Revista Boletim do Gerenciamento

Site: www.nppg.org.br/revistas/boletimdogerenciamento

Budget Structuring Methodology Using 4D and 5D BIM in the Construction Industry: A Systematic Review

Metodologia de Estruturação Orçamentária Utilizando BIM 4D e 5D na Indúistria da Construção: Uma Revisão Sistemática

MACHADO, Michelle[1]; PEREIRA, Giordanna[2]; MACIEL, Ana Carolina Fernandes[3]; COSTA, Bruno Barzellay Ferreira da[4]
michelle.machado@ufu.br[1]; giordanna.pereira@ufu.br[2]; anamaciel@ufu.br[3]; bruno.barzellay@macae.ufrj.br[4].

[1] Mestranda em Engenharia Civil, Programa de Pós-Graduação em Engenharia Civil, Universidade Federal de Uberlândia - UFU
[2] Graduanda em Arquitetura, Faculdade de Arquitetura, Universidade Federal de Uberlândia – UFU
[3] D.Sc. em Engenharia Civil, Programa de Pós-Graduação em Engenharia Civil, Universidade Federal de Uberlândia - UFU
[4] D.Sc. em Engenharia Civil, Instituto Politécnico, Universidade Federal do Rio de Janeiro - UFRJ

Informações do Artigo

Keywords:
4D BIM
5D BIM
Budget
Planning
Construction industry

Palavras-chave:
BIM 4D
BIM 5D
Orçamento
Planejamento
Indústria da construção

Abstract:

Budgeting and planning are fundamental steps in engineering projects. In this context, Building Information Modeling (BIM) presents itself as an efficient methodology that can be used in these stages of construction engineering. The existence of a budget structuring methodology using BIM to optimize supplier payments is necessary, but there is little research directed at this specific area. Therefore, this research aims to develop a systematic literature review on studies published over the last 10 years (2013 to 2023), ratifying the existence of this knowledge gap. The results indicated that there is little research on the topic. Furthermore, there are differences between BIM modeling for budgeting purposes and for quantity extraction, which constitutes another knowledge gap. No articles were found that explain what is necessary in a BIM model aimed at budgeting with commonly used in the public sphere databases.

Resumo

As etapas de orçamento e planejamento são fundamentais em projetos de engenharia. Nesse contexto, o Building Information Modeling (BIM) se destaca como uma metodologia eficiente que pode ser utilizada nessas etapas da engenharia de construção. A existência de uma metodologia de estruturação orçamentária utilizando BIM para otimizar pagamentos a fornecedores é necessária, mas há pouca pesquisa focada nessa área específica. Portanto, esta pesquisa tem como objetivo desenvolver uma revisão sistemática da literatura sobre estudos publicados nos últimos 10 anos (2013 a 2023), confirmando a existência dessa lacuna de conhecimento. Os resultados indicaram que há pouca pesquisa sobre o tema. Além disso, há diferenças entre a modelagem BIM para fins de orçamento e para extração de quantidades, o que constitui outra lacuna de conhecimento. Não foram encontrados artigos que exploram o que é necessário em um modelo BIM voltado para orçamento com bancos de dados comumente utilizados no setor público.

1. Introdução

Budget development and planning for engineering works is a complex and time-consuming process. Usually, quantitative surveys, which are essential for the proper development of both, are conducted manually, which sometimes generates discrepancies that directly impact them. BIM 4D and 5D are tools that can optimize the development process and minimize differences between the real quantity and the surveyed quantity.

According to Araszkiewicz e Bochener [1], the effective implementation of a construction project directly depends on planning, controlling and monitoring its progress. Budgets and schedules are instruments widely used in this process, generally being created in the initial phase of the project and useful for monitoring cost and deadline deviations. In turn, Isac *et al.* [2] highlight that the type of project representation impacts the planner's response time and that visual tools help in decision-making.

There are challenges in monitoring the construction schedule, which directly impacts the measurements to be carried out, leading to significant differences between the budgeted value and the actual value. To achieve this, there are indicators that can be used, such as Earned Value Management (EVM), Added Value Analysis (AVA) or the "S" curve indicator. These references, according to Araszkiewicz e Bochener [1], allow a quick assessment of the real status of the project, as well as the early detection of errors. The authors emphasize, however, that the reliability of the results directly depends on the people involved in the planning and monitoring process. And also that there is greater adequacy of indicators in projects lasting more than one year, a fact that can be mitigated by increasing the number of audits in the process.

The use of technologies such as BIM can facilitate obtaining assertive budgets and planning. According to Aragó *et al.* [3], although the number of publications on 5D BIM has increased since 2010, this represents only about 1.4% of publications on BIM, demonstrating that it is a relatively recent topic and that studies in this area have grown. However, research in the area of 5D BIM typically emphasizes obtaining the initial project budget, and no research is found related to the use of 5D BIM in the operational budget step Fenato *et al.* [4]. In this context, there are still limitations to the use of 5D BIM, as some model updates and adaptations need to be adjusted manually. Furthermore, there is a lack of knowledge regarding how essential budget information can be used in BIM models.

Aragó *et al.* [3] concluded that there is a strong correlation between the success of BIM implementation and the quality of data and human resources in companies. Additionally, a reliable database and a three-dimensional model with the accurate information needed to obtain quantities and subsequently costs, lead to better results and greater user satisfaction. The company typology can also favor or hinder data management and the correct implementation of 5D BIM. Zima [5] explains that the level of detail and the modeling method also have a great impact on the accuracy of the quantities and consequently on their cost. For Hartmann *et al.* [6], the implementation of BIM requires professionals who configure BIM-based tools, well-structured work processes and aligned business models between the companies participating in the project.

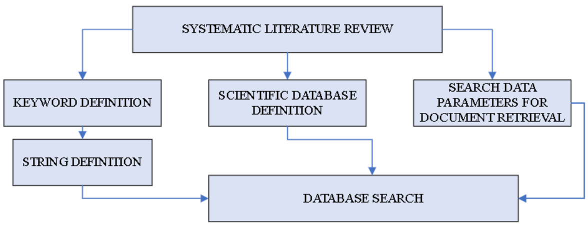
Given all the challenges observed and understanding the importance of a detailed budget linked to the construction planning aimed at monitoring and paying for civil construction services, it becomes essential to use a budgeting methodology that incorporates BIM. However, it is first necessary to understand the context in which research in this area takes place, particularly observing the main challenges.

Therefore, the objective of this article is to identify the challenges present in structuring budgets using BIM, according to the main difficulties encountered in aligning the budget and construction planning.

2. Materials and Methods

This research used Falbo's [7] methodology to conduct a Systematic Literature Mapping (SLM), presented in figure 1, with the aim of identifying the state of the art based on combinations of keywords related to the proposed topic. Falbo explains in detail what an SLM is, the difference between it and a Systematic Review and how to develop a good SLM, in addition to explaining the problems faced during the process and the threats to its validity. This research is conducted through the following steps: Keyword definition; Search string formulation; Definition of the scientific databases where the research will be performed, and; Defining the article selection criteria.

Figure 1 – First phase of the method



Source: Adapted from Falbo [7]

In the second phase, the PRISMA methodology was used to eliminate duplicate articles and those irrelevant to the research. Appendix A shows a summary of this phase. The first step involves eliminating duplicate articles from the search carried out in the databases. Then, the titles are read and those that do not contain any keywords are eliminated. So, the abstracts are read, eliminating those considered unrelated to the topic. Next, the complete articles are read, eliminating all those that are not related to budgeting and/or BIM, those that are inaccessible, and those that have insufficient methodology (articles with undefined methodologies, which are not clear or do not exist). Finally, articles that adhere to the research focus are defined.

3. Results and Discussion

For the first phase of research, the following keywords were defined: 4D BIM or planning; 5D BIM or budget; Measurement on construction; EVM; AVA; S curve; Case study; Field application.

In addition to the keywords applied to obtain the documents to be used in this review, the following parameters were applied (Table 1).

Table 1 – Search data parameters for document retrieval

Parameter	Settings
Type of document	Article
Type of source	Journal
Time span	2013-2023
Citation index	WoS, Science Direct, Scopus, and Springer
Language	English
Knowledge área	Civil Engineering

Source: Authors' elaboration

Applying the above parameters returned 5616 documents. After removing duplicates, this number was reduced to 2,320. Reading the titles, 172 articles were selected, reducing to 90 after reading the abstracts. Of the 90 articles, 31 remained after reading the complete articles. Furthermore, after reading these, 10 articles were found in their references that initially seemed interesting for this research and, after reading, 3 of them were eliminated.

Considering the significant reduction in articles between the Prisma protocol identification and inclusion phase, it was necessary to analyze the reason for this significant reduction. Appendix B shows the main reasons for elimination in the second phase of research.

From Appendix B it is possible to identify that approximately 97% of the articles were eliminated in Phase 1 (Elimination of duplicate articles in the databases) and Phase 2 (Elimination of articles whose title did not present any of the keywords).

Considering that one of the criteria used in this research was the elimination of articles whose title did not present any keywords, and that the initial search in the databases was carried out by selecting "Title, Abstract, and Keywords" as the search field, almost 40% of the articles eliminated in Phase 2 were removed from the study because the keywords were contained in the Abstract or in the list of keywords determined by the author, and not in the title.

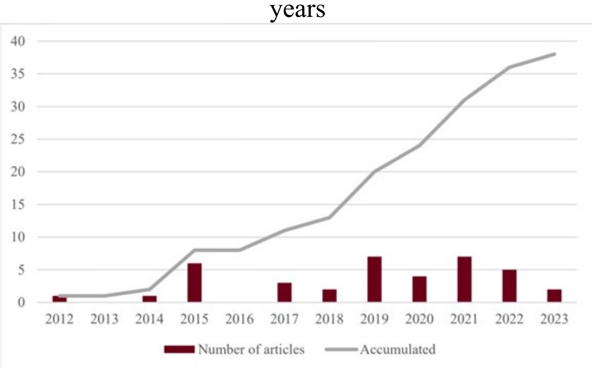
In Phase 3 (Elimination of articles unrelated to the topic based on reading the abstracts), 1.46% of the articles were eliminated, leaving 90. At this stage, articles were selected that addressed the BIM theme, but in other contexts, such as: BIM and augmented reality; BIM related to construction site safety; BIM in prefabrication, and; BIM related to sustainability. Furthermore, articles whose text lacked clarity and/or scientific development was considered unsatisfactory were also excluded.

In Phase 4, all 90 articles were read in full and of these, only 31 remained, which added to the 7 articles found in the references, totaled 38 that were used for the remaining analyses. Of the 59 articles eliminated, 34 deviated from the budget theme, 17 were inaccessible to the authors, 4 presented insufficient methodologies, and 4 did not use BIM in their methodology or were not related to the researched theme.

The complete reading of the remaining 38 articles allowed the compilation and analysis of the data. Appendix C presents the country of origin of the authors of the analyzed articles. From the map it is possible to see that the majority are Brazilians, representing around 17.4% of the total number of authors, followed by Iranians, representing around 12% and in third place, with around 10%, are the Chinese. Cameroon, France, the United Arab Emirates and Indonesia were the countries with the fewest authors, with all four having 1 author each.

In Figure 2, articles are presented by year of publication (bars) and accumulated over the years (line). The years 2019 and 2021 were those with the highest number of publications, together representing almost 37% of publications for the entire period. It can be seen that there was a decrease in publications in 2020. A plausible explanation for this could be the Covid-19 pandemic, which has directly impacted researchers around the world. The years 2021 and 2022 presented a similar number of publications, with 7 in the first year and 5 in the second year. This research was conducted at the beginning of the second half of 2023, which explains why the number of articles this year is not equal to or greater than in previous years.

Figure 2 – Evolution of publications over the past 10 years



Source: Authors' elaboration

Articles addressing 4D BIM and quantity extraction for budgeting have been identified since 2014. However, it was only in 2015, with the study of Cha e Lee [8], that a trend towards using BIM to generate budgets was noted. However, it was only in 2018 that the term 5D BIM was effectively mentioned by Fenato *et al.* [4], which shows that research related to the topic is recent.

Appendix D, created in the VOSviewer software, presents a co-occurrence map of keywords, where it is possible to see that "project management", "budget control", and "construction information modeling" are the ones that appeared most in the analyzed articles, reinforcing the idea of using BIM for project budget, management, and control. It is interesting to note that the term 5D BIM, despite having been mentioned since 2018, began to appear in the keywords between

2020 and 2022, which suggests that it was at that time that authors really began to focus on this topic. It is still possible to observe that cost-benefit analysis has been the subject of recent researches, which can be reinforced by the optimization capacity that occurs in processes due to the use of BIM.

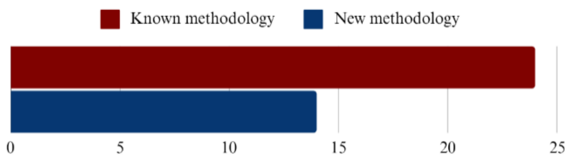
Appendix E presents the 10 journals with the most publications among the articles analyzed, where it is possible to observe that almost 16% of the 38 articles were published in Automation in Construction. This journal publishes articles on the use of Information Technologies in Design, Engineering, Construction and Maintenance Technologies and Management of Constructed Facilities and has an Impact Factor of 10.3. In the Ambiente Construído, the focus is on articles related to Built Environment Technology, whether in design, production, operation, maintenance, demolition and/or recycling or reuse of buildings and their immediate surroundings. The periodical Buildings focuses on publishing articles related to building science, construction engineering, and architectural design. The KSCE Journal of Civil Engineering is a more generalist journal that publishes articles in the broad field of Civil Engineering.

Appendix F presents the 10 authors with the highest H-factor in descending order, through which it is possible to identify the quality of their production and reach in the scientific community. Peter Love and M. Reza Hosseini are the authors with the highest H-factor and represent Australia, one of the countries with the smallest number of authors. In third place is Al-Hussein Mohamed from Canada. In fourth place is Vanhoucke, one of the two Belgian authors, and in fifth place is Formoso, whose nationality is Brazilian and represents the country with the most authors. The country that presented the largest number of authors among the 15 with the highest H-factor was the United Kingdom, with the 3 authors representing the country.

The articles were classified into two distinct categories according to the scope of the research, the first being related to the theoretical nature or case study, and the second quantifying those that presented new methodologies and those that used and/or made adaptations to existing methodologies. It is possible to observe that around 32% of the articles fell into both types of the first category, covering theory and case study. The remainder was divided almost equally, with 11 case studies and 15 theoretical studies.

Regarding the second category, it can be seen in figure 3 that the number of authors who created new methodologies was smaller than those who used existing methodologies, representing around 42% of the articles, three of which are related to 5D BIM and one of which is related to 4D BIM. Bortolini *et al.* [9] proposed the combined use of BIM and Lean Construction principles with application in logistical control for the assembly of prefabricated elements. Fenato *et al.* [4] proposed a method for preparing an operational budget using BIM, with the aim of highlighting calculation considerations and automating the extraction of quantities. Elghaish *et al.* [10] proposed a method to facilitate decision-making during the feasibility analysis process of a project, aiming to use 5D BIM to estimate costs, at this stage in which there is no detail of the chosen solution. Cha e Lee [8] proposed the development of a BIM database in order to use it in the renovation of an old house.

Figure 3 – Evolution of publications over the past 10 years



Source: Authors' elaboration

Kavuma *et al.* [11] developed a study with a similar objective as Konior e Szóstak [12], both seeking to identify the factors that influence excessive construction costs. The first also assessed the factors that influence excessive construction time and the second made a comparison between planned, incurred and actual costs. Both articles fall into the category of review articles and used existing methodologies, and although there are similarities, there are also significant differences between them regarding methodology and results.

Kavuma *et al.* [11] used surveys as a quantitative tool to collect data from construction stakeholders in South Korea. Questionnaires were distributed through a data collection website and analyzed using a 7-point Likert scale. On the other hand, Konior e Szóstak [12] used the Earned Value Method (EVM) to analyze 536 measurements of 40 different construction investments. Schedules, expenses before the construction start and information on the actual progress of implementation were reviewed according to monthly reports. Kavuma *et al.* [11] classified the results into two categories, the first being the factors that influenced delays in construction time and the second being the factors that influenced increases in construction costs.

In the first category, in descending order of influence, are BIM-related factors, manufacturing-related factors, chemical-related factors, contractor-related factors, and externally caused factors. For the second category, client, contractors, BIM-related factors, manufacturing-related factors, and lastly, externally caused factors. Although the two studies had similar objectives, Konior e Szóstak [12] focused on using EVM to analyze their data and very little on identifying the factors that influence cost overruns in construction. In this case, only the delay in delivering cost information and budget differences were responsible for the increase in costs. Furthermore, they concluded that for the proposed objective, the use of the S curve is not viable, as the real and estimated values vary greatly from each other, since the nature of the constructions is very comprehensive and with different levels of complexity. In turn, the calculations performed in accordance with the EVM made it possible to assess the real costs and the individual amounts to be invested.

Based on the studies of Zima [5] and Batselier *et al.* [13], it is possible to observe a convergence of ideas, although different technologies and methods are used to obtain construction costs. In the first, the author presents the potential for using BIM to prepare construction budgets, conducting a study on the insertion and removal of information from the model and showing how this influences the practical budget. In the second, the authors propose testing the EVM technique using a database composed of 51 civil construction projects, in order to verify the accuracy of this technique in predicting the construction costs and deadlines. Zima [5] concluded that the information entered into the model and the accuracy of the calculations can significantly affect a project's costs. In addition, the definition of materials and equipment, the calculation method and the software used directly influence the generation of the quantity and consequently the budget. As a suggestion for improvement, the author highlights the need to standardize modeling methods to allow better use of the potential of BIM for budgeting.

Batselier *et al.* [13] confirmed the effectiveness of EVM in predicting construction cost and time. They also indicated that, for deadline prediction, the Earned Schedule Method (ESM) was the most accurate. Regarding costs, the Cost Estimate at Completion (EAC) showed the best results, in the authors' opinion.

In building engineering, it is very common, especially in the initial phase of feasibility studies, to prepare estimates of construction costs. At this stage, however, there is often little information about the project, a scarcity of projects, and a lack of detail. In this context, two studies were found in different areas that have the ultimate goal of solving this issue. Elghaish *et al.* [10] developed a study with the objective of integrating Target Value Design (TVD), ABC Curve and Monte Carlo simulations into the Integrated Project Delivery (IPD) cost structure, linked to a BIM platform. First, a theoretical review was performed, followed by the development of a methodology for cost estimation using IPD and BIM when there is a shortage of information, and finally a case study to validate this.

Nadafi *et al.* [14] developed a study with the objective of determining the value and completion time of projects using EVM and Interval Gray Numbers (IGN) when there is a scarcity of information. To this end, they carried out a literature review on the IGN concept and the presentation of the EVM method based on IGN, verifying it through a numerical example. It is possible to observe that both works presented similarities not only in terms of objective, but also in terms of the methodology used. Additionally, both parties concluded that the technologies and methodologies used were capable of optimizing the cost assessment of projects and works, generating budgets consistent with reality. Elghaish *et al.* [10] concluded that automating the proposed methodology for determining and allocating indirect costs could increase users' confidence in it. In addition to the proven effectiveness of the union between BIM and IPD, the authors showed in their case study evidence of the feasibility of Monte Carlo simulation integrated with BIM to develop a cost estimate, with a deviation of less than 12%. They also revealed that using the ABC Curve provided a better IPD cost structure. Nadafi *et al.* [14] identified that the IGN-based EVM proved to be an effective step for project management and proved useful in the face of project uncertainties.

Bortolini *et al.* [9] and Bataglin *et al.* [15] developed theoretical and practical studies with some similarities. The authors used 4D BIM concepts and Lean Production principles to optimize logistics management on construction sites for the assembly of engineer-to-order (ETO) prefabricated systems. However, in the first study, this combination of concepts was used to establish guidelines for the joint use of BIM and Lean Production in the logistics management of prefabricated construction systems. In the second, the objective was to develop a logistical planning and control model for the on-site assembly of prefabricated ETO construction systems using 4D BIM modeling. Another similarity was the use of the Design Science Research methodological approach and the action research strategy, enabling the authors to actively participate in the search for solutions to the proposed problem.

According to Bortolini *et al.* [9], logistics management is essential for this type of production system, as there is a high level of complexity involved, deadlines are usually short, there is usually overlapping of project stages and use of shared resources. In the research, three different projects from a steel mill in Brazil were used, whose delivery times were short and with great variability in projects and part dimensions. The chosen projects presented different complexities and restrictions related to logistics management. The first had a restricted area for the construction site and the objective was to optimize the use of space and define the ideal volume of stock. In the second, the area was large and nine different industrial buildings would be assembled, this being the great challenge, providing different components for different projects located on a large construction site. The third was chosen because the client's profile was very demanding in terms of deadlines, safety, and organization, having even requested adjustments to the project in this case to reduce the variability of the parts to be assembled.

In exploratory study 1, the authors identified that the logistics were carried out by the team when the material arrived at the construction site and that it was all mixed up, containing pieces from different stages and locations. The same happened in exploratory study 2 and the material arrived mixed, which led to a lot of time-consuming work to separate it. Based on the two studies, it was possible to conclude that the company did not have a structured logistics plan followed by the management team, which contributed to a lot of work without added value, mainly in the separation and organization of stocks. Additionally, more fragile materials were damaged, causing financial losses. In exploratory study 3, several meetings were held with the team and planning was supported by 4D BIM simulations, in order to optimize the logistics and assembly process of parts at the construction site. This directly contributed to the elimination of wasted time and materials, reduction of stock on the construction site, in addition to enabling the creation of a more reliable and organized process, meeting customer demands.

Bataglin *et al.* [15] identified in a case study inefficient communication between the factory and the construction site, which impacted the company's entire logistics process. The 4D BIM models helped the team define better alternatives for the process on the construction site, emphasizing the organization and flow of materials on site. This made it possible to bring participants together and define guidelines to help companies implement 4D BIM with similar problems. Among the proposed guidelines are:

- Standardizing logistics processes, defining which information is relevant to the model, using naming standards, and adopting color codes for different stages.
- Collaborative processes based on the adoption of BIM 4D in order to integrate the team into planning processes.
- Use of visual resources to disseminate information, such as panels with images of 4D models, including the assembly sequence and location of items on the construction site, for example.
- Adoption of pull production, analysis and control of work in progress, integration of 4D BIM at different levels of planning and integration of manufacturing and assembly information on the construction site.

Although the authors have developed studies with different objectives, they both used the concepts and principles of BIM and Lean Production, which leads us to believe that there is a convergence in their conclusions. As expected, similar conclusions were obtained. The use of BIM and Lean Production in both contexts generated an increase in information reliability, gains in team productivity, and also confirmed one of the main benefits of adopting BIM, which is making the work environment more collaborative. Bataglin *et al.* [15] also highlighted the possibility of identifying the system status, optimizing the integration between factory and construction site. They observed improvements in workflows and information and the need for demand confirmation points and the possibility of aligning short-term plans with load planning. Greater effectiveness in decision making was also verified using the 4D BIM model.

Bortolini *et al.* [9] concluded that in addition to contributing to the planning model based on BIM and Lean Production, their theoretical framework would be very useful for the reader to have a deeper understanding of the synergy between them. They also believe that their planning model can be used as a reference by other companies working with prefabricated ETO systems.

Andrade *et al.* [16] and Felisberto [17] studied the joint use of a federal government database and BIM to obtain construction cost estimates. The first carried out a case study of a public project at a Brazilian public university in the state of São Paulo, using bidding documents and projects in AutoCAD 2D as a basis for creating two BIM models. The second proposed guidelines combining BIM and SINAPI to improve the accuracy of public budget estimates, using the Design Science Research methodology. These guidelines were tested in two projects: a multifamily residential building and a public service institution. Both observed little difference between the quantities, however Andrade *et al.* [16] found that to use SINAPI it is necessary to develop specific models for this purpose. Felisberto [17] concluded that "text parameters can be used to identify material specifications, element geometry and specify substrates, which can improve the process of generating an estimate according to the costs of the elements of the “SINAPI factor tree”.

4. Conclusions

This study presented the state of the art research from 2013 to 2023 on BIM related to budgeting and planning. It was possible to confirm that, as far as the authors know, there are no studies that propose a budget structuring methodology using BIM to improve payment and measurement in works, and some knowledge gaps were also identified.

There are few works that combine BIM with EVM, represented only by Elgaish *et al.* [18] and Kim *et al.* [19]. Elgaish *et al.* [18] conducted a case study bringing together researchers from Australia, Canada and the United Kingdom, and concluded that their research can serve as a basis for the development of a prototype in 4D and 5D BIM platforms. Kim *et al.* [19] conducted a theoretical review and a case study in Korea, and although their work addressed the concepts of BIM and EVM, they left as a suggestion for future work the creation of BIM models that allow the implementation of project management and EVM in the construction phase. The association of BIM with the S-Curve did not present results in this research, and is also considered a gap in knowledge. There are also issues related to 5D BIM focusing on construction measurements, where the only similar work was that of Fenato *et al.* [4], whose research sought to create a method for preparing an operational budget using BIM software. Andrade *et al.* [16] conducted a case study in São Carlos, Brazil, and concluded that modeling BIM projects for quantity extraction is different from modeling BIM projects for budgeting, which leads to another knowledge gap that can be researched.

One can conclude that there is a convergence of ideas between EVM and BIM 5D, as both aim to achieve the final cost of a project. In this context, it is interesting to use them together or even separately, for comparison purposes. Furthermore, it is concluded that the use of 4D BIM in conjunction with Lean Production principles can further optimize processes, increasing transparency and reliability.

Although the use of BIM in public works is mandatory in Brazil, legislation is not clear about how it should be used. There are no detailed explanations and/or step-by-step instructions on what should be done in this context.

This work contributes to obtaining an enlightening view on the proposed theme and as a way of directing future research. Given the data presented, it is suggested that future work study in depth the synergy between EVM and 4D and 5D BIM, such as the development of plugins and/or software that integrate them. Another interesting research would be studying ways to visualize the S curve in 4D and 5D models. Additionally, studies are suggested that focus on the development of models that facilitate measurement in building construction, since studies in this area are scarce and it is essential that there is cooperation between the construction stages for its good development. Finally, it is necessary to turn our attention to public institutions in order to help them understand and implement BIM in their daily routines, enabling them to comply with legislation.

During the research, the authors encountered limitations regarding database searches. Often the searched terms are not found, resulting in many articles that are not related to the defined keywords. The result was the elimination of 97% of the articles in the first and second phases of the research, which were respectively the elimination of duplicate articles and the elimination of articles whose title did not present any of the keywords.

5. Acknowledgements

The authors thank the Universidade Federal de Uberlândia for the scientific initiation scholarship, to the Faculdade de Engenharia Civil da Universidade Federal de Uberlândia and the Universidade Federal do Rio de Janeiro for the research opportunity.

6. References

[1] ARASZKIEWICZ, K. & BOCHENEK, M. *Control of construction projects using the Earned Value Method - case study.* Open Engineering, n. 9(1), p.186-195, 2019. https://doi.org/10.1515/eng-2019-0020

[2] ISAC, J. et al. *Impact of a visual decision support tool in project control: A comparative study using eye tracking.* Automation in Construction, n. 110, 102976, 2020. https://doi.org/10.1016/j.autcon.2019.102976

[3] ARAGÓ, A. et al. *Quantity surveying and BIM 5D. Its implementation and analysis based on a case study approach in Spain.* Journal of Building Engineering, n. 44, 103234, 2021. https://doi.org/10.1016/j.jobe.2021.103234

[4] FENATO, T. et al. *Method for elaborating operational bill of quantities through BIM authoring software.* Ambiente Construído, n. 18(4), Oct-Dec, 2018. https://doi.org/10.1590/s1678-86212018000400305

[5] ZIMA, K. *Impact of information included in the BIM on preparation of Bill of Quantities.* Procedia Engineering, n. 208, p.203-210, 2017. https://doi.org/10.1016/j.proeng.2017.11.039

[6] HARTMANN, T. et al. *Aligning building information model tools and construction management methods.* Automation in Construction, n. 22, p.605-613, 2012. https://doi.org/10.1016/j.autcon.2011.12.011

[7] FALBO, R. Mapeamento Sistemático. 2015. Disponível em: https://inf.ufes.br/~falbo/files/MP/TP/Sobre_MS.pdf. Acesso em 15/03/2024.

[8] CHA, H. & LEE, D. *A case study of time/cost analysis for aged-housing renovation using a pre-made BIM database structure.* KSCE Journal of Civil Engineering, n. 19, p.841-852, 2015.https://doi.org/10.1007/s12205-013-0617-1

[9] BORTOLINI, R. et al. *Site logistics planning and control for engineer-to-order prefabricated building systems using BIM 4D modeling.* Automation in Construction, n. 98, p.248-264, 2019. https://doi.org/10.1016/j.autcon.2018.11.031

[10] ELGHAISH, F. et al. *Revolutionising cost structure for integrated project delivery: a BIM-based solution.* Engineering, Construction and Architectural Management, n. 28(4), p.1214-1240, 2020. https://doi.org/10.1108/ECAM-04-2019-0222

[11] KAVUMA, A. et al. *Factors influencing Time and Cost Overruns on Freeform Construction Projects.* KSCE Journal of Civil Engineering, n. 23, p.1442-1450, 2019.https://doi.org/10.1007/S12205-019-0447-X

[12] KONIOR, J. & SZÓSTAK, M. *Cumulative cost spent on construction projects of different sectors.* Civil Engineering and Architecture, n. 9(4), p.999-1011, 2021. https://doi.org/10.13189/cea.2021.090404

[13] BATSELIER, J. et al. *Empirical Evaluation of Earned Value Management Forecasting Accuracy for Time and Cost.* Journal of Construction Engineering and Management, n. 141(11), 2015.

https://doi.org/10.1061/(ASCE)CO.1943-7862.0001008

[14] NADAFI, S. et al. *Predicting the project time and costs using EVM based on gray numbers.* Engineering, Construction and Architectural Management, n. 26(9), p.2107-2119, 2019. https://doi.org/10.1108/ECAM-07-2018-0291

[15] BATAGLIN, F. et al. *4D BIM applied to logistics management: Implementation in the assembly of engineer-to-order prefabricated concrete systems.* Ambiente Construído, n. 18(1), p.173-192, 2018. https://doi.org/10.1590/s1678-86212018000100215

[16] ANDRADE, F. et al. *5D BIM study for public project budgeting using SINAPI.* VVIII ENTAC, n. 18(1), 2020. https://doi.org/10.46421/entac.v18i.1245

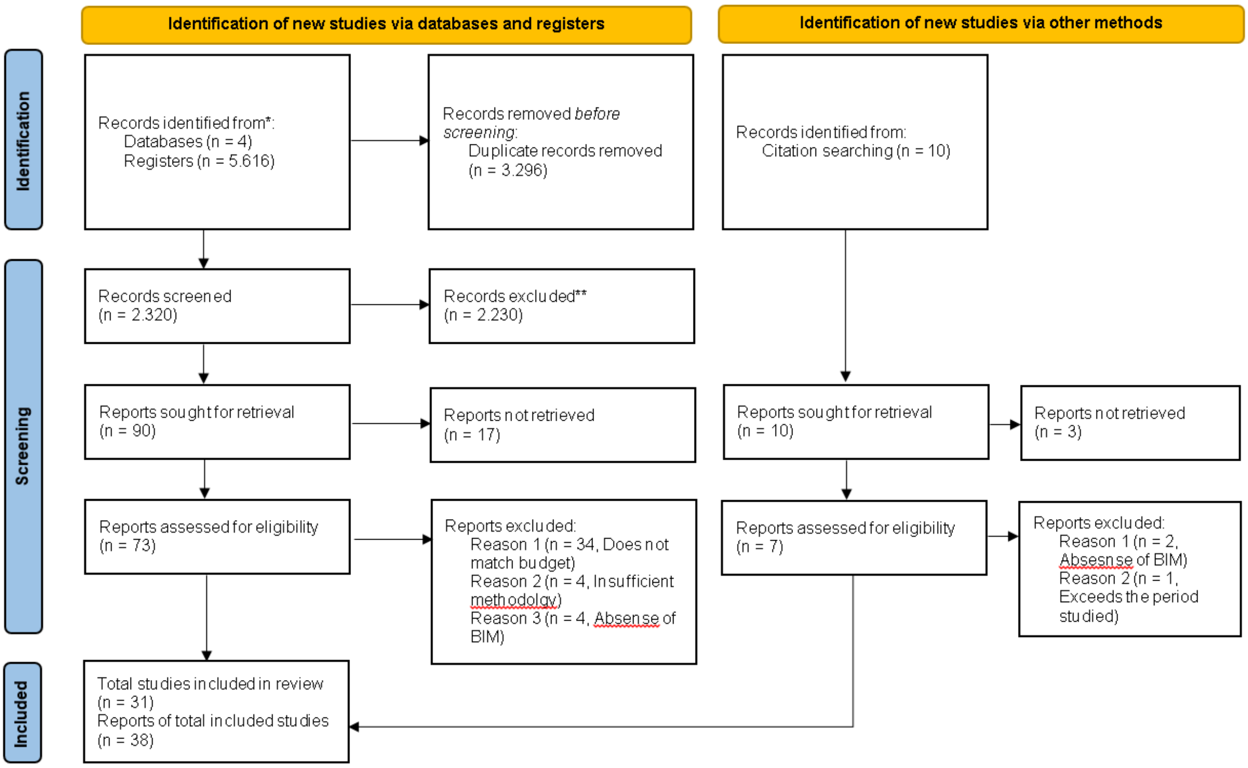
[17] FELISBERTO, A. *Contribuições para elaboração de orçamento de referência de obra pública observando a nova árvore de fatores do sinapi com BIM 5D-LOD 300.* Florianópolis: UFSC, 2017.

[18] ELGHAISH, F. et al. *Integrated project delivery with BIM: An automated EVM-based approach.* Automation in Construction, n. 106, 102907, 2019. https://doi.org/10.1016/j.autcon.2019.102907

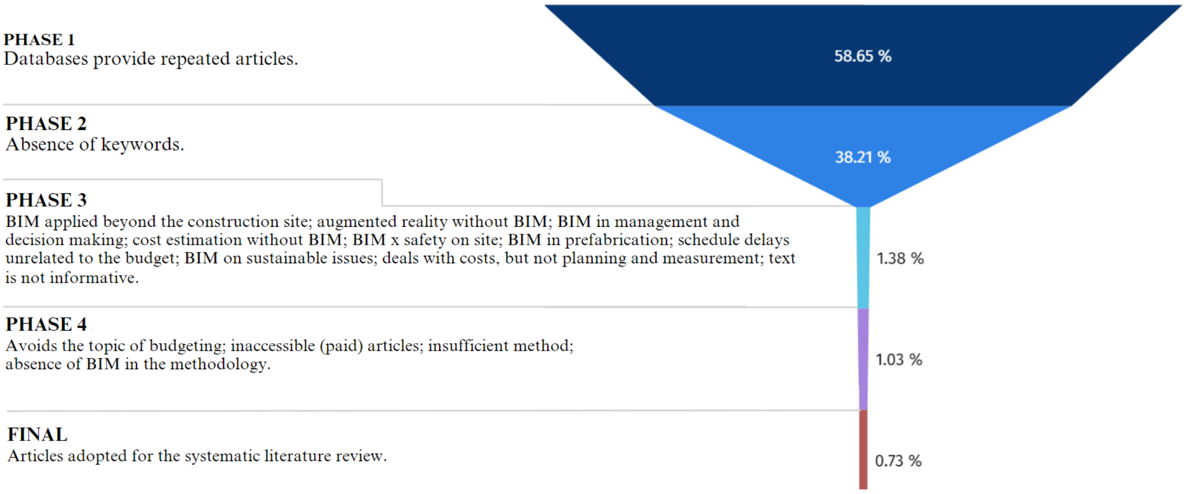
[19] KIM, Y. et al. *A Case Study on BIM Object-Based Earned Value and Process Management in Highway Construction.* KSCE Journal of Civil Engineering, n. 26, p.522-538, 2022. https://doi.org/10.1007/S12205-021-1348-3

6. Appendices

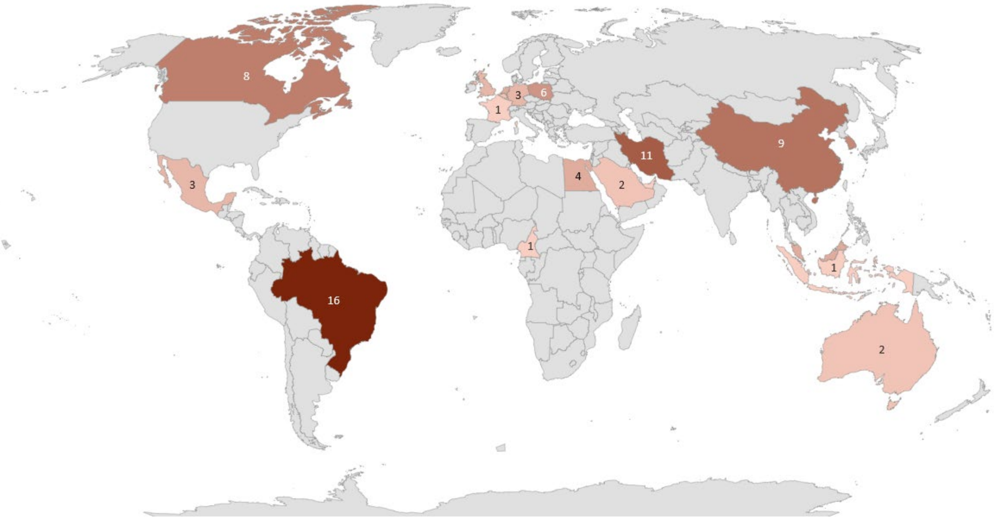
APPENDIX A – Second phase of the method – PRISMA (2020)



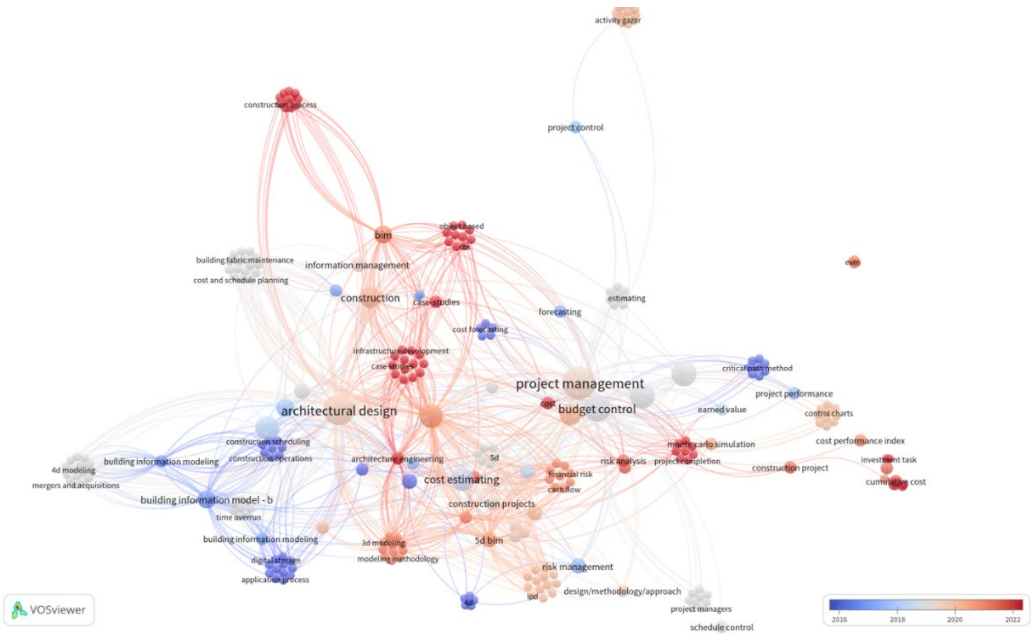
APPENDIX B – Article deletion statistics



APPENDIX C – Distribution of authors' countries



APPENDIX D – Keyword co-ocurrence map



APPENDIX E – Most productive journals

Rank	Journal	Nº papers	%
1	Automation in Construction	6	15.88
2	Ambiente Construído	3	7.89
3	Buildings	3	7.89
4	KSCE Journal od Civil Engineering	3	7.89
5	Engineering, Construction and Architectural Management	2	5.25
6	Journal of Building Engineering	2	5.25
7	Journal of Construction Engineering and Management	2	5.25
8	Advances in Engineering Software	1	2.63
9	Ain Shams Engineering Journal	1	2.63
10	Archives of Civil Engineering	1	2.63

APPENDIX F – Most productive authors

Rank	Authors	H-factor	Nº Citations	Affiliation
1	Peter Love	125	46474	Curtin University
2	M. Reza Hosseini	53	9232	Melbourne University
3	Mohamed Al-Hussein	49	8213	Concordia University
4	M. Vanhoucke	48	8707	Ghent University
5	Carlos Formoso	45	8504	Federal University of Rio Grande do Sul
6	R. Pellerin	37	6963	Polytechnique Montreal
7	Markus König	35	5891	University of Erlangen-Nuremberg
8	Pierre-Majorique Léger	35	4606	Polytechnique Montreal
9	F. H. Abanda	31	3417	National Polytechnic School of Yaoundé
10	Hee Sung Cha	30	2576	Ajou University