







From Pre-design to Operation: A Scoping Review and Bibliometric Analysis of Productivity Metrics Using BIM in Building Projects

Felipe Dutra¹, Carlos Alejandro Diaz Schery^{1,3} , Rodrigo Goyannes Gusmão Caiado^{1,3,*} , Marcello Congro^{2,3} , Eduardo Thadeu Corseuil³  and Antonio Márcio Tavares Thomé¹ 

¹Department of Industrial Engineering, Pontifical Catholic University of Rio de Janeiro, Gávea, Rio de Janeiro, Brazil

²Department of Civil and Environmental Engineering, Pontifical Catholic University of Rio de Janeiro, Gávea, Rio de Janeiro, Brazil

³Tecgraf Institute/PUC-Rio, Pontifícia Universidade Católica do Rio de Janeiro, Gávea, Rio de Janeiro, Brazil

Abstract:

Background: The construction industry has been seeking ways to improve productivity through digitalization, with Building Information Modeling (BIM) emerging as a key methodology. However, the existing literature remains unclear about the relationship between BIM implementation and productivity metrics across different project stages.

Objective: This study aims to analyze productivity indicators applied in construction projects using BIM methodology and their alignment across project lifecycle stages, providing guidance for future research pathways in construction productivity.

Methods: A comprehensive scoping review was conducted using bibliometric and content analysis methods. The study analyzed 151 documents from Scopus and Web of Science databases, supplemented by gray literature. The analysis focused on identifying productivity metrics, project types, and lifecycle stages where BIM is applied.

Results: The analysis revealed that productivity indicators align better when mapped according to project lifecycle stages. Most studies (70%) focused on case studies and surveys, primarily in pre-design and construction phases. China and the United States dominated the literature (73% of publications). The research identified three main project categories: residential, commercial, and industrial/specific buildings. Productivity metrics varied by project complexity, with more complex projects showing greater emphasis on mechanical and electrical assembly team performance indicators.

Conclusion: The study demonstrates that the potential of BIM for productivity enhancement remains partially untapped, particularly in the post-construction phases. While some productivity indicators receive substantial attention, others remain under-researched. The findings suggest the need for establishing standardized productivity metrics across project lifecycles and expanding BIM application beyond traditional construction phases, particularly in the operation and maintenance stages.

Keywords: BIM methodology, Construction productivity, Project life cycle, Literature review, Pre-design, Construction phases.

© 2025 The Author(s). Published by Bentham Open.

This is an open access article distributed under the terms of the Creative Commons Attribution 4.0 International Public License (CC-BY 4.0), a copy of which is available at: <https://creativecommons.org/licenses/by/4.0/legalcode>. This license permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

*Address correspondence to this author at the Department of Industrial Engineering, Pontifical Catholic University of Rio de Janeiro, Gávea, Rio de Janeiro, Brazil and Tecgraf Institute/PUC-Rio, Pontifícia Universidade Católica do Rio de Janeiro, Gávea, Rio de Janeiro, Brazil; E-mail: rodrigocaiado@puc-rio.br

Cite as: Dutra F, Diaz Schery C, Caiado R, Congro M, Corseuil E, Tavares Thomé A. From Pre-design to Operation: A Scoping Review and Bibliometric Analysis of Productivity Metrics Using BIM in Building Projects. Open Constr Build Technol J, 2025; 19: e18748368379847. <http://dx.doi.org/10.2174/0118748368379847250324051020>



Received: January 13, 2025
Revised: January 30, 2025
Accepted: February 11, 2025
Published: ?? ??, 2025



Send Orders for Reprints to
reprints@benthamscience.net

1. INTRODUCTION

In recent years, the adoption of “Building Information Modeling” (BIM) has been discussed by various authors [1, 2]. BIM represents an innovative initiative aimed at addressing specific challenges in the Architecture, Engineering, And Construction (AEC) industry, such as the low productivity of labor [3, 4, 5]. The construction industry faces significant workforce challenges, with studies showing that 82 percent of construction workers experience occupational mobility [6], which can impact project productivity and quality. Succar [7] defined BIM as “a set of interrelated policies, processes, and technologies that produce a methodology for managing the essential design of a building and its project data digitally throughout the structure’s lifecycle.” Thus, the implementation of BIM needs various transformative processes and technologies within an organization [8].

Government incentives, such as the establishment of supportive legislation, have played a pivotal role in encouraging the adoption of BIM methodology in the construction industry, marking a significant stride towards modernization and efficiency [9]. The Brazilian federal government established the National BIM Dissemination Strategy in 2017, aiming to foster a conducive environment for BIM investment and its proliferation in the country as a policy to enhance the performance of the AEC industry. Despite the anticipated benefits of BIM implementation and competitive advantages, its potential remains untapped [10-14], illustrating that BIM implementation in organizations poses challenges.

Recent research highlights the importance of sustainable performance factors in construction [12]. Tayeh *et al.* [15] identified key economic, social, and environmental factors from the perspective of the consultants, where professional fees, energy costs, and environmental regulations stand out. This multidimensional understanding is crucial when evaluating BIM impacts across different project stages [16].

Several authors have highlighted productivity gains from BIM during project, construction, and assembly phases [17, 18, 19]. Lu *et al.* [20] examined productivity differences across the lifecycle stages of two projects and noted productivity enhancements during construction, offset by increased efforts during the design phase. This shift suggests a transfer of efforts from the construction to the design stage, especially concerning the reduction of interference between projects. Currently, there is no formal approach to estimating the costs of architectural and engineering services using BIM [2, 21]. Consequently, costs are projected based on the design or the experience of those involved, leading to inconsistencies. Public agencies must adhere to specific legislative requirements and need an objective foundation for budgeting items related to services using the BIM methodology [22, 23].

In this study, utilizing bibliometric and content analysis methods provided a holistic insight into the literature concerning productivity with BIM. The bibliometric approach allowed for quantitative assessment of publication trends, revealing patterns, prolific authors, and dominant journals. On the other hand, content analysis delved deep into the qualitative aspects, elucidating the nuances, emerging the-

mes, and intricacies of the discussed topics. Together, these analyses highlighted the depth and breadth of research and underscored the complementary nature of quantitative and qualitative assessments, each offering unique perspectives that, when combined, provide a comprehensive understanding of the subject. A structured and reproducible scientific methodology was applied to extract content from the literature, aiming to understand the intellectual structure, map themes and categories concerning productivity with the BIM methodology, assess how productivity is evaluated throughout the project lifecycle, and determine the types of projects and indicators used for such evaluations. Thus, the guiding questions for this research were: i) what is the intellectual structure of the literature regarding productivity using the BIM methodology? ii) What types of projects and construction lifecycle stages use productivity analysis or evaluation using the BIM methodology? iii) What are the productivity indexes or coefficients for analyzing productivity using project modeling with the BIM methodology? and iv) what far-reaching implications will BIM have on construction productivity analysis for future research? This research makes several notable contributions to the literature on BIM and productivity. Firstly, it brings to the forefront lesser-known aspects of productivity indicators and their relevance across various project stages, enriching the existing knowledge base. Secondly, a dual-method approach offers a balanced perspective, ensuring that both quantitative trends and qualitative nuances are well captured. Lastly, the study emphasizes the significance of adopting BIM methodology across diverse project typologies, encouraging more integrated and efficient construction practices. The article proposes an introduction that provides context and highlights the significance of the study, emphasizing its relevance in the domain of BIM and productivity research. It is followed by the theoretical background, which explores current research on BIM and its relationship with productivity. The methodology section details the research techniques and procedures used for the bibliometric and content analysis. In the bibliometric analysis section, the article presents findings that shed light on trends and key contributors in the existing literature. The content analysis results and discussions section interprets these findings. The research agenda section outlines potential areas for future exploration in the field [24]. Finally, the conclusion section summarizes the key insights of the study and its implications for academic and practitioner communities.

2. THEORETICAL BACKGROUND

Productivity is typically evaluated as a rate between the production (output) of a product or service and the labor or equipment used for production (input), and it is often represented by Eq. (1),

$$\text{Productivity} = \frac{\text{Output}}{\text{Input}} = \frac{\text{Installed Quantity}}{\text{Actual Work Hours}} \quad (1)$$

Productivity terms are reversed between numerator and denominator when discussing equipment (output/input) and labor productivity (input/output) [25]. Without standardization in its evaluation, it depends on methods chosen by companies and managers [26-28], plus differences between projects [29]. Productivity is a primary factor for

implementing BIM [1, 4, 30]. According to Jones *et al.* [31] and Ahankoob *et al.* [32], this motivates governments to promote BIM in the industry, as productivity improvements impact economic results and growth in gross domestic product [26]. Certain aspects of civil construction have a greater managerial interest [33]. Park [28] proposed analyzing productivity by listing the following factors: schedule, change orders, materials, climate, and labor productivity management. Productivity is evaluated throughout the project lifecycle, emphasizing construction phases due to labor intensification, expenses, and interferences [27]. Several authors view BIM as a digitization initiative [34, 35] facilitated by technologies like cloud computing, parametric modeling, and visualization [10, 11], enabling benefits, such as automated productivity measurement [17, 18, 36]. Despite its importance, there is a research gap regarding productivity with BIM. Therefore, the AEC industry must internalize technological changes and new business models [1, 3, 10]. Understanding the productivity impact of BIM at each stage is crucial for accelerating adoption.

3. RESEARCH METHODOLOGY

To address the research questions, a bibliometric analysis, co-citation, and content review were carried out. Bibliometric analysis refers to applying mathematical and statistical methods to publications, as defined by the person who coined this term [37].

Co-citation, a bibliometric method [38], examines how frequently two previous publications are cited together in a subsequent one. Its strength is determined by the number of

authors who cited both publications, creating a relationship between citing authors. Documents, authors, or journals selected through co-citation are considered more relevant in their field [39, 40].

Co-citation analysis is performed on cited documents, not the original sample. To obtain a broader yet clear view, cutoff points were established as follows: documents cited three or more times and sources mentioned five or more times. The calculation was performed using the bibliometrix package [41]. The Louvain algorithm was applied for clusters [42] and Kamada-Kawai for visualization.

Content analysis is a systematic process to evaluate printed and electronic documents [43]. Its main goal is to adapt sampled material into a communication model, considering authors' experiences and opinions [44]. Several techniques are applicable based on objectives and analysis type [45], which are applied based on the research objectives and the type of analysis desired. The inductive method was systematically used for this research, adapted to the research context, as shown in Fig. (1).

The definition of analysis categories and the level of abstraction are the central parts of content analysis [43, 45]. The categories and analytical units were defined based on theoretical references, contents extracted from the articles themselves, and references used by the AEC industry, as shown in Table 1 in the supplementary files. The AEC industry uses BIM dimensions up to 10D, although there is little consistency between dimension references beyond the 5D dimension. The categories were used to perform frequency analysis in the final part of the article.

Table 1. Systematic assessment framework for gray literature selection in bim productivity research [48].

Assessment Dimension	Evaluation Criteria	Quality Indicators & Evidence (References)
Authority	<ul style="list-style-type: none"> • Institutional Affiliation, • Author Expertise, • Professional Recognition, • Academic Credentials 	Technical reports from government BIM initiatives [9], Doctoral theses [71], Expert opinions [70]
Accuracy	<ul style="list-style-type: none"> • Methodological Rigor, • Data Validation Process, • Documentation Quality, • Peer Review Status, • Reference Standards 	Empirical evidence [74], Validated metrics [77]
Coverage	<ul style="list-style-type: none"> • Scope Definition, • Population Specification, • Contextual Boundaries, • Methodological Framework 	Project lifecycle stages [78], Industry sectors [80]
Objectivity	<ul style="list-style-type: none"> • Balanced Presentation, • Stakeholder Perspectives, • Bias Recognition, • Evidence-Based Claims 	Mixed methods approaches [4], Multiple viewpoints [36]
Date	<ul style="list-style-type: none"> • Publication Period (2009-2023), • Content Currency, • Version Control, • Update Status 	Contemporary relevance [16], Temporal context [30]
Significance	<ul style="list-style-type: none"> • Research Contribution, • Practice Relevance, • Industry Impact, • Knowledge Gap Address, • Innovation Value 	Implementation insights [82]. Productivity metrics [84]

Adapted from AACODS framework and applied to BIM productivity research context [48].

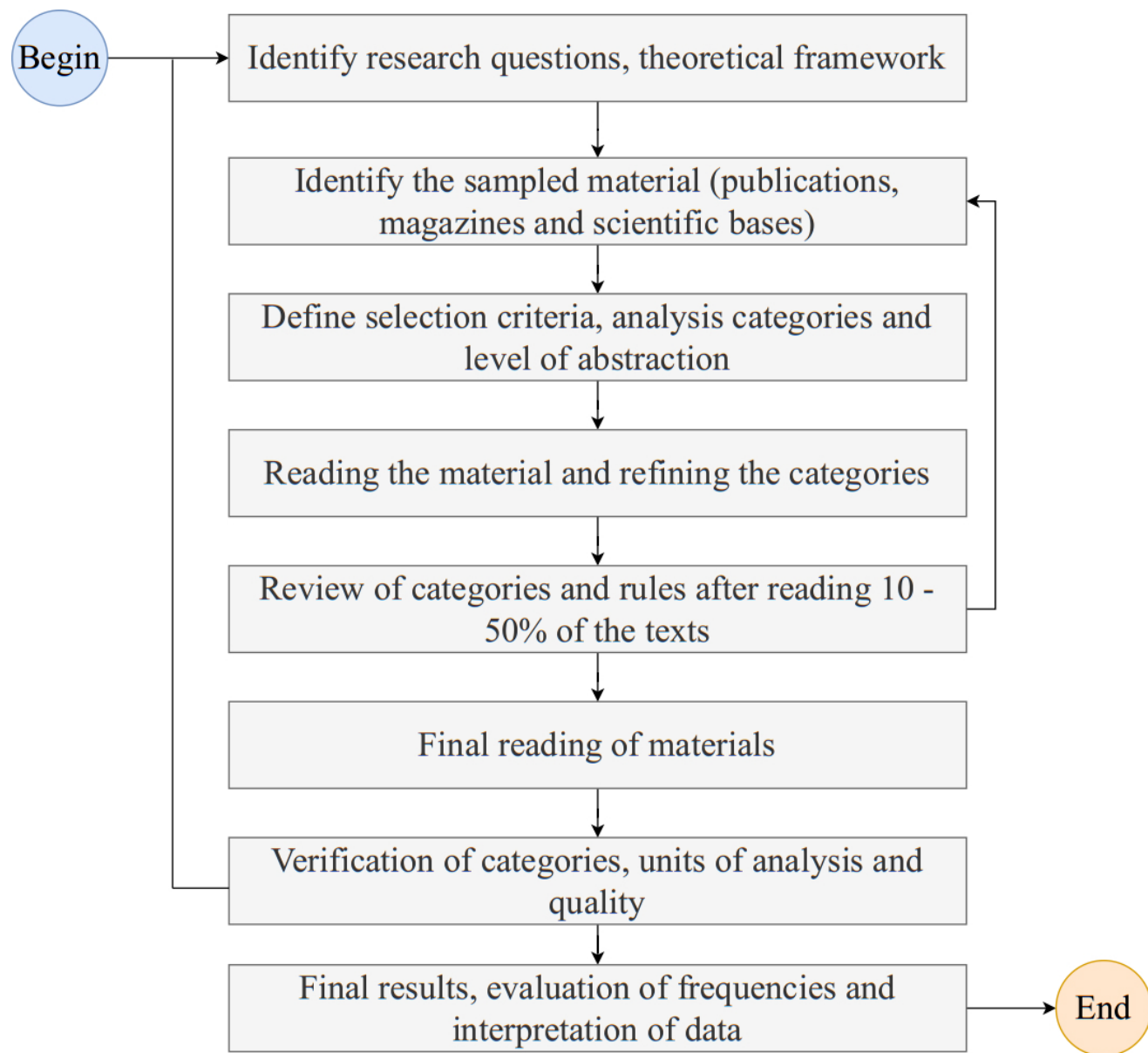


Fig. (1). Inductive content analysis process adopted in this research [45].

The articles were read, and data and information were extracted from the documents through the interpretation of texts, graphics, and existing images. The categories served as references for information searching. The “productivity indicator” variable was interpreted and grouped according to the data collected by the authors. The extraction, interpretation, and data and information entry processes were carried out manually without using any automated tool.

To perform a quality assurance of the categories, the results of the document coding were presented in two workshop sessions, each lasting an hour, for professionals and researchers in the AEC (Architecture, Engineering, and Construction) industry. The industry professionals had experience contracting services and projects in public

agencies in Rio de Janeiro. Participant 01 had over 15 years as a civil construction project development and bidding manager, while Participant 02 had 10 years in the same field. Two seasoned civil construction and BIM methodology researchers participated in the presentation, one with over 20 years of academic experience and the other with 10 years, both holding doctoral degrees.

The participants confirmed that the codes used were appropriate and represented the main analysis categories for this type of study. Following the group's confirmation, the interpretation and analysis of the obtained results continued.

3.1. Identification of Publications

To identify relevant publications in the field of pro-

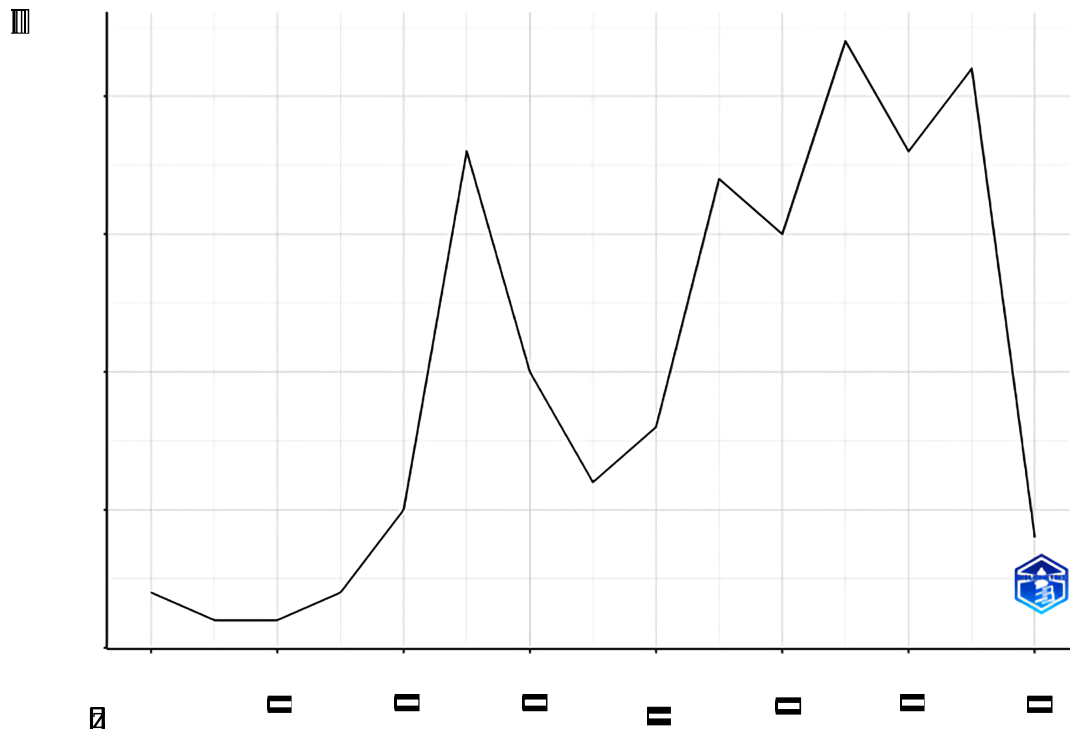


Fig. (3). Annual scientific production.

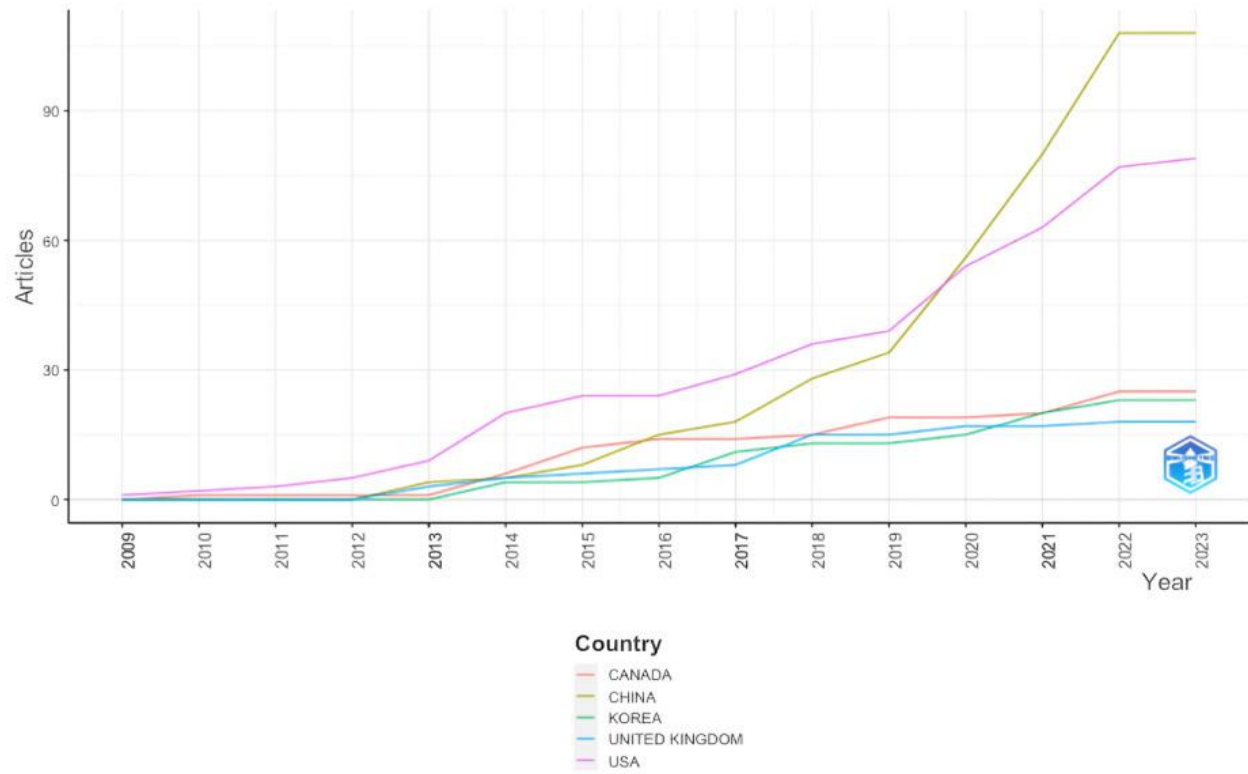


Fig. (4). Evolution of articles from 2009 for top five countries.

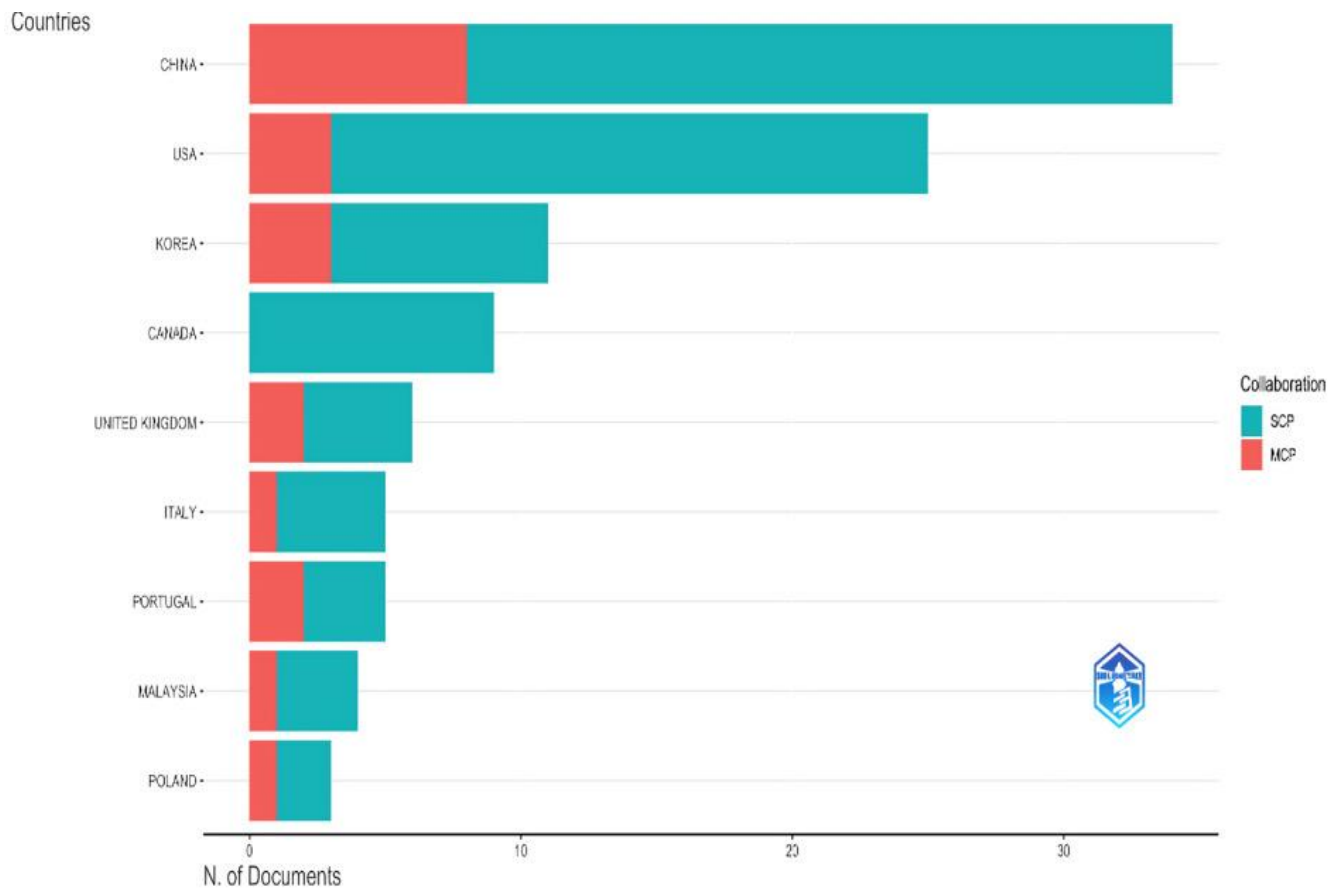


Fig. (5). Number of publications by country, individually or in collaboration.

The proportion of articles between the two leading global research divisions is quite different. Just over 10% of the articles are related to the SSH area, while 90% pertain to STEM disciplines. Furthermore, within the STEM disciplines, Engineering and Technology dominate. This finding aligns with the facilitating factors for the existence of BIM, which are technology use and the digitization of an engineering domain [10].

Research related to BIM and productivity tends to be predominantly conducted by researchers from the same country, also called Single Country Publishing (SCP), as shown in Fig. (5). China has the most multiple country publishing, indicating that its researchers collaborate globally. An initial analysis might suggest that research in this field tends to be less internationalized. However, this cannot be definitively stated since the internationalization process can also occur through knowledge exchange, conference participation, seminars, and visits by international researchers [49].

For analyzing collaboration between countries, network analysis was utilized. This analysis identifies the countries of origin of the researchers from the publications' metadata. When there is more than one author on

a paper, the relationship between countries is explicitly established. Fig. (6) displays the international collaboration network among the 50 countries with the highest scientific production with at least one connection. The predominant influence of China and the United States, leading the two main clusters, is evident. These countries are orbited by nations from Europe, Oceania, Latin America, and Eastern Europe, which have a more diffused collaboration network. Three other smaller, less dominant clusters are formed, likely stemming from specific collaborations or themes. The circle diameters are proportional to publication numbers, line thickness represents the number of existing collaborations, and colors represent clusters formed by proximity. Links are shown starting from a single connection between countries.

Fig. (7) displays the collaboration network among various research institutions. Collaboration mainly occurs between institutions within the same country, with a few instances involving institutions from different countries. Eight institutional collaboration clusters were formed, with the largest collaboration network consisting of four institutions. Five collaboration networks consisted of only two institutions; in these cases, the institutions were from the same country of origin.

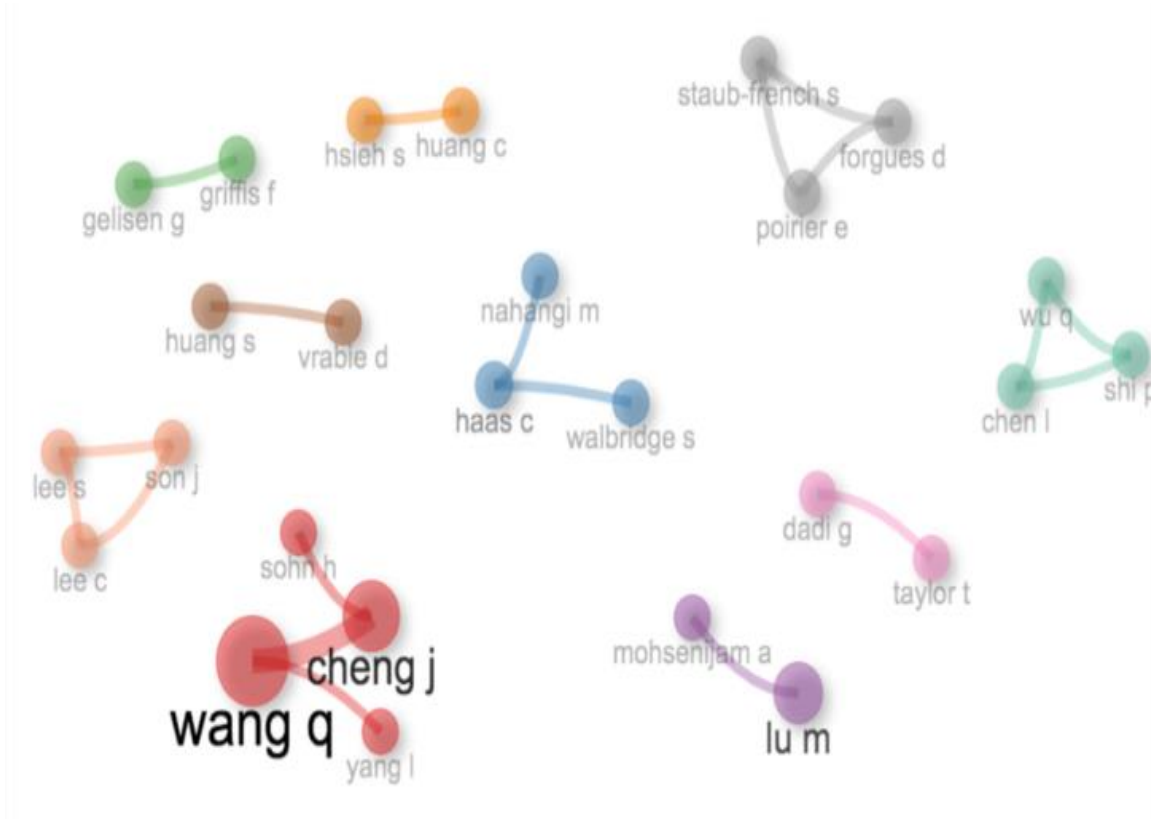


Fig. (8). Collaboration network among the 26 researchers with the highest scientific production.

Following the same pattern of institutional collaboration, Fig. (8) displays the collaboration among authors. In total, ten clusters were formed, with a notable cluster led by Wang Q, which is the only one consisting of 4 researchers. The remaining clusters have either three or two authors in the same group. The collaboration between authors suggests that these clusters generally address the same topic since they share the same references among them. The colors represent the clusters that were formed by association, the size of the circles indicates the number of publications, and the line thickness represents the number of existing collaborations.

The analysis of collaboration patterns, be it at the level of countries, institutions, or individual authors, highlights a hierarchical structure in scientific production and collaboration in the given field. Countries, such as China and the United States emerged as primary hubs of research activity, leading large clusters of international collaboration. Similarly, at the institutional level, collaboration primarily stays within national boundaries, emphasizing the significance of domestic research alliances. The author-based collaboration further reaffirms this observation, where most clusters are formed by authors focusing on similar topics and sharing references.

4.2. Citation Analysis

The most cited documents are presented in Table 4 in the supplementary files. A review of this list unveils the foundational knowledge on the topic of productivity for the BIM methodology and provides insights into which pro-

ductivity topics are tackled using BIM. This is further explored in the co-citation analysis. The most cited document is Li *et al.* [50], with 222 citations. The top of the list is dominated by articles about the impact of BIM methodology implementation in civil construction, the integration of sustainability practices into the BIM methodology, and the application of digital technologies integrated with the BIM model's parametric data. It can be observed that publications from 2019 onward focus on the adoption of new technologies to parametric models generated with the BIM methodology [51-53].

Applying Bradford's law of dispersion to the document base of this analysis yielded three groups [54], with Group 1 being the primary source group. Table 5 in the supplementary files displays the outcome of this law's application, offering a practical look at its behavior and its significance in document analysis. It can be seen that only 14 out of 108 total sources account for 1/3 of all documents published on the subject of productivity using the BIM methodology. The remaining groups account for this dispersion of documents across the following 100 sources. This behavior, known as the "long tail," is common in this type of bibliometric analysis when examining the publication distribution frequency by sources [55].

In accordance with the application of Bradford's law, Table 6 in supplementary files lists the 14 primary sources of published documents, all of which are included in Group 1. Notably, the most cited journal is "Journal Automation

in Construction” with 15 citations, three times that of the second on the list, “Buildings”. The top of the list features a journal with an impact factor of 10.517 and a citation score of 15, specializing in the application of computational methods and technology to civil construction throughout any stage of the lifecycle. However, the majority on the list are journals related to civil construction and architecture, suggesting that productivity using BIM is of interest to this industry sector and not just the new technology domain. There are also conference and symposium sources, highlighting the nature of collaboration in this field as previously explored. In the sixth position, there is a journal called “Sustainability”, which adopts an interdisciplinary scope, covering a wide range of sustainability aspects for various industries.

Table 4. 25 most cited documents on the topic of productivity in BIM.

Total Citations	Document
222	LI H, 2015, SAF SCI
90	SUERMAN PC, 2009, ELECTRON J INF TECHNOL CONSTR
89	OLAWUMI TO, 2018, SUST CITIES SOC
82	BOSCHE F, 2014, AUTOM CONSTR
67	ZHANG W, 2018, J CLEAN PROD
59	POIRIER EA, 2015, AUTOM CONSTR
58	FU P, 2021, FRONT OPTOELECTRON
47	NAHANGI M, 2014, ADV ENG INFORM
44	HANNA A, 2013, J CONSTR ENG MANAGE
43	YANG L, 2020, AUTOM CONSTR
41	BOKTOR J, 2014, J MANAGE ENG
40	JIN R, 2018, ENG CONSTR ARCHIT MANAG
40	MCGUIRK CM, 2018, J AM CHEM SOC
39	WANG Q, 2018, J COMPUT CIVIL ENG
39	ZHANG G, 2015, COMPUT-AIDED CIVIL INFRASTRUCT ENG
37	QIN X, 2020, J CIV ENG MANAG
36	MARZOUK M, 2018, SAF SCI
36	BAGINSKI M, 2020, ADV MATER
34	RATAJCZAK J, 2019, BUILDINGS-BASEL
34	ROCHA G, 2020, HERITAGE
33	SIMONIN K, 2013, APOPTOSIS
32	KWIATEK C, 2019, AUTOM CONSTR
31	MA Z, 2014, PROCEDIA ENG
29	LEE J, 2017, AUTOM CONSTR
29	GUO H, 2018, J CONSTR ENG MANAGE

4.3. Co-citation Analysis

Four intellectual structure groups represent the knowledge base of the literature discussing productivity using the BIM methodology. Fig. (9) displays the formed groups and their relationships. These groups were labeled as: red group: technologies for automating the as-built process; blue group: scanner technologies for measuring construction progress; green group: quality assessment of

3D geometric models; orange group: low-cost technologies and methods for the as-built process; and purple group: return on investment from BIM adoption.

Table 5. Bradford's law applied to BIM publications in scopus and WoS.

Group	Document Count	Source Count
Group 1	51	14
Group 2	51	45
Group 3	49	49
Total	151	108

Table 6. Main publication sources on the topic of productivity using the BIM methodology.

Published Documents	Sources
15	Automation in Construction
5	Buildings
5	Journal of Construction Engineering and Management
3	Canadian Journal of Civil Engineering
3	IOP Conference Series: Earth and Environmental Science
3	Journal of Asian Architecture and Building Engineering
3	Sustainability
2	31st International Symposium on Automation and Robotics in Construction and Mining, ISARC 2014 - Proceedings
2	Advanced Materials Research
2	Applied Sciences
2	Communications in Computer and Information Science
2	Computer-aided Civil and Infrastructure Engineering
2	Construction Research Congress 2022: Computer Applications, Automation, and Data Analytics - selected papers from construction research congress 2022
2	Energy and Buildings

There are four interconnected groups, with only one isolated. The connection among the four groups occurs due to the central use of technology in the BIM methodology, which is one of the significant enablers for its adoption.

The proximity of these groups concerning technology indicates that debates on productivity with BIM applications are directed towards i) improving the as-built process, ii) automating the assessment of construction progress, and iii) analyzing the quality of geometric models. The purple group is isolated and discusses the investment in BIM adoption and general construction performance indicators.

Fig. (10) displays the co-citation network of cited sources. The algorithm originally identified five clusters for the document co-citation analysis of the cited source ; however, one consisted only of conference papers and was treated as an outlier; thus, it was excluded. The four remaining groups were labeled: red group: Journals on technology and computing applied to civil engineering; blue group: Journals on sustainability and energy; green group: Journals on sensing and chemistry; and purple group: Journals on chemistry and materials.

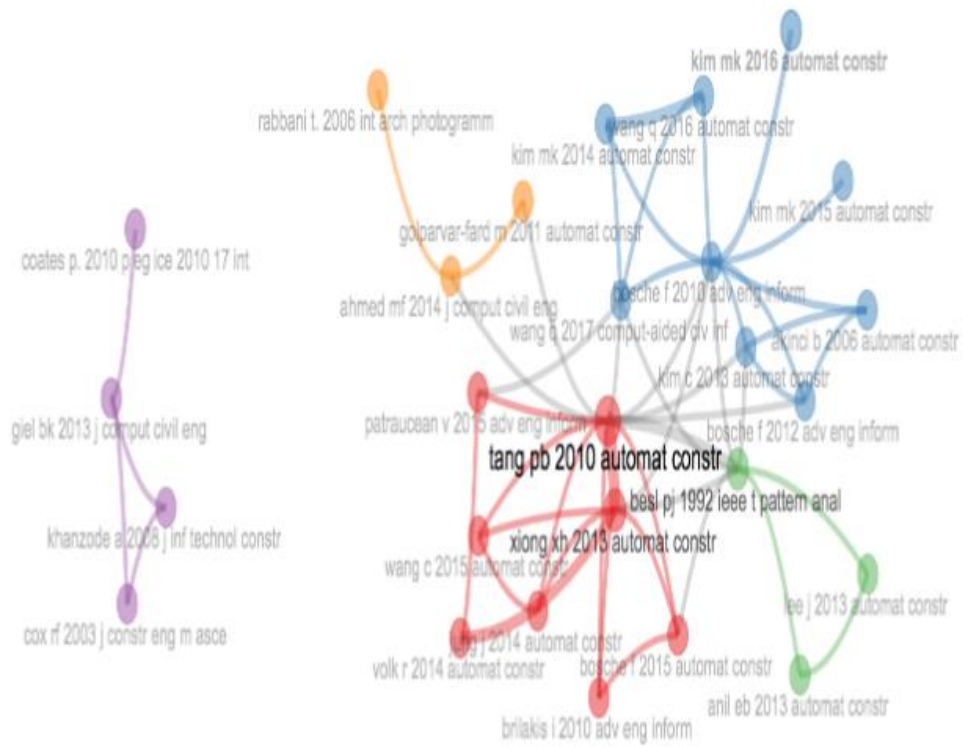


Fig. (9). Co-citation network of works for the groups.

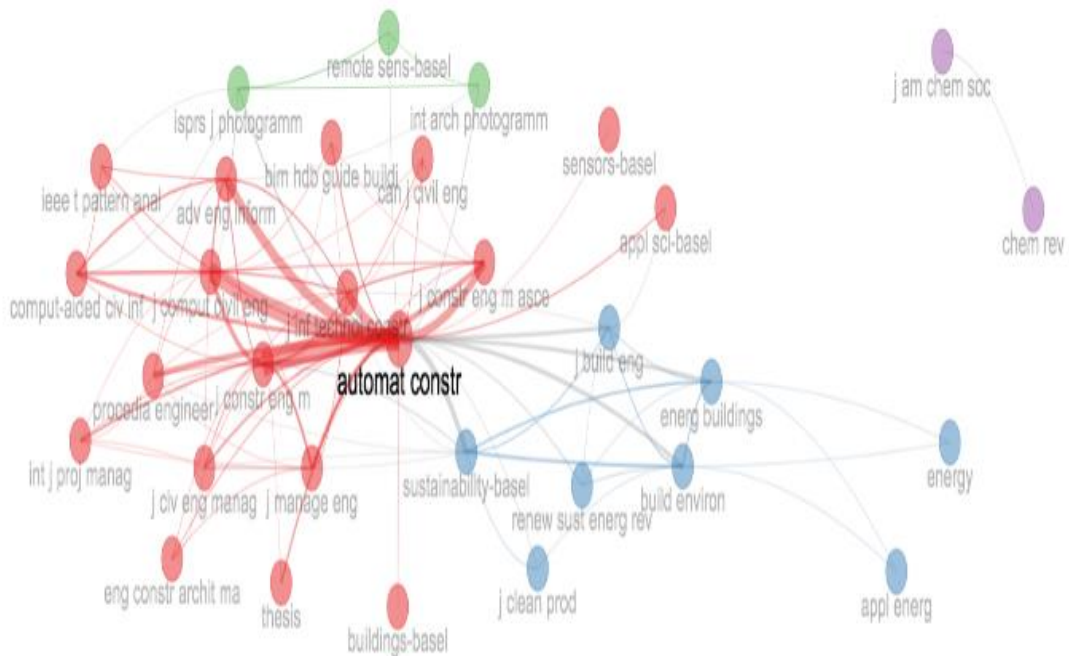


Fig. (10). Co-citation network of cited sources.

The red and blue groups have a strong connection. The red group focuses on applying technologies to the AEC

industry, primarily covering building construction topics. In contrast, the blue group deals with themes spanning

various industries, such as sustainability, energy, and clean production. The green and purple groups are almost isolated and revolve around the two main groups with minimal or no thematic connection.

In conclusion, high citations for the “Automation in Construction” source suggest that technological issues to improve construction processes dominate productivity discussions with BIM adoption. Yet, citations from other journals reveal the interest of a scientific community in productivity in broader fields (*e.g.*, building performance, energy efficiency, or BIM methodology ROI analysis).

Out of the five groups from the document co-citation analysis, only one addresses productivity research for BIM adoption. This implies that most research studies focus on using and applying technologies to enhance civil construction productivity integrated with BIM. Interestingly, the latter cannot occur without the former. In other words, one cannot use technology, considering there is the BIM methodology (geometric and parametric models), without thoroughly discussing productivity and improvement factors stemming from its adoption. This topic will be addressed in more depth in content analyses.

The analysis can serve as guidance for defining future research agendas since the method identified the most impactful publications used by the technology, civil engineering, and science community members who expressed their opinions by citing these documents.

4.3.1. Validation of Bibliometric Results

The identified bibliometric patterns find validation in both the internal structure of the analysis and previous studies on BIM evolution. The observed geographic concentration in China and the United States (73% of publications) (Figs. 4, 5) reflects the findings of Lu *et al.* [20], who documented a similar trend in their BIM implementation analysis, attributing it to proactive government policies and technological maturity. This geographic dominance is further validated through the international collaboration network analysis (Fig. 6), revealing clusters consistent with those reported by Jones *et al.* [31] in their study on global BIM adoption.

The temporal evolution of BIM productivity research (Fig. 3) shows a progression that aligns with the maturity framework proposed by Succar [7], showing a transition from basic implementation studies to more sophisticated research in automation and performance analysis. This progression is additionally validated by Siebelink *et al.* [30], who identified similar patterns in the evolution of organizational BIM capabilities reflected in the co-citation clusters (Fig. 9).

The concentration of publications in specific sources, validated by Bradford's analysis (Table 5), where 14 main sources represent one-third of publications (Table 6), aligns with the findings of Thomé *et al.* [46] on typical literature distribution in operations management. This distribution reflects the field's specialization and knowledge

consolidation in high-impact journals, a pattern also observed by Saieg *et al.* [12] in their systematic review of BIM.

5. DISCUSSION

Scoping reviews are designed to swiftly outline the primary ideas central to a research domain, highlighting major sources and varieties of evidence at hand. They are particularly valuable as independent projects, especially in intricate areas or those not yet extensively reviewed [56]. This work used content analysis to summarize all details related to the evaluated documents. The nomothetic approach was used, which seeks to generalize the results found from the evaluated documents in an aggregated manner. Thus, the identification of themes common to the evaluated documents was sought, particularly regarding the approach to productivity topics using the BIM methodology.

Table 7 below summarizes the characteristics of the examined studies by evaluation themes. It is evident that there is a dominance of “case study” and “survey” research types, which account for just over 70% of the reviewed documents. Case studies often propose applying the BIM methodology and comparing the results of their models with those generated in the traditional way. They typically report comparative results between one methodology and another, aiming to demonstrate the effectiveness of the BIM methodology compared to conventional methods. “Survey” type research evaluates the success factors of implementing the BIM methodology and the assessment of BIM maturity in architectural offices or public administration agencies.

It is observed that almost half of the documents do not identify the BIM dimension in which their models were worked. In some “survey” type research, it is impossible to establish the BIM dimension, as several companies or projects were evaluated. Nevertheless, it was possible to observe that the level of BIM utilization is still at an early stage and limited to activities currently performed by architectural offices, such as geometric and parametric design or modeling (3D), planning and scheduling analysis (4D), and estimation of quantities and costs (5D). Only two BIM applications in the 5D dimension were observed in the studies. Considering the life cycle stages of the projects, there is a broad application of the productivity theme using the BIM methodology for the preliminary design stages or the application in the pre-design and construction stages. The indicators used are related to the quality of projects and models, cost comparisons between traditional models and BIM models, and less about the actual productivity of the modeling work teams.

Such findings emphasize the scarcity of studies discussing the productivity of the project modelling teams in the pre-project phase. The still-emerging state of the BIM methodology is demonstrated by the nature of the studies, which aim to justify the benefits of the BIM methodology or a way to obtain a return on their investments and reviews and surveys exploring critical success factors.

Table 7. Characteristics of the articles reviewed.

Id	Article	Type of Research	Type of Building	BIM Dimension	Project Lifecycle
1	[57]	Case study	Sports centre	3D	Pre-project and construction
2	[17]	Action research	Multi story	3D	Construction
3	[19]	Action research	Industrial	-	Pre-project and construction
4	[21]	Survey	Several	-	-
5	[58]	Modelling	-	-	Pre-project
6	[59]	Case study	Multi-story	-	Construction
7	[60]	Case study	Infrastructure	5D	Pre-project and construction
8	[61]	Survey	-	-	Pre-project and construction
9	[18]	Modelling	Commercial	4D	Pre-project
10	[19]	Action research	Commercial	3D	Pre-project and construction
11	[62]	Survey	Residential	3D	Pre-project
12	[57]	Survey	-	-	-
13	[4]	Mixed methods	-	-	-
14	[36]	Modelling	Hotel	3D	Pre-project and construction
15	[63]	Modelling	-	-	Pre-project
16	[64]	Survey	-	-	-
17	[65]	Modelling	Commercial	4D	Pre-project
18	[66]	Survey	-	-	-
19	[67]	Survey	-	-	Pre-project and construction
20	[68]	Case study	Residential	-	Pre-project
21	[69]	Survey	-	-	-
22	[70]	Survey	Highways	-	-
23	[71]	Case study	Health unit	4D	Construction
24	[72]	Case study	sMulti-story	5D	Pre-project
25	[73]	Case study	One floor commercial	3D	Pre-project and construction
26	[74]	Case study	Retrofit	3D	Pre-project
27	[75]	Case study	Passenger terminal	4D	Pre-project
28	[76]	Survey	-	-	-
29	[77]	Constructive research	Multi-story	3D	Pre-project
30	[78]	Case study	Multi-story	3D	Pre-project
31	[79]	Survey	-	-	-
32	[80]	Case study	One floor commercial	5D	Pre-project
33	[81]	Case study	Multi-story	5D	Pre-project

In the next section, a more detailed interpretation of the thematic groups identified through variables such as the type of projects, stages of the life cycle, and their respective indicators and indexes was carried out.

5.1. Interpretation of Thematic Groups

5.1.1. Types of Projects

The BIM methodology is a new approach to the process of designing, constructing, and managing assets and can be applied to any project [2]. Despite the widespread application of the BIM methodology to any project type, there seems to be a consensus among researchers that more complex projects benefit more from the use of BIM as a form of risk management [1, 10, 11], and also as a way to improve return on investment [20, 82]. Thus, the documents were grouped according to three types of projects with similar characteristics and complexity: residential buildings, commercial buildings, and industrial or specific buildings.

Eight documents, encompassing one—or multi-story

constructions, represented residential building projects. These documents were mostly case studies for the application of the BIM methodology and comparison with traditional project and construction methods. In this regard, the indicators used sought to represent the relative percentage difference between the two evaluated methods.

A characteristic of the application studies for this type of project is the selection of a specific activity for comparison. The comparison between methodologies was also limited to the initial BIM dimensions, notably 3D. In this dimension, it is possible to perform the geometric comparison of objects and elements and establish project compatibility, one of the main factors causing issues in construction [2]. Only two studies used the 5D dimension for project modeling, thereby obtaining project indicators with planning and cost information. Additionally, these studies show a comparison between the two modeling methodologies, traditional and BIM.

Commercial projects, comprising one or multi-story constructions, represented seven documents, three of

which were case studies for the application of the BIM methodology and comparison with traditional project and construction methods. Comparative indicators were used, aiming to represent the relative percentage difference between the two evaluated methods. Indicators were applied to assess the difference between the indicators for evaluating the number of interferences and the project quantity sheet [73, 80]. Three other studies proposed techniques for automating productivity analyses [18, 65]. It was also noted that four documents were used in the pre-project stages up to the construction phase. This also reflects the types of indicators adopted by the research, where some are geared towards evaluating the construction phase, such as (estimated/realized), waste management, and construction management. Other indicators were adopted to assess team productivity for different activities (estimated/realized), budget performance (estimated/realized), and model quality (number of reworks).

The industrial or specific projects include industrial constructions or special constructions (sports centers, art works, and highways). This group had 6 documents, and 5 were case studies for the application of the BIM methodology. However, in contrast to what was observed in the previous two groups, these studies did not aim to compare the BIM methodology to traditional methods but aimed to obtain and report the benefits of BIM adoption in projects. This may indicate that there is already knowledge of the benefits of adopting the BIM methodology in more complex applications [19, 31, 36].

Furthermore, 12 studies did not fit into these defined project groups, and 75% were of the “survey” type. These types of studies sought to deepen knowledge on a specific topic - evaluating the industry concerning BIM use, identifying success factors or the impact of the BIM methodology, and the state of BIM practice in public organizations. Therefore, they tended not to be so specific as to be categorized into just one typology. Some of these studies used specific indicators, based on the emphasis of their analyses and the research questions they wanted to answer. The indicators used by these studies aimed to

assess model quality aspects like rework, project changes, and information requests [4, 83]. However, other studies sought to evaluate indicators related to construction works and team productivity in construction activities or monitor managerial aspects of the works [57, 66, 67].

From this thematic analysis by project type, it can be observed that as project complexity increases, academia shows more interest in analyzing and using productivity indicators more oriented towards the performance of mechanical and electrical assembly teams. One indicator that appears in all types of projects is the identification of project interference, seen by various authors and surveys as one of the main motivators for applying the BIM methodology for model development [1, 2, 19, 31, 84, 85].

The establishment of standardized productivity indicators for BIM implementation requires a multi-faceted strategic approach. According to a previous study [23], successful standardization must integrate technological, organizational, and environmental dimensions while considering industry-specific challenges. This aligns with recent findings [85], which demonstrated that standardized indicators should be mapped across different project lifecycle stages and organizational levels to ensure comprehensive coverage. To operationalize these standards, a recent study [11] proposed a framework that combines both quantitative metrics (such as time, cost, and resource utilization) and qualitative indicators (including quality, safety, and stakeholder satisfaction). Furthermore, another study [10] emphasized that standardization efforts must address three key areas: technical interoperability standards, performance measurement protocols, and process workflow guidelines. To implement these standards effectively, organizations should adopt a phased approach (see Table 8), beginning with basic productivity metrics and gradually incorporating more sophisticated indicators as BIM maturity increases [30]. This strategic framework, detailed in Table 8, provides a practical roadmap for industry practitioners while ensuring sufficient flexibility to accommodate different organizational contexts and project requirements.

Table 8. Progressive framework for BIM productivity indicators based on maturity levels.

Maturity Level	Focus Areas/Refs.	Key Productivity Indicators	Implementation Guidelines
Basic Level 1	3D Geometric Modeling [86], Basic Documentation [87]	Model accuracy rate [%], Design review cycle time [days], Clash detection efficiency [number of conflicts/week]	Start with fundamental modeling metrics and basic workflow measurements
Intermediate Level 2	4D Schedule Integration [88], 5D Cost Analysis [89]	Schedule compliance rate [%], Cost estimation accuracy [%], Resource utilization efficiency [planned vs. actual], Cross-discipline coordination time [hours]	Integrate time and cost metrics with existing indicators
Advanced Level 3	Multi-disciplinary Integration [90], Performance Analysis [91]	Project delivery efficiency [planned vs. actual duration], Team collaboration index [based on information exchange rates], Change order reduction rate [%], Energy performance optimization [kWh/m ²]	Focus on integrated performance metrics across disciplines
Optimized Level 4	Lifecycle Management [92], Predictive Analytics [93]	Operational efficiency [maintenance cost reduction], Asset performance index, Sustainability metrics [carbon footprint], ROI on BIM implementation [%]	Implement comprehensive lifecycle indicators with predictive capabilities

Table 9. Metrics used grouped by project stage.

Productivity Indicator Used Followed by the Unit	Article Id.
Pre-project	-
EPI - Energy Performance Index (Energy Performance)	[5]
Total project duration [days], activity duration [days], and total labor cost [USD]	[10]
Project team productivity [qualitative]; modeling time [hours]; number of errors [units], and project interference [units]	[34, 32, 12]
Employee productivity rate [unit/person-hour]; number of work cycles [units]	[19]
Time taken for quantity estimation [hours] and costs [USD]	[21]
TCPO and SINAPI productivity indices [%]	[30]
Number of criteria in accordance with the standard [units]	[36]
Comparison of quantities across various disciplines [% deviation]; comparison of project execution costs for disciplines [USD]	[39, 37, 40]
Pre-project and construction	-
Number of detected interferences [units]; number of resolved conflicts [units]; labor cost [USD]; rework rate; equipment operation time [qualitative]; operation costs [qualitative].	[31, 13]
Productivity [forecast/actual], scope performance [number of Requests for Information (RFI) and change requests], budget performance [actual/planned], schedule performance [actual/planned], project quality [amount of rework].	[11]
Total construction time [days] and total project cost [USD]	[8]
Quality control [amount of rework], schedule control [qualitative], cost control [qualitative], safety [qualitative], cost per unit [unit/person-hour]	[9]
Productivity and productivity rate of the mechanical assembly team [units/person-hour]	[18, 3]
Conflict reduction [amount], rework cost reduction [qualitative], error reduction [qualitative], as-built cost reduction [qualitative], reduction in information requests [amount].	[23]
Construction	-
Daily construction productivity [work completed in a day/person-hour], adherence to the plan [work done/planned work]	[7, 2]
Reduction of construction waste [m3]; increased productivity in facility execution [qualitative], average daily assembly [units assembled/number of workdays].	[29]

This progressive framework provides organizations with a structured approach to implementing BIM productivity indicators based on their maturity level. As suggested by Siebelink *et al.* [30], organizations should focus first on mastering basic indicators before progressing to more complex metrics. Each level builds upon the previous one, ensuring sustainable development of BIM capabilities while maintaining measurable productivity improvements. This staged approach aligns with previous findings [85] on the importance of systematic integration across project lifecycle stages, while addressing the emphasis on comprehensive standardization efforts suggested in another study [10]. The framework provides clear operational guidance while maintaining sufficient flexibility for adaptation to specific organizational needs and project requirements.

5.2. Project Life Cycle Stages

The BIM project development methodology should be adopted throughout the life cycle of an enterprise to maximize its benefits and optimize the return on investment made [30, 31]. Recent bibliometric evidence supports this view, highlighting how digital transformation through BIM needs to span all project stages to realize its full potential [16]. However, the reviewed studies did not identify any application in the subsequent phases of building construction, such as operation, maintenance, dismantling, and demolition. Out of the analyzed studies, 13 addressed the pre-project phase, 8 covered both the pre-project and construction phases, 3 focused on the construction phase, and 9 studies did not address a

specific area and hence could not be classified under this variable. Table 9 presents the indicators grouped by the project life cycle stages.

Studies focusing on the pre-project phase showed a heightened interest in analyzing project interferences, quantifying construction items (materials and services), and planning and budgeting items. Thus, it is evident that such indicators reflect the project planning aspects inherent to this phase preceding the construction works.

Studies that centered their analyses on the pre-project and construction phases demonstrated an interest in analyzing the productivity of their construction teams and project quality (number of interferences). Some studies assessed rework rates and made comparisons with previous projects (without the adoption of the BIM methodology) to ascertain benefits. Therefore, a significant portion of the indicators is directed towards analyzing various project items, including costs, labor productivity, and schedules, comparing what was planned with what was executed on-site.

Some studies also focused on modeling technologies or processes for automatically verifying work progress and field team productivity.

The studies that focused on the construction phase exclusively displayed an interest in analyzing the productivity of their construction teams or the overall performance of the construction (*e.g.*, Reduction in waste generation). The aim of these studies was to verify planning adherence to what was achieved for specific activities or cost items. These indicators aim to cater to the interests of work executors, whether contractors or construction companies.

Table 10. Research questions.

Pre-design Stage
1. What is the productivity difference between teams in the pre-design phase using traditional methodology versus BIM methodology?
2. What is the impact of the development level on team productivity in the pre-design phase using traditional or BIM methodology?
3. How to establish common productivity indicators for project analysis and compatibility using BIM methodology?
4. How to establish common productivity indicators for building performance using the BIM methodology? (energy efficiency, lighting, security, building safety)
Construction Stage
5. How to expand the spectrum of productivity analysis in the construction industry, adopting other indicators like safety, environment, and materials management through BIM methodology?
Operation Stage
6. How to integrate equipment control and operations using BIM methodology?
7. How to incorporate sensors for the analysis and monitoring of building productivity?
8. How to integrate control and operations of buildings during the occupation and operation phase?
Entire Life Cycle
9. Which productivity indicators can be adopted for BIM dimensions above 5G?
10. How to ensure the integration of project productivity indicators across all life cycle stages using the BIM methodology?

5.3. Research Agenda

The assessed studies showcased a diversity of productivity indicators applied to the pre-design and construction stages, spanning three project typologies, from the simplest to the most complex, based on the number of disciplines and details necessary for construction. The synthesis of indicators showed better adherence according to the project life cycle stages. Considering productivity indicators, some received more attention from the research community, while others still require further research in the future.

Formulating clear and specific research questions based on the analyses and discussions presented in the previous sections is an effective strategy to identify potential directions for future research in the field of productivity using the BIM methodology. Table 10 presents a series of research questions designed to guide new studies following this theme.

Regarding the pre-design stage, studies on building performance and productivity within the context of all project stakeholders, considering operational aspects in asset design, could be considered. Knowing that the sustainability of the civil construction supply chain needs to be advanced [94], studies on building energy simulation, lighting, and waste generation will be highly relevant in the future. Few studies in the literature deal with integrating project aspects and operational productivity assessed through the BIM methodology. Furthermore, it is common among authors that the AEC industry is fragmented across project life cycle stages, and there is an ongoing debate in the literature about setting competing objectives among different project actors, depending on interest and life cycle stage [27]. In this sense, research focusing on establishing goals and productivity indicators common to all life cycle stages is essential.

5.4. Validation of Content Analysis Results

The content analysis validation is supported by multiple lines of evidence that converge with previous research. The identified distribution of project types (Table 7) finds support in the work of Cao *et al.* [1], who documented a similar distribution in their analysis of BIM implementation

motivations. The predominance of studies in the pre-project and construction phases (Tables 7, 9) coincides with Wang and Chen's [85] findings, who identified these stages as critical for BIM-project management integration.

The identified productivity indicators (Table 9) are validated through their alignment with established frameworks. For example, the categorization by life cycle stages coincides with the model proposed by Park [28], who emphasized the importance of evaluating productivity across different project phases. The progression of indicators from basic to advanced (Table 8) finds validation in the work of Poirier *et al.* [19], who documented a similar evolution in BIM performance measurement.

The validity of the proposed progressive indicator framework (Table 8) is reinforced through its alignment with recent studies and identified thematic clusters (Figs. 9, 10). Dixit *et al.* [26] identified similar patterns in the evolution of construction productivity metrics, while Zavadskas *et al.* [11] validated the importance of phase-specific indicators in risk and project performance assessment. This convergence between our findings and existing literature provides robust validation of the obtained results.

CONCLUSION

The construction industry has always been driven to enhance its productivity, whether in project design, organization, or industry terms. The digitization of the construction industry offers an opportunity to accelerate productivity gains throughout its production and service chains. Various aspects of productivity have been studied with the adoption of BIM, yet its implementation remains a subject of study among academics, and the industry is still assessing its benefits. However, the development and application of the BIM methodology remain nascent and limited to the traditional model of the civil construction industry for evaluating its productivity, as reflected in most articles in this field published over the last thirteen years. This article provided a scoping review of the existing literature on productivity using the BIM methodology, aiming to offer guidance on this subject for scholars and outline clear pathways for future research.

The study identified and classified productivity indi-

cators with BIM application into two distinct categories: by project type and by project life cycle stage, directing future research questions to cover areas that remain insufficiently explored or unexplored. Thus, many unanswered paths remain open for academia concerning productivity using the BIM methodology and its usage to propose new productivity assessment methods. While this scoping review provides valuable theoretical insights into BIM productivity metrics and implementation patterns, we acknowledge the need to validate these findings through empirical evidence from actual construction projects. Future research should adopt a mixed-methods approach that combines systematic literature analysis with comprehensive case studies of BIM-implemented projects across different scales and complexities. This integration would serve to validate theoretical frameworks, document real-world challenges, measure actual productivity impacts, and identify gaps between theoretical benefits and practical outcomes. Additionally, longitudinal studies of BIM-implemented projects could reveal how productivity gains evolve over time as organizations mature in their BIM capabilities, providing valuable insights for standardization efforts of productivity metrics in real-world applications.

Beyond intending to stimulate scientific research, this study also aims to provide members of the construction industry with an overview of discussions on productivity with BIM adoption so they can deepen their knowledge on this topic, its practices, and technologies, aiding in the BIM methodology adoption process and formulating more effective strategies for its implementation and dissemination.

AUTHORS' CONTRIBUTIONS

The authors confirm their contribution to the paper as follows: E.T.C. and A.M.T.T.: Validation; M.C.: Data collection; F.D., C.A.D.S., and R.C.: Draft manuscript. All authors reviewed the results and approved the final version of the manuscript.

LIST OF ABBREVIATIONS

SSH = Social Science and Humanities
SCP = Single Country Publishing

CONSENT FOR PUBLICATION

Not applicable.

STANDARDS OF REPORTING

PRISMA guidelines and methodology were followed.

AVAILABILITY OF DATA AND MATERIALS

The data and supportive information are available within the article.

FUNDING

This research was funded by the National Council for Scientific and Technological Development (CNPq) [Grant numbers: 307173/2022-4, 405734/2023-9, 442384/2023-8], Carlos Chagas Filho Foundation for Research Support

of Rio de Janeiro State (FAPERJ) [Grant numbers: E-26/201.363/2021 (260426), E-26/204.408/2024 (297945)], and Coordination of Higher Education Personnel Improvement (CAPES) [Grant numbers: Finance Code 001]. We also thank the Tecgraf Institute of Technical-Scientific Software Development of PUC-Rio (Tecgraf/PUC-Rio).

CONFLICT OF INTEREST

Dr. Rodrigo Goyannes Gousmao Caiado is Editorial Board Member of journal *The Open Construction & Building Technology Journal*.

ACKNOWLEDGEMENTS

Declared none.

SUPPLEMENTARY MATERIAL

Supplementary material is available on the publisher's website along with the published article.

REFERENCES

- [1] D. Cao, H. Li, G. Wang, and T. Huang, "Identifying and contextualising the motivations for BIM implementation in construction projects: An empirical study in China", *Int. J. Proj. Manag.*, vol. 35, no. 4, pp. 658-669, 2017. [<http://dx.doi.org/10.1016/j.ijproman.2016.02.002>]
- [2] R. Sacks, C. Eastman, G. Lee, P. Teicholz, and B.I.M. Handbook, *A Guide to Building Information Modeling for Owners, Designers, Engineers, Contractors, and Facility Managers.*, John Wiley & Sons, 2018. [<http://dx.doi.org/10.1002/9781119287568>]
- [3] B. Abbasnejad, M.P. Nepal, A. Ahankoob, A. Nasirian, and R. Drogemuller, "Building Information Modelling (BIM) adoption and implementation enablers in AEC firms: A systematic literature review", *Archit. Eng. Des. Manag.*, vol. 17, no. 5-6, pp. 411-433, 2021. [<http://dx.doi.org/10.1080/17452007.2020.1793721>]
- [4] Q. Wu, L. Chen, P. Shi, W. Wang, and S. Xu, "Identifying impact factors of MEP installation productivity: An empirical study", *Buildings*, vol. 12, no. 5, p. 565, 2022. [<http://dx.doi.org/10.3390/buildings12050565>]
- [5] C.A. Schery, "BIM critical factors and benefits for public sector: from a systematic review to an empirical fuzzy multicriteria approach", *Braz J Oper Prod Manag*, vol. 20, no. 3, p. e20231837, 2023. [<http://dx.doi.org/10.14488/BJOPM.1837.2023>]
- [6] S. Jide, N. Qi, and S. Liangfa, "Analysis on current situation and development trend of construction worker's occupational mobility", *Open Constr. Build. Technol. J.*, vol. 9, no. 1, pp. 303-310, 2015. [<http://dx.doi.org/10.2174/1874836801509010303>]
- [7] B. Succar, "Building information modelling framework: A research and delivery foundation for industry stakeholders", *Autom. Construct.*, vol. 18, no. 3, pp. 357-375, 2009. [<http://dx.doi.org/10.1016/j.autcon.2008.10.003>]
- [8] B. Succar, W. Sher, and A. Williams, "An integrated approach to BIM competency assessment, acquisition and application", *Autom. Construct.*, vol. 35, pp. 174-189, 2013. [<http://dx.doi.org/10.1016/j.autcon.2013.05.016>]
- [9] C.A.D. Schery, R.G.G. Caiado, Y.R. Vignon, M. Congro, and E.T. Corseuil, "BIM critical factors-based framework towards digitalization of construction in the public sector", In: J.C. Gonçalves dos Reis, F.G. Mendonça Freires, M. Vieira Junior, Eds., *Industrial Engineering and Operations Management. Springer Proceedings in Mathematics & Statistics.*, Springer Nature Switzerland: Cham, 2023, pp. 315-328.

- [http://dx.doi.org/10.1007/978-3-031-47058-5_25]
- [10] A. Ghaffarianhoseini, J. Tookey, A. Ghaffarianhoseini, N. Naismith, S. Azhar, O. Efimova, and K. Raahemifar, "Building Information Modelling (BIM) uptake: Clear benefits, understanding its implementation, risks and challenges", *Renew. Sustain. Energy Rev.*, vol. 75, pp. 1046-1053, 2017.
[http://dx.doi.org/10.1016/j.rser.2016.11.083]
- [11] E.K. Zavadskas, Z. Turskis, and J. Tamošaitiene, "Risk assessment of construction projects", *J. Civ. Eng. Manag.*, vol. 16, no. 1, pp. 33-46, 2010.
[http://dx.doi.org/10.3846/jcem.2010.03]
- [12] P. Saieg, E.D. Sotelino, D. Nascimento, and R.G.G. Caiado, "Interactions of building information modeling, lean and sustainability on the architectural, engineering and construction industry: A systematic review", *J. Clean. Prod.*, vol. 174, pp. 788-806, 2018.
[http://dx.doi.org/10.1016/j.jclepro.2017.11.030]
- [13] D.L.D.M. Nascimento, and R.G.G. Caiado, "A bibliometric review of building information modeling and green in the construction industry", In: *Annals - Economy Series.*, vol. 4. Constantin Brancusi University, Faculty of Economics, 2017, pp. 90-95.
- [14] D.L.M. Nascimento, O.L.G. Quelhas, M.J. Meiriño, R.G.G. Caiado, S.D.J. Barbosa, and P. Ivson, "Facility management using digital obeya room by integrating BIM-Lean approaches - An empirical study", *J. Civ. Eng. Manag.*, vol. 24, no. 8, pp. 581-591, 2018.
[http://dx.doi.org/10.3846/jcem.2018.5609]
- [15] B.A. Tayeh, Y.I. Abu Aisheh, and I.O. Abuzuhri, "Factors affecting sustainability performance during the construction stage in building projects-consultants' perspective", *Open Constr. Build. Technol. J.*, vol. 14, no. 1, pp. 17-26, 2020.
[http://dx.doi.org/10.2174/1874836802014010017]
- [16] C.A. Diaz Schery, R.G.G. Caiado, S. Aguilar Vargas, and Y. Rodriguez Vignon, "Paths to BIM-based digital transformation: A bibliometric and systematic review of critical factors", *Eng. Construct. Architect. Manag.*, 2024.
[http://dx.doi.org/10.1108/ECAM-12-2023-1230]
- [17] J. Lee, Y.J. Park, C.H. Choi, and C.H. Han, "BIM-assisted labor productivity measurement method for structural formwork", *Autom. Construct.*, vol. 84, pp. 121-132, 2017.
[http://dx.doi.org/10.1016/j.autcon.2017.08.009]
- [18] G. Gelisen, and F.H.B. Griffis, "Automated productivity-based schedule animation: Simulation-based approach to time-cost trade-off analysis", *J. Constr. Eng. Manage.*, vol. 140, no. 4, p. B4013007, 2014.
[http://dx.doi.org/10.1061/(ASCE)CO.1943-7862.0000674]
- [19] E.A. Poirier, S. Staub-French, and D. Forgues, "Assessing the performance of the building information modeling (BIM) implementation process within a small specialty contracting enterprise", *Can. J. Civ. Eng.*, vol. 42, no. 10, pp. 766-778, 2015.
[http://dx.doi.org/10.1139/cjce-2014-0484]
- [20] W. Lu, A. Fung, Y. Peng, C. Liang, and S. Rowlinson, "Cost-benefit analysis of building information modeling implementation in building projects through demystification of time-effort distribution curves", *Build. Environ.*, vol. 82, pp. 317-327, 2014.
[http://dx.doi.org/10.1016/j.buildenv.2014.08.030]
- [21] B. Koo, B. Shin, and G. Lee, "A cost-plus estimating framework for BIM related design and engineering services", *KSCE J. Civ. Eng.*, vol. 21, no. 7, pp. 2558-2566, 2017.
[http://dx.doi.org/10.1007/s12205-017-1808-y]
- [22] P.F. Harris, P.R. McCaffer, A. Baldwin, and F. Edum-Fotwe, *Modern Construction Management.*, John Wiley & Sons, 2020.
- [23] T.D. Oesterreich, and F. Teuteberg, "Understanding the implications of digitisation and automation in the context of Industry 4.0: A triangulation approach and elements of a research agenda for the construction industry", *Comput. Ind.*, vol. 83, pp. 121-139, 2016.
[http://dx.doi.org/10.1016/j.compind.2016.09.006]
- [24] F. Santos, M. Carvalho, and M.C. Brandstetter, "Development of a performance concept in the construction field: A critical review", *Open Constr. Build. Technol. J.*, vol. 14, no. 1, pp. 370-381, 2020.
[http://dx.doi.org/10.2174/1874836802014010370]
- [25] S. Woo, *Monte Carlo simulation of labor performance during overtime and its impact on project duration.*, 2000, p. 1.
- [26] S. Dixit, S.N. Mandal, J.V. Thanikal, and K. Saurabh, "Evolution of studies in construction productivity: A systematic literature review (2006-2017)", *Ain Shams Eng. J.*, vol. 10, no. 3, pp. 555-564, 2019.
[http://dx.doi.org/10.1016/j.asej.2018.10.010]
- [27] R.F. Cox, R.R.A. Issa, and D. Ahrens, "Management's perception of key performance indicators for construction", *J. Constr. Eng. Manage.*, vol. 129, no. 2, pp. 142-151, 2003.
[http://dx.doi.org/10.1061/(ASCE)0733-9364(2003)129:2(142)]
- [28] H.S. Park, "Conceptual framework of construction productivity estimation", *KSCE J. Civ. Eng.*, vol. 10, no. 5, pp. 311-317, 2006.
[http://dx.doi.org/10.1007/BF02830084]
- [29] A. Hasan, B. Baroudi, A. Elmualim, and R. Rameezdeen, "Factors affecting construction productivity: A 30 year systematic review", *Eng. Construct. Architect. Manag.*, vol. 25, no. 7, pp. 916-937, 2018.
[http://dx.doi.org/10.1108/ECAM-02-2017-0035]
- [30] S. Siebelink, H. Voordijk, M. Endedijk, and A. Adriaanse, "Understanding barriers to BIM implementation: Their impact across organizational levels in relation to BIM maturity", *Front. Eng. Manag.*, vol. 8, no. 2, pp. 236-257, 2021.
[http://dx.doi.org/10.1007/s42524-019-0088-2]
- [31] B.I. Jones, "A study of building information modeling (BIM) uptake and proposed evaluation framework", *J. Inf. Technol. Constr.*, vol. 25, pp. 452-468, 2020.
[http://dx.doi.org/10.36680/j.itcon.2020.026]
- [32] A. Ahankoob, K. Manley, and B. Abbasnejad, "The role of contractors' building information modelling (BIM) experience in realising the potential values of BIM", *Int. J. Constr. Manag.*, vol. 22, no. 4, pp. 588-599, 2022.
[http://dx.doi.org/10.1080/15623599.2019.1639126]
- [33] A. Alshammari, and F.E.M. Ghazali, "A Comprehensive Review of the Factors and Strategies to Mitigate Construction Projects Delays in Saudi Arabia", *Open Constr. Build. Technol. J.*, vol. 18, no. 1, p. e18748368318470, 2024.
[http://dx.doi.org/10.2174/0118748368318470240806113627]
- [34] P. Leviäkangas, S. Mok Paik, and S. Moon, "Keeping up with the pace of digitization: The case of the Australian construction industry", *Technol. Soc.*, vol. 50, pp. 33-43, 2017.
[http://dx.doi.org/10.1016/j.techsoc.2017.04.003]
- [35] B. Morgan, "Organizing for digitalization through mutual constitution: The case of a design firm", *Construct. Manag. Econ.*, vol. 37, no. 7, pp. 400-417, 2019.
[http://dx.doi.org/10.1080/01446193.2018.1538560]
- [36] L. Chen, P. Shi, and Q. Wu, "Impact of BIM on field pipeline installation productivity based on system dynamics modeling", *IAARC Publications*, vol. 36, pp. 975-981, 2019.
[http://dx.doi.org/10.22260/ISARC2019/0130]
- [37] A. Pritchard, "Statistical bibliography or bibliometrics", *J. Doc.*, vol. 25, p. 348, 1969.
- [38] H. Small, "Co-citation in the scientific literature: A new measure of the relationship between two documents", *J. Am. Soc. Inf. Sci.*, vol. 24, no. 4, pp. 265-269, 1973.
[http://dx.doi.org/10.1002/asi.4630240406]
- [39] K.W. McCain, "Mapping authors in intellectual space: A technical overview", *J. Am. Soc. Inf. Sci.*, vol. 41, no. 6, pp. 433-443, 1990.
[http://dx.doi.org/10.1002/(SICI)1097-4571(199009)41:6<433::AI D-ASI11>3.0.CO;2-Q]
- [40] H.D. White, and B.C. Griffith, "Author cocitation: A literature measure of intellectual structure", *J. Am. Soc. Inf. Sci.*, vol. 32, no. 3, pp. 163-171, 1981.
[http://dx.doi.org/10.1002/asi.4630320302]
- [41] M. Aria, and C. Cuccurullo, "bibliometrix : An R-tool for comprehensive science mapping analysis", *J. Informetrics*, vol. 11, no. 4, pp. 959-975, 2017.
[http://dx.doi.org/10.1016/j.joi.2017.08.007]
- [42] V.D. Blondel, J.L. Guillaume, R. Lambiotte, and E. Lefebvre, "Fast

- unfolding of communities in large networks", *J. Stat. Mech.*, vol. 2008, no. 10, p. P10008, 2008.
[<http://dx.doi.org/10.1088/1742-5468/2008/10/P10008>]
- [43] G.A. Bowen, "Document analysis as a qualitative research method", *Qual. Res. J.*, vol. 9, no. 2, pp. 27-40, 2009.
[<http://dx.doi.org/10.3316/QRJ0902027>]
- [44] S. Elo, and H. Kyngäs, "The qualitative content analysis process", *J. Adv. Nurs.*, vol. 62, no. 1, pp. 107-115, 2008.
[<http://dx.doi.org/10.1111/j.1365-2648.2007.04569.x>] [PMID: 18352969]
- [45] P. Mayring, "Qualitative content analysis: Theoretical background and procedures", In: A. Bikner-Ahsbals, C. Knipping, N. Presmeg, Eds., *Approaches to Qualitative Research in Mathematics Education: Examples of Methodology and Methods.*, Springer Netherlands: Dordrecht, 2015, pp. 365-380.
[http://dx.doi.org/10.1007/978-94-017-9181-6_13]
- [46] A.M.T. Thomé, L.F. Scavarda, and A.J. Scavarda, "Conducting systematic literature review in operations management", *Prod. Plann. Contr.*, vol. 27, no. 5, pp. 408-420, 2016.
[<http://dx.doi.org/10.1080/09537287.2015.1129464>]
- [47] P. Mongeon, and A. Paul-Hus, "The journal coverage of Web of Science and Scopus: A comparative analysis", *Scientometrics*, vol. 106, no. 1, pp. 213-228, 2016.
[<http://dx.doi.org/10.1007/s11192-015-1765-5>]
- [48] A. Burls, *What is critical appraisal?*, 2nd edn Hayward Medical Communications: Newmarket: UK, 2009.
- [49] A.A. Woldegiyorgis, D. Proctor, and H. de Wit, "Internationalization of research: Key considerations and concerns", *J. Stud. Int. Educ.*, vol. 22, no. 2, pp. 161-176, 2018.
[<http://dx.doi.org/10.1177/1028315318762804>]
- [50] H. Li, M. Lu, S.C. Hsu, M. Gray, and T. Huang, "Proactive behavior-based safety management for construction safety improvement", *Saf. Sci.*, vol. 75, pp. 107-117, 2015.
[<http://dx.doi.org/10.1016/j.ssci.2015.01.013>]
- [51] C. Kwiatek, M. Sharif, S. Li, C. Haas, and S. Walbridge, "Impact of augmented reality and spatial cognition on assembly in construction", *Autom. Construct.*, vol. 108, p. 102935, 2019.
[<http://dx.doi.org/10.1016/j.autcon.2019.102935>]
- [52] G. Rocha, L. Mateus, J. Fernández, and V. Ferreira, "A scan-to-BIM methodology applied to heritage buildings", *Heritage*, vol. 3, no. 1, pp. 47-67, 2020.
[<http://dx.doi.org/10.3390/heritage3010004>]
- [53] J. Ratajczak, M. Riedl, and D. Matt, "BIM-based and AR application combined with location-based management system for the improvement of the construction performance", *Buildings*, vol. 9, no. 5, p. 118, 2019.
[<http://dx.doi.org/10.3390/buildings9050118>]
- [54] B.C. Brookes, "Sources of information on specific subjects" by S.C. Bradford", *J. Inf. Sci.*, vol. 10, no. 4, pp. 173-175, 1985.
[<http://dx.doi.org/10.1177/01655158501000406>]
- [55] I.F. Aguillo, B. Granadino, J.L. Ortega, and J.A. Prieto, "Scientific research activity and communication measured with cybermetrics indicators", *J. Am. Soc. Inf. Sci. Technol.*, vol. 57, no. 10, pp. 1296-1302, 2006.
[<http://dx.doi.org/10.1002/asi.20433>]
- [56] T. Greenhalgh, and C. Papoutsis, "Studying complexity in health services research: Desperately seeking an overdue paradigm shift", *BMC Med.*, vol. 16, no. 1, p. 95, 2018.
[<http://dx.doi.org/10.1186/s12916-018-1089-4>] [PMID: 29921272]
- [57] J.Z. Wang, and G.A. Wei, "BIM-based technology implementation on quality management in construction engineering", *J. Phys. Conf. Ser.*, vol. 1601, no. 4, p. 042043, 2020.
[<http://dx.doi.org/10.1088/1742-6596/1601/4/042043>]
- [58] J. Choi, I. Kim, and J. Ryu, "A suggestion for improvement of IFC data in energy performance index (EPI) based on open BIM", *33rd International Symposium on Automation and Robotics in Construction, ISARC 2016* Auburn, USA, 2016, pp. 529-537.
[<http://dx.doi.org/10.22260/ISARC2016/0064>]
- [59] C. Lee, J. Son, and S. Lee, "A system model for analyzing and accumulating construction work crew's productivity data using image processing technologies", *J. Asian Archit. Build. Eng.*, vol. 13, no. 3, pp. 547-554, 2014.
[<http://dx.doi.org/10.3130/jaabe.13.547>]
- [60] H. Wang, R. Zheng, and F. Xiong, "Application of BIM-based 5D construction technique to chenglang bridge", *2016 5th International Conference on Sustainable Energy and Environment Engineering (ICSEEE 2016)* Atlantis Press, Dec. 2016, pp. 31-38.
[<http://dx.doi.org/10.2991/icseee-16.2016.6>]
- [61] P.C. Suermann, and R.R.A. Issa, "Evaluating industry perceptions of building information modelling (BIM) impact on construction", *J. Inf. Technol. Constr.*, vol. 14, no. 37, pp. 574-594, 2009.
- [62] A.Z. Sampaio, and V. Azevedo, "BIM in structural analyses of buildings", JF Silva Gomes, SA Meguid, Eds., *Proceedings of the 6th International Conference on Mechanics and Materials in Design 2015*
- [63] J. Kim, A. Golabchi, S. Han, and D.E. Lee, "Manual operation simulation using motion-time analysis toward labor productivity estimation: A case study of concrete pouring operations", *Autom. Construct.*, vol. 126, p. 103669, 2021.
[<http://dx.doi.org/10.1016/j.autcon.2021.103669>]
- [64] N. Van Tam, T.N. Diep, N. Quoc Toan, and N. Le Dinh Quy, "Factors affecting adoption of building information modeling in construction projects: A case of Vietnam", *Cogent Business & Management*, vol. 8, no. 1, p. 1918848, 2021.
[<http://dx.doi.org/10.1080/23311975.2021.1918848>]
- [65] J.H. Yousif, S.N. Abdul Majeed, and F.J.I. Al Azzawi, "Web-based architecture for automating quantity surveying construction cost calculation", *Infrastructures*, vol. 5, no. 6, p. 6, 2020.
[<http://dx.doi.org/10.3390/infrastructures5060045>]
- [66] S. Chen, Y. Zeng, A. Majidi, A.A. Salameh, T. Alkhalifah, F. Alturise, and H.E. Ali, "Potential features of building information modelling for application of project management knowledge areas as advances modeling tools", *Adv. Eng. Softw.*, vol. 176, p. 103372, 2023.
[<http://dx.doi.org/10.1016/j.advengsoft.2022.103372>]
- [67] A. Hanna, F. Boodai, and M. El Asmar, "State of practice of building information modeling in mechanical and electrical construction industries", *J. Constr. Eng. Manage.*, vol. 139, no. 10, p. 04013009, 2013.
[[http://dx.doi.org/10.1061/\(ASCE\)CO.1943-7862.0000747](http://dx.doi.org/10.1061/(ASCE)CO.1943-7862.0000747)]
- [68] S. Guidera, "Using BIM to support habitat for humanity: A case study", Available from: <https://peer.asee.org/using-bim-to-support-habitat-for-humanity-a-case-study>
- [69] D.M. de Brito, "Critical success factors for implementing Building Information Modeling (BIM) by public organizations", Available from: <https://repositorio.ufba.br/handle/ri/29680>
- [70] V.L.B. Viana, "UnB Institutional Repository: Mapping method for prioritizing risks and assessing the maturity of BIM implementation in public agencies", Available from: <http://www.rlbea.unb.br/jspui/handle/10482/40878>
- [71] A. Hamer, *BIM Un-Caged - A structured Approach To Data Building Information Management.*, 1st ed Andy Hamer, 2016.
- [72] D.V.S. Baia, "Use of BIM tools for planning civil construction works", Dissertation (Master in Structures and Civil Construction)—University of Brasília, Brasília., 2017.
- [73] P.P.F.D. Pinto, *The BIM platform in the compatibility of architectural and structural projects: Case studies.*, University of Brasilia, 2019.
- [74] M.C. Ramirez, "Planning of building projects in public administration: A case study using building information modeling tools", Dissertation (Master in Architecture and Urbanism)—University of Brasília, Brasília, 2018.
- [75] C.R.D. Matos, *The use of BIM in the supervision of public works.*, University of Brasilia, 2016.
[<http://dx.doi.org/10.26512/2016.03.D.20398>]
- [76] S. Siebelink, J.T. Voordijk, and A. Adriaanse, "Developing and testing a tool to evaluate BIM maturity: Sectoral analysis in the dutch construction industry", *J. Constr. Eng. Manage.*, vol. 144, no. 8, p. 05018007, 2018.

- [http://dx.doi.org/10.1061/(ASCE)CO.1943-7862.0001527]
- [77] M.A. Silva Junior, and C.V. Mitidieri Filho, "Verificação de critérios de desempenho em projetos de arquitetura com a modelagem BIM", *PARC Res. Archit. Constr.*, vol. 9, no. 4, pp. 334-343, 2018.
[http://dx.doi.org/10.20396/parc.v9i4.8650453]
- [78] A.D. Felisberto, F.F. Marchiori, P. Love, and R. Signor, "BIM cost estimation guidelines for Brazilian public sector infrastructure", *PARC Res. Archit. Constr.*, vol. 12, pp. e021004-e021004, 2021.
[http://dx.doi.org/10.20396/parc.v12i00.8659766]
- [79] L. L. A. de Souza, and S. R. L. Amorim, "Impacts of the use of bim in architecture offices: Opportunities in the real estate market", *Gest. Tecnol. Proj.*, vol. 4, no. 2, p. 2, 2009.
[http://dx.doi.org/10.4237/gtp.v4i2.100]
- [80] F.M.R. Andrade, C.N. Biotto, and S.M.B. Serra, "Modelagem BIM para orçamentação com uso do SINAPI", *Gest. Tecnol. Proj.*, vol. 16, no. 2, pp. 93-111, 2021.
[http://dx.doi.org/10.11606/gtp.v16i2.170318]
- [81] D. Latreille, and S. Scheer, "Analysis of quantities from a 5D BIM model to adapt to the budgeting process of civil construction companies", *Gest. Tecnol. Proj.*, vol. 16, no. 1, pp. 96-108, 2020.
[http://dx.doi.org/10.11606/gtp.v16i1.163499]
- [82] B. Giel, and R.R.A. Issa, "Framework for evaluating the BIM competencies of facility owners", *J. Manage. Eng.*, vol. 32, no. 1, p. 04015024, 2016.
[http://dx.doi.org/10.1061/(ASCE)ME.1943-5479.0000378]
- [83] P.C. Suermann, and R.R.A. Issa, "The US national building information modeling standard", In: *Handbook of Research on Building Information Modeling and Construction Informatics: Concepts and Technologies.*, IGI Global, 2010, pp. 138-154.
[http://dx.doi.org/10.4018/978-1-60566-928-1.ch006]
- [84] A. Okakpu, A. Ghaffarianhoseini, J. Tookey, J. Haar, A. Ghaffarianhoseini, and A.U. Rehman, "Risk factors that influence adoption of building information modelling (BIM) for refurbishment of complex building projects: stakeholders perceptions", *Int. J. Constr. Manag.*, vol. 22, no. 13, pp. 2446-2458, 2022.
[http://dx.doi.org/10.1080/15623599.2020.1795985]
- [85] T. Wang, and H.M. Chen, "Integration of building information modeling and project management in construction project life cycle", *Autom. Construct.*, vol. 150, p. 104832, 2023.
[http://dx.doi.org/10.1016/j.autcon.2023.104832]
- [86] Y. Ge, X. Xiao, B. Guo, Z. Shao, J. Gong, and D. Li, "A novel LOD rendering method with multilevel structure-keeping mesh simplification and fast texture alignment for realistic 3-D models", *IEEE Trans. Geosci. Remote Sens.*, vol. 62, pp. 1-19, 2024.
[http://dx.doi.org/10.1109/TGRS.2024.3457796]
- [87] M. Yoo, and N. Ham, "Productivity analysis of documentation based on 3D model in plant facility construction project", *Appl. Sci.*, vol. 10, no. 3, p. 1126, 2020.
[http://dx.doi.org/10.3390/app10031126]
- [88] M. Mayouf, J. Jones, F. Elghaish, H. Emam, E.M.A.C. Ekanayake, and I. Ashayeri, "Revolutionising the 4D BIM process to support scheduling requirements in modular construction", *Sustainability*, vol. 16, no. 2, p. 476, 2024.
[http://dx.doi.org/10.3390/su16020476]
- [89] M. Alzara, Y.A. Attia, S.Y. Mahfouz, A.M. Yosri, and A. Ehab, "Building a genetic algorithm-based and BIM-based 5D time and cost optimization model", *IEEE Access*, vol. 11, pp. 122502-122515, 2023.
[http://dx.doi.org/10.1109/ACCESS.2023.3317137]
- [90] A.Z. Sampaio, G. Azevedo, and A. Gomes, "BIM manager role in the integration and coordination of construction projects", *Buildings*, vol. 13, no. 8, p. 2101, 2023.
[http://dx.doi.org/10.3390/buildings13082101]
- [91] H.M. Zhang, H-Y. Chong, Y. Zeng, and W. Zhang, "The effective mediating role of stakeholder management in the relationship between BIM implementation and project performance", *Eng. Construct. Architect. Manag.*, 2022.
[http://dx.doi.org/10.1108/ECAM-04-2020-0225]
- [92] Z. Zheng, J. Zhou, Z. Jiaqin, Y. Yang, F. Xu, and H. Liu, "Review of the building energy performance gap from simulation and building lifecycle perspectives: Magnitude, causes and solutions", *Developments in the Built Environment*, vol. 17, p. 100345, 2024.
[http://dx.doi.org/10.1016/j.dibe.2024.100345]
- [93] B.S. Abdulfattah, H.A. Abdelsalam, M. Abdelsalam, M. Bolpagni, N. Thurairajah, L.F. Perez, and T.E. Butt, "Predicting implications of design changes in BIM-based construction projects through machine learning", *Autom. Construct.*, vol. 155, p. 105057, 2023.
[http://dx.doi.org/10.1016/j.autcon.2023.105057]
- [94] L. Gharaibeh, K.M. Eriksson, B. Lantz, S. Matarneh, and F. Elghaish, "Toward digital construction supply chain-based industry 4.0 solutions: Scientometric-thematic analysis", *Smart Sustain. Built Environ.*, vol. 13, no. 1, pp. 42-62, 2024.
[http://dx.doi.org/10.1108/SASBE-12-2021-0224]