Building Information Modeling from a bibliometric analysis

Modelado de Información de Construcción desde un análisis bibliométrico

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Abstract

Bibliometry is responsible for applying mathematical and statistical methods to scientific research; this discipline is responsible for measuring scientific studies by applying quantitative variables to articles or texts produced by a scientific

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nature. A bibliometric analysis was carried out where the term "BIM" was consulted, which is the acronym for Building Information Modeling. The search was carried out in the scientific research portal Web of Science, obtaining 684 journal articles related to civil engineering and construction technology. Additionally, the bibliometric analysis software (Bibliometrix) was implemented with which analysis of co-occurrence, co-citation, and co-authorship was carried out, which allowed the study carried out to be better visualized in graphic form. The results of the research show growth in Building Information Modeling research in recent years, noting that the countries with the highest contributions are China, the United States, and the United Kingdom in the scientific field on this subject. Finally, it is essential to emphasize that BIM development and research must continue to grow since this methodology and other innovations in construction will revolutionize the field of civil engineering and construction processes towards more effective and efficient solutions, considering counts the life cycle of construction projects.

Keywords: *Bibliometric analysis, BIM, scientific production, Building Information Modeling.*

Resumen

La bibliometría se encarga de aplicar métodos matemáticos y estadísticos a lo que es cuantificable en la producción y en el consumo de la información científica. Esta disciplina se encarga de medir los estudios científicos aplicando variables cuantitativas a los diferentes artículos o textos producidos de carácter científico. Se realizó un análisis bibliométrico donde se consultó el término "BIM", el cual, es el acrónimo de Building Information Modeling. La búsqueda se realizó en el portal de investigación científica Web of Science, obteniendo un resultado de 684 artículos de revista relacionados con ingeniería civil y tecnología de la construcción. Adicionalmente, se implementó el software de

análisis bibliométrico (Bibliometrix) con el que se realizaron análisis de co-ocurrencia, co-citacion y co-autoría que permitió visualizar de mejor forma el estudio realizado en forma gráfica. Los resultados de la investigación evidencian un crecimiento en las investigaciones de Building Information Modeling en los últimos años, notando que las potencias (China, Estados Unidos y Reino Unido) son las que más aportan al desarrollo científico sobre este tema. Así mismo, los autores más destacados son Wang X. y Cheng JCP, ya que son los que mayor cantidad de aportes han realizado. Finalmente, es importante que el desarrollo sobre BIM siga en aumento ya que la utilización de este sistema revolucionará el campo de la ingeniería y los procesos constructivos hacia soluciones más eficaces y eficientes.

Palabras clave: *Análisis bibliométrico, BIM, producción científica, Bibliometrix, Building Information Modeling.*

Introduction

Years ago, bibliometrics stood out for being a statistical bibliography tool with functions related to the analysis of library activities, theory, processes, and regularities of the scientific documentation archived in the physical document repositories. On the other hand, bibliometrics has evolved in the digital age as a metric discipline whose objective, based on exact sciences, is to assess the behavior of the advance of scientific processes linked to social phenomena, and, consequently, to extract making the most of the literary heritage (Morales Morejón, 1995).

For his part, Spinak (2001) highlights in bibliometrics the benefit of the quantitative characteristics of mathematics and statistical techniques in the process of knowledge of trends and advances in scientific topics. On the other hand, the term "bibliometrics" coined by Alan Pritchard at the end of the '60s, refers to the part of Scientometrics that applies mathematical and statistical methods to scientific literature (Bellis, 2009). Initially,

this science was introduced by Eugene Garfield in the middle of the 20th century, and since then, it has become widespread in scientific research in the revision of knowledge in recent years (Abad-Segura et al., 2020). In bibliometric studies on BIM, there are two main objectives, the first is to analyze the background of all the work published in relation to BIM as bibliometric maps of this subject, and to see which groupings of the scientific field are common among them, and the second objective is to identify the improvements and barriers in the implementation, given the importance that BIM has in the improvements of the value chain and sustainability in construction (Mehdi et al. 2019).

This research aims to identify and examine trends, particularities, and scientific bibliographic progress in the BIM field worldwide through a bibliometric analysis, in addition to highlighting some main characteristics of the BIM process and its importance to increase the added value of construction (Osorio -Gómez et al. 2020). It should be said that Building Information Modeling is not a methodology of the future, but is already a reality in many countries, and it can also become a competitive advantage and a guarantee of permanence for companies in the construction market. It is a comprehensive and diverse concept since it does not only encompass project modeling (Brugarolas et al., 2016).

Building Information Modeling (BIM) is a collaborative work methodology for the creation and management of a construction project. Its objective is to centralize all project information in a digital information model created by all its agents (Loyola, 2014).On the other hand, (Pacheco, 2017) defines BIM as a process focused on the development and use of a digital information model of a civil works project, for the design, construction, and operation of a portfolio of facilities that comprise the entire project. This methodology has slowly become popular in recent years in Colombia and Latin America

in general, although in various parts of the world, it is already implemented with defined standards, countries such as Singapore, Spain, the United Kingdom, among others.

The BIM concept was suggested by Eastman and later used by Van Nederveen and Tolman (Rojas-Sola & Aguilera-García, 2020), and it has been implemented since the early 2000s, since then its methodology has contributed to the development of innovative techniques for the construction industry today BIM has revolutionized construction technology and has become a tool that allows achieving more efficient projects (Rojas-Sola & Aguilera-García, 2020). This methodology arises in response to a series of needs and deficiencies in the construction industry to improve its processes and utilities(Granados, 2018), but their implementation has not had a very rapid evolution due to different cultural aspects of the necessary infrastructure, assuming the limitations of the context in which they are executed in terms of the availability of financing and the possible supplies of resources according to the strategies developed, with the level of integration that functional structures and organizations allow (Guere Oussouboure, 2017). Worldwide, technology changes with accelerated speeds; for this reason, the BIM methodology must be adopted and managed in the right way (Cerón & Liévano Ramos, 2017).

The purpose of this study is to carry out a detailed bibliometric analysis of the scientific production of BIM in one of the most central databases such as Web of Science, and to submit them to different bibliometric indexes where they are identified: the authors, prominent universities, number of articles and citations, documents per author, the average number of citations per documents, keywords, co-authorship networks, among others. The results of the analysis made it possible to show that in recent years the scientific production on BIM has had notable growth, the average number of citations per year, the most relevant sources,

the most relevant authors, the impact of the authors, is presented in this article the most relevant *words and the co-occurrence.*

Materials and methods

A search was carried out in the Web of Science (WoS), which is one of the most recognized portals in the world for scientific research. After analyzing various equations, the end was reached. TI = ("BIM"), the word BIM was filtered by title, and the quotation marks denote that it must be an exact search for the word. In this search, conference articles and early Access were excluded, thus leaving only journal articles. The search was carried out in April 2020. With this search, you can find a relationship with the sources that publish the most on the subject and their distribution in the selected period. Also, an exclusion was made of other topics where the word BIM usually appears, these being mainly areas such as Biology and molecular chemistry.

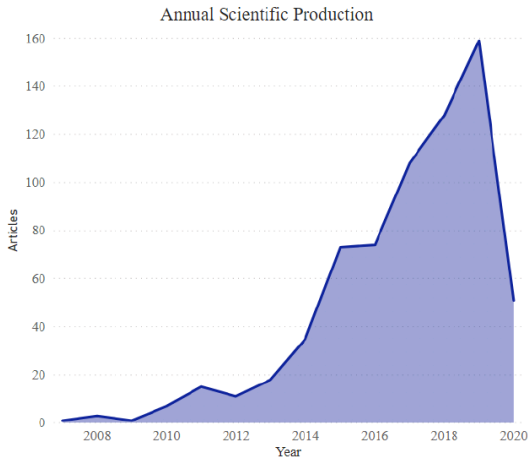
A TXT file was exported with the information from the search, later with said file. A bibliometric analysis was performed in an R-studio program (Bibliometrix) that has been used in multiple bibliometric analyzes. For this analysis, the emphasis was placed on the bibliometric indicator H index (H Index), or Hirsh index, which is an indicator that allows evaluating scientific production per researcher, measuring its quality and quantity, thus being able to identify the most prominent authors in this area of knowledge (Castro Forero et al., 2020).

In this way, several analyzes were obtained, such as co-occurrence, co-citation, co- authorship; that allowed to visualize better the data obtained from the WoS search. This type of analysis is recommended to understand how research on the subject has gained relevance in recent times. Finally, an analysis of the data and graphs obtained through the free program VOSviewer was carried out (Jan van Eck & Waltman, 2010).

Results and discussion

The Figure 1 allows to chronologically identify the annual scientific production; it could be said that the search for BIM in the field of civil engineering and construction has been increasing over the years, thanks to its efficiency in the processes and the improvements in productivity. In 2007, almost until 2011, an increase of around 20 articles was discovered, allowing more information to be found on the net; however, until 2015, the number of publications rises in a higher percentage since the concept went viral in the sector and at the same time, they were finding their most significant potential, determining their highest peak in 2019 with more than 150 articles published.

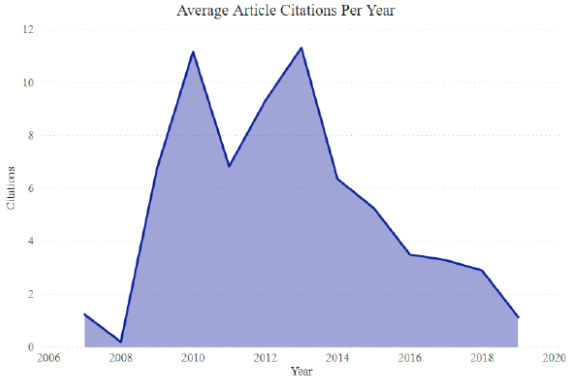
Figure 1. *Annual scientific production*



The average number of citations per year in Figure 2 indicates that it increases between 2009 and 2010, where the first publications on the subject are mostly found; that is, the increase in publications are focused on these years since the authors collect information that is already found on the Internet. From there, they build their own articles citing the authors. In 2011 the number of

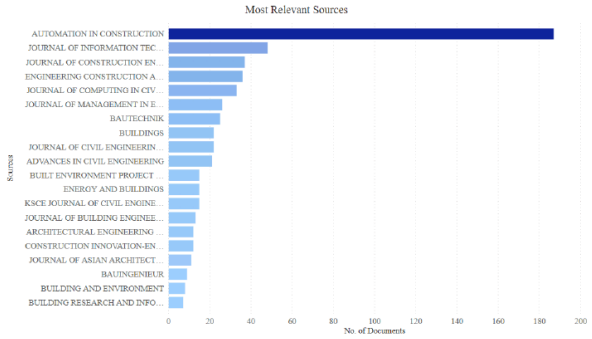
citations decreased and again reached its peak in 2013. However, from then until 2019, this number decreases as the volume of articles about BIM increases, then the average of citations of articles per year is decreasing because the amount of bibliography for consultation is more. Besides, many new authors generate their content since BIM has become a relevant topic in industry and academia; therefore, it has led to an increase in published research on the subject. BIM has stood out most for its key and innovative approach to construction and civil engineering, and these new studies cover various areas, including various technical and non-technical issues.

Figure 2. *Average citations per year*



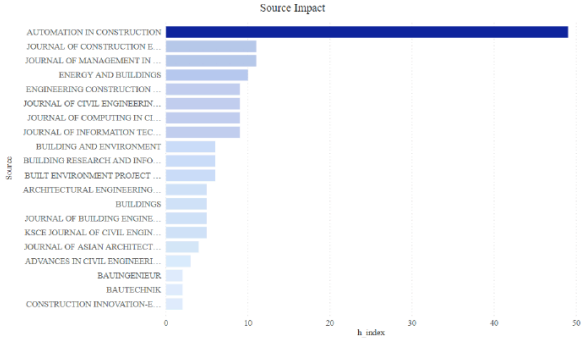
In the Figure 3 it is identified that the magazine Automation in Construction dramatically exceeds the number of documents compared to the other sources, which has more than 150, taking into account that the following magazine Information Technology in Construction "is made up of a little less than 50 documents and from then on the percentages are reduced. The main aspects towards which the sources are inclined were identified, becoming bibliometric indicators; thus, they allow the analysis of various features of scientific activity, linked to both the production and consumption of information (Ardanuy, 2012).

Figure 3. *Most relevant sources*



The impact of a source is classified from the h index, which is defined as the h-index of a researcher R is defined by Hirsch as the unique number h such that R has h publications that received h or more citations and all R's other publications received at most h citations (Bar-Ilan, 2008). That is, this becomes a quality classifier element, the measurement is carried out approximately from 0 to 50 according to the implemented sources, in the Figure 4, Automation in Construction magazine reaches almost 50 of the h index, surpassing all the others, from then on, the journals decrease from the value 10 to approximately 2 of the h index.

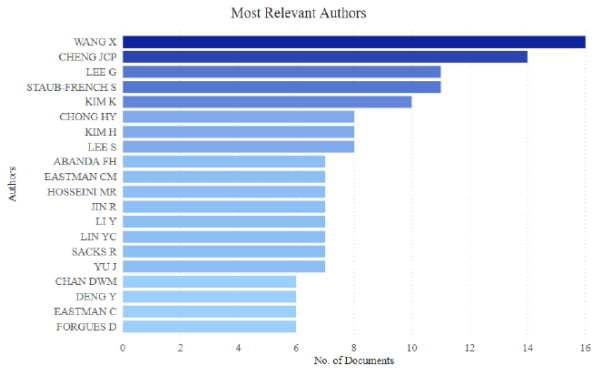
Figure 4. *Impact of sources*



The most relevant authors are identified from the number of documents they have, in the Figure 5. They are classified in a range of approximately 0 to 15; the most relevant author or the one with

a greater number of documents is Wang X with a little more than 15, in second place is Cheng JCP with around 14, both top the list. From then on, the number decreases, although all of them exceed five documents.

Figure 5. *Most relevant authors*



According to Figure 6, the author who generates the greatest impact according to the h index is Cheng JCP. In the second place, there is Wang X with a difference of one point. Point 5 of the h index is where the largest number of authors are located, made up of 11 authors, their level of impact, a little more than half of all authors. The impact range is from 4 to 8 h index.

Figure 6. *Impact of the authors*

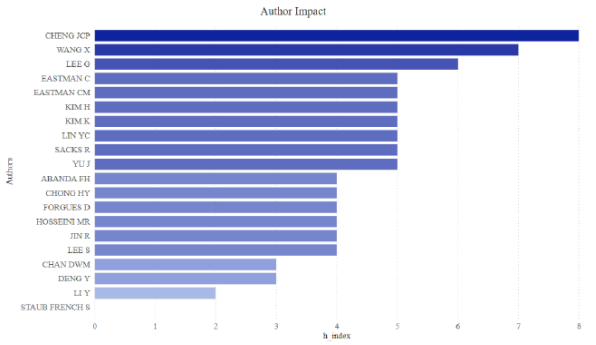
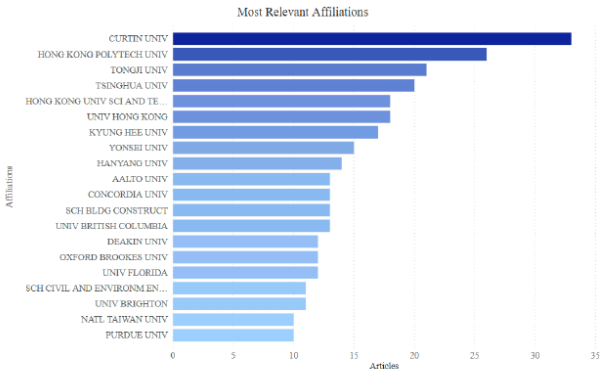


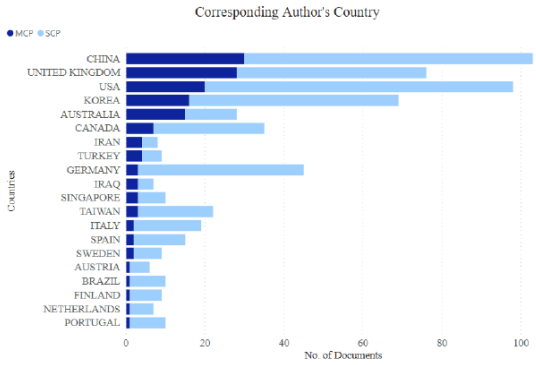
Figure 7, according to the number of documents in a range from 0 to 30, the most relevant universities are classified, in which Curtin University ranks with more than 30 documents, in second place, Hong Kong Polytech University accompanies it very closely with 26 documents. The other universities have more than ten units, and they are progressively decreasing from Tongji University to Purdue University.

Figure 7. *Most relevant universities*



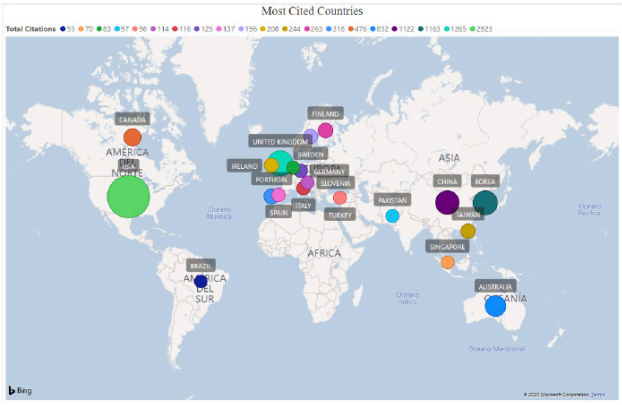
In Figure 8, the figures of the collaborations of some countries are identified from the creation of documents in a range of 0 to 100. Initially, in the national collaboration (SCP), the country that has a more significant number in China with a little more than 100. However, very close to the United States in second place and from there, the graph decreases, with Austria with the lowest percentage, only four countries exceed 50 documents (China, United States, United Kingdom, and Korea). In the MCP international collaboration index, only two countries exceed 25 documents, firstly China and secondly the United Kingdom. The graph falls in a large proportion compared to the SCP.

Figure 8. *Country of the corresponding author*



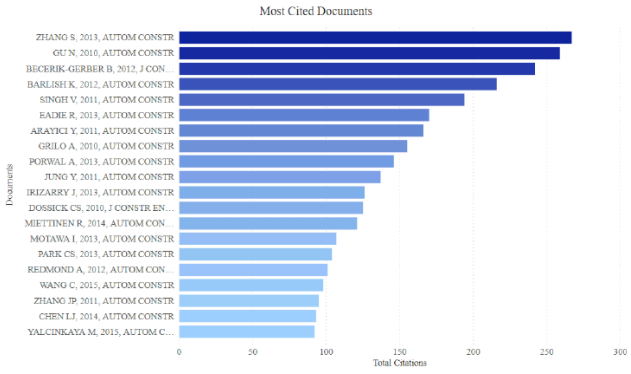
Regarding the most cited countries as expressed in Figure 9, The United States is the most productive country, although with a relative impact factor more generous than the average due to the dispersion of its publications in medium and low impact journals(RojasSola & Aguilera-García, 2020). The United States tops the list with a significant advantage, with its number of citations approaching nearly 3,000; Only three more countries exceed a thousand citations, the other countries are well below this margin, the graph is decreasing, leaving Brazil in the last place.

Figure 9. *Most cited countries*



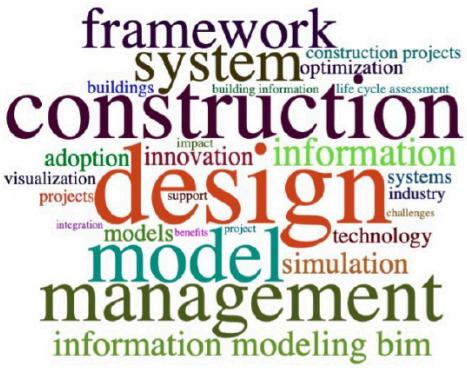
Regarding the most cited documents shown in Figure 10, only four articles do not exceed 100 citations, but are very close to overcoming this barrier. Also, only 4 exceed 200 citations; among these is Zhang, 2013, Automation Construction, which occupies the number one position in its totality of citations. It should be noted that the date it has is not a determining variable, however, if it is within a 5-year margin (2010-2015). From this analysis of citations, the impact indicators are evaluated, that is, one of its variables, where growth elements could be analyzed.

Figure 10. *Most cited documents*



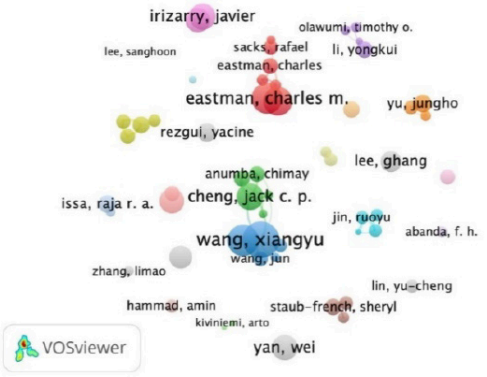
In the Figure 11, cloud of keywords is obtained, that is, the most mentioned in the keywords of the documents that are being analyzed. This classification is made from the size of the words; without a doubt, one of the words that stands out the most is a design, and it is mentioned in both graphs in the same dimension. Some of the words that were found, it could be said that they are in second place, but they continue to be very striking are Model, Management, Construction are common in the same way in both word clouds. From there, two more classifications in size were delimited, around 30 classified words are calculated.

Figure 11. *Word cloud*



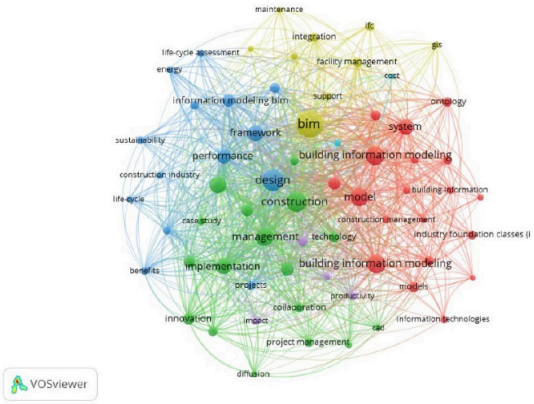
From the networks raised in Figure 12, connection nodes between authors were identified from the development of common themes and authors who are expanding their subject by themselves; no doubt in the graph, two extensive node connections were identified. In the first place, the Eastman C and Sacks R nodes which come together to display information around the same common purpose or theme. There is also the case of Cheng J and Anumba X, in addition to Wang X and Wang J, in which the same dynamics mentioned above happens. New nodes develop around them, some with fewer connections than others.

Figure 12. *Co-authorship*



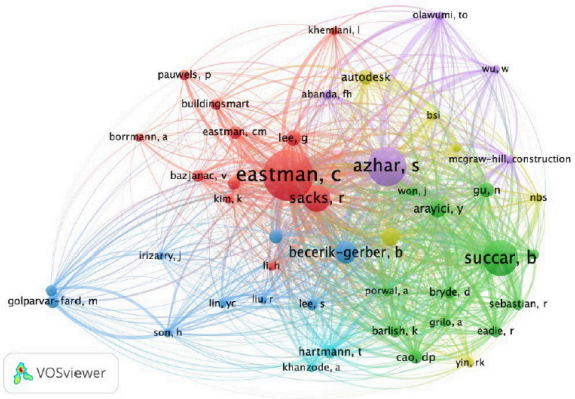
In the Figure 13, it is visualized in a network all of the connections of the key terms around taking into account their frequency; in some central nodes, the words with the highest occurrence are identified and from which most of the terms are derived, identifying the number of times that are mentioned, little by little they are joining each other. In the center, there is evidence of BIM, Design, Construction, Model, Building Information Modeling, which are divided into colors that facilitate analyzing the classification and union between the nodes. Those that are closer to the limits are those that do not have as many occurrences, reducing the size of their node.

Figure 13. *Co-occurrence*



The co-citation network is embodied in Figure 14, which reflects the way in which the authors mention each other and generate new knowledge content. It is possible to show a cluster where reciprocal citations are made. The primary node from which the most extensive connections are deployed is from the author Eastman C; that has connections with smaller nodes where authors like Sacks R and others are located. Finally, there are other large clusters headed by Azhar S and Succar B.

Figure 14. *Co-citation.*



4. Conclusions

Bibliometry is a tool that helps us quantify information through graphs and tables. That allows interpreting the data much more comfortably and more dynamic (Ardanuy & Rey Vázquez, 2009). In this research, it can be seen that scientific production on BIM has increased in recent years, and this is reflected in the development of this methodology and becomes more relevant for the development of large, medium, and small projects; thus obtaining an increase in productivity, efficiency, value, quality and sustainability in projects(Doumbouya, Gao, & Guan, 2016). Likewise, these investigations will be the basis for future developments in BIM investigations, not only in pioneer countries but also in countries that are beginning to learn about this methodology. Industry 4.0 (I4.0) is a facilitator of cutting-edge technology developed in major countries, which calls for the digital revolution in industries (Ramos-Sanz, 2019). The compound annual growth rate worldwide should total 17.3% for BIM products and services over the eight-year period, Pike Research predicted; This figure includes both revenues from BIM software and revenue from related BIM services, such as training, support, management, and collaboration on the project. (D'Paola

Punche, 2014). Consequently, companies and construction companies can obtain significant benefits in the value chain by implementing this methodology (Osorio-Gómez et al. 2019).

One of the most critical challenges in current construction is the research and implementation of the BIM methodology; However, BIM adoption is much slower than anticipated (Fischer & Kunz, 2004). Since it is necessary to standardize the BIM process and define its implementation (Azhar et al., 2007), those who contribute the most are countries such as China, South Korea, the United States, and the United Kingdom; in the latter, the use of BIM in public works is mandatory(Smith, 2014). While in Latin American countries, this methodology has an immature implementation in general and in some isolated cases, that is why these countries should be encouraged to make more contributions and promote the implementation and research on Building Information Modeling.

From these data, it could be defined if it is related to geographic areas. The AngloSaxon area leads to the set of innovations that support BIM adoption (Fernández-Tamases & Zamarrón-Mieza, 2018). Regarding the practical contribution, many conclusions made by the bibliometric approach have been verified, such as that the legal system and standards in each country are different, which leads to an international project with BIM that can be efficiently conducted with contradictory information and risk of information loss, affecting the result of the project(Tsenguun, Heap-Yih, & Liao, 2018). Future BIM-related problems would be about how to perform construction works in different places that have different BIM standards. Different BIM constructs could demonstrate how to standardize modeling methods between different groups or countries and how to precise international information with BIM (Tsenguun, Heap-Yih, & Liao, 2018). The most relevant authors in BIM research are Eastman C, Sack R, Wang X. and Cheng JCP since they are the ones who have made the most significant

amount of contributions. The most used words in articles about BIM are Design and Construction since they are concepts closely related to civil engineering and architecture.

The construction industry has a significant impact on the environment; different studies showed the high contribution of the construction industry on energy consumption, the use of raw materials, and CO2 emissions; due to this high negative impact on the environment and the growing awareness of environmental protection, there is a sense of urgency for the construction industry to be more sustainable in its projects and work processes(van Eldik et al., 2020). However, there is no doubt that the implementation of this new methodology worldwide in engineering will reduce the environmental impact framed in the generation of gases and the misuse of raw materials in waste and residues. In turn, this methodology will help achieve greater efficiency in construction processes (Jiménez-Roberto et al., 2017), avoiding reprocessing and downtime on-site, having total control of the project from its design, construction, and throughout its life cycle.

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