic method according to the research question Defintion of keywords
Compilation of bibliometric data	Advanced search on Scopus (and Web of Science?) databases Elaboration and compilation of Scopus (=) databases files Filtering and exportating of bibliographic data using the Bibliometrix package for the statistics software R
Analysis	Data cleaning Results generation in the Bibliometrix package (R) Data and graphics selection
Visualization	Tables and graphs development with the resulting data from Bibliometrix (R) Choice of the most suitable software for the bibliometrics maps visualization Generation of bibliometric maps in the VOSviewer
Interpretation	

Source: Adapted from Zupic and Čater (2015)

The first step of the research design started with the following research question: What is the scientific landscape of Industry 4.0 at the Business and Management research Stream?

the definition of keywords starts with the keyword “Industry 4.0”. In order to find synonyms, we conducted searches for similar words in the websites Wordtracker and Google Trends on 11/28/2019. These tools enable the identification of internet searches with similar keywords and, consequently, the insertion of other relevant and similar terms in the bibliographical search. Although searches in Wordtracker return a high global number of monthly searches using the term (127.075 on average), it did not return significant keywords that expanded the number of articles at the searches. The same was observed in the case of Google Trends.

The compilation of bibliometrics data (second step) started with advanced searches at the Scopus database. The research was conducted between 11/25/2019 and 11/27/2019 using the keyword “Industry 4.0” at the title, abstract, and keywords field (TITLE-ABS-KEY). Subsequently, we created and downloaded 25 “.BIB” and “.CSV” files with the results and divided them according to the following categories: overall (general areas); Business Administration; CP (conference paper) and; AR (article).

The categorization of these results served as the basis for the analyses concerning the present work. It also should be noted that, in addition to the primary information about the documents (e.g., title, author, and keywords), we also gathered the references used in the studies. This type of information is essential to build bibliographical networks through bibliographic coupling and also to measure the influence of references on the analyzed studies.

To carry out the analysis, we load the results in the statistical software R and we used the bibliometrix package (http://www.bibliometrix.org - Aria & Cuccurullo, 2017). In this

stage, we also eliminate the inconsistences and duplicated registers in the databases and extract general statistics about the files.

Using the loaded files in bibliometrix, we start the fourth stage of the research: visualization, which was splited into two steps: data generation, and bibliometric maps preparation.

The data generation step consists of the aggregation of statistical data from the files using the bibliometrix package (R). It is necessary to split the information from the bibliographical files according to some categories, such as most-cited authors, production per countries/research center, and indicators of collaboration between authors. In order to create the bibliometric maps, we use the VOSviewer software created by van Eck & Waltman (2010), which provides data graphic visualization of the labels, density, cluster, and dispersion levels.

this software creates distance-based maps using an algorithm developed by the authors. In these maps, the strength of the relation between two items is illustrated by the distance between them using multidimensional scaling. Then, smaller distances reflect stronger relationships between the items (e.g., authors, documents, keywords). Besides that, the item size demonstrates the number of citations that it received in the literature. Thus, the higer is the number study citations, item, the higher will be its size on the map.

The next section presents the results based achieved according to this methodology, which allowed us to conduct the data interpretation

Results

This section presents the results from the bibliometric research obtained from the bibliographical data; Thus, it will serve as a basis for further analysis in the discussion and conclusion section of our study.

Descriptive Results

To start off, it is essential to situate the academic studies related to Industry 4.0 of the Scopus database in a broader context. Considering that, this section begins by describing the bibliographical results in other knowledge areas, followed by the results in the area of Business and Administration.

Between 2012-2020, we identified 7,057 bibliographical occurrences in the Scopus database. From this data, 55.2% is composed of CP, 32.7% by AR, and 12.1% by other types of data (e.g., book chapter, note, and editorial). The overall ratio between CP and AR is 62,8% of CP and 37,2% of AR. Table 3 and Figure 1 show the evolution in the number of publications for the period between 2012-2020 concerning all types of works at the Scopus database that contained the expression "Industry 4.0" in their title, abstract, or keywords.

Table 3.
Evolution in the number of publications between 2012-2020 (all areas)

Document type	**Publication year**								
	2012	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Conference Paper	1	8	35	79	258	608	1,227	1,626	51
Article	1	11	42	95	207	393	643	890	25
Subtotal CP + AR (1)	**2**	**19**	**77**	**174**	**465**	**1,001**	**1,870**	**2,516**	**76**
% relative AR/CP	100,0	137,5	120,0	120,2	80,2	64,6	52,4	54.7	49,0

Subtotal other types (2)	**0**	**12**	**15**	**34**	**78**	**130**	**247**	**286**	**55**
Total (1+2)	**2**	**31**	**92**	**208**	**543**	**1,131**	**2,117**	**2,802**	**131**

Source: The Authors (2019)

Moreover, in order to answer the research question and also to enhance our understanding of Industry 4.0 in the area of Business and Management, we narrow the bibliographic data according to their knowledge area. In this sense, Table 4 shows this delimitation and an overall ranking with ten knowledge areas with the highest number of documents.

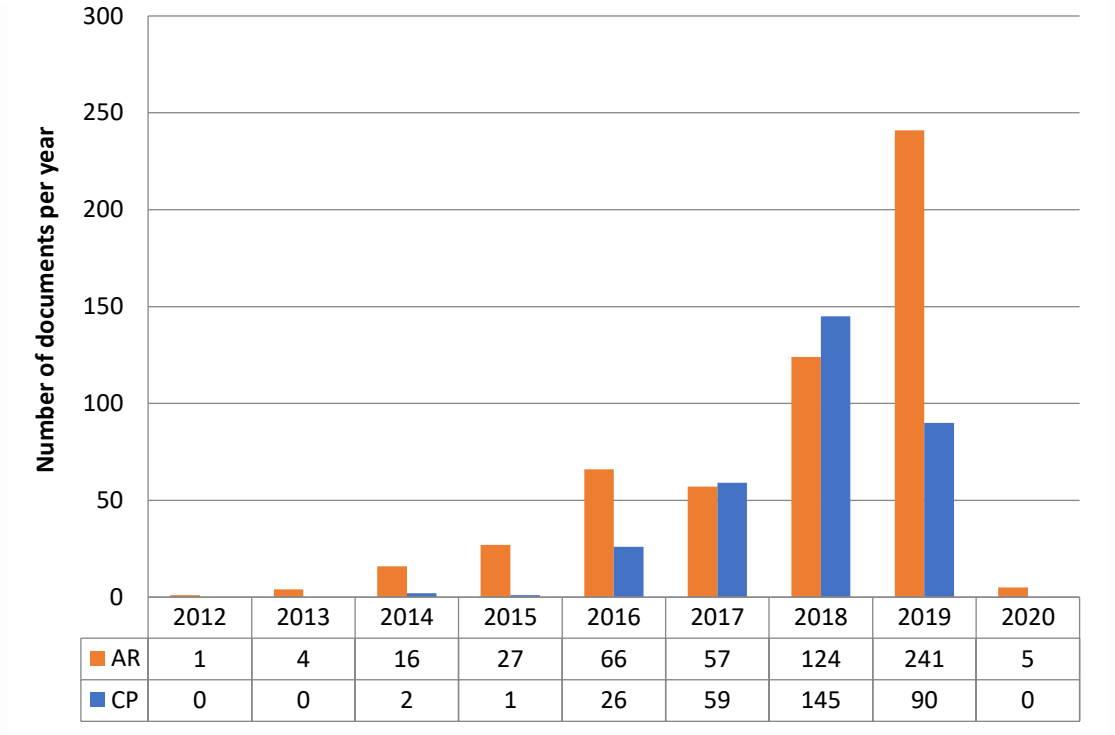
Table 4.
Top ten subject areas according to the number of documents

Subject area	Nº of documents	CP	CP ranking	AR	AR ranking	CP+ AR	CP+AR ranking
Engineering	4,400	2,383	2	1,501	1	3,884	1
Computer Science	3,828	2,623	1	812	2	3,435	2
Mathematics	1,126	866	3	128	8	994	3
Business, Management and Accounting	1,029	323	8	541	3	864	4
Decision Sciences	977	569	5	284	4	853	5
Physics and Astronomy	772	598	4	138	7	736	6
Materials Science	760	381	6	273	5	654	7
Social Sciences	608	292	9	247	6	539	8
Energy	459	329	7	103	11	432	9
Environmental Science	252	115	10	119	10	234	10

Source: The Authors (2019)

From an initial analysis, we can verify the dominance of the Engineering and Computer Science areas, representing 54.7% of the overall AR and CP results. It's important to note that since one study can be related to more than one knowledge area, the overall number of results (13,357) is higher than the actual number of studies (7,057). Furthermore, although the Business, Management, and Accounting subject area are positioned eighth when we consider only CP standings (323 CP), when we consider AR it is currently in third place, (with 864 studies).

In this sense, when we consider the analysis related the field of Business, Management, and Accounting, we verify a prevalence of AR, with a representation of 267% higher than the CP.



	2012	2013	2014	2015	2016	2017	2018	2019	2020
AR	1	4	16	27	66	57	124	241	5
CP	0	0	2	1	26	59	145	90	0

Figure 1. Evolution in the number of AR and CP documents between 2012-2020 at Business, Management, and Accounting.
Source: The Authors (2019)

Figure 1 shows a critical difference between the relative percentage of AR/CP at the Business Management and Accounting area and the other ones, since concerning the other areas, the average participation of AR documents in comparison with CP between 2017-2019 is 57.3%, while for the area of Business, Management, and Accounting this percentage is 150% for the same period. In other words, Business areas display higher participation in terms of AR, when we compare it with the other knowledge areas.

The number and source of references is another type of data extracted to be used at the bibliometrix package. From the references obtained from 864 AR and CP documents in the BMA area, we verify that the five most referenced journals do not have BMA as their main subject area. Table 5 illustrates these results.

Table 5.
Ranking with the five most referenced journals

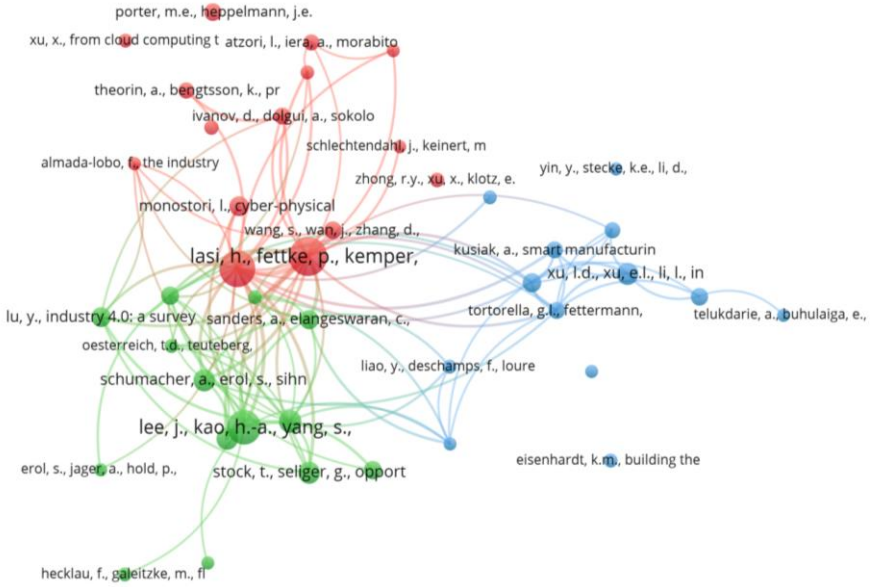
Sources	**Nº of references**	**Subject area (from the websites of journals)**
International Journal of Production Research	710	Manufacturing, production, and operations management research
Procedia CIRP	513	Production Engineering
International Journal of Production Economics	417	Engineering and Management
Computers In Industry	197	Information and Communication Technology
Journal of Operations Management	171	Operations and Management

Soure: The Authors (2019)

Despite the fact that three journals of

Table 4 contain some reference to Management, only the eighth journal of our list had a specific focus on Business Administration, the Strategic Management Journal, which receive 140 mentions from the reference list.

In order to assess the intellectual base of Industry 4.0 in the field of Business Administration, we gathered data from the reference lists of AR and CP documents and elaborate a co-citation analysis. This technique groups the works that are most times cited (TC) in the same study. Using co-citation analysis in VOSviewer, we identified three clusters, as shown in Figure 2.



Type of work	Type of analysis	Unit of analysis	Minimium number of citations	Number of references selected	Normalization method
AR+CP	Co-citation	References	7	42	Association strength

Figure 2. Co-citation analysis from reference lists of AR and CP documents
Source: The Authors (2019)

Figure 2 also demonstrates the red, green, and blue clusters created by the VOSviewer algorithm, which were respectively numbered as one, two, and three. Table 6 detail the most cited (TC) documents among the references of the 864 documents related to the Business Administration subject area.

Table 6.
Most-cited documents from three clusters

Cluster	TC	Year	Authors	Title	Journal
1 (red)	51	2014	Lasi, H., Fettke, P., Kemper, H. G., Feld, T., & Hoffmann, M.	Industry 4.0	Business & Information Systems Engineering
	47	2015	Lee, J., Bagheri, B., & Kao, H. A.	A cyber-physical systems architecture for industry 4.0-based manufacturing systems	Manufacturing Letters
	15	2014	Monostori, L.	Cyber-physical production systems: Roots,	Procedia Cirp

				expectations and R&D challenges	
2 (green)	42	2014	Lee, J., Kao, H. A., & Yang, S.	Service innovation and smart analytics for industry 4.0 and big data environment	Procedia Cirp
	19	2017	Hofmann, E., & Rüsch, M.	Industry 4.0 and the current status as well as future prospects on logistics	Computers in Industry
	18	2016	Qin, J., Liu, Y., & Grosvenor, R.	A categorical framework of manufacturing for industry 4.0 and beyond	Procedia Cirp
	18	2016	Stock, T., & Seliger, G.	Opportunities of sustainable manufacturing in industry 4.0	Procedia Cirp
	18	2016	Schumacher, A., Erol, S., & Sihn, W.	A maturity model for assessing Industry 4.0 readiness and maturity of manufacturing enterprises	Procedia Cirp
3 (blue)	11	2016	Sanders, A., Elangeswaran, C., & Wulfsberg, J. P.	Industry 4.0 implies lean manufacturing: Research activities in industry 4.0 function as enablers for lean manufacturing	Journal of Industrial Engineering and Management
	18	2018	Xu, L. D., Xu, E. L., & Li, L.	Industry 4.0: state of the art and future trends	International Journal of Production Research
	14	2018	Moeuf, A., Pellerin, R., Lamouri, S., Tamayo-Giraldo, S., & Barbaray, R.	The industrial management of SMEs in the era of Industry 4.0	International Journal of Production Research
	12	2018	Fatorachian, H., & Kazemi, H.	A critical investigation of Industry 4.0 in manufacturing: theoretical operationalisation framework	Production Planning & Control

Source: The Authors (2019).

Although there are no significative characteristics that allow the definition of these clusters according to authors or the subject area of the documents, we can see that the period of publication is relevant for the information in the clusters composition. Thus, cluster one is based on documents published between 2014-2015, cluster two between 2014-2016, and the cluster three contains three of their four documents published in 2018. Cluster two also present three of their four documents published in the same journal (Procedia Cirp).

About the impact of documents, Table 7 shows the five most-cited documents per type (AR or CP). We can observe a higher consistency in AR documents, with the five most-cited documents totalizing 732 works, with the three most-cited representing 75,5% of this total. At the same time, the five most-cited CP totalize 443 documents, with 93,7% of this result concentred in their three most-cited works. The work of Xu, L. D., Xu, E. L., & Li, L. (2018) is noteworthy because, in only one year since their publication, it is in second place in the AR category.

Table 7.
Five most-cited documents per type (AR or CP)

Document type = AR	**Times Cited**
Kang, H. S., Lee, J. Y., Choi, S., Kim, H., Park, J. H., Son, J. Y., ... & Do Noh, S. (2016). Smart manufacturing: Past research, present findings, and future directions. International Journal of Precision Engineering and Manufacturing-Green Technology, 3(1), 111-128.	259
Xu, L. D., Xu, E. L., & Li, L. (2018). Industry 4.0: state of the art and future trends. International Journal of Production Research, 56(8), 2941-2962.	157
Ivanov, D., Dolgui, A., Sokolov, B., Werner, F., & Ivanova, M. (2016). A dynamic model and an algorithm for short-term supply chain scheduling in the smart factory industry 4.0. International Journal of Production Research, 54(2), 386-402.	137
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Li, L. (2018). China's manufacturing locus in 2025: With a comparison of "Made-in-China 2025" and "Industry 4.0". *Technological Forecasting and Social Change*, *135*, 66-74.	82
Subtotal AR	**732**
Document type = CP	**Times Cited**
Shrouf, F., Ordieres, J., & Miragliotta, G. (2014, December). Smart factories in Industry 4.0: A review of the concept and of energy management approached in production based on the Internet of Things paradigm. In *2014 IEEE international conference on industrial engineering and engineering management* (pp. 697-701). IEEE.	239
Schmidt, R., Möhring, M., Härting, R. C., Reichstein, C., Neumaier, P., & Jozinović, P. (2015, June). Industry 4.0-potentials for creating smart products: empirical research results. In *International Conference on Business Information Systems* (pp. 16-27). Springer, Cham.	132
Ahram, T., Sargolzaei, A., Sargolzaei, S., Daniels, J., & Amaba, B. (2017, June). Blockchain technology innovations. In *2017 IEEE Technology & Engineering Management Conference (TEMSCON)* (pp. 137-141). IEEE.	44
Foidl, H., & Felderer, M. (2015, November). Research challenges of industry 4.0 for quality management. In *International Conference on Enterprise Resource Planning Systems* (pp. 121-137). Springer, Cham.	15
Demartini, M., Tonelli, F., Damiani, L., Revetria, R., & Cassettari, L. (2017). Digitalization of manufacturing execution systems: The core technology for realizing future smart factories. In *Proceedings of the Summer School Francesco Turco* (pp. 326-333).	13
Subtotal CP	**443**

Source: The Authors (2019)

Concerning authors with the largest number of published documents, we split their production according to their AR and CP works. Thus, it enabled the identification to see if the researchers submit their works most for journals or conferences. Table 8 illustrates these results.

Table 8.
Most AR and CP productive authors

Most AR-productive authors			**Most CP-productive authors**		
Authors	**AR**	**CP**	**Authors**	**CP**	**AR**
VOIGT KI	7	0	TELUKDARIE A	11	2
LANZA G	6	0	RAUCH E	8	5
KLETTI J	5	0	MATT DT	6	3
METTERNICH J	5	0	BASL J	5	1

MLLER JM	5	0	SHAH S	5	0
RAUCH E	5	8	BOTTANI E	4	0
SASMOKO S	5	0	COUTROUBIS A	4	0

Source: The Authors (2019)

Except for Rauch (five AR published), none of the seven authors with the highest number of published AR have at least one CP published. On the other hand, with CP, four out of the 7 authors listed in table 8 have at least one AR each.

The geographical analysis of the most-productive and most-cited regions also shows a prevalence of Germany and Italy. Table 9 demonstrates the most productive and most cited regions according to the type of published documents (AR or CP).

Table 9.
Most-productive and most-cited countries

Country scientific production				**Most cited countries**			
Region	**Nº of AR**	**Region**	**Nº of CP**	**Country**	**Nº of AR citations**	**Country**	**Nº of CP citations**
Germany	331	Germany	102	Germany	553	Italy	310
Italy	56	Italy	67	Korea	318	Germany	219
USA	51	UK	31	Brazil	99	USA	50
India	46	USA	30	Poland	91	China	18
UK	46	South Africa	27	USA	86	Norway	15

Source: The Authors (2019)

4. Discussion, Conclusions, And Future Research Directions

Despite the research related to Industry 4.0 had started in the year of 2012, we can observe that most consistent academic production started from 2016 (with 465 overall documents). In this sense, and also considering the number of novel technologies that are related to this concept, bibliometric studies in the field are will most likely not display consistent results as those achieved in mature research fields. However, some bibliographical variables enable a useful estimation of the overall results and the role of BMA in this context.

Starting from the analysis of results in all research fields, we can verify from table 5 that between 2015 and 2019, the relative percentage of AR/PC decreased from 120.2% to 54.7%. This conversion shows an increase in the maturity of the research field by the consolidation of the research through the publication of AR in specialized journals.

Furthermore, by considering the AR production in a specific year versus the CP production in the precedent year, we can estimate a rate of maturity in the research subject. When we analyze the period between 2017 and 2019 using data from table 4, we verify that this rate lowered from 105.8% (643/608) to 72.5% (890/1,227). In the specific case of BMA, this percentage lowered from 210.2% (124/59) to 166.2% (241/145) for the same period. Despite the fact that we cant certify that all AR comes from CP, this can be a useful variable in analyzing the maturity of the field. At the BMA area, as these ones tend to be presented in conferences. In this area, the AR documents represent a vast majority of the works in the field.

This comparison between AR and CP publications is also evident in the data displayed in table 5. Although BMA is in the eighth position when we consider only CP publications (323), this area also occupies the third position when we consider only AR publications (541),

(on the period between 2012 and 2020). Thus, despite the fact that CP production in this subject area is not so strong, the number of AR publications in journals represents a maturity level and a search for consolidation of this subject in the BMA areas at the academic literature. That situation can also also be related to the fact that these studies seek to analyze the impacts regarding the implementation of technologies in the BMA area. In this sense, subject areas studying more technical knowledge, like Engineering and Computer Science, are in the vanguard regarding studies that first explore this type of subject.

Nevertheless, it appears that the BMA research field was not yet able to produce its own knowledge to be used as reference for documents about Industry 4.0. As we can see from Table 6, none of the five most-cited journals in the dataset composed of 864 documents has BMA as their specific subject. Only in the eighth place, we find a journal from the BMA area, the Strategic Management Journal.

A prevalence of studies from other knowledge areas is also evident from data Table 7, and the bibliometric map presented in **Erro! Fonte de referência não encontrada.**. Considering Table 7, the composition of clusters has Engineering and Computer Science streams as the most-cited documents, while the analysis of figure 5 does not suggest characteristics capable of drawing more precise conclusions about the structure of the three clusters (such as clusters demonstrating sub-divisions inside the area of BMA). This can be due to the newness of the research subject, which is thus characterized by studies that aim to identify features that would assist to have future studies developed.

Considering the relationship between AR and CP for the most productive authors, Table 9 demonstrates a lack of transition from CP to AR authors. Among the seven authors that more published AR, only one (Rauch, E.) published a study in a conference apart from the journal articles. This non-interaction can cause communication problems, since recent studies published in conferences may not be consolidated by AR publications in specialized journals. Furthermore, the questions arise concerning whether these authors have also debated their findings in discussions with other authors, something that usually takes place in specialized conferences.

Furthermore, the prevalence of foreign knowledge areas as the basis for the works in BMA area should not be a cause for concern at that time. As we stated at the beginning of this section, Industry 4.0 is an emerging topic in the literature most of its initial studies came from technical areas, such as Engineering and Computer Science.

Considering this discussion, we can verify that, despite the growth of studies in BMA area, the intellectual base of Industry 4.0 is still very concentrated with Engineering and Computer Science references. As we stated before, it is a characteristic of studies involving new technologies. However, this is an opportunity for the BMA fields to analyze the subject according to their specialized lens in disciplines such as Organizational Studies, Competitive Advantage, Human Resources, and Entrepreneurship.

The present work sought as a contribution to map the academic studies that deal with Industry 4.0 in the area of Management and Business, serving as a basis for future research on the theme, demonstrating the main authors, countries and works related to the theme.

Based on the results and the growth of the scientific landscape, we also cannot discard the possibility of Industry 4.0 being a "hot topic" in the literature. Considering that the use of the term can be related to works that does not directly address the topic itself, only mentioned it a more general context. This inappropriate use can be further addressed by systematic review of literatures, which explores in more detail a smaller number of papers. Furthermore, future studies can also integrate the recent findings involving the application of the industry 4.0 technologies and their impact on the BMA area and its related fields of knowledge.

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