Analysis of Critical Factors and Strategies for Implementing and Using BIM in the Public Sector

Paula dos Santos Cunha Boumann[1], Rudemberg Felipe Eloi Tavares[1] & Bianca Maria Vasconcelos[1]

[1] University of Pernambuco, Recife-PE, Brazil

Correspondence: Paula dos Santos Cunha Boumann, University of Pernambuco, Recife-PE, Brazil.

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Abstract

Building Information Modeling (BIM) is a widely adopted technology in the Architecture, Engineering, and Construction (AECO) sector, with a commercial applicability of over 20 years. However, it has not yet reached all sectors and professionals within the industry. Given this reality, this work aims to identify successful strategies and critical factors reported in global public sector experiences of BIM implementation and usage, to pinpoint the necessary approaches for its development. A systematic literature review was conducted with a qualitative-quantitative approach to achieve this. The results highlight that factors related to cultural change and training are the most critical, along with integrating technology into processes, the lack of BIM standardization, and a lack of government incentives. In light of these findings, it is understood that BIM is predominantly used for modeling, and there are still gaps in understanding the technology's use for information management. This research also presents correlations between the factors identified by authors, associating them with suggested or implemented strategies in successful experiences. These contributions can serve as the basis for further studies on maturity diagnosis or assist in formulating future BIM implementation strategies.

Keywords: building information modeling, implementation, public sector

1. Introduction

One of the biggest challenges of Civil Construction works is the conclusion within the deadline and cost defined in the physical and financial schedule. This need is even more pronounced in the context of public works, where delivering a work translates into a possibility of changing the reality of a society, promoting dignity and quality of life for its citizens. It is exactly in this sector, where the role of the works has relevant prominence in public administration (Altounian, 2016), either by its social nature or its materiality, where the biggest challenges in the management of planning and control of the works are presented, in search of the best efficiency in conducting the enterprise as a whole.

Alvarenga *et al.* (2021) indicate that the main causes of cost deviations in public works are service additions (31%) and project modifications (29%), or even services not foreseen in the budget (14%), which defines a scenario of low project quality and inefficient planning since these aggregate causes represent about 74% of the cost deviations, a problem that also triggers non-compliance with deadlines and consequent stoppages. Display quotations of over 40 words, or as needed.

In this context, Building Information Modeling (BIM) emerges as a promising technology to mitigate these obstacles in the works, since it provides accuracy, speed, transparency and traceability of the analysis, planning and control processes of the works, and can also provide data for monitoring the operation and maintenance of the project, through the information management that BIM models carry since their conception (Amuda-Yusuf, 2018). Thus, the present work seeks to identify in the global scenario, the successful strategies and critical factors reported in experiences of BIM implementation and management, to identify the necessary approaches for the development of BIM in the public sector and assist future research.

1.1 Theoretical Foundation

For Sacks *et al.* (2018), construction information modeling is a technology already widespread in the AECO sector, whose commercial applicability already exceeds 20 years. This tool is important to improve the quality of the project, and consequently, the safety and management of the enterprise, bringing a competitive advantage to its users (Xu *et* *al.*, 2014). However, even nowadays, in some countries, the dissemination of the tool faces limitations and low effectiveness, which has led some researchers to study these causes and try to study the risks and strategies for global implementation. Succar (2010) states that the development of BIM performance metrics is paramount for organizations to be able to measure their failures and successes and that these must be adaptable and accurate to different sectors and organizational realities.

Leusin (2021) states that the projects developed within the BIM processes differ from those conducted in the traditional processes, with software for project development and other non-communicable interfaces for planning and conducting the works, since in BIM structure the information flows are focused greatly to refine communication, integration of all stages of the life cycle of the enterprise, from its conception to commissioning and use.

The lack of knowledge by project managers and mistaken approaches have caused failures in the BIM implementation process, consequently causing a low diffusion of the technology (Leusin, 2021). BIM is not a product, but a structured process that may require time, resources and technology that companies do not always have or are not always willing to invest, even though all the returns that BIM provides are already known.

According to Leusin (2021), the success of BIM depends on technology, resources, procedures, and people, the latter being the factor that causes the most impact, since it depends on organizational restructuring, training, and knowledge consolidation. For this reason, BIM technology can be considered a disruptive technological innovation, because it changes the technical solutions to a deeper level of knowledge, only possible through a cultural change of the process participants.

Jasinski (2020) points out that architectural education practices should focus on human, structural, and business barriers and emphasizes that the biggest cost of implementing BIM technology is concentrated in these practices.

Other studies, such as those by Hong *et al.* (2018) and by Khosrowshahi and Arayici (2012), evaluate the correlation between technology, processes, and people to assess progression on the maturity scale, as well as correlate costs, benefits, and challenges to BIM implementation, indicating that the path to successful implementation lies less in the diffusion of benefits per se and more in the ability to assess implementation issues, establish knowledge support, and engage staff in the process.

The Brazilian Agency for Industrial Development (ABDI, 2017) defines technology as the infrastructure needed to operationalize the programs and the graphic interface, the storage and communication of information, and that this dimension is interconnected with the people involved, who should be the focal point in the implementation strategy. He also states that it is the people who reflect the successful experience of the strategy. For this reason, the professionals involved with BIM must be focused on innovation, collaborative work, and continuous updating, so that this performance profile is reflected in the processes, the other dimension. The processes will be as well defined as the people involved are trained. This means that having the proper tools and trained personnel will bring positive results if this process is designed using timelines, flowcharts, and deliverables that are compatible with this organization, feasible, and efficient. Succar (2010) also emphasizes that these three dimensions of BIM (people, processes, and technology) are linked together in the form of procedures, standards, and best practices, so this documentary framework provides the consolidation of knowledge in the organization, as shown in Figure 1.

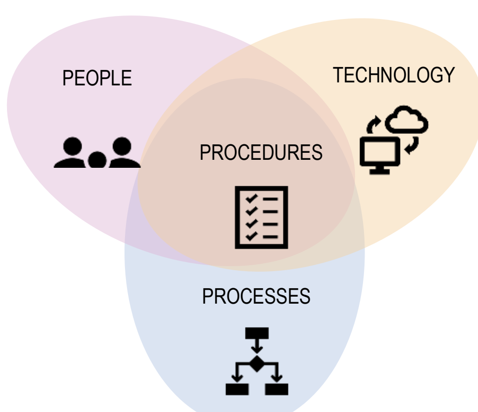

Figure 1. BIM Fundamentals (Adapted by Succar, 2010)

According to Aragó *et al.* (2021), government agencies should promote the incentive to use BIM and this is a fundamental aspect to advance the implementation of this technology. In this study it is demonstrated that in Spain, the use of BIM for surveys and estimates has been growing as its use for projects, however, the use in the construction itself still corresponds to 75% for projects and 63% for estimates. However, it is important to point out that in that country, the present study states that the use in the public sector, to raise them and estimates, exceeds the use in the private sector.

However, Aragó *et al.* (2021), as well as Valdepeñas *et al.* (2020) emphasize that the major challenge in the use of technology is resistance to change due to a lack of knowledge of the advantages of the tool, which affects the focus on people and technology, about the inefficient interoperability between software, and also the lack of a collaborative culture of information management processes.

Nikal and Wodyński (2016) state that in Poland and the Czech Republic, what hinders the BIM-based revolution is no longer the lack of technological solutions, but rather the inability of the construction industry to cooperate. This perception regarding the inertia of the AECO industry is also perceived by Delgado *et al.* (2019) in the UK.

De Souza *et al.* (2021) point out that the lack of professional experience in BIM and the lack of familiarity with the processes related to this technology hinder the transfer of concepts from classical modeling to BIM management and coordination, despite governmental efforts, industry bodies, and academia. Checcuchi (2019) shows that in Brazilian universities, from 2013 to 2018, the interest in training is growing, although the level of maturity in this country is still incipient, which demonstrates that academia is at the forefront of knowledge dissemination.

The work of Costa, Teti and Vasconcelos (2021) points out that in Brazil the dissemination of the use of BIM is still in its early stages and points out the factors of cost and training of people as important challenges for this implementation in civil construction companies, citing studies by Kassen & Succar (2017) and Souza *et al.* (2009). Medeiros, Figueiras and Vasconcelos (2022) highlight the link between BIM and the virtualization of processes to promote technological advancement in Brazilian civil construction.

2. Method

The work was conducted through a Systematic Literature Review (SLR), defined by Keele *et al.* (2007), as a secondary study that seeks to identify, evaluate, and extract interpretations based on primary studies of a particular research area or phenomenon of interest. This strategy is quite acceptable in academia, as it allows for the traceability and reproducibility of the study and can provide a broad, current, and delimited background and indicate research gaps or directions for future studies.RSL begins with the planning of the delimited study through the preparation of a research protocol, where the necessary criteria for the development of the work are detailed. In this study, the theme of the work was transformed into research questions, which in turn were detailed in search terms and synonyms, which together with the selection criteria (exclusion and inclusion) resulted in the intended data extraction. The PICo (Population - Interest - Context) strategy defined by Akobeng (2005) was used to assist in the definition of the title, research question and keywords. From the PICo criteria and research questions, the search string that can be used or adapted in the research databases was defined. To present the process of the research execution, the flowchart used by Page *et al.* (2021) will be used, based on the method illustrating the Main Items for Reporting Systematic Reviews and Meta-analyses (PRISMA). The main information of the research protocol is structured in Chart 01.

Chart 1. Research protocol (Authors)

Item	Content
Purpose	Identify in the global scenario, successful strategies and critical factors reported in BIM implementation and management experiences, to identify the approaches needed for the development of BIM in the public sector and to assist future research
Search Terms	Building Information Modeling, BIM design; BIM methodology, collaborative work methodology, Public works; design of public buildings; constructions of public works; public buildings, public agencies, public infrastructure design
Databases	ASCE Library, Engineering Village, IEEE Xplore, Scielo, Science Direct, Scopus, Springer Link, Taylor & Francis, Web of Science e Wiley Online Library.
Limitations	Publications of the type Journal articles, published from 2012 to 2022 and in English, Portuguese and Spanish languages.

Inclusion Criteria	CI1: primary studies containing the search terms in the title, abstract or keywords.
Exclusion Criteria	CE1: duplicate articles CE2: non-AECO articles CE3: articles that do not deal with BIM implementation or management CE4: systematic literature review articles. CE5: articles that are not available for full reading.
Research Questions	Q1: Is BIM in the public sector worldwide being implemented and used effectively or are there critical factors that hinder good performance? What are these factors? Q2: What are the strategies used in the implementation and use of BIM in the public sector? Q3: Which strategy(s) or approach(es) need further study? Q4: Where can science contribute to the dissemination of the use of BIM for the public sector?

According to the PRISMA methodology, the search consists of the identification, selection, eligibility, and inclusion stages. In the identification phase, the Boolean operators "AND" and "OR" were associated with the search terms defined in the protocol, to define the search string: ("BIM" OR building information modeling) AND (public works" OR "public agencies" OR "public buildings" OR "public infrastructure"). However, the databases whose initial search returned less than 20 (twenty) results were discarded, leaving, from the protocol definition and following this criterion, the following databases: ASCE Library, Engineering Village, Science Direct, Scopus, Springer Link, Taylor & Francis and Web of Science. From the initial search in the research bases and applying the exclusion and inclusion criteria defined in the protocol, after eliminating the non-applicable studies, we arrived at many selected studies through which the data are tabulated for extraction of the quantitative and qualitative analyses, and finally, the writing of the ana-lytic report of these results.

3. Results

In the identification stage, 789 results were found, as illustrated in Figure 02, of which 232 results using the Science Direct database, 55 in Scopus, 37 in Engineering Village, 50 in Web of Science,48 in Springer Link, 159 in Taylor & Francis and 208 in the AS-CE Library.

Still in this stage, a search was carried out in the databases, using the defined string, making use of the filters programmed in the databases to apply the limitations to the search. Thus, studies that do not have journal articles were excluded, as well as studies outside the defined period (2012-2022). Since it was not possible to apply language as a limitation in all databases, it was decided to make this exclusion regarding language in the selection phase, considering that most studies are developed in English and that this initial filter does not bring significant numerical difference for the next step. To filter duplicate articles (CE1), we used the Microsoft Excel filter tool, which detected repetitions between the databases and kept only one copy of each study.

Then, in the selection phase, by restricting only articles in Portuguese, English or Spanish and excluding the duplicates, 723 eligible articles remained, where by reading the titles and abstracts of the articles, the articles that are not from the AECO area were excluded (CE2), as well as the studies that are from the area, but do not deal with BIM implementation and management (CE3), systematic review articles (CE4) and studies whose texts are unavailable for full reading (CE5), given that the study does not provide resources for the acquisition of studies by private means, but only with access by the educational institution. After completing the selection stage, after the exclusion of 658 articles, the 53 remaining articles were included for the quantitative and qualitative synthesis. In the full reading stage of the 53 selected articles, 8 studies were still excluded by quality criteria, resulting then in 45 studies for summarization and qualitative report, according to the flow in Figure 2.

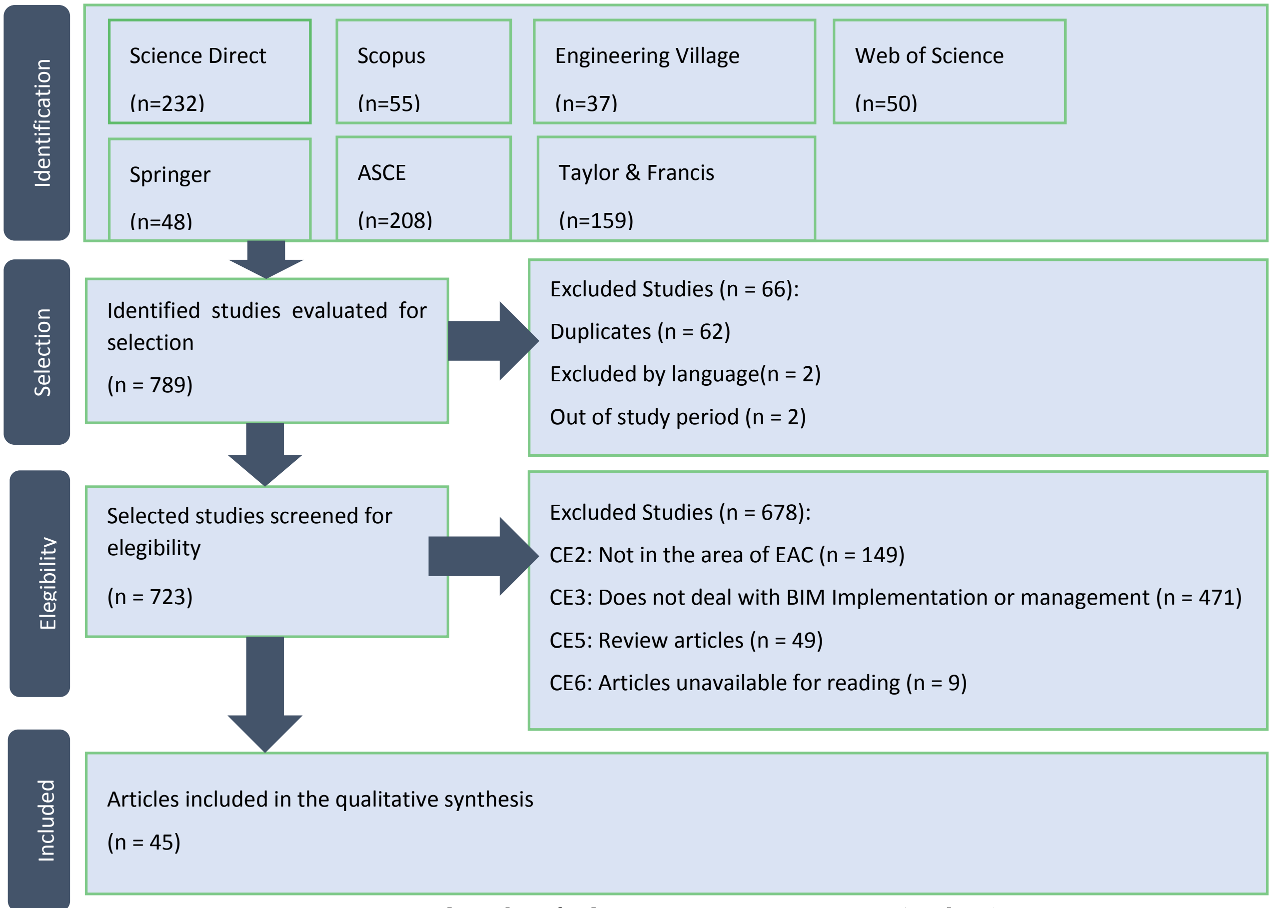

Figure 2. Flow chart for literature review – PRISMA (Authors)

4. Discussion

Figure 3 shows the ratio of the number of articles selected by the number of results obtained in each database, identifying those more efficient in the research theme. Science Direct was the most efficient database, with 39% of its search results selected for the qualitative synthesis, followed by Scopus (24%), Taylor & Francis (13%), ASCE Library (10%), Web of Science (7%) and Engineering Village (2%). The reason for the low number of articles selected from Engineering Village was a large number of duplicates about the other databases previously checked. It is important to note that the behavior of the graph from identification to eligibility remained approximately the same trend, denoting the stability of the Science Direct and Scopus databases as comprehensive for the research theme.

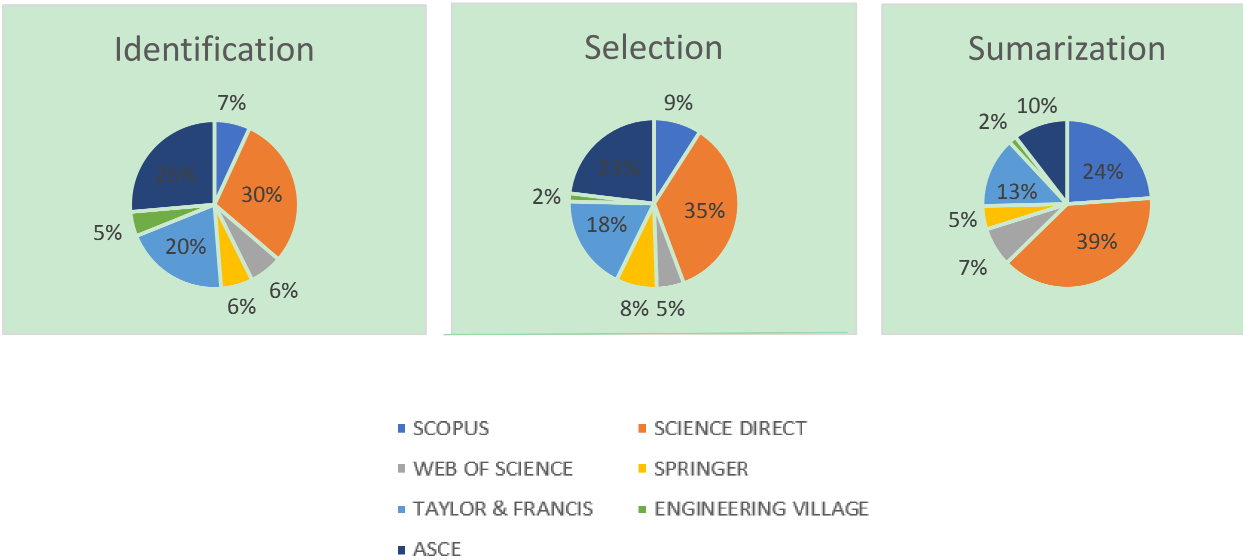

Figure 3. Database Efficiency (Authors)

About the analysis of the publication period of the articles included in the research, indicated in Figure 04, it is possible to see that the number of publications on the subject of BIM in the public sector has been on an upward trend since 2012, dropping in 2018 and having a significant increase in 2020. Since this advance, the theme has been showing a decline in the number of studies.

Figure 4. Publication period (Authors)

In Figure 5, the locations (country) where the research was applied are listed, with China, with 8 publications, being the most prominent, followed by Spain (5), the UK (4), Italy (3), Israel, Poland, Portugal, Sweden, and the USA (2), and the others, with 1 study.

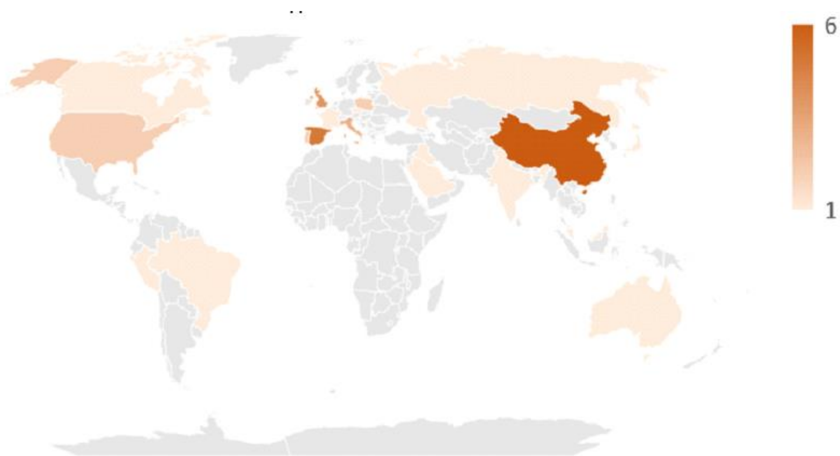

Figure 5. Countries where the research was applied (Authors)

Figure 6 shows the relation of the keywords present in the qualitative analysis articles. As expected, the acronym BIM appears as the main highlight, as well as its derivatives, such as "BIM adoption" or "BIM design" or even the isolated terms "In-formation modeling" and synonyms. However, it is important to highlight the themes that appeared with some frequency in the search, namely: construction, maturity, management, adoption, and innovation, among others that denote the theme of BIM management and implementation, not modeling. The breadth of keywords found may favor the development of future research on more specific themes involving the use of BIM.

Figure 6. Keyword Cloud (Authors by Word Cloud)

The selected studies show that the obstacles to effective implementation of management are predominantly concentrated in the dimensions of people, processes and resources, as indicated by Succar (2010) and ABDI (2017), and that specifically for the public sector two other factors stand out, which are related to the management and the initiatives of the public sector (Chien, Wu & Huang, 2014). Thus, based on these parameters, the critical factors were classified into the following groups: people, processes, resources, public power, and management, as shown in Table 1, where the results and conclusions of the research are synthetically represented. We classified and grouped the critical factors with a code FC-N (N=1, 2, 3...), to facilitate the presentation of the correlation of these factors with the strategies that will be presented next in Chart 2.

Chart 2. Critical factors for using BIM

Group	Critical Factor	Code	References
People	The number of qualified professionals does not supply the demand of the market	FC-1	Chien *et al.* (2014); Juszczyk *et al.* (2015); Zaia *et al.* (2022); Pakhale & Pal (2020); Vass & Gustavsson (2017); Saka *et al.* (2022); Ai Lin Teo (2018)
	Difficulty in workflow transition	FC-2	Chien *et al.* (2014); Pakhale & Pal (2020)
	Attitude, willingness and interest to use BIM, Resistance to change	FC-3	Xu *et al.* (2014); Baldrich Aragó *et al.* (2021); Valdepeñas *et al.* (2020)
	Field experience of the mode-later	FC-4	Xu *et al.* (2014); Belyakov *et al.* (2020)
	Low knowledge of BIM management software	FC-5	Baldrich Aragó *et al.* (2021); Abd Shukor *et al.* (2021); Liao & Ai Lin Teo (2018)
	Lack of BIM culture and information sharing	FC-6	Baldrich Aragó *et al.* (2021); Ciribini *et al.* (2016); Nical & Wodynski (2016); Delgado *et al.* (2019); Borges Viana & Marques Carvalho (2021); Gurevich & Sacks (2020); Baharuddin *et al.* (2020); Jensen & Jóhannesson (2013); Saka *et al.* (2022); Liao & Ai Lin Teo (2018); Beach *et al.* (2017)
Processes	Lack of BIM standards	FC-7	Chien *et al.* (2014); Borges Viana & Marques Carvalho (2021); Gurevich & Sacks (2020); Jensen & Jóhannesson (2013); Weisheng Lu *et al.* (2021); Troiani *et al.* (2020)
	Difficulties in Interoperability	FC-8	Chien *et al.* (2014); Baldrich Aragó *et al.* (2021); Nical & Wodynski (2016); Borges Viana & Marques Carvalho (2021); Valdepeñas *et al.* (2020); Jensen & Jóhannesson (2013); Vass & Gustavsson (2017)
	The software available in the market still does not supply all the needs in an integrated manner	FC-9	Baldrich Aragó *et al.* (2021)
	In O&M, the use of several tools without interconnection generates loss of information	FC-10	Minagawa & Kusayanagi (2015)
	Lack of BIM training at the construction stage	FC-11	Sodangi *et al.* (2018)
Resources	Need to allocate resources for BIM implementation	FC-12	Chien *et al.* (2014); Delgado *et al.* (2019); Abd Shukor *et al.* (2021); Valdepeñas *et al.* (2020); Weisheng Lu *et al.* (2021); Vass & Gustavsson (2017)
	Software value	FC-13	Juszczyk *et al.* (2015)
Public power	Insipient incentive by the public power	FC-14	Chien *et al.* (2014); Xu *et al.* (2014); Sergeeva & Winch (2020); Weisheng Lu *et al.* (2021); Yuan & Yang (2020)
	Lack of enforced legislation on BIM and/or regulatory factors	FC-15	Juszczyk *et al.*(2015); Troiani *et al.* (2020); Phang *et al.* (2020)
	Rigid public procurement rules may prevent the effective use of the tool	FC-16	Ciribini *et al.* (2016); Zaia *et al.* (2022)
Management	Project management difficulty	FC-17	Chien *et al.* (2014); Tchan *et al.* (2019); Marinho *et al.* (2021)
	Early-stage adoption of BIM in AEC (Unknown risks)	FC-18	Chien *et al.* (2014); Delgado *et al.* (2019)

The qualitative review brings recurrently that one of the major challenges faced by the public sector when it comes to BIM implementation is related to the low culture of inter-ope-ability and adherence to a 3D design by the construction sector, being considered at an early stage by AECO (Delgado et al, 2019; Chien *et al.* 2014; Valdepeñas *et al.*, 2020), and that specifically in the public sector, the governmental incentive is still incipient (Chien *et al.*, 2014); Sergeeva & Winch, 2020), indicating that there is legislation applied, but there is still a lack of clear guidelines and a certain degree of collection by stakeholders and clients, which may indicate that the promoter of effective and permanent implementation of BIM in AECO in the public sector may be the government.

Lack of skilled personnel is also a recurring cause (Chien *et al.*, 2014; Zaia *et al.*, 2022; Pakhale & Pal, 2020; Vass & Gustavsson, 2017; Saka *et al.*, 2022; Ai Lin Teo, 2018), which also explains the difficulty in workflow transition (Chien *et al.* 2014; Pakhale & Pal, 2020) and the lack of attitude, willingness, and interest in using BIM associated with a resistance to change (Xu *et al.* 2014; Baldrich Aragó *et al.*, 2021; Valdepeñas *et al.*, 2020).

Other relevant factors intrinsically linked to the people dimension are the modelers' lack of field experience, as well as the low rate of BIM software training, and the low or insipient culture of information sharing, being these causes the most cited and recurrent in the selected studies (Xu *et al.* 2014; Belyakov *et al.* 2020, Baldrich Aragó et al, 2021; Abd Shukor *et al.*, 2021; Liao & Ai Lin Teo, 2018; Ciribini *et al.*, 2016; Nical & Wodynski, 2016; Delgado *et al.*, 2019; Borges Viana & Marques Carvalho, 2021; Gurevich & Sacks, 2020; Baharuddin *et al.*, 2020; Jensen & Jóhan-Nesson, 2013; Saka *et al.*, 2022; Beach *et al.*, 2017).

As for BIM processes, the main critical factors cited in the studies are due to the user, such as lack of standards or difficulty of interoperability (Chien *et al.*, 2014; Borges Viana & Marques Carvalho, 2021; Gurevich & Sacks, 2020; Jensen & Jóhannesson, 2013; Weisheng Lu *et al.*,2021; Troiani et al, 2020, Baldrich Aragó *et al.*,2021; Nical & Wodynski, 2016; Valdepeñas *et al.*, 2020; Vass & Gustavsson, 2017), but also highlight factors linked to software developers, such as that available software on the market still do not supply all the needs in an integrated manner (Baldrich Aragó *et al.*, 2021). In the operation and maintenance sector, it is emphasized the need to use several tools for O&M management, otherwise, there may be a loss of information (Minagawa & Kusayanagi, 2015). Some authors highlight as a critical point the lack of BIM training by technicians in the construction stage (Sodangi *et al.*, 2018). The resource factor also appears in the works, even on a smaller scale, highlighting that BIM generates an extra need for financial allocation (Chien *et al.*, 2014; Delgado *et al.*, 2019; Abd Shukor *et al.*, 2021; Valdepeñas *et al.*, 2020; Weisheng Lu *et al.*, 2021; Vass & Gustavsson, 2017), with the value of BIM software being another motivator for the low uptake of the technology (Juszczyk *et al.*, 2015).

When it comes to the public sector, government action emerges as a representative factor, indicating that low or incipient encouragement by the government is an important critical factor for BIM implementation (Chien *et al.*, 2014; Xu *et al.*, 2014; Sergeeva & Winch, 2020; Weisheng Lu et al, 2021; Yuan & Yang, 2020), which can be explained by the lack of enforced legislation and/or regulatory factors (Juszczyk *et al.*, 2015; Troiani et al, 2020; Phang *et al.*, 2020) or even by the need to adapt the legislation applied to bidding that by its nature does not encourage innovation (Ciribini *et al.*, 2016; Zaia *et al.*, 2022).

As for management, the critical factors associated with BIM are the same that hindered classical project management, before BIM, which shows that some practices have not evolved in project management and reflected in the implementation of BIM, appearing to be a difficulty linked to technology, but which is a remnant of a non-matured management process (Chien *et al.*, 2014; Tchan *et al.*, 2019); Marinho *et al.*, 2021). Notably, there is still an association between BIM use to unknown risks, by the slow action of the AECO sector in this evolution (Chien *et al.*, 2014; Delgado *et al.* (2019).

Most of the articles summarized in this study presented a diagnosis of the implementation and management of BIM in their locality, but some made an important contribution by presenting success strategies or lessons learned to mitigate or annul the adverse effects of critical factors, as shown in Chart 3.

Chart 3. Strategies for mitigating the obstacles (Authors)

Strategies	Code	References
Training of modelers and managers	E-1	Chien *et al.* (2014); Juszczyk *et al.* (2015); Zaia *et al.* (2022); Pakhale & Pal (2020); Vass & Gustavsson (2017); Saka *et al.* (2022); Ai Lin Teo (2018)
BIM must be used as a competitive tool	E-2	Phang *et al.* (2020); Murguia *et al.* (2021)
There must be a commitment from the company's top management	E-3	Phang *et al.* (2020)
BIM tools are useful for maintenance management (FM)	E-4	Matos *et al.* (2021); Ciribini *et al.* (2016); Cheng *et al.* (2020); Hu & Liu (2020); Javier Montiel-Santiago *et al.* (2020); Pavon *et al.* (2020)
4D tool to help the customer visualize the final product	E-5	Ciribini *et al.* (2016)
Implementation costs dissipate as maturity progresses	E-6	Fanning *et al.* (2015)
Passing on BIM implementation costs to customers	E-7	Xu *et al.* (2014)
Software developers encourage use through free trials and training	E-8	Xu *et al.* (2014); Baldrich Aragó *et al.* (2021); Valdepeñas *et al.* (2020); Baharuddin *et al.* (2020)
The critical role of influencers (customers), who must demand BIM	E-9	Hannes (2019); Murguia *et al.* (2021)
Incorporating BIM into academic programs	E-10	Troiani *et al.* (2020)
BIM technology must be integrated into project management	E-11	Chien *et al.* (2014)

The strategy most often cited in the studies object of this sample is related to the training of modelers, which is strongly related to most of the critical facts raised in this dimension (people), demonstrating that the massive implementation of BIM is preceded by an effort in training and culture change of its technicians and operators (Chien *et al.* 2014; Juszczyk *et al.*, 2015; Zaia *et al.*, 2022; Pakhale & Pal, 2020; Vass & Gustavsson, 2017; Saka *et al.*, 2022; Ai Lin Teo, 2018)

In this context, when dealing with the public sector, where the customer is the government itself and/or its agents and development agencies, there is a correlation between the need of this customer (government) to increase its influence through clear and temporal guidelines, such as mentioned in the previous section, related to the critical factors. This influence of the government customer can be materialized through the incorporation of BIM in academic programs (Troiani *et al.*, 2020), which can mitigate many critical factors related to the culture of use and the training of skilled personnel. Software developers can also collaborate in this capacity building by providing free test versions and training for modelers and managers (Xu *et al.*, 2014; Baldrich Aragó *et al.*, 2021; Valdepeñas *et al.*, 2020; Baharuddin *et al.*, 2020).

This training of a new generation of graduated professionals is a medium-term strategy for the BIM methodology to be implemented and maintained with a certain degree of maturity in a locality or a company, creating in the business and technical structure the culture of 3D information and evolutions and of collaborative work, with commitment from the base to the top management of the company, the latter being a determining factor for the consolidation of the culture in the company or public institution (Phang *et al.*, 2020), incorporating the use of BIM to project management (Chien *et al.*, 2014).

In aspects related to customer interaction, it is highlighted that strategies for BIM implementation should include its use as a competitive advantage (Phang *et al.*, 2020; Murguia *et al.*, 2021) since it is a tool that facilitates communication with the client and allows him to visualize his final product with much more materiality through 4D tools (Ciribini *et al.*, 2016) and for this reason it is fair that the costs demanded for the implementation and use of BIM be shared with the client (Xu *et al.*, 2014). Still, about implementation costs, this factor cannot be considered an obstacle to the implementation of the methodology, since the financial demand will dissipate as the degree of maturity advances (Fanning *et al.*, 2015). This use of BIM as a differential tool should be felt by clients as an upgrade in their project, which confers accuracy and quality since the pre-conception, in the visual communication with the client itself and transmits to all phases of the project life cycle the necessary accuracy for a successful project, with minimization of inconsistencies and for this reason, one of the important strategies for the advancement of BIM use is that the client feels this need and exercises a critical role of influencer in the demand for the technology (Hannes, 2019; Murguia *et al.*, 2021).

Another strategy recurrently mentioned in the studies makes mention of maintenance and operation activities, about how beneficial the use of BIM can be to O&M management. However, to work, the modeling must be born in the project with all the information of the sub-systems standardized, to maintain the database of the substrate specifications that will be useful throughout the use phase of the enterprise, the longest and most expensive phase of the product (Matos et al, 2021; Ciribini *et al.*, 2016; Cheng *et al.*,2020; Hu & Liu, 2020; Javier Monti-El-Santiago & Jesus Hermoso-Orzaez; Terrados-Cepeda, 2020; Pavon *et al.*, 2020).

Figure 7 shows the links between the critical factors with their respective mitigation strategies suggested in the studies, where it is possible to graphically visualize the links and interrelationships of problem x solution, just like the strategy used by Liao and Ai Lin Teo (2018). As an example, the obstacles linked to the people factor (FC-1, FC-2, FC-3, FC-4) are strictly related to capacity building (E-1) and software training in trial versions (E-8), while the factors related to BIM costs (FC-12 and FC-13) are related to the strategies of involving the client as financial co-responsible and with the developers in the financing of demo software to minimize costs and motivating use by modelers (E-6, E7 and E-8).

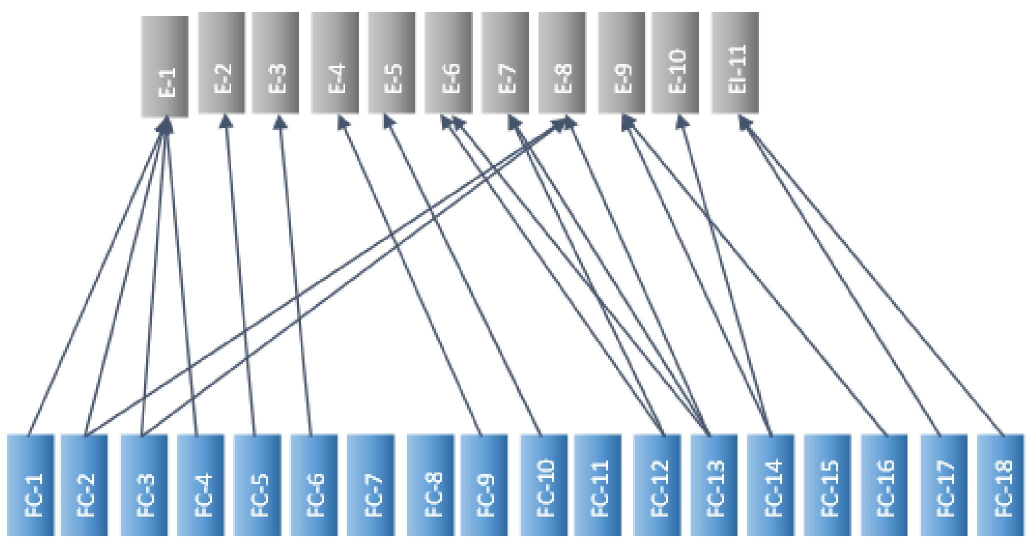

Figure 7. Linking critical factors to mitigation strategies (Authors)

These correlations are useful and can be used to develop macro evaluation strategies and implementation plans in locations and/or sectors where the context is temporal and similar, i.e., the use of BIM in the public sector and related.

5. Conclusion

From the systematic literature review, it was possible to identify the main critical factors in the implementation and use of BIM methodology in the context of public works. The PRISMA methodology allows the execution of the literature review in a standardized, traceable and reproducible way, which confers coherence to the results and reliability to the conclusions made. The contemporaneity of the studies allowed the visualization of the general panorama of studies in the area of interest, within the required context, demonstrating that about the BIM theme, in the context of public works and dealing with information modeling management, the studies are not yet as extensive as those that deal with modeling itself, indicating that there is still a need for maturation of what the BIM tool is, beyond the graphic modeling.

The results of this study showed that in the global context, the public sector presents some critical factors that point to actions aimed at training and capacity building of personnel and that this action may result in a change of culture of collaborative work and sharing of information necessary for the fluidity of BIM, but that is still incipient. On a second level, it is noted that government actions and public incentives generate impacts on the production chain as a whole and may be a driving factor for technology in this sector, conferring greater quality and efficiency to public works. To this end, the integration between the training of professionals in the AECO sector aligned to BIM also emerges as a relevant driving factor. Through the study it was possible to realize that worldwide cultural barriers still prevent the full use of BIM as a consolidated project management tool, relegating 3D tools only to graphic and commercial presentation, which underestimates the potential and need to advance in the quality of projects, planning and especially execution of works with fewer distortions.

The results of the systematic review present critical points or successful BIM implementation strategies, based on case studies, in different locations and economic contexts, in the public sector. The present study sought to correlate these diverse experiences with the solution proposed or applied to each case, to mitigate risks in future strategies management.

The correlations made in this study, among the critical factors, pointed out by the authors associated with the mitigation actions suggested or implemented, can be the object of future studies of maturity diagnosis in a given location or can still serve as a subsidy for the development of future BIM implementation strategies with greater assertiveness and effectiveness.

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Authors' contributions

Paula dos Santos Cunha Boumann was responsible for the study, methodology, data collection, investigation, drafted the manuscript and revising. Rudemberg Felipe Eloi Tavares collaborated for data collection. Dra. Bianca Maria Vasconcelos was responsible for planning, orientation and revising. All authors read and approved the final manuscript.

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Competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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