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Abstract

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Pillars of Technological Advancement and Indicators of Scientific Production of Industry 4.0

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Abstract

From the first Industrial Revolution to Industry 4.0, technological advances have had a great influence on the increase in industrial productivity, highlighting characteristics such as the incorporation of information and productivity gains through the connection between University, Industry and Government, to measure the indices of scientific production and dissemination of knowledge, helping to develop the innovative potential of a nation, a quantitative and statistical technique called bibliometrics is used. In this context, this research proposes to identify the pillars of technological advancement and the indicators of scientific production in Industry 4.0. In order to verify the panorama of the exploration of the theme and to reach the objective of the research, quantitative and descriptive analysis was carried out with bibliometric procedures in the Scopus and Web of Science databases, from which 259 and 280 scientific articles were extracted respectively. The analysed data allowed the identification of pillars of technological advancement of Industry 4.0 and provided indicators of the quantity of articles published between 2013 and 2019, of countries with greater and less research prominence, and of quantitative distribution of publications by University. The results proved to be promising for the development of new research on this theme.

Keywords - Industry 4.0, Technological, Bibliometrics.

1. Introduction

Since the beginning of the Industrial Revolution, technological advances have been considered driving engines in increasing industrial productivity, since the 19th century with its steam-powered factories, through the conductive electrification of mass production in the 20th century, until its automation in the 1970s. The subsequent incremental industrial technological advances show a comparative disparity in relation to the transformation that occurred in mobile communications, electronic commerce and information technologies. In the present century, we are immersed in the middle of a fourth wave of technological advancement marked by the emergence of new digital industrial technologies known as Industry 4.0 with the potential to revolutionize and transform design and manufacturing into single cells for integrated and automated installations for data analysis, failure prevention aimed at communicability, increased flexibility, speed of operations, product services and production systems 30% faster and 25% more efficient with the use of connectivity between machines, human beings leading mass customization to new levels of technological innovation (Rüßmann, Lorenz, Gerbert, Waldner, Justus, Engel, & Harnisch, 2015).

Industry 4.0 has been referred to as the 4th Industrial Revolution, as in a similar way to other previous revolutions, technological innovation is the starting point for breaking the old paradigms towards intensified remodelling of production systems, showing characteristics such as the incorporation of technology information with a capacity to promote substantial gains in productivity, flexibility and the transforming nature of industrial work (Tessarini & Saltorato, 2018).

This research is justified in the understanding that the formation of the pillars of technological advances in Industry 4.0 and the process of transferring information technology occur in a constant, gradual and complex way, connected through the relationship between University, Industry and Government. In this sense, the dissemination, assimilation of information and scientific and technological knowledge is achieved by Universities through their scientific production, directly contributing to a nation's innovative potential. To measure the production and dissemination rates of knowledge, as well as to monitor the development of several scientific areas, the standards of authorship, publication and use of research results quantitative and statistical technique called bibliometrics is used (Silva, Kovaleski, Pagani, 2019; Palleta, Silva, Santos, 2014; S. Lopes, Costa, Fernández-Llimós, Amante, & P. F. Lopes, 2012).

Therefore, this research aims to identify the pillars or bases of technological advancement and indicators of scientific production, showing the quantity of world production, main countries, main universities and main areas of knowledge which approach the theme Industry 4.0.

2. Industry’s Historical Process

Industry 4.0 is a milestone in a new industrial scenario with its origins rooted in the Internet. This new industrial revolution potentially holds the capacity to impact manufacturing projects, making products more intelligent and more endowed with individualized identification processes involving the generation, storage, recovery and use of data connected to production resources (Grotti, 2019).

This new revolutionary trend of breaking the paradigm in world production known as Industry 4.0, researched and applied with avidity mainly in Europe, is based on a system of automation and integration between the internet and the factory in a cyber-physical space, connecting and interconnecting machines in an equal way in all social organization (Freitas, Fraga, & Souza, 2016).

The historical process of the Industry, according to Coelho (2016), begins with the first industrial revolution in 1760 and 1840, culminating in the present century with Industry 4.0, as can be viewed in Table 1:

Table 1. Industries’s historical process

Industry 1.0	Industry 2.0	Industry 3.0	Industry 4.0
The first Industrial revolution began somewhere between 1760 and 1840 in England, with the progressive replacement	In the decades that followed the end of the Second World War (1945), developments were	In the 1950s and 1970s, what was to be considered the third Industrial Revolution, the	In the beginning of the 21st century, with the development of the internet, with increasingly smaller

of artisanal methods by machines and tools, through the exploitation of coal as an alternative energy to wood and other biofuels, and through the increasing use of steam energy. Changes in production processes cause significant economic and social consequences. The craftsman who, until then, controlled the entire production process, from the exploration of the raw material to the commercialization of the final product, started to work for a master who controlled the process, the raw material, the final product and the profits.	significant in the area of chemical, electrical and steel industries, as well as improvement was significant in existing techniques. The first steel boats appeared, powered by powerful steam engines, revolutionizing the freight transport. The first production lines also appeared, which would allow mass production at low costs. Invention and innovation went hand in hand in what has been known as the second Industrial revolution.	digital revolution, began to be designed, with the proliferation and use of semiconductors, computers, automation and robotization in production lines, with information digitally stored and processed., with the communications, with mobile phones and the internet.	and powerful sensors, with increasingly affordable prices, with increasingly sophisticated software and hardware, plus the ability of machines to learn and collaborate by creating gigantic networks of "things", a transformation in industry has begun, whose impact on competitiveness, society and the economy will be such that it will transform the world as we know it.

Source: Adapted from Coelho (2016).

Industry 4.0 will cause profound changes in economic society, in values, in forms of relationships in the choice of products and services, in collaborative innovation, additional manufacturing, networks and digital platforms, constituting a promising environment for opportunities to create competitive advantages among the vanguard industry and the others. Although these changes may take 20 years to materialize, in the next 5 to 10 years the most important technological advances will be established, making it possible to gather and analyse data between machines, faster, more flexible and efficient processes in the production of goods with higher quality and cost reduction, increasing manufacturing productivity, promoting industrial growth, changing the profile of the workforce, influencing the competitiveness of companies and regions and consequently impacting the economy (Coelho, 2016; Rüßmann, *et al*., 2015).

2.1 Pillars of the Technological Advances of Industry 4.0

The technological advancement, considered as one of the five global megatrends, is causing profound social transformations and disruptions in all sectors of the economy and in the generation of value for companies that find in innovation its main growth engine. Assuming that these new technologies will require substantial changes in the standards of the businesses we know, the identification and understanding of the pillars of technological advances is essential for adoption, adaptation and use in the competitive business environment at this special moment in history called the 4th Industrial Revolution or Industry 4.0 (PWC Brasil, 2016).

Seeking to explore impressive technologies for global and intersectoral business, among more than 150 technologies, explored (with data from companies, startups, academia and research institutes), evaluated (in terms of intersectoral relevance, technical feasibility, global scalability) and selected (those whose impact is considered greater in the next 3 to 7 years), PWC Brasil (2016) identified eight essential technological advances, as can be seen in Table 2.

Table 2. Technological Advances

1. Artificial intelligence (AI)	Software algorithms capable of performing tasks that normally require human intelligence, such as visual perception, voice recognition, decision making and language translation. AI is a broad concept, which includes several subfields, such as machine learning, aimed at developing programs capable of teaching the computer to learn, understand, reason, plan and act (that is, to become more "intelligent") when exposed to new data in proper quantities.
2. Augmented reality (AR)	Adding information or visual aids to the physical world, through a graphic and/or audio overlay, to improve the user experience in relation to a task or a product. This “increase” in the real world is achieved with supplementary devices that transmit and display information. AR is different from virtual reality (VR), conceived and used to recreate reality within a confined experience.
3. Blockchain	Distributed electronic accounting that uses software algorithms to record and confirm transactions reliably and anonymously. The event log is shared between several parties. Once entered, the information cannot be changed, as the new elements of the chain reinforce previous operations.
4. Drones	Aerial or water-based devices and vehicles, such as unmanned aerial vehicles that fly or move without a human pilot on board. Drones can operate autonomously (via on-board computers), according to a predefined flight plan or by remote control. (Note: This category is different from autonomous ground vehicles).
5. Internet of things	Object network - devices, vehicles, among others - with built-in sensors, software, network connectivity and computing capacity. They can collect and exchange data over the Internet. IoT allows devices to be connected and remotely monitored or controlled. The term IoT represents any “connected” device accessible via a network connection. Industrial IoT (IIoT) is a subset of IoT and refers to the use of this technology in the industrial and manufacturing sectors.
6. Robots	Electromechanical machines or virtual agents that automate, expand or assist human activities, autonomously or according to defined instructions - usually a computer program.

7. Virtual reality (VR)	Computer generated simulation of a three-dimensional image or a complete environment, within a defined and contained space (as opposed to AR), where viewers can interact with this image in a realistic way. VR is intended to be an immersive experience and requires equipment, usually a helmet or headset.
8. 3D printing	Layered manufacturing techniques used to create three-dimensional objects based on digital models, arranging or "printing" successive layers of materials. 3D printing uses innovative "inks", such as plastic, metal and, more recently, glass and wood.

Source: adapted from PWC Brasil (2016).

Aligned with this same line of reasoning Oliveira (2017) highlights the constant need for organizations to seek competitiveness, stimulate the search for systematic changes, aiming to meet the desires of avid and demanding consumers with ever more diverse and continuous demands. In this context, the search for the adaptation of business processes aiming at a more efficient production leading to the path of Industry 4.0, which conditions, among other factors, the intensive use of the Internet of Things (IoT), Cyber-Physical Systems, Big-Data etc., in production environments. The main expectation is the increase in level of monitoring capacity and control of the equipment distributed in order to positively impact the costs and quality of the products offered.

In Industry 4.0, intensely focused on continuous progress in terms of efficiency, safety and productivity of operations, especially in return on investment, several technologies are available, in Table 3 the pillars of the intelligent industry will be highlighted in Coelho's view (2016); they are: Internet of Things and Services (IoT); Cyber-Physical Systems (CPS); Big data (Table 3).

Table 3. Pillars of Intelligent Industry

Internet of Things and Services	Cyber-Physical Systems	Big-Data
The term "Internet of Things (IoT)" refers to physical and virtual objects connected to the internet. It has its roots in MIT (Massachusetts Institute of Technology) when, in 1999, a group developed work in the area of connected radio frequency identification (RFID). Since then, it has been driven by the appearance and widespread use of increasingly smaller and cheaper sensors, as well as a breakthrough in mobile devices, wireless communications and cloud technologies.	Cyber-Physical Systems (CPS) are systems that integrate computing, communication networks, embedded computers and physical processes interacting with each other and influencing one another. It is the result of the technological evolution of computers, sensors, and communication technologies, which, by evolving towards greater agility, processing capacity and increasingly accessible prices, have allowed them to be combined effectively and in real time.	The term BIG-Data refers to large amounts of data that are stored at every moment resulting from the existence of millions of systems currently connected to the network (IoT), producing real-time data on a multitude of subjects and almost anywhere.

Source: Adapted from Coelho (2016).

In a realistic and practical view of the potential of technological advances in Industry 4.0, Collabo Brasil (2016) presents a business environment using available technologies (Internet of Things and Services (IoT); Cyber-Physical Systems (CPS); Big-Data, etc.), starting from digitalization, connectivity from the factory floor to the logistics system, in an environment where machines talk to machines, with tools, parts and human beings, where interaction and exchange of information occur when machines act as decision makers for the best flow of the production process aiming at cost reduction.

In turn, Rüßmann *et al*. (2015) outlines 9 pillars of technological advancement as the basis of Industry 4.0, which are described and explored for their technical and economic benefits along with their potential for transforming production through the union of isolated and optimized cells as a fully integrated and integrated system in search for greater efficiency between traditional production relationships between suppliers, producers and customers, humans and machines, namely:

Big Data and Analytics

It consists of the process of collecting and comprehensively evaluating countless different sources, equipment and production systems, and management systems for companies and customers that are increasingly standardized and aims at assisting decision making in real time, optimizing production quality, saving energy and improving equipment services.

Autonomous Robots

Robots are already used in several sectors to perform complex tasks. The process of robotic evolution with increasingly lower costs and resources for their production is heading towards a dizzyingly wide use with the development of more autonomous, flexible and cooperative robots, aiming at mutual robot-human interactivity in a continuous learning process.

Simulation

3D product simulations are already used in engineering, materials and production processes, pointing to a future with the possibility of including machines, products and humans, simulating plant operations more extensively, taking advantage of real-time data, reflecting the physical world in a virtual model, allowing operators to test and optimize machine configurations, reducing machine setup time and increasing quality.

Horizontal and Vertical System Integration

Today, most IT systems, the company's functions at the shop floor level and product engineering itself are not fully integrated. In Industry 4.0, The evolution of universal data integration networks between companies enables genuinely automated and more coherent value chains.

The Industrial Internet of Things

Allows devices, including unfinished products, to be connected, enriched and incorporated with computers using standard technology, allowing communication and interactivity of field devices with each other and with central controllers, decentralizing analysis and decision making in real time.

Cybersecurity

The use of standard communication protocols and increased connectivity accompany Industry 4.0, resulting in the need for sophisticated identity management and access to users/machines that essentially guarantee safe and reliable communications against cyber security threats.

The Cloud

Industry 4.0, aiming at a greater sharing of data between sites and aspects of the company, mainly in production-related ventures, will increasingly demand the performance of more improved cloud technologies reaching reaction times of a few milliseconds; consequently, the data and the machine functionality will allow more data-driven services for production systems.

Additive Manufacturing

The additive manufacturing methods in Industry 4.0 will be widely used in the production of small customized batches providing advantages in the construction of light and complex projects, with decentralized and high-performance additive manufacturing systems and the potential to reduce transport distances and available stock.

Augmented Reality

Systems based on augmented reality are currently taking their first steps. In the future, they will be used more widely to provide information to workers in real-time to improve decision-making and work procedures.

The 9 pillars of technological advances, previously described, share levels of similarity with the Pillars of Industry 4.0 presented by Falcão (2019), however, this latter author understands that the migration process to Industry 4.0 requires changes in the management model and in the culture of organizational and technological decision makers that led to the systematized development of the Pillars of Industry 4.0 in a matrix proposal, as can be seen in Figure 1:

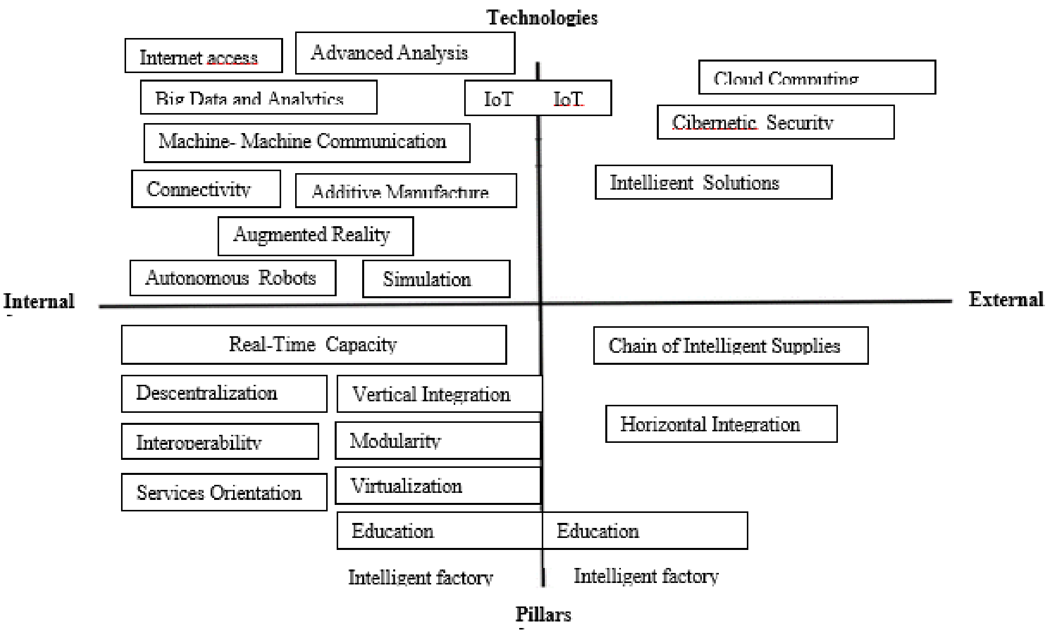

Figure 1. Matrix proposal for the systematization of the pillars of industry 4.0.

Source: Falcão (2019)

The Intelligent Factory, in relation to its implementation, was considered an internal pillar (due to significance of the adequate internal structure) and external pillar (due to dependence on external factors

such as improvement on the internet, cyber security). Horizontal integration consists of connectivity between the links in the supply chain in which the industry is inserted, and its plausibility depends on the participatory work of everyone in smart factories, that is, the emergence of the smart supply chain that comes from horizontal integration. In the matrix, internal technologies were listed, such as: internet access focused on working with the Internet of Things (IoT), use of elements (such as Simulation, Augmented Reality, Autonomous Robots and Additive Manufacturing) in order to assist the company in connected work and integration of people (Machine-Machine Communication). Big Data and Data Analysis for data collection and analysis, synchronized with the decentralization pillar aim to assist the company in reaching the peak of capacity in real time. In turn, external technologies (Cloud Computing, Cybersecurity and Intelligent Solutions, IoT) build Industry 4.0, linking its development to dependence on external incentives from companies. In view of the widespread business concern regarding the prevention of cyber-attacks and the like, Cybersecurity and Intelligent Solutions potentially present themselves as responses (Falcão, 2019).
The generation of new knowledge of technological advances in Industry 4.0 and various areas of scientific production is achieved by the Universities. The analysis of the production of this scientific knowledge is carried out through research with bibliometric approaches with the potential to identify theoretical trends and outline methodological trends (Vasconcelos & Santos, 2019).

3. Methodology

In order to achieve the objective, a descriptive and quantitative analysis research was carried out, with bibliometric procedures, in articles of scientific journals that addressed the subject matter of this study, that is, “Industry 4.0”. Data collection was carried out through the Capes Periodical Portal, specifically in the Scopus and Web of Science databases. These bases are sources of scientific information, with a multidisciplinary character, with international scope. In addition, they favour metric research through indicators. The search strategy was through the combination of the terms: "Industry 4.0", "Fourth industrial", in the advanced search field all fields were used as a filter. Subsequently, the following variables were defined for measurement: Year of publication of the research, Country, Knowledge Area and Periodical. The research covered a time period that encompassed the years from 2013 to 2019.
For the measurement of the data, the variables were listed in a database, using the Excel Software, where it was possible to construct the graphs and the quantitative analysis of the results.

Table 4. Scopus and Web of Science searches.

Keywords	Scopus	Web Of Science
"Industry 4.0" "Fourth industrial"	Publications found: 259	Publications found: 280

Source: Own authorship (2020).

4. Results

The combination of the terms searched, "Industry 4.0" and "Fourth industrial", culminated in 539 articles published in scientific journals, indexed in the Scopus and Web of Science databases. The data represented in the Figures below illustrate the panorama of this research, by measuring the variables: Year of publication; Countries; Knowledge area and Universities.

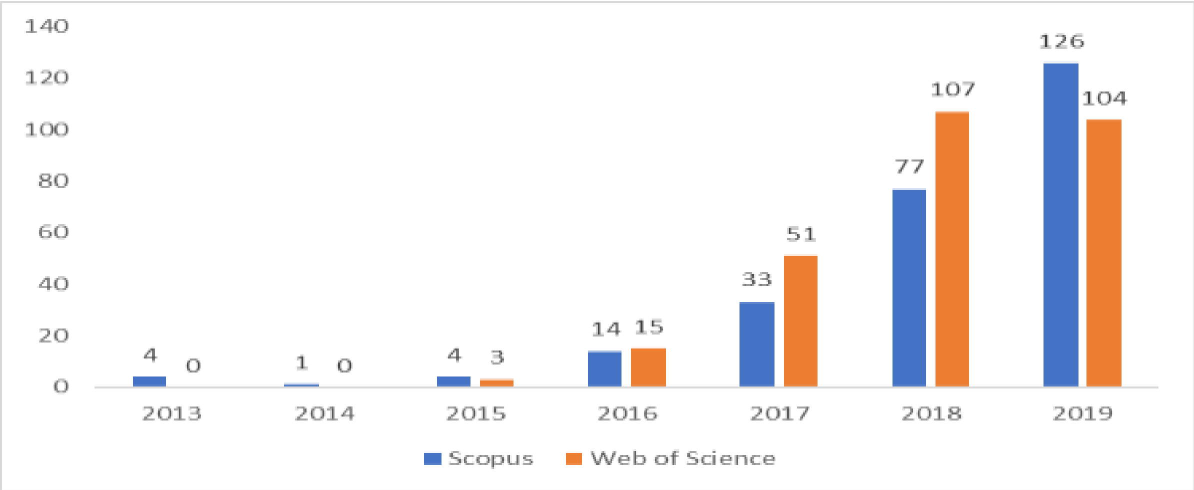

Figure 2. Distribution of publications by year on Web of Science and Scopus database.

Source: Adapted from the Web of Science and Scopus database (2020).

The evolutionary process of publications per year was verified in the years between 2013 and 2019. A gradual evolution and a quantitative increase during the researched period, in both bases was perceived; see figure 2; however, the Scopus database has fewer articles indexed in relation to the Web of Science, yielding respectively 259 and 280.

With regard to the number of surveys by countries, Figure 3 presents the 17 most prominent countries that conduct research on Industry 4.0. It is possible to see that, in the Web of Science and Scopus database, Italy is ahead of the other countries presented with 29 and 27 publications, in sequence, Germany, United Kingdom, United States, Poland and Brazil stand out.

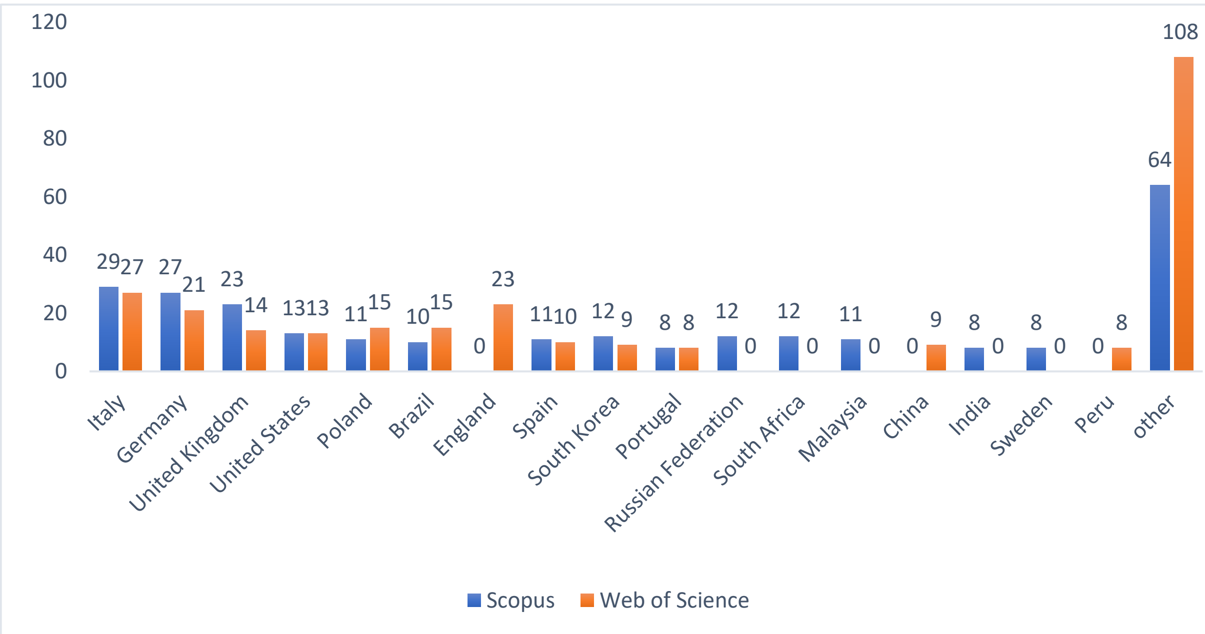

Figure 3. Distribution of publications by country in Web of Science and Scopus database.

Source: Adapted from Web of Science and Scopus database (2020).

On both bases, it is worth noting that Brazil occupies the sixth place with 10 and 15 publications, standing out as a potential for qualitative and quantitative growth that fosters the national and international academic framework in the theme of Industry 4.0.

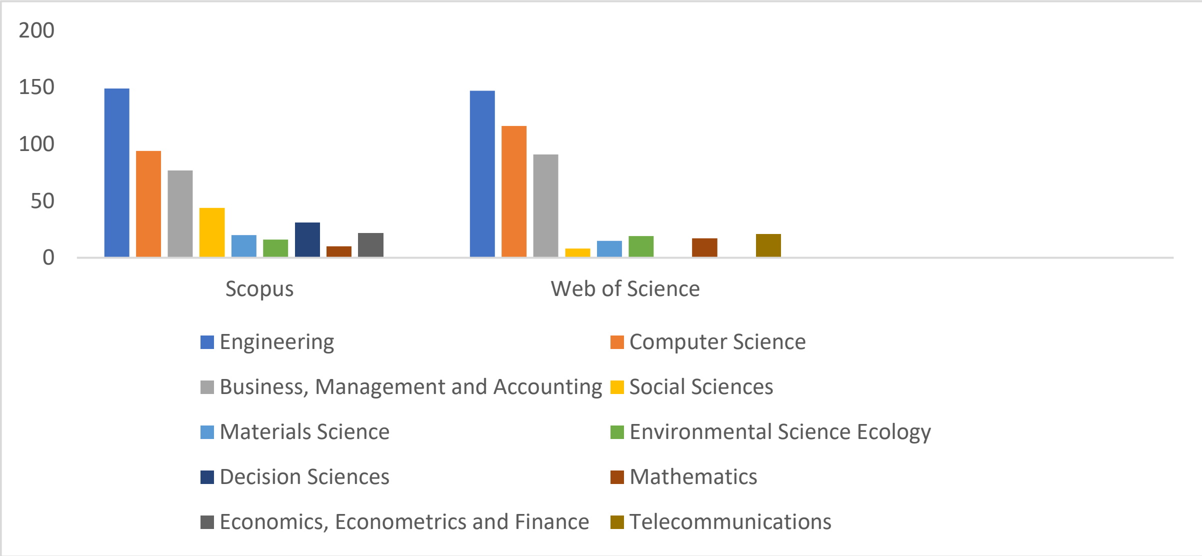

Figure 4. Distribution of publications by area of knowledge in the Web of Science and Scopus database.

Source: Adapted from Web of Science and Scopus database (2020).

Regarding the distribution of publications in the ten largest areas of knowledge, it can be seen in Figure 4 that in the Web of Science and Scopus database, the areas of Engineering, Computer Sciences, Business, Management and Accounting, Social Sciences, stand out. Material Sciences, Environmental Sciences and Management Sciences, in turn, the areas with less distribution, namely: Economics, Econometrics and Finance, Telecommunications and Mathematics.

In Figure 5, it appears that both databases of this research share journals and articles in common. Regarding the quantitative distribution in a decreasing order of 50% of publications by Universities, especially the University of Minho, North-West University, Rheinisch-Westfälische Technische Hochschule Aachen, Pontifical Catholic University of Paraná, Università degli Studi di Napoli Federico II and Russian Academy of Sciences, among other Universities, the percentages of publication of articles are equally distributed, with national prominence for Universidade de São Paulo and Universidade Federal de Santa Catarina. Thus, mentioning the remarkable and relevant presence of 3 (three) Brazilian Universities, representing significantly an average (15%) of the articles published in Universities worldwide, demonstrating the continuous effort of Brazilian (or Brazil-based) academic researchers towards the construction of a relevant national and international scientific knowledge on the theme of Industry 4.0.

Figure 5. Distribution of publications by university in the Web of Science and Scopus database.

Source: Adapted from Web of Science and Scopus database (2020).

5. Conclusion

This research aimed to identify the pillars of technological advancement and indicators of scientific production, indicating the quantity of world academic production, main countries, main universities and main areas of knowledge within the theme of Industry 4.0.

Regarding the identification of the pillars of technological advancement, the researchers consulted listed convergent and complementary views, which clearly indicates a quantitative growth of new pillars concomitant with technological evolution.

The combination of the terms searched, "Industry 4.0" and "Fourth industrial", culminated with the result of 539 articles published in scientific journals indexed in the Web of Science and Scopus databases. In the period ranging from 2013 to 2019, there was a significant and impactful evolution of articles indexed in the databases of this research, with quantitative prominence in the publication of articles mainly in the followingcountries: Italy, Germany, United Kingdom, United States, Poland and Brazil.

It is important to highlight that within the theme of industry 4.0, the Brazilian scenario deserves to be highlighted among the 17 countries with greater and more significant relevance in the publication of articles. Representing an average quantitative percentage of 15% of the Universities' articles published worldwide, the Brazilian presence of 3 (three) Universities stands out, namely: Pontifical Catholic University of Paraná, University of São Paulo and Federal University of Santa Catarina, towards the construction of an expressive national academic framework with an international impact on the theme of industry 4.0.

Engineering, Computer Sciences, Business, Management and Accounting, Social Sciences, Materials Sciences, Environmental Sciences and Management Sciences are the areas of knowledge with the greatest distribution of publications. On the other hand, the areas with the least quantitative distribution are Economics, Econometrics and Finance, Telecommunications and Mathematics.

For the purpose of future works, research related to a larger number of databases is suggested. This research can, nonetheless, serve as a basis for future professional works that can potentially provide research related to bibliometric indicators or for the deepening of the theme of Industry 4.0 in Academic circles.

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