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City Information Modeling (CIM) and Smart Cities (SC): A Bibliometric Analysis with VOSViewer and R Software with Bibliometrix Package (2010-2020)

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SUMMARY

The present paper aimed to carry out a bibliometric analysis using the VOSViewer and R software, and to discuss the results obtained from queries accomplished by combining the keywords City Information Modeling and Smart Cities, as well as their relationship in the contemporary context of cities. To this end, the Web of Science referential platform was adopted as a scientific database and the adopted filter published articles in English journals from 2010 to 2020. This way, the data obtained were downloaded and inserted into the mentioned software, which allowed the performance of qualitative and quantitative analyses. The sentences used in the research revealed certain particularities, from the elevated and constant production of scientific articles to the absence of publications regarding the direct use of the terms "CIM" and "Smart Cities". Therefore, the use of the proposed tools can contribute to the survey of specific studies in the area in question, as well as revealing research trends in the scientific environment and consequently its evolution in the academic scenario.

KEYWORDS: Smart city. City Information Modeling. Bibliometric analysis.

INTRODUCTION

It is in cities that people seek opportunities and better living conditions, so it is the locus of the production, circulation and consumption of everything that is necessary for the development of contemporary social activities. However, such development has proved extremely fragile and unsustainable.

In this sense, complex urban arrangements, systems and services require solutions, planning, design, construction, management, and renovation, which can be achieved through a systemic and holistic approach for the implementation of a Smart City (SC), that can be named City Information Modeling (CIM).

The bibliometric analysis was instituted as a manner to measure and monitor scientific production. Because of its multidisciplinary aspect, it helped to start a new research area, scientometrics. Bibliometric analysis provides an instrument to support decisions aimed at the scientific production and, in some research, can be applied to direct its progress, such as methodology and results.

Because it is a current and emerging subject, several studies address the concepts observed. Thus, bibliometric analysis can be of great value, mainly by indicating the most relevant studies, as well as informing what was already produced and published about a certain aspect (GUMPENBERGER, WIELAND, GORR, 2012).

This paper is organized in five sections: the first, being the introduction, the second, summarizing the concepts of CIM and SC, the third, detailing the proposed methodology, the fourth, presenting the results achieved and the fifth, discussing and concluding the study.

OBJECTIVE

The aim of this paper is to develop a bibliometric analysis, using two different softwares (VOSViewer and R software), and discuss the results obtained from consultations conducted with the keywords City Information Modeling and Smart Cities. This way, it is expected to determine research trends and point out some gaps.

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CITY INFORMATION MODELING (CIM) AND SMART CITIES (SC)

The CIM comprises a systemic and holistic approach in which it aggregates the areas of urbanism, geography, cartography, engineering, computer and information science. The term was initially used by researcher Lachmi Khemlani in an article titled Hurricanes and their Aftermath: How Can Technology Help? published in 2005, discussing the role of technology in the prevention and mitigation of natural disasters. Among the discussions held, the author points to the application of GIS (Geographic Information System) and BIM (Building Information Modeling) as technologies that can be applied to meet this demand, and discusses the need to extend BIM to the scale of neighborhoods and cities, so that it is then possible to obtain information and data about the various city components and, therefore, to propose different urban space analysis and simulations (KHEMLANI, 2005; ALMEIDA, ANDRADE, 2018).

As an emerging theme, CIM presents several approaches, two of them are the most widespread among researchers, the first is about the integration between GIS and CAD (Computer Aided Design) as a support tool for decision-making in urban design and the second addresses the georeferenced three-dimensional representations of urban space built through the interoperability of digital models (ALMEIDA, ANDRADE, 2018).

Generally speaking, CIM is a representation of technologies and practices applied to the development of a city's information model, i.e., while the BIM information scope is limited to the level of buildings and represents the three-dimensional building components of the construction, the CIM establishes the connection of these buildings with the city and other sources of information, such as furniture, vegetation, landscape and people, as well as issues relates to SC such as transport-related applications, climate and urban morphology issues that are usually related to SC (XUE, WU and LU, 2021). The SC field of research has been thoroughly studied, mainly because of the various challenges and consequences attributed to the accelerated urbanization faced by several cities around the globe. It is estimated that by 2050, two-thirds of the population will reside in cities, that is, the world population is expected to reach 6.5 billion people in the urban area (UNDP, 2019).

Facing this scenario, the existing problems that plague cities such as violence, urban beaching, inappropriate places occupation, pollution, traffic jam, among others have been aggravated. However, solutions have been proposed to cope with such crises, also the approach of smart cities meets these issues and they have been debated since the 1990s and evolved, assuming several nomenclatures, definitions, and aspects throughout this time.

For Thompson (2016, p. 360), the smart city is one in which "an effective integration of physical, digital and human systems into the environment is built to offer a sustainable, prosperous and inclusive future for its citizens". In other words, it must be inclusive, integrated and citizen-oriented, so public participation and engagement are priorities. The phenomenon of SC has direct relationships with two biases: the first involving the technological, evolution of data in cities (open data and big data), the fourth industrial revolution, the Internet of Things (IoT) and its devices, and the second the social and human bias – by which the individual, social and cultural dynamics are predominant for the formation of a city. Such issues should be consonants and break the paradigm that SC are associated purely to the implementation and

sale of generic technologies or their adoption through the simple marketing strategy (PETROVA-ANTONOVA, ILLEVA, 2019; BRAZIL, 2021). Taking these points in consideration, the smart city:

> Is not the one that simply uses technology in the urban environment, but invests in human and social capital, sustainable economic development, innovation and entrepreneurship and use of available technologies to improve and interconnect the services and infrastructure of cities, all in an equitable and creative way, always focusing on citizenship, quality of life and the well-being of citizens. (BRAZIL, 2021, p. 9).

In this sense, initiatives should not only be related to specific conditions of application, such as smart traffic lights or street lighting, but rather to models that support the "planning, design and analysis of all dimensions of the city" (PETROVA-ANTONOVA, ILLEVA, 2019, p. 1), because, otherwise, the approach becomes empty and generic.

PROPOSED METHODOLOGY

To evaluate the existing production on CIM and SC, this paper has a descriptive quantitative and qualitative character. The descriptive analysis results from the data collection performed in the Web of Science database. Web of Science is a multidisciplinary database that indexes articles of great relevance around the world. The quantitative character refers to the identification of how many articles of the given theme exist in the database, while the qualitative character will come from the discussion of the results obtained during the analysis. The research was carried out in May 2021 and included the period from 2010 to 2020, the typology of scientific productions where articles in English published in journals.

Two different softwares were used for data analysis: VOSViewer (LEIDEN UNIVERSITY, 2020) and R (THE R FOUNDATION, 2020). VOSViewer is a tool capable of building and visualizing bibliometric networks. The network may include journals, researchers, or individual publications, and it is developed based on citations, bibliographic coupling, cocitation, or co-authorship relationships. Ultimately, the software offers text mining functionality from terms extracted from the body of scientific literature, which can culminate in the construction and visualization of co-occurrence. VOSViewer was the chosen software for the network and word connection of this article, mainly because the creation of networks from downloaded Web of Science data is native to it, that is, the use is simple and straightforward when compared to other tools, also the generated graphics have better resolution and layout than the R software.

R is a GNU (open-source system) project and is known to be the language and environment for statistical computing and graphics. Its main advantage is that provides a wide variety of statistical - linear and nonlinear modeling, classical statistical tests, time series analysis, classification, grouping and others - and graphical techniques, in addition to accepting a variety of different extensions, facilitating the development of bibliometric analysis. The paper used the Bibliometrix package (ARIA and CUCCURULLO, 2017) with the Biblioshiny function, this

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choice resulted from the pre-designed functions of the Bibliometrix package, interesting for data analysis, and the web page interface promoted by Biblioshiny.

Three retrieval scans, using the data delimiters and established typology were performed in the database: (1) (BIM OR "BUILDING INFORMATION MODELING") And (CIT* And MODEL*) (2) (BIM OR "BUILDING INFORMATION MODELING") E (CIM OR "CITY INFORMATION MODELING") (3) (CITY INFORMATION MODELING OR CIM) AND BIM AND SMART CIT*).

The CIM comprises a systemic and holistic approach in which it aggregates the areas of urbanism, geography, cartography, engineering and computer science.

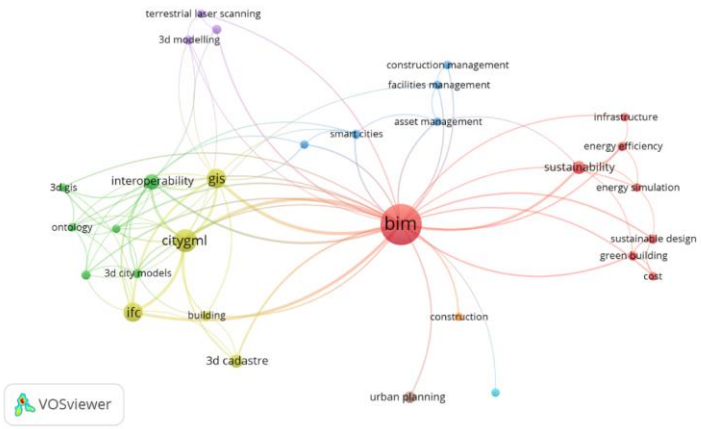
RESULTS

As it can be seen by the explored terms, the first search is the most comprehensive among the three, returning 192 results. The second search obtained 7 results, the lowest value among searches. Finally, the third consultation resulted in 30 papers. Due to the small volume of publications obtained from the second search, it was decided to perform a third consultation, dividing the terms using boolean operators, by which it was obtained a greater number of studies. The next section will present the quantitative aspects of the products obtained by using the two softwares.

VOSViewer

The focus in VOSViewer was the authors keywords and for each research three different graphics were generated. Each chart had one of the following objectives: show the existing network between expressions, the density of terms, and the average number of citations of each word. Figure 1 shows the network of the first research:

Figure 1: First Search: Network View.



Source: AUTHORS, 2022.

According to Figure 1, it can be verified that the main word related to the theme under study is BIM, even having the prominent position in the creation of the network. For this network, eight groups were created, each represented by a color (red, green, blue, yellow,

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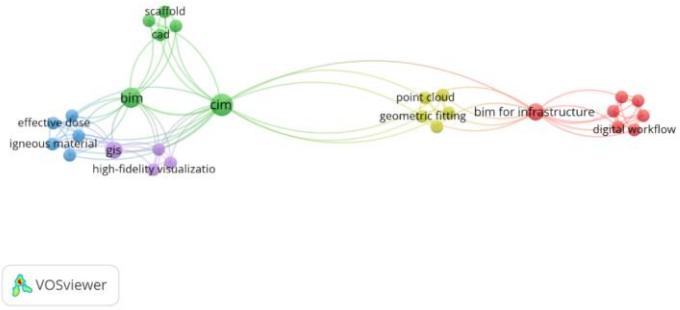
purple, orange, lilac, and light blue), among the groups, five stand out, being the main terms related to them:

- Red: sustainable design, green building, energy efficiency, cost, sustainability, infrastructure, and energy simulation.
- Blue: smart cities, internet of things, asset management, facilities management, construction management.
- Yellow: geographic information system (GIS), building, 3D cadastre, ifc, citygml, the latter two being file format.
- Green: interoperability, 3D city models, ontology, 3D GIS, semantics, and industry foundation classes.
- Purple: 3D modeling, terrestrial laser scanning, reconstruction.

Another point to be highlighted by the network generated in the first search is the large number of connections on the left side of the scheme, between the green and yellow groups, indicating affinity between the issues addressed by both groups. Figure 2 displays the network of the second search:

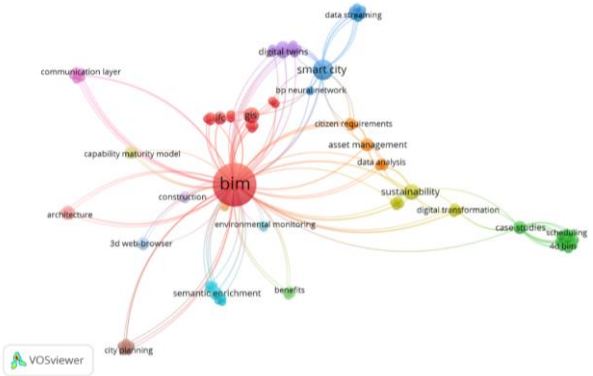
Figure 2: Second Search: Network View.



Source: AUTHORS, 2022.

As in Figure 1, Figure 2 shows a division into groups of terms, in this case five ones: red, yellow, green, blue, and purple. As a difference, in relation to the previous research, there is an absence of a prominent term, but the network had a "balance" between the terms BIM and CIM. Finally, the visualization of the third search demonstrated by Figure 3:

Figure 3: Third Search: Network View.



Source: AUTHORS, 2022.

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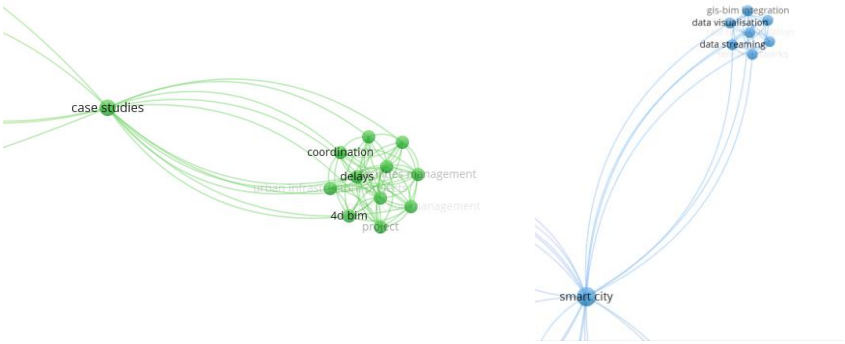
Figure 3 showed a similarity to Figure 1, with the disposition of terms as well as the highlight of the term BIM. As a difference in relation to the first search, there is a division into a greater number of groups, 13, and the focus given to the term "intelligent city". In relation to the groups, five of them stand out:

- Red: similarity of attributes, cost approach, domain-specific recovery, game environment, GIS, ifc, internal navigation, information retrieval, post-conflict cities, real estate valuation, reconstruction and intelligent city management.
- Green: 4D BIM, case studies, construction management, coordination, delays, facility management, infrastructure management, project, relocation, schedule, utility relocation, urban infrastructure projects.
- Blue: bp neural network, data streaming, data visualization, GIS-BIM integration, infrastructure networks, real-time simulation, sensor networks, smart city, utility resource streams.
- Yellow: construction projects, critical success factors, delphi survey, digital transformation, institutional logistics, sustainability, sustainable smart city, technology.
- Purple: interoperability, internet of things, digital twins, parking, risk management, internal risk management, wireless sensor network, support vector machine.

In Figure 3 it was noticed for the green and blue groups a number of terms derived from the words case study and intelligent city, respectively, with many connections to each other, forming interconnected circles (Figure 4). This fact was not observed in any other search.

Figure 4: Third Search: Interconnected circles.



Source: AUTHORS, 2022.

Figures 5, 6 and 7 show the distribution density of terms for searches 1, 2 and 3, respectively:

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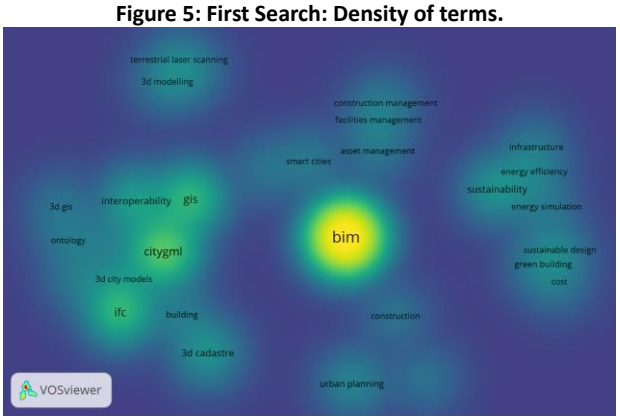
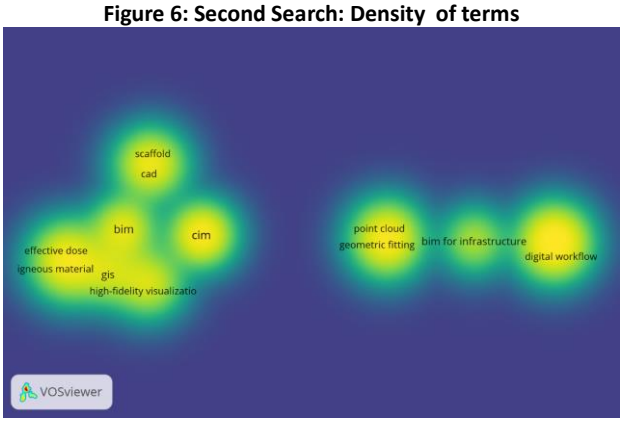
Figure 5: First Search: Density of terms.



Source: AUTHORS, 2022.

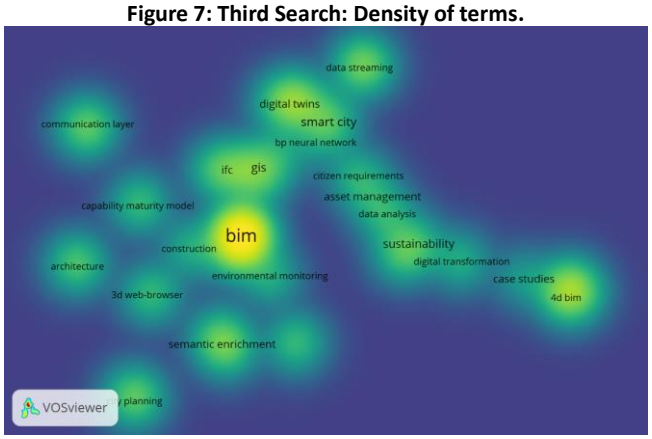
Figure 6: Second Search: Density of terms



Source: AUTHORS, 2022.

The density of keywords in the first research (Figure 5) presented a concentration in the term BIM, as it was observed for the connections (Figure 1), the terms GIS, citygml and ifc appear in a second place, the rest of the terms displays a homogeneous distribution. For the second survey (Figure 6) all terms have an analogous concentration. Finally, for the third research (Figure 7), there is a scenario like the first, a concentration in the term BIM, but in this case the concentration is not so great in a single term, that is, the other words also have a more yellow tone (better mentioned).

Figure 7: Third Search: Density of terms.



Source: AUTHORS, 2022.

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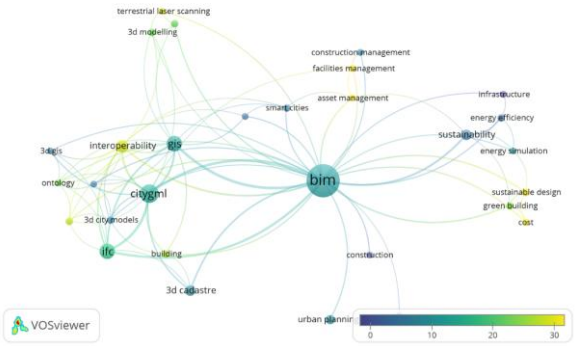
According to the VOSViewer manual (2017) the average number of citations is an indicator that presents the average number of citations received by studies containing a keyword or a term. This indicator varies from blue (low) to yellow (high), Figure 8 shows the results of the first search.

Figure 8 shows the predominance of terms such as: interoperability, cost, sustainable design, asset management, facilities management, construction, semantics, 3D ground scan. On the other hand, the least cited are 3D GIS, 3D city models, industry foundation classes, infrastructure, bibliometric analysis.

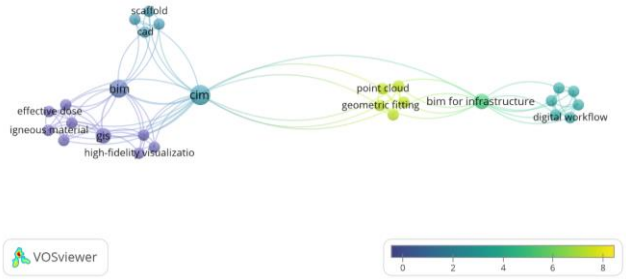
Figure 8: First search: average number of citations.



Source: AUTHORS, 2022.

Additionally, it is remarked that the term BIM is the main connection between the terms, but in the case of an average number of citations on a low scale, it lies between 10 and 20. Figure 9 presents the terms for the second search:

Figure 9: Second search: average number of citations.



Source: AUTHORS, 2022.

For the second search none of the terms had the highest value of the scale, the maximal value are those between 6 and 8, being the terms: point cloud, geometric fitting, polygonization. The terms GIS, CIM and BIM are in the lower half of the scale. The last VOSViewer chart is represented by Figure 10.

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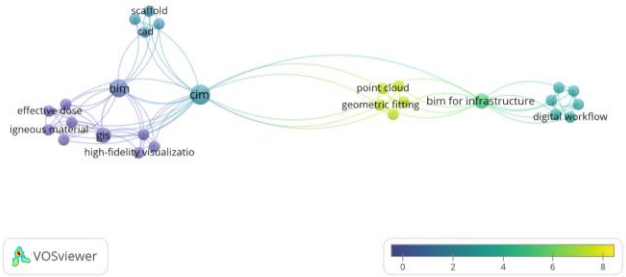
Figure 10: Third search: average number of citations.



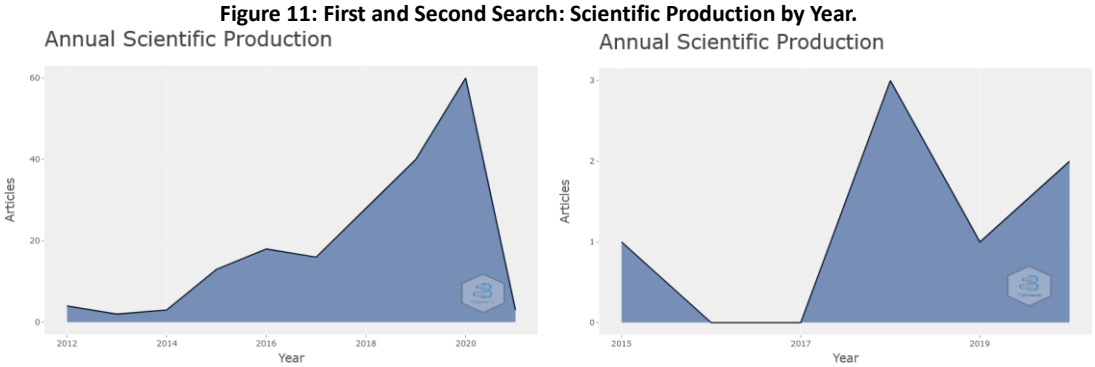
Source: AUTHORS, 2022.

Figure 10 presents as main keywords: architecture, CIM, city with high density, topographic map, cloud points, benefits, construction industry, sustainable practices, delphi survey, construction projects, critical success factors, sustainable smart city. It is interesting to note that for this search the term BIM can be classified at the top of the scale, with a value between 10 and 15, contrastingly from what was observed in the first and second searches.

Software R using Bibliometrix

The R software was applied in the research with the objectives of informing the quantity of publications over the years, what the main themes are and to generate a word cloud, also indicating the main term relationships and subtopics. Figures 11 and 12 indicate the number of publications for the first, second and third research, respectively.

Figure 11: First and Second Search: Scientific Production by Year.



Source: AUTHORS, 2022.

Analyzing the Figure 11, for the first consultation, it is verified that the production of articles about the subject has been uninterrupted since 2012, showing a large growth since 2017. The peak production was reached in 2020, with a production of 60 articles. A slight fall occurred in 2017, as productions were growing almost exponentially.

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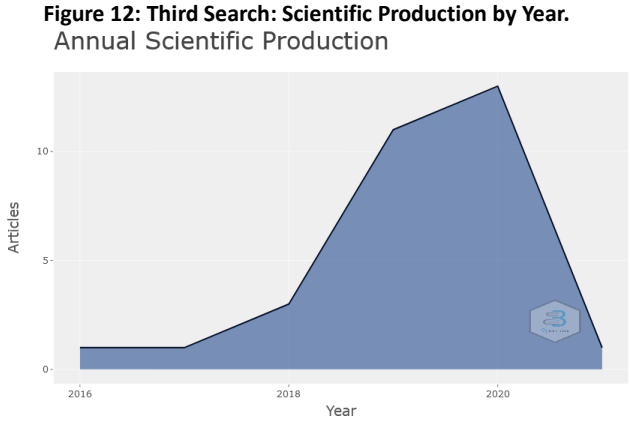
Figure 12: Third Search: Scientific Production by Year.

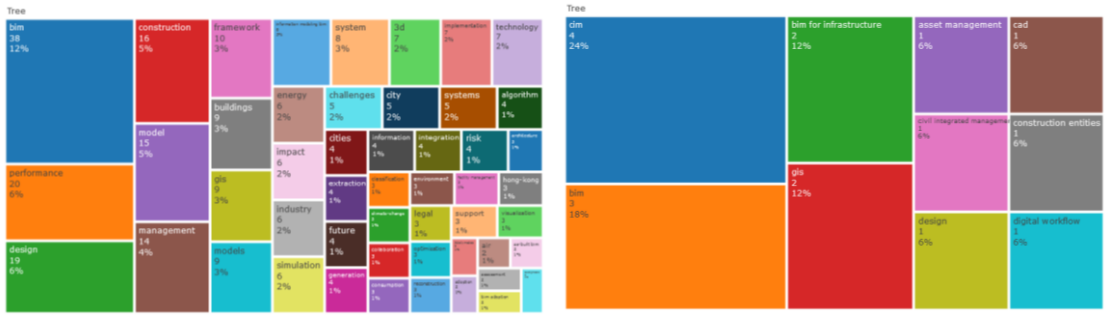


Source: AUTHORS, 2022.

The second consultation presented a distribution that has a peak in 2018 with 3 articles published. Differently from what was observed for the first search, there was an absence of publications in 2016 and 2017. It is noteworthy that the analyzed period began in 2010, so until 2016 there were no related articles.

According to the Figure 12, the last search only started in 2016, since then it has been uninterrupted having its peak in 2020, with 14 papers published. Like the first query, the curve presents an almost exponential design indicating a growth in production. The next set, Figures 13 and 14, will present the main themes, topics obtained by the searches:

Figure 13: First and Second Search: Terms tree.



Source: AUTHORS, 2022.

As shown in Figure 13, of the 192 returned articles, the biggest result obtained throughout this research was verified that the keywords address a diverse range of subjects: 38 articles (12%) are directly linked to BIM, 20 articles (6%) with performance, followed by the term design, with 19 articles (6%) and construction, with 16 articles (5%). The results reflect the focus on BIM-oriented issues and specific questions regarding the city.

In the second approach, the terms adopted were (BIM OR "BUILDING INFORMATION MODELING") AND (CIM OR "CITY INFORMATION MODELING"), whose result was one of the most surprising, only 7 results returned, as shown in Figure 14, the terms CIM respond to 4 articles (24%) and the term BIM to three articles (18%). In this sense, at least in view of the cutout established, the data presented somehow a break of the current paradigm of direct relationship between BIM and CIM, going against what is discussed in the literature in general, especially regarding the origin of the term CIM.

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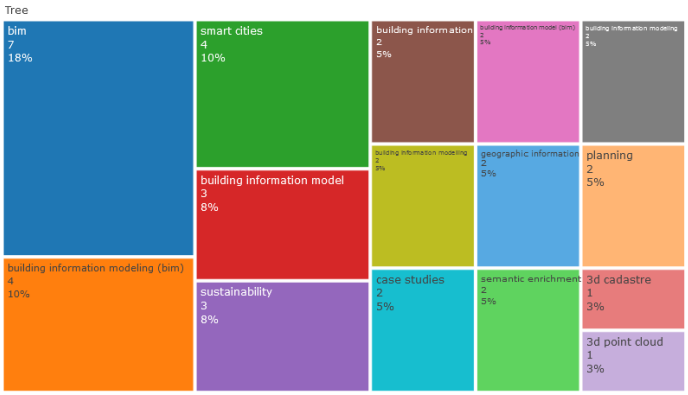
Figure 14: Third Search: Terms tree.



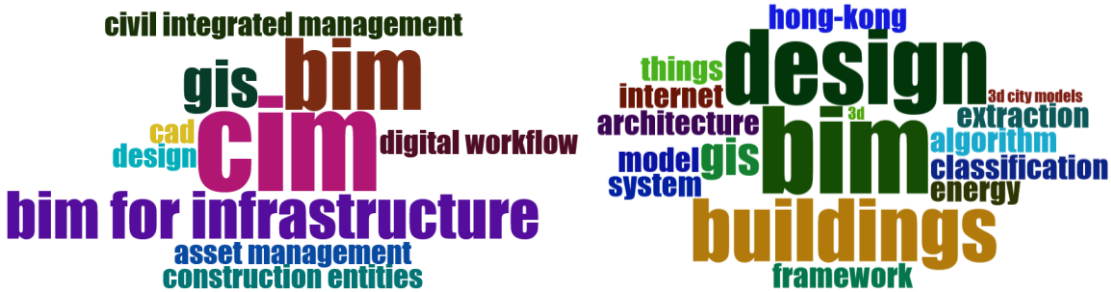
Source: AUTHORS, 2022.

In turn, the third approach performed for the study used the following sentence (CITY INFORMATION MODELING OR CIM) AND BIM And SMART CIT*), the research returned a total of 39 articles, in which the terms related to BIM (building information modeling, build information model, building information modelling) account for 20 articles (36%), followed by the term smart cities with 4 articles (10%), as evidenced by Figure 15. The last result is the word clouds (Figures 15 and 16):

Figure 15: First Search: Word Cloud.

Source: AUTHORS, 2022.

Figure 16: Second and Third Search: Word Cloud.



Source: AUTHORS, 2022.

As it can be seen in the images, the word cloud has introduced some new terms for searches. The first and third research present, as the main keyword, BIM, while the second presents CIM. Among the three word clouds, the results of the first and third search stand out, in both of them arise some interesting keywords within the subject, together with the design.

The terms: framework and GIS were not used during the Web of Science query but they frequently appear and are relevant to the subject.

DISCUSSION

The purpose of this section is to establish and discuss some aspects observed during the development of the results. In addition, possible causes may be presented, as well as some research gaps.

VOSViewer

Among the results obtained by VOSViewer, for the visualization of the network (Figures 1, 2 and 3), at first it is evident that, for the general terms searched (first search), the existing division of the groups involves similar themes. It can be said that the groups can be categorized as follows: red – sustainability/environment, blue – smart cities /management technologies, yellow - GIS for construction, green - BIM and practical application and purple - BIM and modeling. For this division, some relevant studies stand out, such as Olawumi and Chan (2019) whose study explored and evaluated the critical success factors to expand the integration of BIM and sustainability. In this regard, they developed a form of determining the factors and later analyzed the responses with statistical tools, and they have eventually achieved results that enabled authorities, politicians, and decision makers to achieve the application of the "green" BIM.

Li and Cao (2020) on the other hand, verified how the data generated and used within BIM in conjunction with geographic data, such as those of the GIS, are extremely interesting for training neural networks, which can later assist the making of "intelligent" decisions throughout the living cycle of cities, obtaining the smart city as a final product.

Wang *et al.* (2019) created a hybrid working structure, using BIM and GIS to develop a 3D model of pipe networks. This structure facilitates both in the process of building new networks and in the maintenance of existing ones. As a result they achieved a framework with great efficiency and with reduction of computer processing.

Shadram *et al.* (2016) presents the existing interoperability problem between BIM and the ecological footprint analysis software of certain materials during the construction design process. As a resolution, a framework that supports design decisions for the problem and allows the evaluation of embedded energy associated with the use of certain materials. Such structure was tested and approved in a prototype achieving excellent results.

Zaczek-Pepilinska *et al.* (2020) made a comparison between terrestrial laser scanning and the tacheometric measurement method, reaching the conclusion that, in addition to the advantages of laser scanning, such as limiting daytime work, capacity of monitoring during the work night break and limiting the impact of vibrations, laser scanning can be integrated into BIM as one of its components.

The third search, focused on smart cities, may have its division in the defined groups: red-modeling, green-management, blue-technologies, yellow-sustainability, purple-hazards. It is also important to point out that the 30 results obtained in the third search are contained in the 192 results of the first search, that is, it may indicate an existence of research involving smart

cities without the use of the term smart city. This can be proven by Wang and Liu (2019) paper. They developed a BIM 7D model that generated significant cost and time savings, improving project quality and work efficiency, a solution for smart cities. However for not adopting the smart term throughout the study, it was not presented at the third search.

Another factor verified through the groups analysis is that the domain related to SC already exists in city modeling (BIM), represented by the blue group (Figure 1). However as it can be proven by the results of the second search, something similar to what happened with the term smart, there was no direct use of the term CIM. Added to these facts is the absence of the term CIM in the groups of the last generated network (Figure 3), even though the keyword had integrated the search term.

Ultimately, the Figure 4 indicates a large exchange of information between case studies, mainly because management integrates and depends on different factors, as well as smart cities, which depend on the application at the same time of various tools connected with the needs of citizens to obtain their "intelligence".

The density of terms indicated a great concentration in the term BIM. However this fact can be pointed out as natural, considering that for all consultations the used keywords were "BIM" or "Building Information Modeling", so the results had to have some relation with this tool. However, Figure 5 shows the low concentration of the term smart cities, while GIS, citygml and ifc have a considerable concentration. Citygml and ifc are GIS file formats, and these three in conjunction with BIM are tools used to find solutions for smart cities, so the questioning is: if developed studies are generating intelligent solutions, why are they not classified and exploited as such?

Finally, the graphs of the average number of citations are discussed. For the first search it can be pointed out as the most widely used terms interoperability, cost, sustainable design, asset management, installations management, construction, semantics, 3D terrestrial scan. The interoperability and cost are some of the problems involving the use of software, mainly BIM, in the construction. On the other hand construction, sustainable design, 3D terrestrial scan, are related to proposals and premises established by the modeling, while managing facilities and assets is about establishing other dimensions for BIM, i.e. being able to better manage the buildings by taking the projects beyond the computer area. Therefore, the citation of these terms in the studies shows the research both to seek answers to problems found in the full adoption of BIM, in all its dimensions, and the yet application of BIM in more advanced domains.

Figure 10 presented an interesting combination of most cited terms, mainly because the word CIM is among them, which indicates the connection of the information modeling of the cities and, thus, obtaining a smart city. The following terms should also be highlighted: benefits, sustainable practices, critical success factors, sustainable smart city, which demonstrate that the smart city is the one which thinks of meeting the present needs without harming future generations, a premise that can be a key part in the use of the CIM, in view of its power to simulate future scenarios and determine the best measures at present.

Software R using Bibliometrix

In relation to production over the years it can be said, based on the first and third searches, that the production of studies related to the BIM area and cities, as well as BIM and Smart cities is growing exponentially, well demonstrating the evolution resulting from the so-called "digital revolution" and "industry 4.0" where solutions are sought to solve daily problems.

For the theme tree (Figures 14 and 15), it was found that research related to BIM was the most developed one, reflecting the increasing research in this knowledge field. As a method or technology applied to development, however, given the adopted conditions, there is a low occurrence between the terms CIM, BIM and SCs, which reveals a mismatch between the discourse and its actual application in recently developed research.

Finally, the word cloud demonstrated some terms not presented by the networks generated in VOSViewer, highlighting framework, i.e. studies that establish new structures that apply BIM to create city models, often obtaining as a result intelligent cities, as observed in the paper of Marzhouk and Othman (2020), who carried out the integration of BIM and GIS simulating scenarios to create infrastructures that meet the future needs of cities.

With this cloud it is possible to verify some words that can be integrated in a future query to obtain a greater number of studies involving smart cities, somewhat similar to what was done in the first and third search, where the term CIM was divided, and, thus, more expressive results were obtained.

CONCLUSIONS

In order to identify the production on the selected discussion, analysis techniques were carried out on a highly reliable database with a wide range of available publications.

As it used three sentences, the bibliometric analysis revealed some particularities. In the first case there has been a high and constant production of articles since 2012, thus showing how emerging the subject is and consequently the relevance of the theme in the literature and academic community. The second and third searches revealed a small number of publications that address the subject, however, the evolution in the annual number of publications over the analyzed period indicates a trend point, i.e., demonstrates that these may occur with greater frequency in the future. In this way, by verifying and assessing the frequency in which subjects and themes are developed, it is possible to contribute to the survey of specific studies in the questioned area, as well as to reveal research trends in the scientific environment and consequently their evolution in the academic scenario.

Therefore, studies with this theme and using the proposed tools constitute an important vehicle for the understanding of specific subjects, which can contribute to the monitoring of the developed scientific production. It was also possible to identify trends in publications and consequently to reveal gaps and encourage the future area research, one of them being the lack of the direct use in studies of the terms "CIM" and "smart cities", resulting in a smaller number of publications than expected, as well as, for a greater result, the need for consultation with the integration of technologies and terms that are closely involved with smart cities, such as framework, design and GIS.

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