Industry 4.0: using science mapping to understand the strategic themes, main challenges, trends, and opportunities

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Abstract: Technology is developing rapidly and transforming our actions, functions and activities, new forms of production increasingly incorporate Industry 4.0 technologies. The aim of this paper is to identify trends, gaps, and opportunities in scientific research on Industry 4.0. Through the systematic analysis of articles indexed in WoS, EBSCO and Scopus journals. It was identified that research is focused on major proportion in the adoption of technologies, performance improvements and on less proportion on technical issues and technological developments. Areas of opportunity, where it is pertinent to make are sustainability and integration of Industry 4.0 to the production processes of organisations, the development of human capital, and training to take advantage of the changes.

Keywords: Emerging research; Industry 4.0; Trends and opportunities.

1. Introduction

The World Economic Forum's Global Competitiveness Report (2018) described that a determining factor for the prosperity or stagnation of countries is the adaptation and transition of organisations towards the Fourth Industrial Revolution (4IR) (Schwab, 2018; Cepal, 2018).

Within the 4IR the Industry 4.0 (I4.0) paradigm presents opportunities for companies to take advantage of new technology. It is the chance to enhance the creation of economic value, improve the quality of jobs, and increase the skills of their workers to offer markets high value-added products and services (Lee & Malerba, 2017; World Economic Forum, 2018).

Industry 4.0 provides opportunities for innovative producers, system suppliers, economic sectors, and entire geographic regions. As with previous transformations in industry, commerce, and lifestyle these changes pose a threat to laggards (Rübmann et al., 2015). Scientific community is interested in determining the economic, social, political, and technological impact brought by the technological advances of Industry 4.0. Arouses the interest of researchers to know the definition of work roles, adoption barriers, challenges, and opportunities among others details of the transition of the enterprise to these new technologies.

The aim of this work was to perform systematic mappings of the scientific literature to identify trends in research on Industry 4.0 that will allow identifying areas of opportunity for scientific work in the process of transition and adoption of new technologies in organisations.

An industrial revolution represents radical changes in socioeconomic and political systems promoted by the introduction of new methods and technologies that generate a significant increase in efficiency and productivity (Tarry, 2019). Historically, First Industrial Revolution (1IR) is considered to have taken place in England in the 18th century with the introduction of steam engines in production processes and the use of new machines built with iron (Thoben et al., 2017).

The Second Industrial Revolution (2IR) began in Germany and the United States of North America between 1870 and 1914 with the implementation of mass production lines, the use of electricity, and the creation of steel and plastic. The Third Industrial Revolution (3IR) emerged at the end of the 20th century in multiple industries and countries, driven by the automation of production processes through information and communication technologies and biotechnology accelerated by the use of silicon and smart materials (Von Tunzelman, 2003; Thoben et al, 2017). The Fourth Industrial Revolution (4IR) started in 2011, when for the first time the term Industry 4.0 was used at the Hannover Fair, Germany. From that moment, the scientific community began its interest in the changes generated in institutions and organisations by the processes of transition and adoption of new technologies.

In scientific literature, Industry 4.0 has been studied from different perspectives with interest of identifying the work roles in companies (Benešová et al., 2018), determining barriers to its adoption (Kamble, et al., 2018), and defining needs for its implementation (Knolle, 2016; Felix & Rosa, 2018; Dalenogare et al., 2018). Other research studied the relevance of strategic planning, implementation of key technologies, opportunities, and challenges for organisations (Zhou, et al., 2016).

Research has been developed focusing on issues of cybersecurity in the operation of Industry 4.0 technologies (Thames, 2017), effects on workplaces and working conditions in companies (Reuter et al., 2017), and the introduction of the Industry 4.0 concept in small and medium-sized enterprises (SME) (Nowotarski & Paslawski, 2017).

Another area of interest for the scientific community has been the study of the necessary skills, knowledge, and experiences that young engineers need in the framework of Industry 4.0 (Motyl et al., 2017). Defining and addressing the training needs of workers as a key strategy for the success of manufacturing companies has been established as a class point (Rocha et al., 2018).

The impact of Industry 4.0 on higher education and the importance of statistical data analysis has also been studied (Baygin et al., 2016; Olmo, 2017). In addition, the process of transforming a fabrication shops into a space for Industry 4.0 training (Baena et al., 2017).

2. Methods

We used a case-based empirical study approach as our research method (Hernández-Sampieri & Torres, 2018). For the elaboration of systematic mapping, we employed the method proposed by Petersen et al. (2008) as well as the literature review methodology proposed by Kitchenham & Charters (2007).

The process of analysing the set of publications was conducted in two stages: first, a quantitative analysis to describe the set of selected publications. Second, a qualitative analysis to make sense of the maps constructed.

Work developed, began with the definition of research questions that allowed us to delimit the area of interest. We carried out searches in the chosen databases, made the selection of publications using inclusion and exclusion criteria. Then, we identified the most prominent authors, constructed maps of scientific communities, and research trends in the Industry 4.0 area.

To delimit the area of interest for our work, the following research questions related to Industry 4.0 were posed: RQ1. How many scientific articles have been published from 2016 to 2021 in journals indexed in Web of Science (WoS), Scopus or EBSCO?; RQ2. Which journals are the most important?; RQ3. What are the geographic regions reporting related results?; RQ4. Are there scientific communities working in this area?; and, RQ5. What are the research areas that have been addressed?.

Search for publications of interest was performed manually in the databases meeting the following Inclusion Criteria (IC): IC1. Academic journal articles, conference papers or book sections published in scientific repositories WoS, Scopus or EBSCO; IC2. Publications in the period from January 2016 to January 2021; and, IC3. Articles with the terms 'Industry 4.0' or 'I4.0'.

Set of publications obtained from the database searches was analysed and refined to achieve a better-quality set of articles using the Exclusion Criteria (EC): EC1. Outreach articles, e.g., editorial paragraphs; EC2. Duplicate articles; and, EC3. Incomplete articles.

For the analysis and cleaning process we used the PRISMA scheme (Moher et al., 2009) to guide the activities and guarantee good results in the selection.

For the construction of the systematic maps of scientific communities and topics addressed by the authors, VOSViewer tool was used, which is widely used to perform bibliometric analysis (Bornmann & Mutz, 2015; Leydesdorff & Bornmann, 2016). Text analysis algorithms allow the construction of maps, metrics of the set of publications, and present results visually (Van Eck, & Waltman, 2014).

3. Results and Discussion

Initial set of publications obtained from searches in the multidisciplinary bibliographic databases WoS, EBSCO and Scopus were 309 articles. The distribution of publications by data source was 46% in Scopus, 34% in WoS, and 20% in EBSCO. Table 1 presents the results of the searches performed, including the totals by data source after applying EC1. Set of publications obtained after eliminating the dissemination papers was 284 articles: 47% from Scopus, 34% from WoS, and 19% from EBSCO.

Table 1. Initial set of publications

	WoS	EBSCO	Scopus	TOTAL
Articles	104	62	143	309
CE1 applied	96	55	133	284

We eliminated 125 duplicate articles applying EC2, which were reported in more than one data source; result was a set of 181 publications. Table 2 presents the total published articles related to the data source that contains them; 17% of the articles (31) appear in the three sources consulted, 28% (51) of the publications only appear in Scopus, being the source with the highest number of papers retrieved for analysis.

Table 2. Set of publications without duplicates.

	WoS	EBSCO	Scopus	
WoS	13	-	-	WoS & EBSCO & Scopus
EBSCO	2	10	-	
Scopus	63	11	51	
WoS & EBSCO & Scopus				31

Application of EC3 eliminated 14 incomplete publications, without text or doi, resulting in a final set of 145 unique publications that meet the inclusion and exclusion criteria. Figure 1 shows the PRISMA diagram describing the phases of the process of choosing the set of publications used in this work.

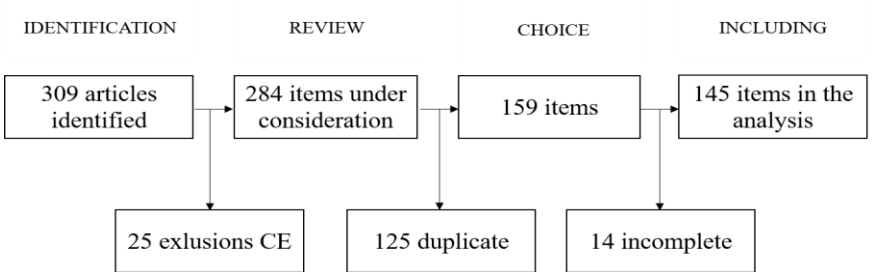

Figure 1. PRISMA diagram of the selection process. Adapted from Moher et al. (2009).

Set of selected publications was organised manually in a data table format file. In this, each row represents an article, and the columns contain the information obtained from the consulted repositories. Data retrieved were title, authors, year of publication, source database, doi, keywords, and abstract. Through manual and individual review of each article considered, columns were incorporated for the region where the study was conducted, country of origin of the authors, institution of authors' affiliation, and research focus.

3.1 Quantitative analysis

Quantitative analysis used the set of selected publications to determine the distribution of publications by year, identification of the most representative journals and geographical analysis. Table 3 shows the years in which the articles included in the analysis were published. Eighty-six percent (134) of the publications correspond to the period 2019 - 2020.

Table 3. Distribution of publications by year.

Year	2016	2017	2018	2019	2020	2021	Total
Number of articles	1	5	13	46	78	2	145
Percentage	1	3	9	32	54	1	100

Articles published between 2016 and 2021 indexed in WoS, Scopus, and EBSCO databases were published in 86 different journals. Bardford's Law (1934) served us to identify the most representative group of journals (Nicolaisen & Hjorland, 2007). Following this principle, we considered that most of the articles on Industry 4.0 could be published by a few journals especially dedicated to that subject, in conjunction with certain frontier journals, and many generals (Urbizagastegui, 2016).

In Figure 2 we present the grouping of journals with a two-zone model. Seven main journals were identified in the publication of Industry 4.0 topics: *Procedia Manufacturing, IFAC-Papers online, Journal of Manufacturing Technology Management, Sustainability (Switzerland), Computers in Industry, International Journal of Production Research, and International Journal of Advanced Manufacturing Technology*.

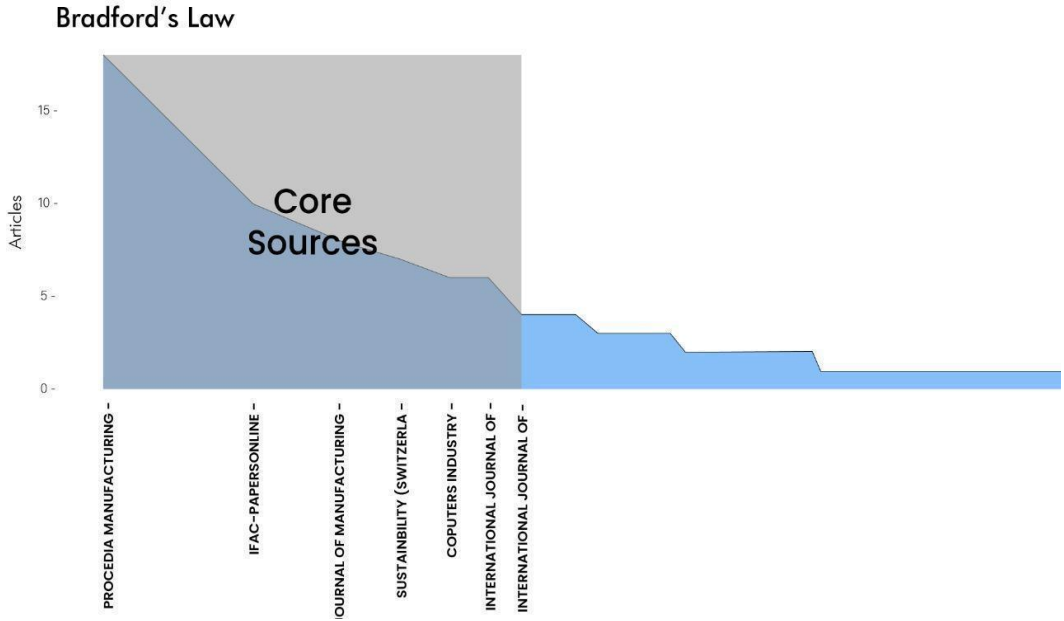

Figure 2. Analysis of the journals in the set of publications.

Geographical analysis of the set of publications shows that Europe is the region with the highest number of papers reported (64%). Table 4 shows that Asia (16%) and Latin America (13%) are the other regions highlighted by the work of researchers and results reported in the databases studied.

Table 4 Analysis by geographic region.

Region	Africa	Asia	Europe	Latin America	North America
Percentage	2%	16%	65%	13%	4%

In the case of countries, 56% of the publications analysed were generated by authors located in Italy (16), Germany (14), Brazil (9), India (6) and Portugal (6), Table 5. Scientific community in Industry 4.0 considering the number of researchers included in the analysis set is concentrated in Italy (15%), Germany (10%), Brazil (8%), Portugal (8%), and India (7%).

Table 5. Analysis by country and number of researchers.

Country	Italy	Germany	Brazil	India	Portugal
No. articles	16	14	9	6	6
Researchers	29	19	15	13	16

Quantitative indicators of the set analysed are included in Table 6, articles with only one author (13), proportion of articles per author (0.292), average number of authors per article (3.43), co-authorship per article (3.82), collaboration index (3.64), and total citations (219).

Table 6. Indicators of the set of publications.

Indicator	Single author	Articles /Author	Authors per article	Co-authorship per article	Collaboration index	Citations in the set
Value	13	0.292	3.43	3.82	3.64	219

3.2 Qualitative analysis

First part of the qualitative analysis was carried out through an in-depth reading of each article included in the study set to identify the most prominent authors, research approaches, thematic areas, and objectives. Table 7 lists the most prominent authors during the last 3 years: Garza-Reyes, Charnley, Facchini, Okorie, Putnik, and Sawhney.

Table 7. Main authors in Industry 4.0.

Author	Reference
Garza-Reyes	(Mendoza-Del Villar et al., 2020); (Tortorella et al., 2020a); (Luthra et al., 2020); (Caiado et al., 2021).
Charnley	(Okorie et al., 2018); (Charnley et al., 2019); (Okorie et al., 2020).
Facchini	(Ante et al., 2018); (Luccato et al., 2019); (Gomes et al., 2020).
Okorie	(Okorie et al., 2018); (Okorie et al., 2020); (Charnley et al., 2019).
Putnik	(Varela et al., 2018); (Varela et al., 2019); (Alves & Putnik, 2019).
Sawhney	(Tortorella, et al., 2020a); (Tortorella et al., 2020b); (Tortorella et al., 2020c).

Result of the analysis of the research approach used by the authors is presented in Table 8. Quantitative method was used in 43% of the articles, 35% used the qualitative approach, and 22% were scientific literature review.

Table 8. Research approach.

Type		Percentage	
Quantitative	Not specified	35%	43%
	Model / Simulation	5%	
	Laboratory application	3%	

Qualitative	Not specified	28%	35%
	Cases	7%	
Literature review			22%

Result of the analysis of the topics studied by each article included in our set, as well as the objectives of the materials, was built Table 9, it was established that 80% of the publications focus on the adoption of Industry 4.0 in organisations and their impact on performance.

Table 9. Themes addressed in the research.

Themes	Adoption	Performance	Literature review	Technology develops	Prototypes Technology	Adoption	Performance
Percentage	41%	29%	22%	3%	3%	41%	29%

For the second part of the qualitative analysis process the set of publications in the data table format file was exported to a new file in comma separated text (CSV) format to be processed in the VOSViewer software.

Using VOSViewer's text analysis tools we analysed the data to create semantic maps to identify scientific communities and research areas in Industry 4.0. The Map of collaboration of scientific communities presented in Figure 3 was obtained by processing the authors' data.

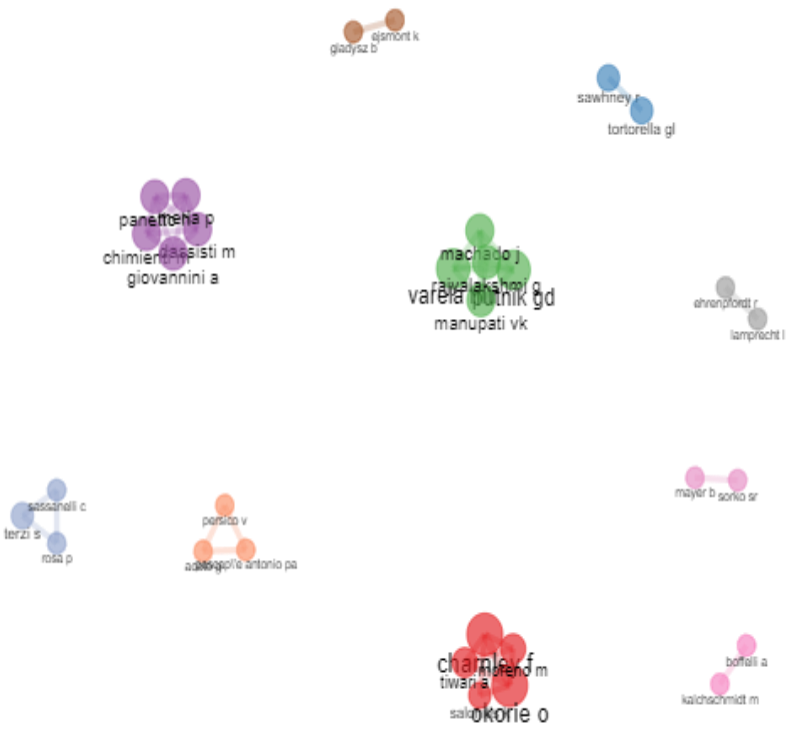

Figure 3. Industry 4.0 scientific community.

We identified three main groups, two triads, and five binary groups of authors that collaborate to generate scientific products related to Industry 4.0.

To identify the study topics addressed, abstracts of the articles were processed to give the map of recurrent terms shown in Figure 4; size of the bubbles represents the number of times the term was mentioned while connecting lines indicate the relationship between them.

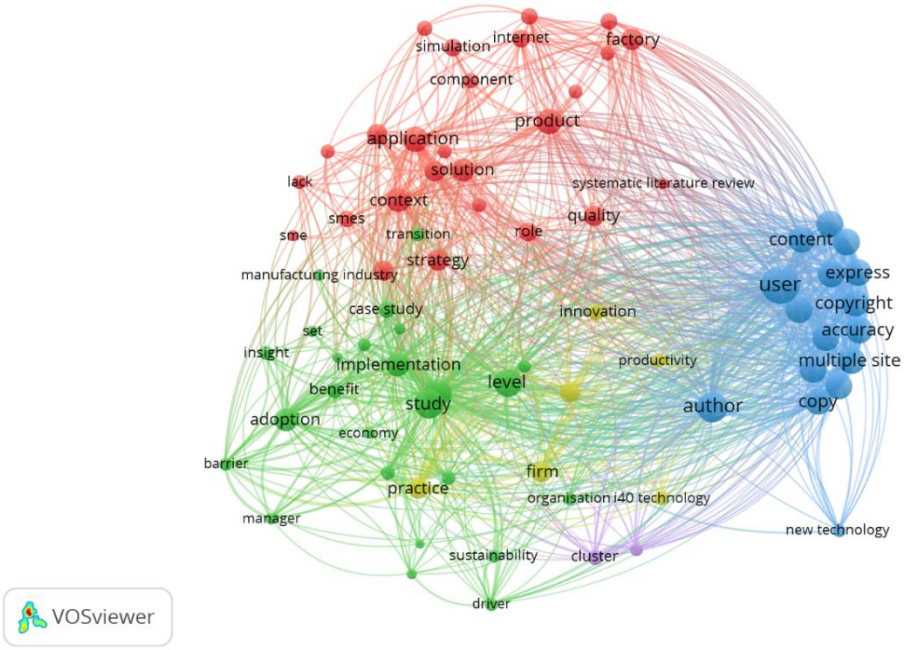

Figure. 4 Map of recurrent terms in article abstracts.

Map of recurrent terms includes 3 main groups with a uniform distribution and homogeneous distances between them. In Table 10 we describe the red, green, and blue groups.

Table 10. Groups of terms.

Color	Themes
red	study, analysis, work, solution, implementation, adoption, practice, manager organisation, tool, sme, firm, lack, case study, tool, insight, design methodology approach, manager, survey, paradigm
green	process, model, framework, area, product, internet, Smart manufacturing, simulation, iot, circular economy
blue	copyright, author, property, multiple sites, individual use

In Table 11, we presented the analysis result of groups of terms, articles obtained by using the combination of the terms *'Industry 4.0' OR 'I4.0' AND 'Manufacture*' represent 34% (50) of the articles in the review, this was evidence of the relevance of Industry 4.0 and associated technologies for the manufacturing sector. In addition, the number of citations of these papers represent 68% of the total (149).

Table 11. Groups of terms.

Industry 4.0 +	Articles	Year of publication	Citations
Manufacture	50	2017, 2018, 2019, 2020	149
Strategy	21	2018, 2019, 2020	-
Work	14	2019, 2020	29
Competitiveness	5	2018, 2019, 2020	26
University	2	2020	-

Results of the combinations with the terms *'Strategy' AND 'Work'* represent 24% of the articles in the study, 21 and 14, respectively. Human capital formation, linked to terms *'Competitiveness' AND 'University'* is the least addressed by the authors.

3.2. Discussion

Results in Table 3 described that prior to the year 2017 there were not frequent works related to the subject of Industry 4.0 in the chosen data sources. In 2018 the growth in the number of articles began; in 2020 a great interest in the subject was reflected. The value for 2021 was low because the data collection was carried out in January.
With the results presented in Figure 2 of the main journals where the analysed articles appear. Considering the area of knowledge to expand the analysis, we obtained that 62% of the publications correspond to the areas of *Engineering* (34%), *Business economics* (17%), and *Computer science* (11%). Table 12 shows the areas identified together with total number of publications and percentage.

Table 12. Analysis by knowledge area.

Area	Art	%	Area	Art	%
Engineering	49	34	Operation research management	14	9
Business economics	24	17	Science Technology	11	8
Computer Science	16	11	Environmental Science Ecology	10	7
Automation control systems	15	10	Telecommunications	6	4
			Total	145	100

Results of the analysis by geographic region presented in Table 4 described an overwhelming difference between them, Europe (65%) and Asia (16%) together accounting for 81% of the articles analysed.

In the results of Table 5, it is established that in Europe the countries most interested in Industry 4.0 were Italy, Germany, and Portugal; in Asia was India. On the other hand, in Latin America 90% principal authors were from Brazil, while in North America the contributions were from authors from USA and Canada. In the sample studied, 48 of the articles were regional studies; 29 Italian authors have studied 19 objects of study in their country while 19 German researchers have analysed 19 objects of study in their geographical location.

The most research approach used by the authors was quantitative (43%) related to the development of simulation models and applications in laboratories. Thirty-five percent used the qualitative approach, and in this category, case development stands out. Literature reviews represent 22% of research in Industry 4.0.

According to the results presented in Table 8, there were few articles that detail and report on experimental technological issues in laboratories or industry (8%). While 22% of the papers were literature reviews which was indicative of the active construction of the body of scientific knowledge. Forty-one percent of the analysed papers focus on the adoption of the paradigm, and 29% on impact on the performance of organisations.

Scientific communities presented in Figure 3 focus their work on smart manufacturing and its relationship with the circular economy (red group); incremental and low-cost frameworks for small businesses (purple group), and the definition of the Industry 4.0 body of knowledge through systematic literature reviews (green group).

In the term recurrent map in Figure 4, the blue cluster was related to new Industry 4.0 technologies, authorship, and intellectual property management, as well as user needs in organisations. Red group was the largest and was oriented towards applications and solutions for industry, particularly in small and medium-sized enterprises (SME).

Green group addressed the study of the opportunities and benefits of the implementation of technologies and Industry 4.0 paradigm in companies through work frameworks and process simulations. Yellow group included the topics of practice, productivity, and innovation in companies. Purple group included term clusters related to the management of organisations, they have interest in productivity, innovation, and technological developments in companies.

4. Conclusions

We retrieved and analysed 145 articles published in journals indexed in WoS, Scopus, and EBSCO in the period from January 2016 to January 2021. Eighty-six percent of the analysed articles were published in the period 2019 - 2020.

The most relevant journals in the Industry 4.0 area were *Procedia Manufacturing, IFAC-Papers online, Journal of Manufacturing Technology Management, Sustainability (Switzerland), Computers in Industry, International Journal of Production Research, and International Journal of Advanced Manufacturing*. Engineering, business economics, and computer science were specialisation areas where Industry 4.0 was published.

Europe was the continent with the most research on Industry 4.0 (65%). Objects studied were in Italy, Germany, and Portugal. In Asia (16%) the studies were located mostly in India; in Latin America (13%), studies developed in Brazil were reported. Researches developed were local, objects of study were chosen from the same country, it is scope was regional, and they reported results in these contexts.

Need for research with a regional focus can be established. This could facilitate the adoption and development of Industry 4.0, because it requires the design of appropriate strategies for the contexts. Research was focused on *technology adoption* (41%), *productivity increase and performance improvements* (29%), and *technical issues and technological developments* (8%). Networks constructed by identifying keywords with more cooccurrences confirm the above.

Results of the analysis, we identified the following areas on which studies have focused in the last 5 years: *a*) Manufacturing sector was looking for ways to adopt Industry 4.0, *b*) Design of implementation strategies for Industry 4.0 linked to smart manufacturing and sustainability, and *c*) Generation of technological developments in Industry 4.0.

Emerging themes were lean manufacturing, sustainability, logistics, and circular economy related to sustainability and integration into the production processes of organisations. Other unexplored areas of interest are related to human capital (Work, Strategy, Work, Competitiveness, and University) and its implications with the strategies to face changes at work.

It will be important to conduct studies: *1*) for specific latitudes, *2*) of empirical cut, *3*) in relation to competitiveness, *4*) that develop particular adoption strategies in the manufacturing sector, *5*) that analyse the linkage with agile work methodologies in organisations and factories, *6*) for the development of technology and horizontally and vertically integrated strategies for its proper exploitation, *7*) the development of public policy (including the ethical part) that provides the right conditions for the adoption, development, and evolution of Industry 4. 0, and *8*) it is necessary to study the relationship between labour and human capital formation. That will be required to take advantage of the benefits that can be derived from the incorporation of Industry 4.0 and its technologies.

This study was focused only on WoS, Scopus, and EBSCO publications. Thus, articles included in journals not considered in the chosen data sources were left out; therefore, the set of analysis was reduced and with trends that cannot be resolved in advance.

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