

4D BUILDING INFORMATION MODELLING: A SYSTEMATIC MAPPING STUDY

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Abstract –

Building Information Modeling (BIM) represents a procedural and technological transition that emerges as a change agent in the Architecture, Engineering and Construction (AEC) industry. 4D modeling refers to a BIM dimension that associates the 3D model of an enterprise with the planning schedule information, providing the visualization of the actual sequence of construction activity. Interactions with 3D models are discussed and debated extensively in research, when in fact, 4D modeling is less discussed, thus there is a knowledge gap that can be explored. In this way, this article aims to know the current scenario of the studies that approach the 4D modeling theme in an international context. For this, a systematic mapping study was performed, covering only the researches in scientific paper format published between the years of 2006 and 2016. After establishing inclusion and exclusion criteria, a total of 148 articles were analyzed in this study. In the logical organization of the subject phase, bibliometric indicators were applied for analysis of the sample regarding the temporal evolution of the publications, publications by country, institution and author, and most commonly used keywords. Finally, the articles were also classified as to their content, and 10 categories were identified for them. The category containing the highest number of articles refers to the barriers, opportunities and impacts observed in the implementation of BIM 4D. It also includes surveys that measure the 4D BIM utilization rate by professionals, companies and countries. The results show that the number of studies published on 4D BIM has grown over the years, with the United States being the country that produces the most in the area. This fact suggests that US policies to encourage the adoption of BIM have been providing positive effects, serving as an example for other countries.

Keywords –

Building Information Modeling; BIM; 4D Modeling; Systematic Mapping Study; Scientific Production.

1 Introduction

Building Information Modeling (BIM) means a procedural and technological change that is considered a very promising evolution in the Architecture, Engineering and Construction (AEC) industry [1]. BIM is disseminated as a broad process of improving the techniques of designing, planning, constructing, occupying/using and maintaining a building throughout its life cycle, based on a data model that contains all the necessary information to stakeholders [2]. BIM is a digital representation of the physical and functional characteristics of a building [3].

Therefore, Building Information Modeling can be understood as a process that uses a variety of tools capable of generating and sharing information about a given construction, which will help in decision making during its life cycle. In this way, BIM is evident from project conception to demolition of the construction. It is noteworthy that the AEC industry is increasingly open to approaches that associate elements of 3D BIM (geometric shapes in three dimensions) with time and programming information, aiming to improve Integrated Project Delivery [4].

One of the biggest problems in construction projects is that their increasing complexity has made it difficult to accurately predict some extremely important performance indicators, for example, the project schedule. 4D models allow project participants to communicate performance deviations based on commitments from coordination sessions, measure readiness of the upcoming tasks based on inter-dependencies of current schedule tasks and their constraints, and highlight locations that are at-risk of potential performance

problems [5].

While interactions with 3D models are widely addressed and discussed in surveys, the uses of 4D modeling are less debated, so there is an "urgent need to explore and evaluate these models" [6]. According to There is a need for an improved interoperability between BIM and softwares of scheduling. Their related research efforts in this field have demonstrated advancements in utilizing 4D models, but remains to be done comprehensively leveraging of the intelligence of BIM for automated scheduling generation. To reach this purpose, a systematic mapping of the literature is done in relation to 4D BIM, involving only the works published in scientific paper format [7].

Thus, this research focuses on the study of only one of the areas of scope attributed to BIM, which is the effective planning of the construction. Hence, it is important to inform that a 4D model (3D model plus time dimension) is a powerful and effective tool in planning, capable of exposing the sequence of construction phases linked to a three-dimensional model of the building. Therefore, the visualization of the elements is tied to the exact time (phase) in which they are to be constructed. This allows an effective and tangible communication between the professionals involved in the construction, and with the client, improving the understanding of the project's lifecycle and its construction strategies.

2 Previous Studies

The authors haven't found any previous studies involving this kind of approach in the context of the international production of 4D BIM. However, it should be noted that the authors Pérez, Fernandes and Costa [8] have reviewed the literature on BIM 4D studies, focusing on logistics operations and workspace management (construction sites). For the accomplishment of the mentioned research, only 20 articles, published in the period from 2005 to 2015, were selected for use. The articles were classified according to their respective vehicle of publication, year and subject.

Although it contributes to the understanding of the production of articles on the mentioned theme, there is not the required deeping for the characterization of this production due to the low number of analyzed works. In contrast, the present study mapped 148 articles, classifying them into fourteen different categories and analyzing a series of indicators. It's important to highlight that the articles were searched in both Portuguese and English languages, and the period of coverage selected includes the years from 2006 to 2016.

3 Research Method

A Systematic Mapping Study was developed in order to obtain an overview of the publications about the uses of 4D BIM. By presenting a detailed and explained approach, the chosen method aims the future repetition of this work in a more comprehensive way by other researchers or the authors themselves. The starting point of this search was the selection of journals and databases that publish or store contents related to architecture, civil engineering, construction, planning and management methods, technologies and software related to 4D BIM. It seeks to identify the articles of greater relevance to the proposed mapping. The research design is illustrated in Figure 1.

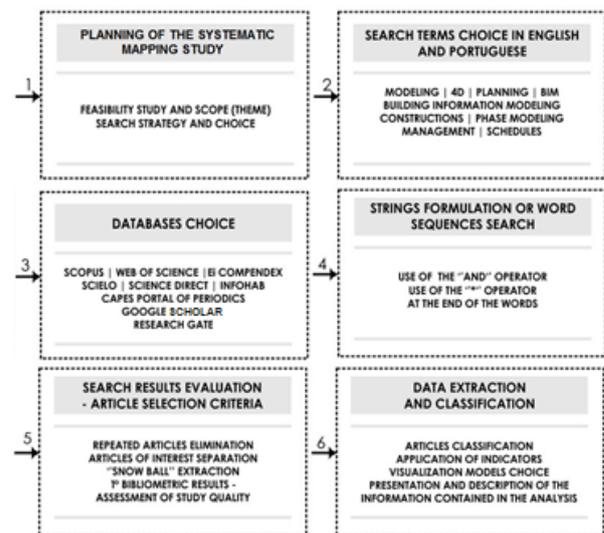


Figure 1. Methodological research steps

After the keywords were defined, the source search step was performed in two moments. In the first one, the publications were searched in the following digital databases: Scopus, Ei Compendex, SciELO, Science Direct, Web of Science, Google Scholar, the Capes portal of periodics and brazilian's Infohab (Centro de Referência e Informação em Habitação). Papers found in the ResearchGate social network were also tabbed. They led to a new search, characterizing the second moment, in which were included the collection of articles from the International Group for Lean Construction and electronic journals related to the industry of the AEC, as some of the Elsevier (Automation in Construction, Computers in Industry, Journal of Occupational Accidents, Advanced Engineering Informatics and Procedia Engineering), the EmeraldInsight (Construction Innovation, International Journal of Innovation Science, The International Journal of Logistics Management, International Journal of Operations & Production Management; International

Journal of Physical Distribution & Logistics Management, Journal of Engineering, Construction and Architectural Management) and the ASCE Library (Journal of Computing in Civil Engineering and Journal of Construction Engineering and Management). Other journals were found in the digital databases. Then, the Snowball Sampling mapping was carried out, in order to identify pertinent articles that were not previously selected. Snowball Sampling is a non-probability sampling technique that investigates the hidden population, which in this case refers to the papers that are not found in the search step [9].

At the end of this procedure, 314 articles were selected. Beyond the interval of time that was initially established, other criteria for the inclusion and exclusion of the data obtained were defined. It was necessary to have at least one keyword in the title, abstract, or keywords; and the access to the full text should be available for electronic consultation. Finally, articles that appeared in more than one base were eliminated, leaving a total of 148 articles.

The search results were moved to a Microsoft Excel spreadsheet and sorted according to their main subject. In the phase of logical organization of the subject, the following indicators were applied for the sample analysis: (i) time evolution of publications; (ii) publications by country, institution and author; (iii) most commonly used keywords; (iv) most used publication vehicles; (v) main subject.

4 Results and Discussions

In this section, the results of the international and national databases are summarized. Following the methodological procedures described in section 3, the search step resulted in a sample of 148 articles, in which 78 are from journals, and 74 from conferences.

4.1 Indicators

4.1.1 Time evolution of the publications

The evolution of the annual publication of the selected articles in the international search is showed in Figure 2, where it's possible to notice that all articles were published in a maximum of one decade. It is emphasized that there a considerable increase in publications happened after the year of 2014. The peak of the publications is marked by the year of 2015, with 33 articles published. In view of this, it is noted that the 4D BIM subject is recent and has not been much explored.

4.1.2 Publications per country, institution and author

The distribution of countries with more publications

regarding 4D BIM, following the methodological procedures described in section 3, is presented in Figure 3. The most prominent country is the United States of America, with 40 articles, a value that is higher than the double of papers from the country in second place, which is Brazil. This result reinforces the SmartMarket Report study on the use of BIM in the United States, where it jumped from 40% in 2009 to 71% in 2012 [10]. The increase in the adoption of BIM is related to a national program called the 3D-4D-BIM Program, created in 2003 by the General Services Administration (GSA) in the USA. Subsequently, in 2006, the GSA decreed that all the new projected public buildings should use BIM at the conception stage, which also positively influenced the adoption of the technology [11].

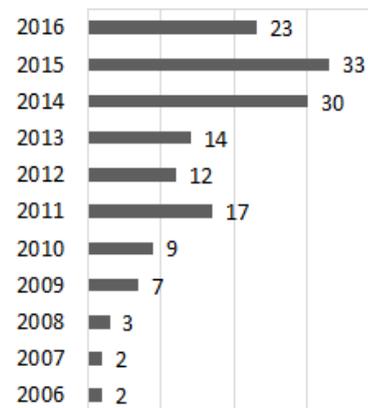


Figure 2. Articles published per year

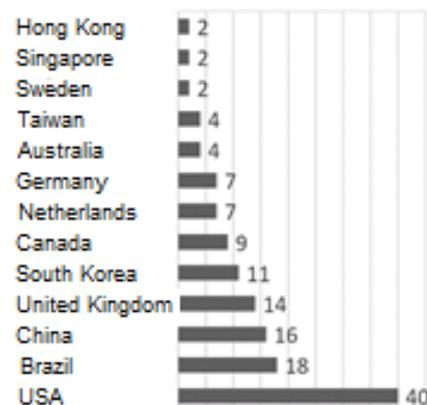


Figure 3. Articles published per country

The Figure 4 shows the number of institutions with more publications per country. Again, the United States of America appears in first place, with 15 institutions on the list, more than twice as many as the second, a position occupied by both China, South Korea and the United Kingdom, with 7 institutions on the list of selected

articles.



Figure 4. Institutions per country

Figure 5, however, represents the number of publications per institution. The university that publishes the most about 4D BIM is the University of Illinois, in the United States, with 11 articles, accounting for 27.5% of all publications in this country. Then, with 7 publications, are tied the institutions University of Twente, in the Netherlands, and Tsinghua University, in China.



Figure 5. Publications per institution

Figure 6 shows the number of publications per author, but only those who collaborated in 3 or more articles on the subject, totaling 38 authors. In addition to these, 264 are present in the final sample of articles. The author with highest number of publications is Mani Golparvar-Fard, an assistant professor at the University of Illinois, in the United States. The second author on the list is Timo Hartmann, an assistant professor at the University of Twente, in the Netherlands. In the third place, two assistant professors are tied. They are LeenSeok Kang, from Gyeongsang National University, in South Korea, and Jianping Zhang, from the Chinese institution named as Tsinghua University.

4.1.3 Most used keywords

It is important to note that keywords represent the

main subjects addressed in articles objectively, and are essential for tracking jobs quickly and accurately in a search. Thus, it's crucial for authors to choose the keywords of their articles carefully, otherwise it can hinder their propagation and the dissemination of their ideas. Figure 7 shows that the most used keyword in the articles was "4D", with 60 applications. Soon after, the word "BIM" comes up with 56 uses. In the third position comes the word "construction", with 48 uses.



Figure 6. Publications per author

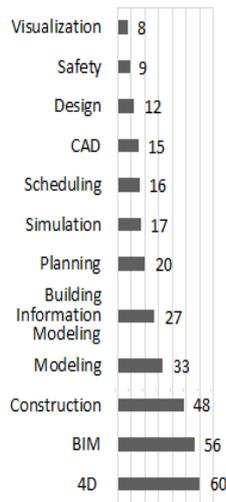


Figure 7. Publications per keyword

4.1.4 Most used publication vehicles

The journals in which it was possible to find the largest number of publications related to 4D BIM are those presented in Figure 8. “Automation in Construction” is highlighted, with 24 articles, followed by the “Journal of Construction Engineering and Management”, with 11 publications.



Figure 8. Publications per Journal

The conferences (Figure 9) that concentrate more publications were two, the “International Conference on Computing in Civil and Building Engineering” and the “Conference of the International Group for Lean Construction”, both with 12 articles. Soon thereafter, the event titled “Construction Research Congress” appears with 11 publications.



Figure 9. Publications per Conference

4.1.5 Main subject

In regard to identify the topics covered in the 148 articles chosen, a classification was made with 14 items. For a better understanding of the main subject categories, a brief explanation will be given on each one of them, in descending order of number of published articles.

The categorization generated Table 1, in which can be observed that the subject "Implementation of 4D BIM" was the most treated in the articles, with 51 apparitions. This category refers to research efforts that seek to identify challenges and opportunities encountered in the adoption of BIM 4D, at both organizational and governmental levels. In general, questionnaires are applied, and interviews are conducted to obtain insights from the AEC industry professionals. This classification also includes the growth rate in the adoption of 4D BIM by companies.

Implementation of 4D BIM	51
Logistics operations and workspace management	30
Dynamic planning - comparison between the as-planned and the as-built	23
Risk management in construction using 4D BIM	14
Management of space-time conflicts in projects	11
Integration between physical schedule and cost	6
Construction quality control through the integration of 4D BIM and other methods	5
Development and improvement of 4D BIM softwares	4
Comparison between different planning methods and 4D BIM	3
Development of components libraries	1

Table 1. Publications per main subject

Secondly, with 30 articles, is the "Logistics operations and workspace management" subject. The planning of logistics in a construction is fundamental to avoid waiting time, to manage the transportation of materials and waste, people movements and workflow of the various activities. Some problems such as lack of workspace, competing and restricted areas cause significant loss of time, thus being essential for construction planning.

The "Dynamic planning - comparison between the as-planned and the as-built" category, with 23 articles, is an actual performance analysis compared to the planned model for an early detection of initially idealized project designs.

In "Risk management in construction using 4D BIM", containing 14 articles, it refers to the evaluation of risks related to the safety and health of construction professionals associated with the work environment through BIM 4D.

The "Management of space-time conflicts in projects

using 4D BIM " category has 11 articles. It refers to the the generation of modeling for the detection of conflicts between time, space and the 3D elements of projects, aiming the resolution of interferences before the beginning of construction. These problems can occur between the overlapping of activities in the schedule or different components of the building, such as, structure and installations, frames and sanitary pieces, among others.

The category named as "Integration between physical schedule and cost planning" contains 6 articles. It consists in papers that report the simultaneous use of 4D and 5D BIM softwares.

5 articles were put in the category called "Construction quality control through the integration of 4D BIM and other methods". It basically consists of integrating or comparing the use of BIM 4D with other methods, such as the Last Planner System (LPS). 4D scheduling is one example of synergy where BIM can be used to achieve lean effects.

The category "Development and improvement of BIM 4D tools" has 4 articles of the sample. With the increasing adoption of BIM, many tools are being developed and it is normal for existing ones to undergo improvement processes. As inherent in new technologies, one of the challenges related to 4D modeling tools is the lack of visualization patterns to represent construction elements and tasks, since each tool typically has its own standards.

With 3 articles in its sample, the ninth category is "Comparison between different planning methods and 4D BIM". It's a comparison of the acceptance of construction scheduling visualizations in 4D BIM and traditional planning tools, such as bar-charts and flowline-charts.

Lastly, only 1 article was found to the category named as "Development of a components library" category. It refers to the use of 4D BIM simulations to help in the creation of components libraries for projects.

5 Conclusions

This study aimed to characterize the international production of scientific articles in the area of 4D modeling. A sample of 148 papers was obtained in a time span from 2006 to 2016. The pioneering of this detailed research makes an important contribution to the identification of the subtopics related to 4D BIM.

This paper did not analyze the articles published in congresses related to 4D BIM, since most of them are not accessible to the researchers, unless they have participated in the events. The difficulty of finding conferences publications evidences the need to disseminate the articles produced by the students and professionals that make up the AEC industry. This may

have caused a distortion in the search results, which identified that 49% of the publications came from events, while 51% were from journals. For this reason, it is recommended that other systematic mapping studies of the literature be done, including this kind of papers. It is noteworthy that articles of congresses contained in the research bases were counted in the present study.

The results show that the number of studies published on 4D BIM has been increasing over the years. It was also observed that the largest volume of publications occurred in 2015, with a slight decrease in 2016. The journal that most generated publications in the studied subject was the "Automation in Construction", with 24 titles. The United States of America was the most representative country, with 40 publications. It also has the institution with the highest number of articles published, the University of Illinois, with 11 papers in its domain. This indicates that USA policies to encourage the adoption of BIM in public works have had positive effects.

Regarding the main subject of the articles, the fact that 51 of them approached the implementation of BIM 4D, totaling about 32% of the total sample, in which almost all of them are case studies, shows that the BIM methodology for planning is not only being studied in Academic world, but is also being applied in real construction projects.

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