Big Data and Artificial Intelligence in the Development of Industry 4.0; A Bibliometric Analysis

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Abstract*. Industry 4.0, also known as the Fourth Industrial Revolution, is characterized by process automation and digitization and the use of technologies such as the Internet of Things, cloud, big data, artificial intelligence (AI), and embedded systems, among others. In fact, AI and big data are two driving forces behind several technological innovations that have shaped the current digital environment and Industry 4.0. These two trends share a common goal, i.e., to obtain the maximal data out of the vast amount of data being generated today. Therefore, within the context of substantial scientific development in this subject, this work provides an overview of the development of Industry 4.0 based on big data and AI. The methodological design commenced from the development of a bibliometric exercise for the identification of scientific papers addressing this subject. The main results of this work include the identification of scientific development based on big data and AI in the advancement of Industry 4.0. Moreover, conclusions regarding the importance of these pillars in the new digitization era are obtained.*

I.   Introduction

Throughout history, the First Industrial Revolution has been regarded as an important step that led to the current technological development. Today, Industry 4.0, also known as the Fourth Industrial Revolution, is at its height, marked by numerous sophisticated technologies and the advent of several digital industries. In fact, Industry 4.0 focuses on the introduction and development of digital technologies, particularly the digitization of production processes to increase efficiency, quality, and safety within the industry. In other words, the integration of intelligent systems into the production environment based on concepts such as cloud, big data, artificial intelligence (AI), and 3D printing [1]. Some of these technologies have been in use for years but in an abandoned and reserved manner. However, their consolidation into current production models can boost the production industry with fully integrated, automated, and streamlined processes. Therefore, the technological evolution being fostered requires an effort from companies to adapt to the new networked society.

Consequently, in this new era of digital transformation, data have become one of the most important pillars of Industry 4.0. Actually, big data technology is the key for managing and transforming large amounts of data because such a magnitude of data cannot be processed using conventional processes and infrastructures. The role of big data in Industry 4.0 in terms of managing and assessing large volumes of data is critical for understanding the current technological context, market demands and requirements, and user information and their feedback regarding new products and services. Hence, data have not only become a necessity for organizations but also the foundation for conducting business in the 21st century. A large part of daily activities is performed or somewhat connected to the Internet; therefore, the number of data registered, accrued, and stored by organizations, both online and offline, is rapidly increasing [2]. Hence, every year, companies continue to face increasing numbers of challenges in terms of the management and assessment of these data. Still, what would big data be without a self-learning application? In fact, AI is advancing further because its concept includes facilitating machines or equipment with cognitive learning for conducting tasks in an "intelligent" manner and providing support to users when making operational decisions. AI applied to data management and transformation is another complement of this revolution, wherein new algorithms allow the development of predictive and behavior analyses, detect frauds, assist in medical diagnoses, and improve sales and supply processes. Furthermore, currently, there is a wide field of applications that employ AI coupled with big data, which will continue to be of great use in all industrial sectors and society [3].

Our new normal assumes that the Fourth Industrial Revolution is identified by its permissiveness and focuses on involving customers in the whole process, thus assimilating the constant change in demands inherent to the current market. In most parts of the world, this work is conducted as part of a government strategic policy to disseminate these technologies to become more competent in the market.

Therefore, because abundant scientific development has been achieved in this subject, this work provides an overview of the development of Industry 4.0 based on big data and AI. However, the approach used in this work differs from that used in other reviews or research papers addressing this topic. In other words, this study performed a bibliometric analysis based on the principle that the quantity and quality of published papers available in international databases are indicators of the contributions by different countries and institutions to this research area [4]. In fact, bibliometrics have been employed in the literature for many years. In this tool, contents from publications are analyzed using statistical methods to determine patterns [5], thus providing researchers with a clear overview of the research field. This tool can be used to study big data and AI for advancing Industry 4.0. Based on the generated maps and bibliometric information, we can unveil trends observed in this research area. Moreover, educators and researchers can use this information to identify problems or evaluate unanswered questions in the literature to indicate the orientation for future studies on industry digitization based on big data and AI within the universe of Industry 4.0.

II.   Theoretical Framework

As a theoretical support for this work, the following concepts were used as a referential framework for our bibliometric assessment: Industry 4.0, AI, big data, bibliometrics. These concepts allowed us to select the appropriate approaches, authors, and concepts as the theoretical support for the research.

Over time, technological development has exerted an impact on the production field. For this reason, Navarro & Sabalza [6] reported that different Industrial Revolutions have emerged throughout history. The First Industrial Revolution started at the end of the 18th century, and it was prompted by the introduction of mechanical equipment characterized by steam engines. The Second Industrial Revolution was a consequence of industrialization and the new line production system. The Third Industrial Revolution integrated technologies such as electronics, automation, and Information and Communication Technologies (ICTs). Finally, the most recent, the Fourth Industrial Revolution, also known as Industry 4.0, brought about the Internet of Things (IoT), big data, AI, digital coordination, cyberphysical systems, and robotics.

Industry 4.0 has emerged to address the challenge of different industry issues. According to Martin [7], companies need to deploy new techniques, such as implementing technologies, adopting new management strategies, and developing new business models.

Industry 4.0 was first discussed was in Germany in 2011 during the Hannover Messe Industrial Technology Show. In fact, this term was promoted by three German engineers: Henning Kagermann, Wolfagang Wahlster, and Wolf-Dieter Lukas. Industry 4.0 is characterized by process automation and digitization, which was generated through the combination of digital and physical systems, in addition to the use of electronics and information technologies in manufacturing [8]. Moreover, service provision, production customization, and the creation and development of new value-added business models promote the exchange of information between humans and machines [9, 10].

Thus, there are several definitions that include the common points. Neugebauer et al. [11] states that Industry 4.0 is "The integration of human resources, physical elements, and systems in a dynamic, self-organized way in real time with autonomously optimized value-added systems." Alternatively, according to Sipsas et al. [12], "Industry 4.0 is a paradigm that promotes the connection of physical elements, such as sensors, devices, and business assets, with each other and with the Internet."

The Fourth Industrial Revolution is known for the integration and birth of new technologies, including robotics, AI, big data, quantum computing, nanotechnology, biotechnology, and IoT. To a significant extent, the digital evolution of industries and their survival in the market are currently dependent on the data they generate and their influence in decision-making strategies. They also depend on the correct implementation of AI. Moreover, it is the aforementioned technologies that allow organizations to rely on facts, data, and forecasts, instead of only assumptions when making decisions [13].

The concept of big data involves a collection of data obtained from both systems and objects, such as the reading of a sensor [14]. Alternatively, Lycett [15] stated that this technology has an advanced predictive capacity to identify the events that may affect production before it is conducted. In other words, it identifies patterns.

As reported by Stoicescu [16], using big data, it is possible to know which data are missing. Furthermore, big data can be considered as a perfect tool for achieving specific results and increased profits for a company within the production sector. Additionally, big data allows access to a number of valuable information related to customers, as well as any process that is directly related to performance along with unforeseen correlations and connections that can be used in the industry.

The concept of AI is defined [17] as a "branch of computational science that introduces the simulation of intelligent behavior in computers" and "the ability of a machine to imitate intelligent human behavior." Hence, these technologies have emerged to stay in our lives. They have been implemented in sectors that were never considered before. AI systems independently assimilate, learn, and adapt to organizations. Over time, an

increasing number of applications will be developed, which will render the consumer the core of the entire marketing process. In turn, services would be highly personalized to suit the user's demands. Thus, the implementation of AI in industries leads to a high level of production through process automation, thus providing significant values and competitive advantages to organizations [18].

Today, AI and robotic technologies are adopted around the world, including in manufacturing sectors that use industrial robots and in other economic activities, such as transportation via autonomous vehicles, trade in the financial markets, customer relationship management based on Chatbots, legal provisions, and medical diagnostics and surgeries [19]. AI and big data are the two driving forces behind various technological innovations that have shaped the current digital environment and Industry 4.0. These two trends have a common goal, i.e., to obtain maximal data from the data generated in companies today.

In this research, a bibliometric analysis was conducted, which allowed the examination and quantitative analysis of the literature and academic research. This analysis was conducted using statistical and mathematical techniques, which have been integrated in multiple fields and disciplines over time [20]. Kostoff et al. [21] stated that these bibliometric techniques provide an evaluative analysis of publications, patents, citations, and other elements that provide potential informative for developing indicators, which assist in evaluating the performance achieved in science and technology. In other words, bibliometric analysis identifies the infrastructure (authors, journals, institutions, keywords, etc.) of a technical officer through whom experts are identified. This tool also allows the development of web visit strategies for evaluating organizations that are in the process of rapid growth worldwide. Additionally, it identifies the impacts (bibliographic citations) of people, research units, organizations, and countries, as well as all information regarding the subject of research.

Despite all positive qualities expressed by the authors, it is appropriate to mention that the application of a bibliometric analysis is not always convenient for the development of new research, as noted by Krauskopf [22], Johnson [23], and Johnson et al. [24] when discussing the impact of the bibliometric analysis on the transparency and benefit of the production of scientific articles. They mention how it is the function of the editors to choose the methods using which they can employ appropriate measurements for each field of research. Therefore, the benefits and weaknesses offered by the application of a bibliometric analysis to a quantitative and qualitative research can be easily identified. In this regard, Carvalho et al. [25], Bounes et al. [26], and Urquhart and Dunn [27], highlight how the quantitative refinement of bibliometrics strengthens the qualitative analysis of research results.

III.   Methodology

In this section, we focus on obtaining a vision with respect to the digitization trend of industries based on big data and AI in the development of Industry 4.0. Therefore, the methodological design commenced from the development of a bibliometric exercise for the identification of scientific articles on the subject of big data, AI, and Industry 4.0.

To synthesize the existing analysis, determining patterns, themes and problems, as well as recognizing the conceptual content of the field contributing to the development of a theory, an adequate literature review was conducted. This process involved a methodical, organized, specific, and reproducible design for identifying, evaluating, and interpreting a body of existing documents. Hence, the process relied on the use of quantitative methods that analyze publications according to authors, countries, and institutes as well as the methods that map the science employing bibliometric software [28]. For this particular case, the analysis was limited to the purification and processing of scientific development based on the parameters established in the following methodological design subsection.

3.1 Methodological design

The methodological design of the present study included a documentary-type research design and correlational study by consulting documents (database, patents, scientific articles, reports, and journals) [29]. This approach allowed us to obtain an overview of the digitization trends of industries based on big data and AI in the world of Industry 4.0. The analysis performed in this study involved three phases, as detailed in Figure 1.
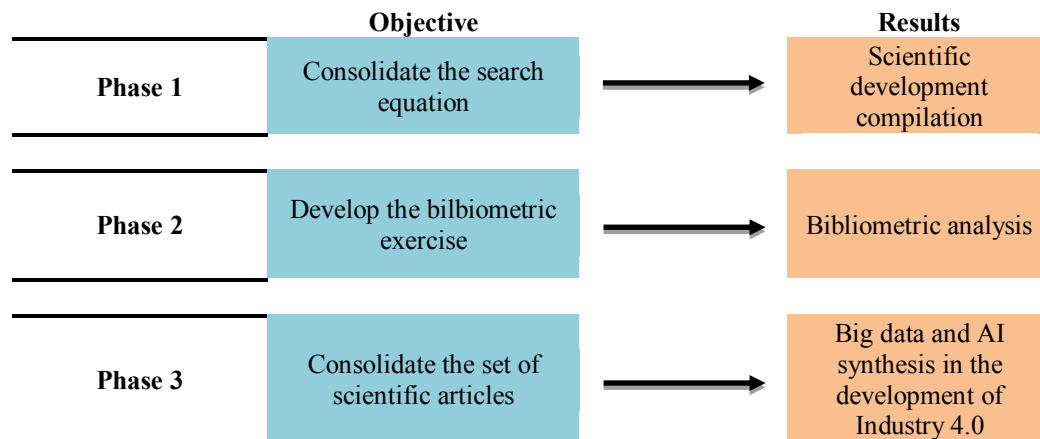
	Objective		Results
Phase 1	Consolidate the search equation	→	Scientific development compilation
Phase 2	Develop the bilbiometric exercise	→	Bibliometric analysis
Phase 3	Consolidate the set of scientific articles	→	Big data and AI synthesis in the development of Industry 4.0

Figure 1. Study of the methodological design.

Figure 1 shows three methodological phases. In phase 1, the search equations were proposed and tested based on a combination of keywords characterizing the profile of the articles to be selected according to the study topic. Consequently, the search expression consigned in equation (1) was selected:

(TITLE-ABS-KEY ((Big Data) OR (Artificial intelligence)) AND ((Industry 4.0) OR (Smart manufacturing) OR (Fourth Industrial Revolution) OR (Cyberphysical system) OR (Smart factory)) (Equation (1)).

This equation was entered in the Scopus database (www.scopus.com), which yielded 2,155 results. This database was selected based on an information criterion of availability and accessibility. Moreover, it contains validated references in the development of bibliometric analyses.

In the second phase, the collected documents were refined using the information provided by the database, such as the publication year, keywords, research field, the type and source of document, language, institutions, and countries. This process was performed using an Excel spreadsheet.

Finally, the information gathered from the selected documents was processed using the cross-content analysis, which suggested a digitization trend of big data and AI for the development of Industry 4.0.

3.2 Content analysis

VOSviewer software (version 1.6.15) [30] was used to analyze the information. The analysis involved the determination of the co-occurrence of keywords and terms in the titles and abstracts of the publications using a co-occurrence method, revealing only the elements connected with others. The complete count method was established with several records for each term ≥15 and a minimum cluster size of 15 [31]. Based on different terms presented in the software, the maps of the network visualization were prepared. The algorithm was designed so that the terms exhibiting the highest correlation were positioned closer to each other with large bubbles that suggested a significant frequency. Those terms irrelevant to the map were not considered; therefore, they were removed.

IV.   Results

According to the Scopus database, 2,155 documents were identified between 2012 and August 5, 2020. The five-year period (2016–2020) was the period with the highest record of publications associated with big data and AI toward the development of Industry 4.0. The year 2019 showed the highest number of references. From 2012 to 2014, a poor performance was observed with an average of 1–9 publications per year. In 2015, the publication trend significantly improved compared with the previous years, reaching a total of 800 published documents in 2019 with an average of 354 publications per year. In fact, this topic has acquired further prominence within different areas of research, particularly in the field of computer science (27.7% of the publications classified in this area) and engineering (25.3%). To a small extent, this topic was prominent in business science, management and accounting (7.1%), mathematics (6.9%), decision sciences (6.2%), and 20 other areas of research.

Regarding the research fields and keywords, the vast majority of the collected documents originated in the field of computer science, where keywords such as Industry 4.0, big data, AI, IoT, and embedded systems showed the highest number of repetitions. In addition to the analysis of keywords, according to the documents identified by type and source, most of the obtained results were articles published in conferences (49.8%) and magazines (37.3%).

Following this analysis, the countries of origin of the documents were described. In general, the results reflect that there was a high concentration of scientific development in the United States, China, and Germany. At an institution level, South China University of Technology, Universidade do Minho, and University of

Johannesburg were the most prominent. With reference to America, in addition to the USA, other countries such as Brazil, Colombia, and Mexico and institutions such as the Universidade de Sao Paulo, Tecnologico de Monterrey, and Universidad Distrital Francisco José de Caldas showed prominent research.

As far as the language of the documents, 96% of these are originally published in English and a small percentage in Chinese, Russian, Spanish, and German. In terms of the identification of the writings, using the search equation, it was easy to characterize scientific development associated with the digitization of industries based on big data and AI in the world of Industry 4.0 as a group of articles in magazines that mainly originated in institutions of higher education in the United States, and China, growing from various fields of knowledge according to computer science and engineering.

4.1 Content analysis

The keyword co-occurrence analysis provided an overview of trends in research studies by indicating the topics covered. The analysis was performed using VOSviewer software, which yielded a network visualization of big data and AI in Industry 4.0.

This bibliometric analysis is a map based on distance, where the distance between one element and another indicates the relationship strength among the two elements. A small distance reflects a stronger relationship. In this way, the frequency or level of occurrence and strength exiting between the words was measured. Hence, the words within the center of the map were as important as those on the periphery.

The results produced by the VOSviewer software reflect 205 terms, in which only those that had an occurrence greater than 15 were considered, thus delimiting the terms. Therefore, the terms were organized into six clusters with 9832 links.
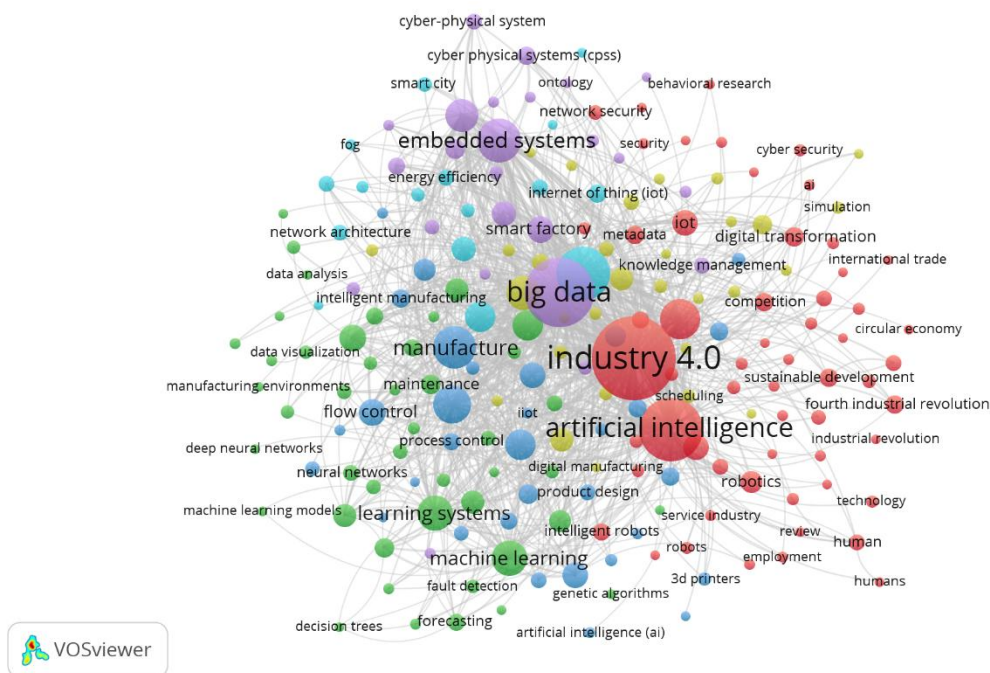
Figure 2. Visualization of the big data network and artificial intelligence in Industry 4.0.

A clustering method was implemented, wherein the unit of analysis was the keywords (author's words and indexed words) obtained from the dataset. The colors express the similarity and the level of relationship between the elements or nodes of the cluster. In this way, this map of the co-occurrence of keywords helped to determine the relationships between keywords of the research based on proximity within the map. In Fig. 2, clusters are observed to be associated with Industry 4.0, AI, big data, IoT, smart factories, and machine learning. All previous terms are interrelated topics; however, they cannot be consolidated as an individual cluster. Note that the clusters with the highest occurrence were INDUSTRY 4.0, ARTIFICIAL INTELLIGENGE, BIG DATA.

The aforementioned words are the nodes that have the most influence within the network. Therefore, the central-word sets reflect the semantic structure of the research field. Because it is built using keywords, this map reflects descriptors that have been selected by both the authors and journals.

Figure 3. Visualization of the network overlap of big data and AI in Industry 4.0.

In Figure 3, the overlay visualization shows the transition and evolution of articles, reports, journals, and patents over the years. Moreover, the relationships and trends between them are shown. The themes Industry 4.0 and AI had more relevance at the end of 2018. The term big data showed higher relevance at the beginning of 2018, and the term Industry 4.0. was also included.

V.   Discussion

The study conducted revealed that there is a significant co-occurrence of big data and AI in the development of Industry 4.0. From the previous analysis, it could be observed that the key paradigms in the development of digitization of industries are Industry 4.0, big data and AI. Moreover, the digital evolution of industries and their survival in the market depends, to a great extent, on the good use of data (big data) and AI. Because the use of these technologies allows organizations to make strategic decisions based on data, forecasts, information, and facts and not on hunches or strokes of wits, it must also be borne in mind that AI and big data projects are neither easy nor are the expected objectives achieved in a single phase because they require an iterative and careful approach that yields the expected results in continuous stages. The co-occurrence of the variables big data, IA and Industry 4.0 is evidenced by the bibliometric analysis and the number of documents found in the implemented databases. In addition, it is observed that it has a growing projection every year. Hence, it is said that we are currently living in the Fourth Industrial Revolution, an era where digital has taken on enormous importance. For this reason, big data and AI play a fundamental role in the businesses developed in Industry 4.0 because using these techniques, large volumes of data are managed and analyzed. This is crucial for understanding market demands, user profiles, and their response to new products or services.

The continuous technological development that marks this digital age offers an abundance of possibilities in the different areas of our lives. That is why the technological trends are currently being marked are diverse, but two particularly stand out: Big Data and AI. Admitted as the new Industrial Revolution, Industry 4.0 related research has garnered undue attention from academia, government, and industries. Furthermore, it is the development of Industry 4.0 characterized by the development of big data and AI that are necessary skills in this era and include advanced analysis, the IoT, and digital security.

As per Muktiarni et al. [32] every industrial sector in the world will be affected by the development of the Industrial Revolution 4.0. Because it is a new pattern, it is spreading so rapidly that all circles, especially industries, should be able to adapt immediately to industrial development 4.0. That is why big data and AI are born in this new digital era as tools that allow organizations to develop and evaluate strategies that benefit their businesses through data analysis. In addition, it is important to emphasize that the handling of the data, the interpretation, and what the company does with this information is more important than the quantity of data.

That is why a good data analysis will help organizations in their productivity, the optimization of their processes, growth and economic development and, above all, good decision-making. This is reflected in the increase in its usefulness, which for any business is beneficial and important because, in this way, it maintains and/or increases its competitiveness in the market. In this new digital era, industries are betting on greater automation of their processes, connectivity, and globalization. We observe that the correlation between different areas, such as products, services, processes, and business models, has penetrated the industrial world, bringing with it the IoT, big data, and analytics.

The information analysis proposed for the Fourth Industrial Revolution allowed to have a broader perspective of the benefits, scope, challenges, and implications of Industry 4.0. These discoveries coincide with previous studies on this same topic, in which it has been reported that this new digital era encompasses a set of technologies that allow the integration of products into interconnected digital and physical processes at the same time. Likewise, these technologies such as big data and AI have contributed to the development of Industry 4.0 and are considered two fundamental pillars. Because data collection in industries has been continuously increasing, it is achieved through the incorporation of new data sources. Therefore, organizations can detect failures in real time, and in turn find points of improvement and forecast workloads. Consequently, big data is one of the essential technological tools for the digital transformation of organizations.

For this reason, companies are currently fighting to win the data battle because whoever does it will win the future. Through this strategy, they benefit since they understand the behavior of the market that is increasingly dynamic and competitive, as well as their clients. These new clients are increasingly demanding, and essential to progress on the path of maximizing profits. The industries, in addition to big data and AI, have complemented utilities such as IoT and machine learning, since a large amount of data is continuously generated by means of it. The abovementioned, together with those already collected, represent a new source of knowledge and that over time has taken on great importance for organizations that create competitive advantage through these tools and are in continuous transformation and innovation. To define the strategies for developing these technological tools, considerations regarding the storage and handling of data must be taken as well as compliance with the legislation and all technological support necessary to perform these strategies.

However, not everything is as easy as it seems. As industries present an increasing amount of hassles for the management and analysis of data, due to the large amount of data generated, AI arises as another important pillar of Industry 4.0. Although many years ago seemed unimaginable, AI has managed to replicate human intelligence in machines. Even so, robots will not become successors, or will replace people, but undoubtedly, they can contribute to streamline and optimize some activities, tasks, and processes, which are time and costs consuming resulting into savings for companies and organizations. Furthermore, it is precisely in the AI way of working where the key to its correlation with big data can be found since it is mainly this type of intelligence that feeds on the data generated by companies. Yes, AI feeds on data, and it uses it to develop algorithms and constitute the 'logic' of machines. In short, data can also be used to acquire information from the environment and interact with it. Big Data and AI work increasingly closely, and this is achieved to continue advancing in the progress of the industry digitization. Even so, it is true that prejudices continue to appear about the possible contradictory effects that robots can produce in humans. Moreover, there is a certain fear that working with intelligent machines will replace working with people and, precisely for this reason, it is essential to work on creating an ecosystem in which both actors, robots and human beings, can coexist and complement each other [33].

The results obtained in this study can help as a guide to learn to publicize the importance of big data and AI in the development of Industry 4.0. In addition, the industries may manage according to the characteristics, needs, and skills of digitization. Big Data and AI in the world of Industry 4.0. allow us to have a vision of the trend of digitization in industries, making industries increasingly profitable and durable, and meeting the needs of the Fourth Industrial Revolution.

VI. Conclusion

This study shows the evolution of scientific research on AI and big data published in the Scopus database as part of the development of Industry 4.0. Within this context, 2155 documents were published between 2012 and August 5, 2020. The bibliometric analysis showed the results of the number of publications per year, the productivity of countries, research area, journals, and the analysis of the most frequent keywords and the relationship between them.

As presented in this work, based on the description of the texts on big data and AI in Industry 4.0 and its bibliometric analysis, we conclude that these research fields are generally developed within the scientific literature. Despite the fact that this literature focuses on aspects related to companies and industries, the importance of big data and AI was prominent as two pillars in the development of organizational digitization. In the forthcoming years of the Fourth Industrial Revolution, machines will be able to communicate with each other to absorb or transfer information and establish actions.

Moreover, considering that we are living in an era of digital transformation, which involves the fusion of the physical and digital systems, information transformation in a format that is understandable to all people has reinforced collaboration and the shared use of data relying on the automation of processes based on big data and AI. This new Industrial Revolution is characterized by the speed in facilitating visible results and the degree to which it affects people. Therefore, this new era, together with its pillars, is causing a stir today because of the advantages it offers.

Regarding the methodological aspects, the obtained results demonstrate how bibliometrics allow the collection, purification, and analysis of scientific development of studies associated with the subject, thus enriching this new research despite the limitations of the method.

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