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Construction 4.0: Cluster analysis and Research perspectives.

Construcción 4.0: Análisis de clusters y perspectivas de investigación.

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Abstract

Construction is a sector that has been operating with lower productivity rates than other industries; historically, it has used artisanal methods, which have generated low competitiveness and efficiency, leading to considerable cost overruns and waste. For these reasons, the industrial revolution 4.0 is a movement involving large-scale changes and a transversal implementation of technology in industries' value chains. In the same way, the basic principles of Industry 4.0 can be applied to the construction sector in the term Construction 4.0, a movement that seeks to integrate new technologies with the processes of the industry, generating added value that allows for increased productivity, and close gaps with other industries. Therefore, a bibliometric analysis focused on Cluster analysis is presented, which allows knowing the research state of Construction 4.0 and its implications in developing the Construction sector. The search equation in the Web of Science (WOS) database was queried by topic (Construction 4.0), from which 225 scientific articles related to the subject were obtained. These articles are directly related to this new movement from new materials, more efficient construction processes, BIM, Digital Twin (DT), Artificial Intelligence (AI), and other topics of research relevance in Construction 4.0. The main results show low research participation of Latin America in implementing technologies and methodologies offered by Construction 4.0. In contrast, developed countries, such as the United Kingdom, China, the United States, and Australia, show a greater interest in research and adopting these trends.

Keywords: *Industry 4.0; Construction 4.0; Engineering 4.0; Cluster Analysis.*

Resumen

La construcción es un sector que viene operando con tasas de productividad más bajas que otras industrias; históricamente ha utilizado métodos artesanales, que han generado baja competitividad y eficiencia, lo que ha generado sobrecostos y desperdicios considerables. Por estas razones, la revolución industrial 4.0 es un movimiento que implica cambios a gran escala y una implementación transversal de la tecnología en las cadenas de valor de las industrias. Del mismo modo, los principios básicos de la Industria 4.0 se pueden aplicar al sector de la construcción en el término Construcción 4.0, un movimiento que busca integrar las nuevas tecnologías con los procesos de la industria, generando un valor agregado que permita aumentar la productividad y cerrar brechas con otras industrias. Por ello, se presenta un análisis bibliométrico centrado en el análisis tipo Cluster, que permite conocer el estado de investigación de la Construcción 4.0 y sus implicaciones en el desarrollo del sector de la construcción. Se consultó la ecuación de búsqueda en la base de datos Web of Science (WOS) por tema (Construcción 4.0), de la cual se obtuvieron 225 artículos científicos relacionados con el tema. Estos artículos están directamente relacionados con este nuevo movimiento de nuevos materiales, procesos constructivos más eficientes, BIM, Gemelos Digitales, Inteligencia Artificial (AI), y otros temas de relevancia investigativa en Construcción 4.0. Los principales resultados muestran una baja participación investigativa de América Latina en la implementación de tecnologías y metodologías que ofrece la Construcción 4.0. En cambio, los países desarrollados, como Reino Unido, China, Estados Unidos y Australia, muestran un mayor interés por investigar y adoptar estas tendencias.

Palabras clave: Industria 4.0, Construcción 4.0, Ingeniería 4.0, Análisis de Cluster.

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1. Introduction

The construction industry is one of the main drivers of economic growth and infrastructure development worldwide. However, this industry remains one of the most polluting and least involved in implementing long-term solutions for sustainable development. The construction industry is old, but the lack of innovative technologies and methodologies has made it a more inefficient (Nagy et al., 2021). Unlike other sectors, this industry has not taken advantage of the opportunities offered by technology and data management advances to improve the industry's efficiency and performance and the consistency and quality of its results (Sawhney et al., 2020). One of the main factors is the waste of materials, which has been identified as a significant problem in the construction industry and has a negative impact on the environment (Farida et al., 2019). Likewise, the safety performance in the construction industry has reached parlous levels and is considered one of the most hazardous industries (Karakhan et al., 2019).

In another order of ideas, the industrial revolutions have been used by many industries to improve their productivity; the first industrial revolution integrated the hydraulic and thermal power systems into the manufacturing systems for the increase in industrial production, in addition to causing the creation and development of Mechanical Engineering programs (Carvajal Rojas, 2017). In the second industrial revolution, electrical power was introduced, forming a critical system known as the mass production (Alaloul et al., 2020). Next, the third industrial revolution provided electricity and increased productivity through advanced electronics, increasing the calculation and storage capabilities of the system (García and García, 2019). However, construction continues to function as it has done over the last century, with manual work based on classical mechanics and the operational and commercial models of the past, resulting in a not very dynamic productivity (García Giraldo and González Palacio, 2020).

In recent years, the fourth industrial revolution has been introduced as a popular concept to describe the tendency toward digitization and automation of the manufacturing environment (Oesterreich and Teuteberg, 2016); this movement also encompasses intelligent products or processes that are integrated with various technological developments to control the entire value chain (Zabidin et al., 2020); a notion such as Construction 4.0 appears to describe the adoption and adaptation of industry 4.0 in the construction sector. Construction 4.0 is a movement that contributes through innovative, sustainable, and workflow-focused technological solutions, which can provide growth through the balance between costs and benefits in managing civil projects (de Almeida Barbosa Franco et al., 2022). Construction 4.0 has as its fundamental purpose to revolutionize how construction and management processes are developed with physical and digital technologies in an integrated manner (Sawhney et al., 2020); Construction 4.0 takes advantage of the potential caused by the digitization of information, innovative materials (Osorio-Gómez et al., 2021), and large amounts of data in digital form; which are obtained from technological tools and provide information on construction objects and the built environment (Klinc and Turk, 2019); however, as construction is widely known as a low-tech industry, the goals proposed by this construction revolution remain incipient today, compared to other sectors such as electronic engineering and computer science (Zabidin et al., 2020).

Construction 4.0 achieve from this new industrial revolution and gradually began to make a change in the manual approaches of traditional production, with a more digital and autonomous production approach in its processes (García Giraldo and González Palacio, 2020); likewise, a significant number of associated technologies during the life cycle of the construction project, which presents physical cyberspace that is classified into layers of security and physical interoperability, digital tool, data and primary data (Karmakar and Delhi, 2021). This new concept would significantly impact this industry through an improved value chain of projects, a betterment in productivity, and a sustainable methodology (Hossain and Nadeem, 2019).

On the other hand, various new processes have been developed; for this reason, transversal changes in the value chain should be aimed at improving productivity and reducing the environmental footprint (Osorio-Gómez et al., 2020). One of these is Modular integrated construction (MiC), which consists of an innovative construction technology in which complete construction modules are produced and pre-assembled in an external factory; before their final installation on-site (Darko et al., 2020). Building Information Modeling (BIM) is another methodology considered the most convenient digital technology to make a qualitative improvement in construction worldwide (Papadonikolaki et al., 2020). BIM has positioned itself as an actual implementation for the digital transformation and the creation of Digital Twin (Boton et al., 2020); (Winfield, 2020).

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Construction 4.0 dramatically affects the way products are manufactured, distributed, procured, and consumed, as well as changing the expectations of companies, employees, and society, as these are redefining job requirements. Therefore, it becomes necessary to become familiar with the demands of this revolution for better adaptability (Adepoju et al., 2021). Construction 4.0, in a strategic vision, recommends transformations in organizational structures towards more collaborative and integrated systems, which allow better interaction between phases of the project life cycle (García de Soto et al., 2019).

Consequently, the need to conduct a bibliographic review from the perspective of clusters is relevant, which consists of the search for statistically typical behaviors in the different elements related to the production and consumption of scientific information (Ardanuy and Rey Vázquez, 2009). This allows us to identify the growth of scientific research, topics of interest, and future trends of the subject in question. Historically, bibliometrics has been linked to the idea that it can represent knowledge by quantifying documents and the elements that compose it (Jiménez-Contreras, 2000). Furthermore, it is recognized as the set of methodological expertise, through indicators, such as the number of published documents and the citations they receive, according to their geographical origin and their group of authors (Cortéz, 2007).

Carrying out bibliometric analyses allows us to deepen our knowledge about the habits of researchers and, therefore, to get to know users better (Iribarren-Maestro, 2019). In the same way, to verify the quality and quantity of scientific production, it is necessary to resort to bibliometrics as an essential tool to achieve a measurable result in the scientific production (Rodríguez et al., 2009). Based on those mentioned above, there is evidence of a great motivation in the construction sector for the advances that Construction 4.0 presents in research and industrial terms.

2. Methodology

The present research is quantitative from a bibliometric analysis of Construction 4.0; for this investigation, a search was carried out using the Web of Science (WOS) database in the month of April 2022, determining the search equation which is: (Construction 4.0). To classify the articles found, the following filters were made, 1) WOS Categories filtered the information in areas of "Civil Engineering and Construction Building Technology"; 2) it was also filtered by documents type "Article"; obtaining 225 articles for the development of this analysis.

Afterwards, a BibTeX file and a TXT file with the search information were exported, and through these, the bibliometric variables were calculated through the Bibliometrix software (Aria and Cuccurullo, 2017). Moreover, the association networks were extracted in Vosviewer (van Eck and Waltman, 2010) (Figure 1) shows the methodological process under the proposed methodology for bibliometric analysis (Donthu et al., 2021).

The variables that were studied are: annual scientific production, average citations per year, most cited countries, co-authorship by countries, co-citation of authors, and co-occurrence of words; these indicators are essential since they constitute the variables of analysis and evaluation to know the quality and the deficiencies in the scientific activity (López et al., 2009).

Furthermore, the generation of the Clusters network was carried out; according to (Donthu et al., 2021), it can be affirmed that the grouping through Clusters is helpful to understand how a field of research is manifested. Analysis and graphs were developed from Gephi. The most relevant indicator for each node's construction and relative weight is PageRank, which can be used to calculate the prestige and influence of publications, despite not being cited (Donthu et al., 2021). In this tool, each item is represented by a node and each connection by an edge (Duque and Cervantes-Cervantes, 2019).

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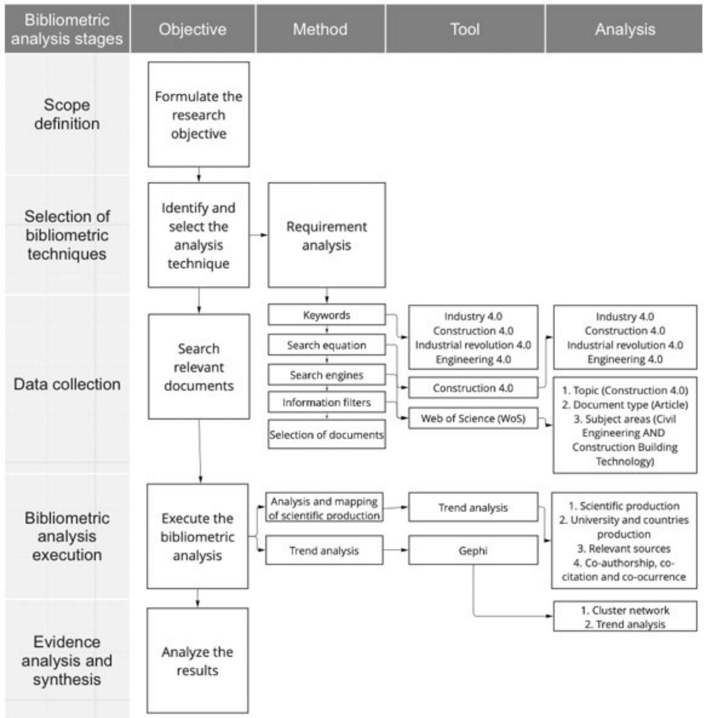

Figure 1. *Bibliometric analysis methodology*

3. Results

(Figure 2) shows the annual scientific production and the average number of citations; through this, it can be seen that the field of Construction 4.0 has had an increasing trend and research interest. Since 2016, an increase in interest articles can be noted, determining its peak in 2021 with 80 research articles. The peak of investigations will probably increase since this analysis was carried out in the first part of the year 2022. The average citations were maximum in 2019 at 6.5 because the volume of published articles was lower. In recent years, the growing increase that has been generated in scientific production is due to the exploration and application of technologies in the construction industry; this application allows for better decision-making, fewer construction errors, and an increased perception of quality (Wang et al., 2022).

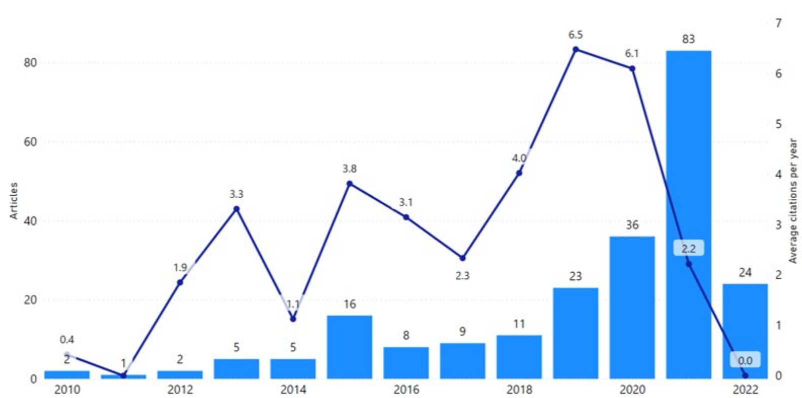

Figure 2. *Annual scientific production*

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(Figure 3) shows the most cited countries, among which the one that heads the list is the United Kingdom, with more than 400 citations; among the other countries, only five more exceed 100 citations, and the other countries are below 90 citations. Latin America is a continent that has few citations due to the scientific and technological gap since only 0.8% of its GDP is invested in research and development on average. In comparison, 2,8% in the US, 2 .5% in the European Union, and 2.2% in China (Villar, 2021), the preceding can be seen reflected in the development of technologies such as BIM, which has had significant growth and implementing in the United Kingdom, which presents a plan to implement these new technologies in all public works. However, these digitization processes are potentially spreading in Latin America (Jordán, 2020).

Country	Total Citations
UNITED KINGDOM	440
CHINA	299
USA	204
AUSTRALIA	186
INDIA	138
CANADA	100
PORTUGAL	85
SPAIN	56
ITALY	51
POLAND	49
BRAZIL	47
IRAN	46
GERMANY	40
EGYPT	39
SWITZERLAND	39
KOREA	37
NETHERLANDS	34
ECUADOR	30
VIETNAM	30
MALAYSIA	28

***Figure 3.** Most cited countries*

(Figure 4) identifies connection nodes between countries that develop the same theme or are expanding research on a specific topic; this result was filtered by considering countries with a minimum of three (3) articles and zero (0) citations. The graph shows a broad connection between some nodes. Namely, the nodes with the most significant size are China, Australia, England, and the United States; in addition, it can be identified that countries such as India, Turkey, and New Zealand have less participation than others. It can also be seen that the countries with the most participation, such as China, Australia, and the United Kingdom, have an essential role in most of the nodes since they are the central connection of the entire network.

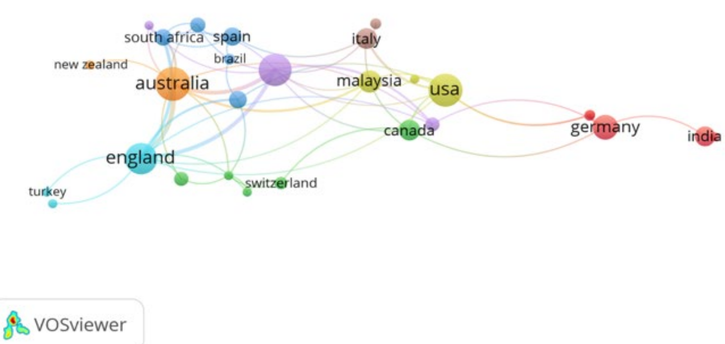

***Figure 4.** Co-authorship by countries*

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(Figure 5) illustrates the co-citation network; this result accounted for authors with a minimum of ten (10) citations. The figure shows that the authors mention each other and thus expand the knowledge content. Among the central nodes, we can highlight Oesterreich T.D., and Sepasgozar S.M, which generate connections with smaller nodes such as De Soto B.G., Mechtcherine V., Sacks R., Koskela L., and Wang X.Y., other nodes that can be highlighted are Golpavar-Fard M., and European Commission.

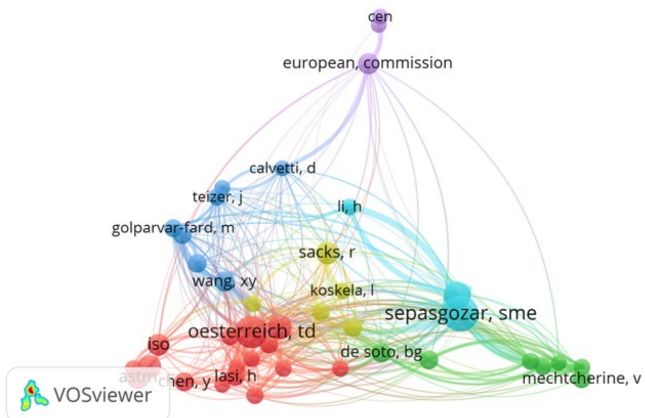

Figure 5. *Co-citation*

Based on (Figure 6), a network is evidenced by the connections of the critical concepts taking into account their frequency; this result was filtered with a minimum of six (6) frequencies. In the central nodes, the words with the most remarkable occurrence can be seen and from where the other terms emanate: Industry 4.0, Construction, Construction 4.0, and Challenges are the most relevant. Those that are within limits are those that have fewer occurrences. In addition, this graph shows a precise distribution of the nodes, showing that the blue nodes are innovations, challenges, and barriers; the green nodes are focused on industry 4.0 systems such as modeling, methods, and BIM. In the same way, the yellow nodes demonstrate the connection between construction, innovation, and technology; finally, the red nodes expose the relationship between the properties, behaviors, and optimization of materials in construction.

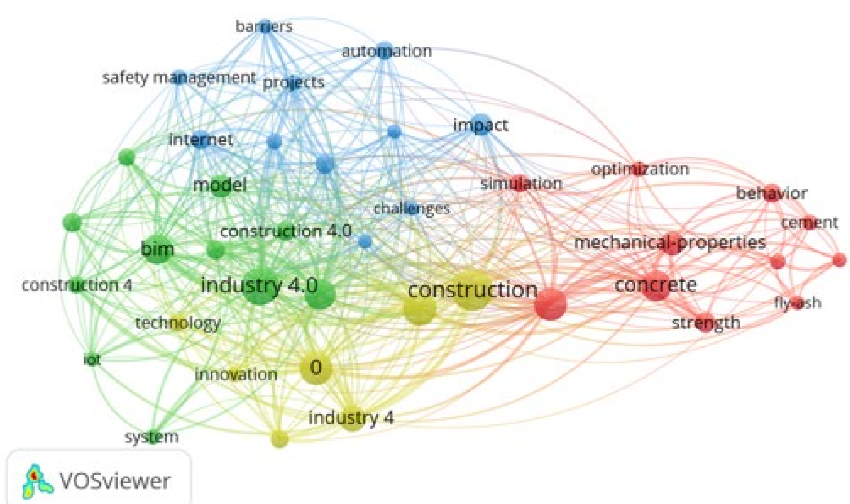

Figure 6. *Co-occurrence*

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Cluster Analysis

The cluster network is explained in (Figure 7), showing five main groups, which make up 54.15% of the network; this percentage is distributed as follows: Cluster 1: 11.77%, Cluster 2: 11.28%, Cluster 3: 11.15 %, Cluster 4: 10.04%, Cluster 5: 9.91%. Therefore, the analysis of each one of the five clusters is carried out, mentioning the principal articles and authors that compose it.

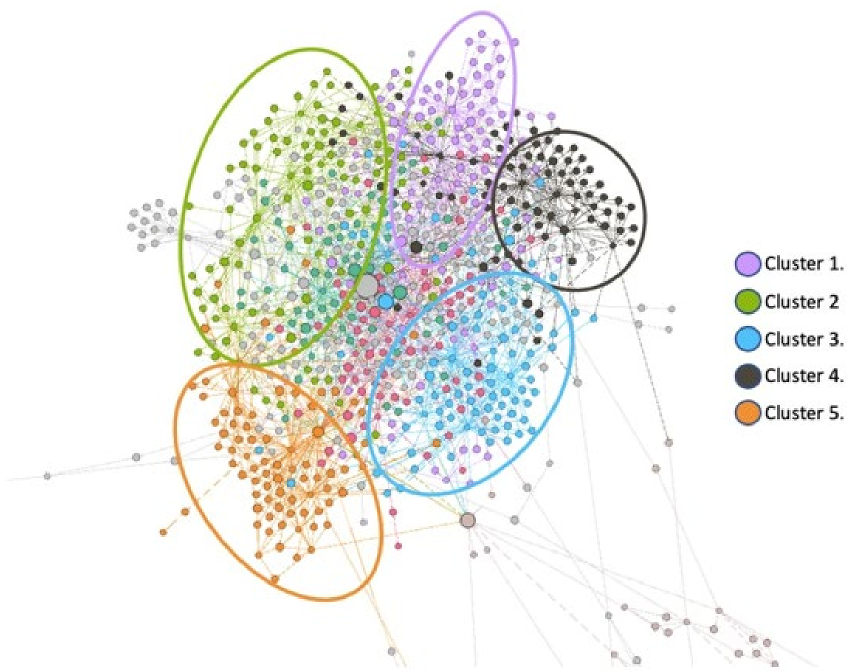

Figure 7. *Network of clusters*

Cluster I:
Building Information Modeling (BIM) and Digitial Twin (DT) (Figure 8)

This cluster focuses on Building information modeling (BIM) and Digital Twin (DT) technologies. After years of experimentation and development, automation has proven to increase the productivity of construction processes (Chen et al., 2018). Currently, industry professionals have focused on implementing BIM in private and public initiatives (Newman et al., 2020); BIM has had positive impacts on productivity; however, monitoring large-scale projects and highlighting them in BIM models can be time-consuming and likely error-prone, which could be a barrier to implementation. (Pour Rahimian et al., 2020); furthermore, BIM still lacks full integration with sensors, control tools, and social systems that function beyond residential applications; it is a gap that must be covered. (Boje et al., 2020). An automatic update of the virtual environment with the current status of the work was proposed to improve the decision-making (Pour Rahimian et al., 2020). To take advantage of BIM, there is a direct interaction with Virtual and Augmented Reality (VR/AR), which is characterized by improving the performance of complex work and risk prevention through training. (Li et al., 2018).

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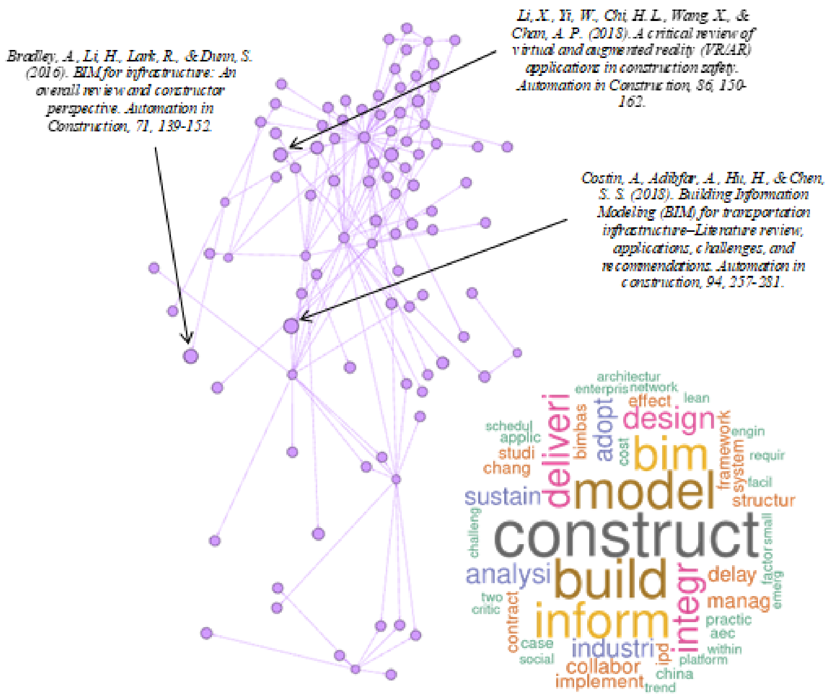

Figure 8. Cluster I

Cluster II:
Potentials of Industry 4.0 in the construction industry (Figure 9)

This cluster analyzes the potential of Industry 4.0 in the construction industry and where its application is taking (Klinc and Turk, 2019). The number of scientific publications on Construction 4.0 has grown significantly, with leaders like the UK, USA, and China (Forcael et al., 2020). There is significant potential in the implementation of advanced digital technologies, but there is a conservative nature of construction companies that prevents wide adoption in the long-term (Sepasgozar and Davis, 2018). Autonomous synchronizations and collaboration systems can handle large amounts of data, allowing the design and construction processes to be automated. (Maskuriy et al., 2019).

Furthermore, these are critical enablers in the digital transformation like Digital Twin (DT), and its benefits in industrial sectors should be analyzed (Kritzinger et al., 2018). Nevertheless, compatibility in BIM processes is necessary for a successful implementation that implies changes in adoption behaviors at the organizational level (Shirowzhan et al., 2020). In this way, there is a trend of a significant increase in investment in technological processes and research development in Construction 4.0.

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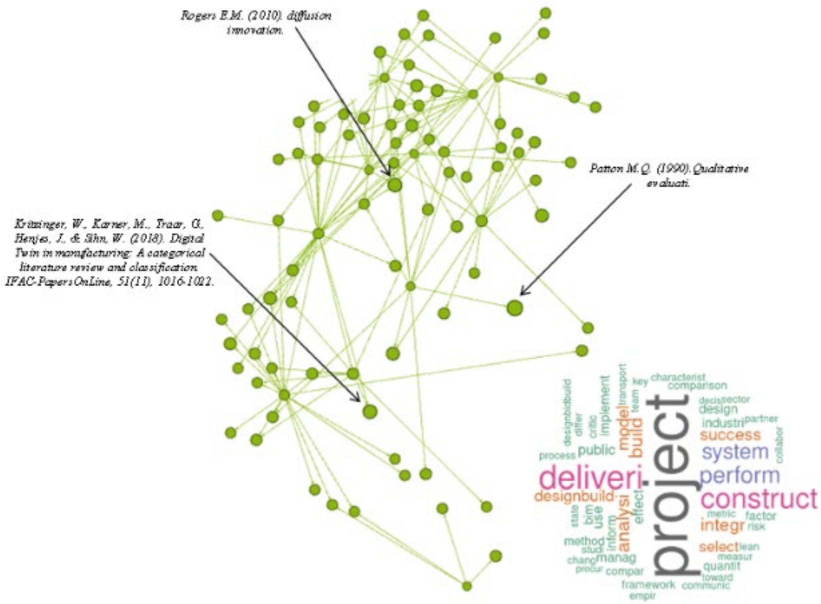

Figure 9. Cluster II

Cluster III:
Construction Supply Chains (CSC) (Figure 10).

This cluster concentrate on Construction Supply Chains (CSCs) and the concept of proximity used to examine the supply chain and the job site (Dallasega et al., 2018). The interest in 'off-site' construction has increased exponentially in recent years due to its advantages (Hosseini et al., 2018). The benefits that this construction method offers, among which are a higher construction speed, a lower cost, and a better quality (Xu et al., 2018); it should be noted that this method also has its fundamental disadvantages of fragmentation, discontinuity, poor interoperability and limited availability of information in real-time (Li et al., 2017); on the other hand, the integration of BIM is essential in the use of off-site manufacturing techniques, as it increases the response to the challenges that have affected the construction sector (Abanda et al., 2017).

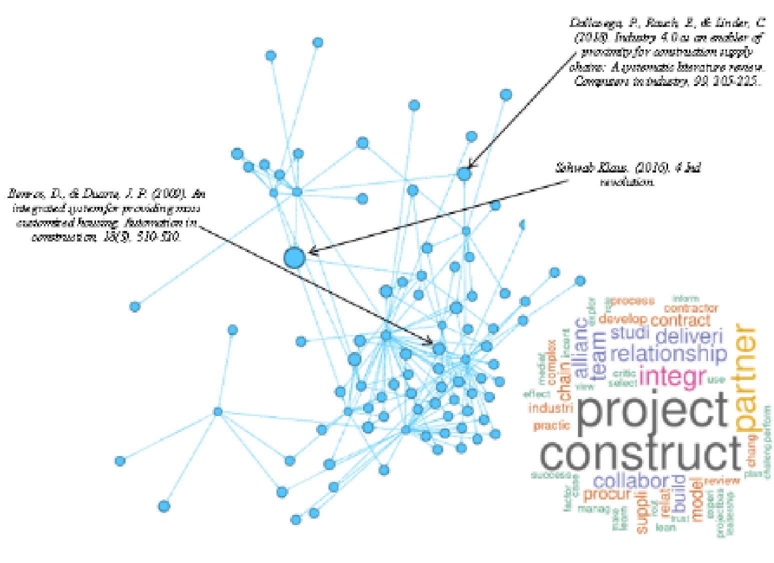

Figure 10. Cluster III

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Cluster IV:
Management of data present in the construction. (Figure 11)

This cluster aims to manage information present during the construction; data for construction operations is rarely collected for analysis and visualization, which limits the quality of project management decision-making, specifically in complex and resource-intensive operations (Cheng and Teizer, 2013). Big Data can process large amounts of data and extract proper information (Bilal et al., 2016), which would generate real-time monitoring and visualization of field operations to achieve greater awareness of the situation of workers and operators from a remote location or in any part of the project (Cheng and Teizer, 2013), facilitating the process of collecting and analyzing performance data so that professionals can make project control decisions (Yang et al., 2015), which generates an urgent need for the digitization of information to facilitate the development of intelligent management of systems (Hu et al., 2018).

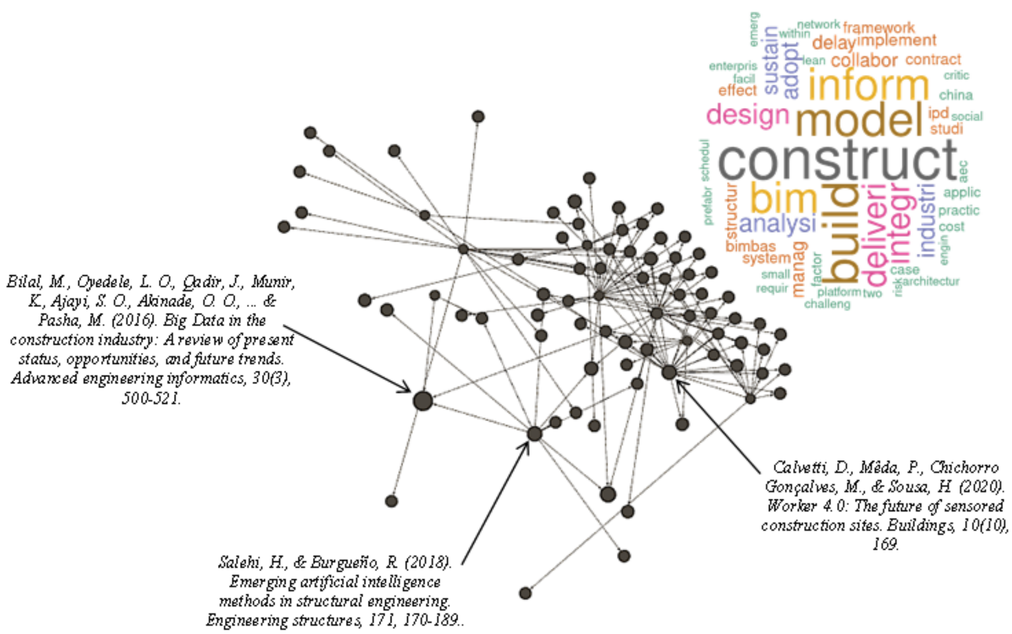

Figure 11. *Cluster IV*

Cluster V:
Innovative technologies of materials in construction. (Figure 12)

This cluster targets the innovative technologies of materials in construction, but since it still uses traditional procurement methods, production methods must change to solve these problems (Buswell et al., 2007). New technologies, materials, and processes should help reduce waste, cost overruns, and time delays (Craveiro et al., 2019). One of the proposed solutions is 3D concrete printing, which involves changes in the value chain of form, making the process more effective. However, this process has some limitations (Gosselin et al., 2016). The potential benefits of integrating this solution into construction are significant; the new trends in materials must allow massive design customization taking into account functionality and aesthetics. Improving the processes will allow for high accuracy and the use of recycled materials (Lim et al., 2012).

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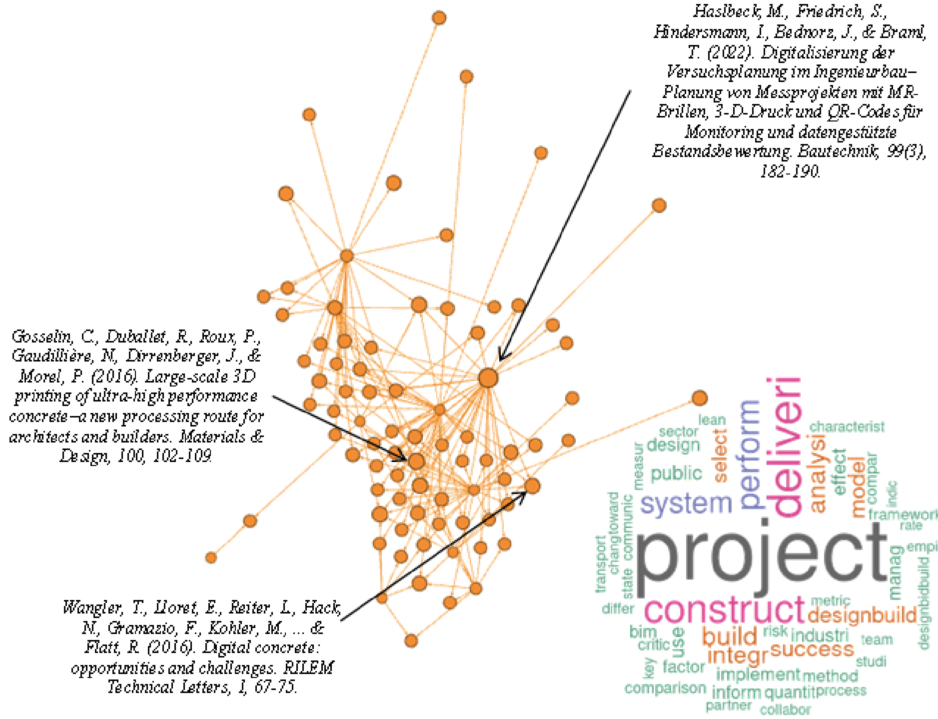

Figure 12. Cluster V

4. Conclusions

With the growing scientific development, it is necessary to objectively evaluate research results, which is why bibliometrics has become an essential evaluation system for this (Rodríguez et al., 2009). Consequently, this tool has helped to interpret scientific production and its consumption from a statistical perspective (Aristizabal Torres et al., 2021). Focusing on cluster analysis and trends allows us to observe relevant thematic areas and new research opportunities.

In this case of Construction 4.0, there is evidence of a significant growth in scientific production, which could be interpreted as the great interest that the construction sector is developing in the technologies offered by Industry 4.0. This production is taking place mainly in universities in developed countries such as the United Kingdom, US, China, and Australia, showing high progress in researching and implementing these technologies. Unfortunately, none of these leading belongs to Latin American and African countries. it is perceived that this continent is beginning its development by implementing this new movement. Better integration between stakeholders from the universities, public, and private sectors in Latin America is essential precisely to align interests and efforts for the adoption and development of Construction 4.0.

For this analysis, five perspectives of Construction 4.0 were found. The first cluster analyzes BIM) and Digital Twin, revealing the benefits of new methodologies in construction, improving the flow of information and reducing the lack of integration of the value chain. In addition, the second cluster deals with the potential of Industry 4.0, in which there is evidence of an increased interest in Construction 4.0. and the need to integrate technological changes with organizational changes is evident. The third cluster deals with construction supply chains and synchronization, focusing on alternative off-site construction methods to improve on-site efficiency, with improved results if synergies with other methodologies such as BIM. The fourth cluster is approached in the management of the data present in construction; Big Data appears as a process for processing large amounts of data that allows for improving decision-making; the cyber-physical space is also highlighted as a crucial part of the digital transformation. Finally, the fifth cluster proposes using innovative materials to reduce waste and improve construction performance. Additionally, innovative materials have an enhancement in efficiency and allow reducing the environmental *footprint of materials.*

Through this research, it can be concluded that this sector must make an effort to implement methodologies that optimize the processes in the life cycle of projects, from the design phase to operation and maintenance, focusing on improvements in both the cyber-physical and digital spaces. These improvements would change the operation processes, construction procedures, management techniques, innovative materials, and relationships with interested parties. Future research proposes reviewing the industrial adoption of Construction 4.0 in Latin American and African countries since a gap with more economically developed countries is evident from scientific production. Finally, the need to know how organizational changes in construction companies are a determining factor in generating a more suitable environment for the sector's digital transformation.

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