EXPLORING THE INFLUENCE OF RISKS IN BIM IMPLEMENTATION:

A REVIEW EXPLORING BIM CRITICAL SUCCESS FACTORS AND BIM IMPLEMENTATION PHASES

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Abstract: The adoption of building information modeling (BIM) has a strong potential to influence project performance positively. However, the implementation and use of BIM also involve challenges and risks that must be considered for its practice's success. This study aims to identify gaps and future research direction within the field of BIM and risk management. Besides, it explores the relationship between risks related to BIM implementation and project success dimensions. For this, a literature review is applied, merging bibliometric and content analysis. The results show that the three most frequently mentioned risks are technological interface among programs, followed by interoperability issues, and inadequate knowledge or expertise. Besides, insights pinpoint the positive relation between the BIM critical success factors and the risks associated with BIM, particularly in the design phase.

INTRODUCTION

As the construction industry has been facing different challenges, the related techniques are rapidly changing and risk factors in construction projects are becoming increasingly diverse [1]. The success of a project, if considering time, cost and other aspects integrated to project management requirements, depends on a large scale on how projects deal with the risks embedded in [2]. According to [3], building information modeling (BIM) can create opportunities to reduce threats for the project and for the client. BIM has considerable potential for enhancing construction projects performance by providing collaboration between designers, engineers, constructors and all the stakeholders involved over the whole project life cycle [4]. Therefore, BIM can contain all the information on a project within a single comprehensive model [5]. The published literature presented other innumerable benefits in the use of BIM, such as design consistency and visualization, cost estimations, automatic quantities extraction [6], clash detection, stakeholder collaboration, risk mitigation and improved data management [7]. Another benefit of BIM is that once the information created is inserted into the system, it can be reused, resulting in fewer errors, better consistency, clarity and accuracy [4].

Taking into account all these positives aspects, [8] stated that BIM could reduce risks in the project. Yet BIM is still considered experimental in the architectural, engineering, construction and operations (AECO) industries [5]. The use of BIM presents potential risks involving challenges concerning teamwork, collaboration, and information sharing [9]. Considering the increased use of BIM in the AECO field due to its benefits and strengths, [10] describe initiatives already developed by researchers in relation to the integration of BIM and risk management. However, the literature shows that such integration still has some gaps. According to [11], the analysis of eliminating existing risks or having newer ones with the use of BIM is yet to be investigated. The authors evaluated the evolution of the risks before and after applying BIM through case studies; this analysis brought important contributions to the theme. Nonetheless, studies related to risks associated with the BIM implementation and their relationship with the criteria success factors (CSFs) have not been addressed in the academy yet. [12] report that a number of CSFs for successful BIM implementation have been suggested in the literature, and they also summarize a common set of CSFs that provide guidance to professional and academic areas. This study aims to review the domain knowledge and to identify gaps and future research direction within the field of BIM and risk management in engineering projects. For this, a mixed-method is employed. In general, this method consists in combining elements of qualitative and quantitative research approaches, in order to have an extended and in-depth understanding of the research analysis for better comprehension [13]. Also, with extensive research provided by the mixed method, it is possible to eliminate subjective analysis interpretation or conclusions [14]. Therefore, a systematic literature review, applying bibliometric and content analysis, are applied. This process seeks to contribute to the body of knowledge by exploring the following research questions: (RQ1) What are the main topics, trends and gaps in the literature concerning risk management and BIM? (RQ2) Which risks related to the implementation and use of BIM have a greater influence on the success dimensions of the project? A conceptual model is presented linking the main constructs, variables, and their relations to better understand the role of BIM in risk management.

BIM AND RISK MANAGEMENT

Risk and uncertainty are extensively explored in the literature on project management in reference guides and in the academic context [15]. Risk assessments are effectively established in the existence of appropriate data and clearly defined boundaries for their use. Statistical and probabilistic tools have been developed and provide decision support for risks responses. However, many risk decisions are defined by numerous uncertainties, which lead to challenges and improvements for an effective risk assessment [16].

Risk management is not accomplished in the same way for all projects, as risks do not impact all projects to the same extent [17]. Despite the fact that risk analysis using traditional processes may be satisfactory for small projects, it presents limitations for large and complex projects, which need more attention and effective management [18]. A survey developed by [19] demonstrated that professionals perceive that inadequate risk management can lead to different negative impacts, including an unfavorable project performance.

According to [20], there are a number of techniques for identifying, analyzing and evaluating projects risks. The standard recommends that risk identification includes all risks, even if their sources and causes may not be evident or under the control of the organization. However, risk techniques produce limited statistical data, which are ineffective in practice [21], and decisions are mostly based on existing knowledge and previous experience through a brainstorming method [10]. Moreover, risk analyses are still manual undertaking, leading to a need for automation improvement in order to have a better performance of risk management [11].

Concerning this demand, BIM is a process to improve the creation and management of information throughout the design process [22] and has been globally applied to assist early identification and assessment of risks [10; 23]. Furthermore, [24] found out that BIM has a notable impact on reducing rework by decreasing the risk of errors in construction projects. New regulations from the UK government incentivize the integration between BIM and risk management due to its importance in managing risks successfully [25].

Nevertheless, BIM presents different challenges, difficulties, and risks in its implementation [26] concerning teamwork, collaboration, information sharing and technology issues [9]. Also, BIM and risk management integration are a new field of study and, while some features of BIM can help address project risks, it is not possible to conduct comprehensive risk management [27]. A suitable system to help designers identify and mitigate risks is still lacking [28].

BIM, RISK MANAGEMENT AND PROJECT SUCCESS

Project success is defined by different authors through the triangle of scope, time and cost [29]. However, apart from researches related to deadlines, budget and deliverables compliance, there are few studies associated to risks and success [15] and success factors with BIM [12]. BIM evolution is expected to be effective in improving project quality and performance [29]; nevertheless, BIM implementation implies varied and complex risks [30]. [31] affirm that BIM lead to many challenges and a better understanding of the critical success factors (CSFs) is necessary to organize strategies for its implementation.

[32] reported many studies that described success factors that could affect BIM implementation, but few have investigated the interrelationship among these factors. Moreover, there is a lack of understanding of the influence of risks on the potential benefits provided by BIM [33].

RESEARCH METHOD

The literature review is important to address the diversity of knowledge in a specific academic area [34]. [35] affirm that effective research presents what is already known and what needs to be known.

The research workflow of this study is shown in **Figure. 1**.

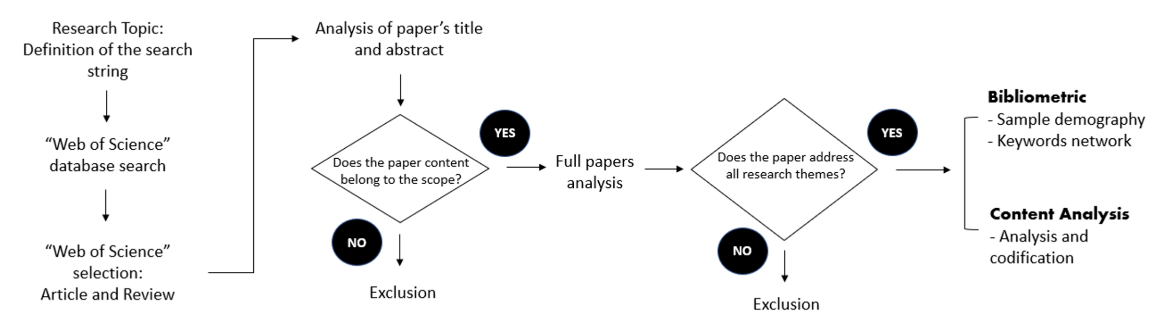


Figure 1 – Research workflow

SAMPLING PROCESS

The dataset was generated through a topic search in the Web of Science Core Collection. This selected database was chosen because it provides access to the main journals and publishers across different sources [36]. The strings "Build* Information model*" AND (uncertain* OR risk) were used for all topics. Following the keyword input, the publication source was limited to articles and reviews, since they are published in journals only after being evaluated through processes and criteria [37]. The review started in 2019, and during the whole period of analysis, we maintain a monthly updating process until October 2020. The initial sample in 2029 using 219 and the last update in October 2020 with the same string, logical operators, and filters results in 291 publications, i.e., an increase of 72 (32%) publications in a year shoes the increasing interest in the topic.

In the second phase, all publications in the initial sample follow the screening selection protocol, based on exclusion criteria is detailed in **Table 1.**

Criteria for paper exclusion	
Criteria	Criteria for elimination
BIM concepts	Not addressed or just mentioned without in-depth content
Risk or uncertainty concepts	Not addressed or just mentioned risk management or uncertainty theme without in-depth content
Research theme	Not related to the research topic

Table 1 – Criteria for paper exclusion

Firstly, each research individually analyzed paper adherence to paper exclusion criteria (see Table 1), based on the paper's title and abstract. The papers that all researchers agree (consensus) in excluding were automatically out of the sample; otherwise (lack of consensus), the analysis should go further. Secondly, all researchers read the full papers that lack consensus in the exclusion to analyze and decide about the exclusion. Although many papers introduce both topics in the title and in the abstract, many of them do not address a relationship between them or present BIM and risk management (or uncertainty) superficially.
After all the stages of selection, 107 papers were selected for bibliometric and content analysis due to their potential relevance.

DATA ANALYSIS

According to [38], the literature review can combine different methodological approaches, such as bibliometric analysis, network analysis, meta-analysis, semantic analysis, and content analysis. In this study, we combine bibliometric, network, and content analysis. The bibliometric analysis is based on the description and quantification of publications and consists of analyzing the publications' elements with statistical and mathematic methods. In the case of scientific publications, it is possible to identify all the periodicals that publish a specific theme. These authors work or are considered a reference in the theme, citations, and the number of published papers.
Content analysis is a method that selects, filters, and summarizes large volumes of data, besides determining viewpoints and tendencies [39]. The key activities include encoding based on the literature and identified categories, frequency counts on categories, cross-tabulations, and results' interpretation [40].

BIBLIOMETRIC STUDY

In this study, the bibliometric analysis of the literature was conducted using VOSViewer®, the science mapping tool developed by [41]. VOSViewer® is a software that supports the analysis of clustering solutions with visualizations [42]. For the bibliometrics, analysis concerning the publication evolution over time, most productive journals and keywords network were developed.

CONTENT ANALYSIS

In order to identify the contents covered by each study, the papers selected were analyzed and coded. Coding is a fundamental skill for qualitative analysis and provides managing, identifying, sorting and ordering data. Thoughtful coding ensures familiarity with the detail of data [43]. The content analysis was applied to address the research question regarding the influence of risks (or uncertainties) related to BIM on the success dimensions of the project (RQ2). Thus, the coding schema developed

The coding schema starts with BIM codes, classified into macro, meso, and micro levels. The BIM codes explored technology, people, and process issues, as suggested by [45]. Then, emerging codes were identified, and the final BIM codes group has 33 codes and sub-codes.
The theoretical codes (axial) related to BIM critical success factors (CSFs) were grounded in [12] were summarized a set of thirty-four CSFs. CSFs codes were classified according to each phase of the project life cycle: design (11 codes), pre-construction (12 codes), construction (9 codes), and operation (2 codes).
The starting point for risks associated with BIM codes was the 16 risks suggested by [33], and then new codes emerged during the content analysis reaching 80 codes. Finally, project success codes influenced by BIM risk was based on the emerging codes added during the content analysis process. The coding cycles result in the whole coding schema presented in Section 4.

BIBLIOMETRIC ANALYSIS

The papers selected were published in different journals and the top 7 journals that published the most papers are Automation in Construction, Journal of Construction Engineering and Management, Engineering Construction and Architectural Management, Journal of Computing in Civil Engineering, Journal of Management in Engineering, KSCE Journal of Civil Engineering and Safety Science, respectively. For the journals network presented in **Figure 2**, a setting on the minimum number of documents and minimum citation number of a journal to be 3 and 10, respectively, were considered and a total of 9 journals met the threshold. Although the journals Renewable & Sustainable Energy Reviews and Journal of Civil Engineering and Management are not among the top 7 journals concerning the publication number, they were considered in the network of main outlets due to their number of citations.

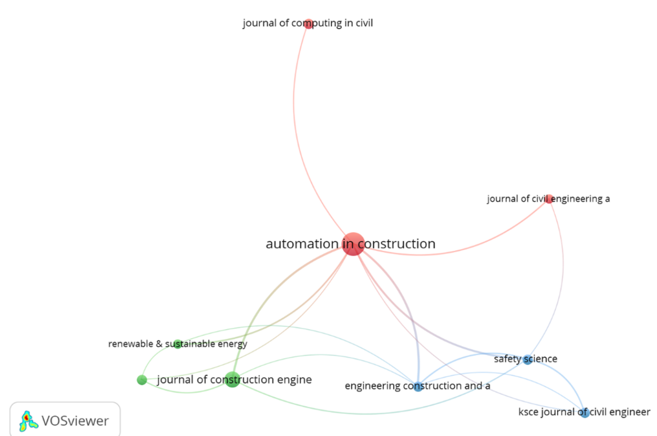


Figure 2 – Main journals concerning publication and citation
Note: Journal names may not be fully presented in VOSViewer.

Figure 3 shows the keyword network containing at least 4 occurrences. The keywords distance reveals the proximity between the terms, and the lines represent the links and concomitant occurrences. The relationships among the keywords can be summarised as follows:

- BIM and management are widely discussed in the literature with the highest number of occurrences (37 and 34, respectively) and they are linked among all the 5 different clusters identified by the software VosViewer®. According to [46], an effective BIM implementation requires an improvement in the management practices as well as extensive changes in all the project process [7].
- construction safety is another important research area giving the increasing number of topics related to safety monitoring, hazard identification and systems for safety information [47; 48].
- the keywords risk and performance emerge as the tenth (10th) and eleventh (11th) largest hotspot in the occurrences ranking, respectively, and these keywords presented 13 occurrences each (**Table 2**). They were grouped into the same cluster, but they do not belong to BIM or building information modeling or any other BIM name variation cluster, resulting in a gap between these themes. As projects often involve multiple risk factors, their identification can guide BIM users resulting in a better project performance [9].
- a cluster involving risk management and building information modeling is identified; however, these themes can be considered as an emerging topic as they only present 6 occurrences. Despite the upward research trend between risk management and BIM, there is a lack of studies integrating both topics [25].

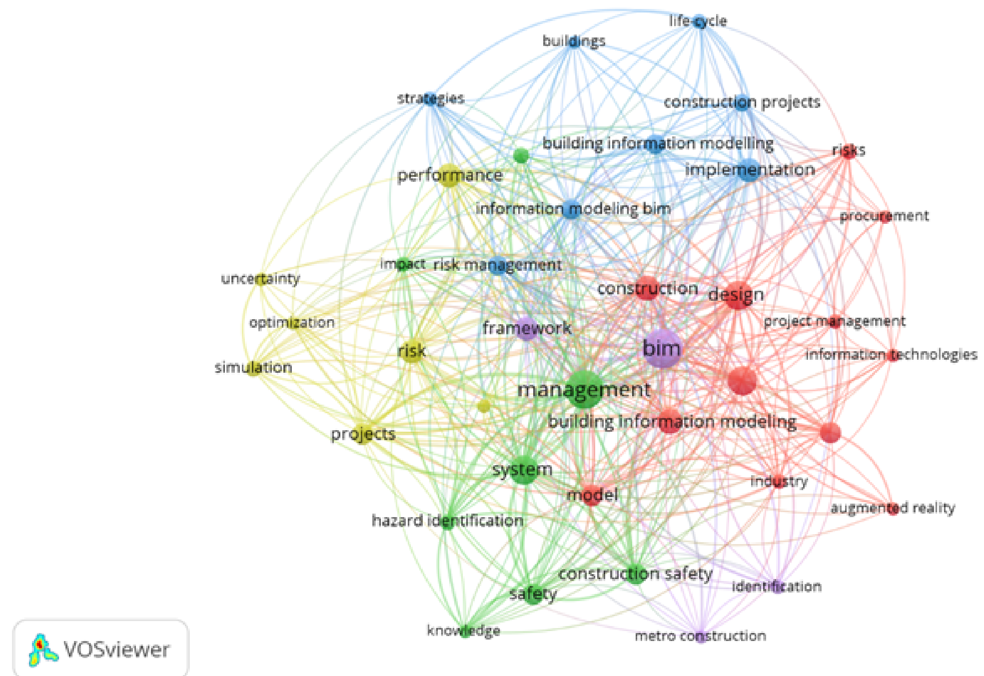


Figure 3 – Keywords co-occurrence network

Keyword	Ocurrences	Keyword	Ocurrences	Keyword	Ocurrences
bim	37	safety	11	life-cycle	5
mamangement	34	adoption	11	identification	5
system	21	information	11	project management	5
design	21	building information modelling	10	checking	4
building information modeling	21	information modeling bim	9	knowledge	4
construction	15	risk management	9	buildings	4
building information modeling (bim)	15	construction projects	7	optimization	4
implementation	14	hazard identification	6	metro construction	4
framework	14	risks	6	construction management	4
risk	13	building information modelling (bim)	6	information technologies	4
performance	13	simulation	6	ontology	4
projects	11	industry	5	uncertainty	4
model	11	strategies	5	augmented reality	4
construction safety	11	impact	5	procurement	4

Figure 3 – Keywords co-occurrence network

CONTENT ANALYSIS

BIM influence on project success dimensions

The results show that the three most frequently mentioned risks are technological interface among programs (BR2), inadequate knowledge or expertise (BR4), and followed by interoperability issues (BR3) (see **Table 3**).

Figure 4 exhibits the cross-tabulation between the 16 risks associated with BIM, identified in extensive research by [33], and the dimension of project success presented by [15], both presented in **Table 4**. The relative amount (column "%") was calculated based on the number of papers selected and the code frequency is demonstrated in column "n".

The data analysis allows affirming that project management efficiency (PSD2) is the success dimension most frequently discussed in the literature, followed by the future impact on business (PSD5). The analysis shows a closer relationship between PSD2 and: (a) technological interface among programs (BR2); (b) interoperability issues (BR3); and (c) inadequate relevant knowledge or expertise (BR4), respectively. [49] state that BIM implementation presents many challenges, including technological barriers and an analysis conducted by [50] of 35 construction projects; interoperability issues were highlighted as a major negative effect in the use of BIM. [51] also stated that there are countless technological challenges to be addressed as a key to BIM effective implementation.

A study conducted across countries by [52] demonstrated that technical issues were tightly present in BIM adoption by construction companies. According to [53], construction projects still have concerns related to interoperability problems, which are considered not only technical issue, but also a support for collaboration. This collaboration consists in involving process, culture and management of all the stakeholders involved [46]. Some efforts have been made in order to solve this issue, such as the industry foundation classes (IFCs). However, there are some barriers to its implementation and adoption due to incomplete and incompatible data exchanges for specific tasks [54]. Concerning the risk related to inadequate relevant knowledge or expertise, for [9], inadequate experience and lack of available skilled professionals are considerable risks and they are mostly present in an early stage of BIM development.

With reference to the success dimension related to PSD5, the same risks were shown as the greatest influencers for the future impact on business (BR2, BR3 and BR4, respectively). [30] state that many companies that use BIM, mostly the smaller ones, present a low return on business. Difficulties involving interoperability issues combined with the lack of professionals' skills and experience are the main concerns that tend to affect a business outcome. Considerable attention and investments in these factors are required to overturn this scenario and have positive trends in the company business.

Category	Sub-category	Code	n	%*
Risks in BIM implementation	Lack of BIM protocols	BR1	26	24%
	Technological interface among programs	BR2	45	42%
	Interoperability issues	BR3	36	34%
	Inadequate relevant knowledge or expertise	BR4	37	35%
	Cultural resistance	BR5	14	13%
	Unclear ownership of the BIM data	BR6	17	16%
	Data security	BR7	18	17%
	Low quality of BIM data	BR8	18	17%
	Reluctance to share information	BR9	10	9%
	Poor communication among project participants	BR10	20	19%
	Lack of collaboration among project participants	BR11	19	18%
	Lack of a check mechanism for designs	BR12	6	6%
	Professional licensing issues	BR13	5	5%
	Uncertainty over design liability	BR14	23	21%
	Changes in the BIM model by unauthorized parties	BR15	5	5%
	Cost overrun with BIM	BR16	26	24%

* % in 107 articles

Table 3 – Coding schema: Risks in BIM implementation

	PSD1	PSD2	PSD3	PSD4	PSD5	PSD6	PSD7
BR1	9	26	14	2	17	2	6
BR2	8	40	16	1	21	4	15
BR3	5	33	13	2	19	4	11
BR4	7	31	20	0	19	1	10
BR5	1	13	11	0	9	1	3
BR6	4	17	11	2	9	3	3
BR7	6	16	10	2	11	2	5
BR8	4	17	9	2	8	1	4
BR9	2	9	7	1	7	1	2
BR10	3	17	9	0	9	0	7
BR11	2	17	10	1	10	1	4
BR12	0	6	3	0	4	0	1
BR13	1	5	4	0	5	1	1
BR14	5	22	14	1	14	3	4
BR15	1	5	4	0	4	0	0
BR16	4	25	14	2	15	2	4

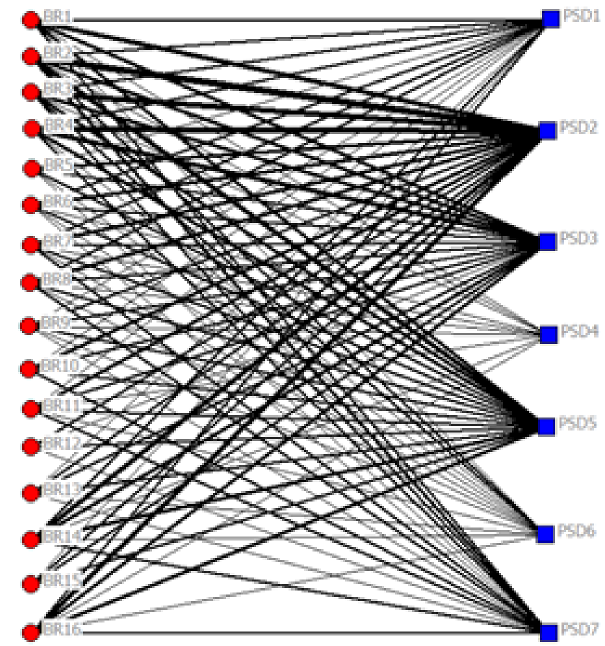


Figure 4 - Project Success Dimensions X Risks associated with BIM

Category	Sub-category	Code	n	%*
Project Success Dimensions	Product/Service	PSD1	16	15%
	Project Management Efficiency	PSD2	85	79%
	Impact on Team	PSD3	24	22%
	Present impact on business	PSD4	7	7%
	Future impact on business	PSD5	35	33%
	Impact on the customer	PSD6	6	6%
	Social and Environmental Impact	PSD7	48	45%

* % in 107 articles

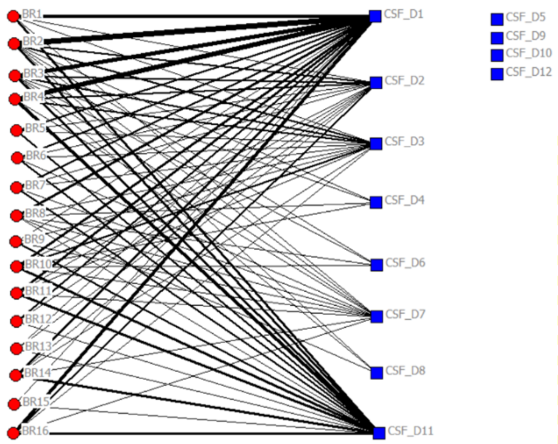
Table 4 – Coding schema: Project success dimensions

BIM risk influence on design critical success factors

The literature explored convergences in the identification of a positive relationship between the critical success factors and the risks associated with BIM. The cross-analysis indicate that the link between earlier and accurate 3D visualization of design (CSF_D1) and reduced claims or litigation (CSF_D11) with BR2, BR3 and BR4 is the most discussed in the literature (**Figure 5**). The technology embedded in BIM contributes to the precision and quality of the design visualisation [10]; however, software-interoperability is still a challenge for successful BIM adoption [55] and the lack of integrity of three-dimensional (3D) models issued by designers create uncertainties to BIM users [56]. A survey developed by [57] to identify risks in implementing BIM shows that limited functions within existing BIM software tools were the major risk identified by the participants from different professions, including architects, engineers, owners, BIM consultants, and other AEC practitioners. Conversely, BIM has played an important role in developing new opportunities to improve risk management [58] as researches established a strong link concerning the support to risk identification and risk assessment [58; 27; 11; 25]. [23] confirm that BIM has been effective in identifying and mitigating risks in the early stages of the project.

BIM risks influence factors that affect the project performance

The connections between communication (MesC3a) and the risks technology (BR2), knowledge and expertise (BR4) and interoperability (BR3) are the most frequent co-occurrence, respectively (see **Figure 6**).



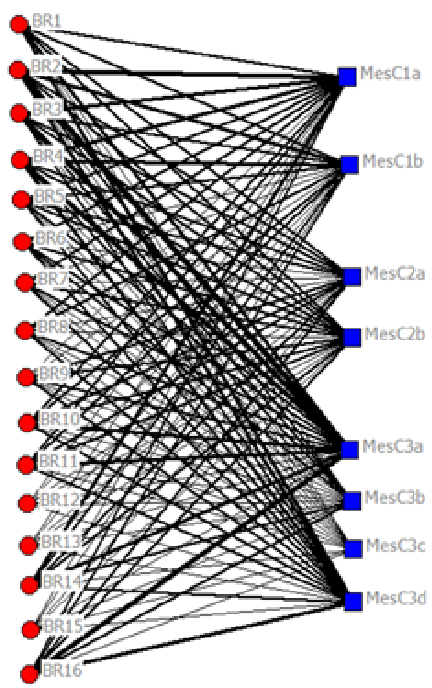
	CSF_D1	CSF_D2	CSF_D3	CSF_D4	CSF_D5	CSF_D6	CSF_D7	CSF_D8	CSF_D9	CSF_D10	CSF_D11
BR1	16	3	3	0	0	0	1	0	0	0	9
BR2	27	7	6	2	0	1	2	1	0	0	11
BR3	19	7	5	1	0	1	1	1	0	0	11
BR4	21	6	5	0	0	0	2	0	0	0	12
BR5	7	2	2	0	0	0	0	0	0	0	5
BR6	7	2	1	0	0	0	1	0	0	0	6
BR7	7	3	2	0	0	0	1	0	0	0	7
BR8	9	0	1	2	0	1	1	1	0	0	3
BR9	3	0	1	0	0	0	1	0	0	0	5
BR10	8	2	4	1	0	1	2	0	0	0	9
BR11	9	1	2	0	0	0	1	0	0	0	8
BR12	4	1	0	0	0	0	0	0	0	0	3
BR13	2	1	0	0	0	0	0	0	0	0	3
BR14	11	3	1	0	0	0	1	0	0	0	9
BR15	1	0	0	0	0	0	0	0	0	0	2
BR16	15	4	2	0	0	0	1	0	0	0	9

Figure 5 - Critical success factors X Risks associated with BIM

[59] conducted face-to-face interviews with experts from engineering projects to investigate which risks have occurred more frequently and the result showed that risks related to the lack of communication between stakeholders were the most common. BIM effectiveness is related to communication, cooperation and collaboration between the designers and all the agents involved [56]. Technology and interoperability are key factors for successful information exchange. According to [60], interoperability issues have a direct relation with communication and information exchange among all stakeholders, outstandingly with subcontractors.

For a communication improvement using BIM, strong computer design skills and specialized software knowledge are required [61]. Furthermore, IT capacity (MesC1a), the most frequent factor is also tightly linked with BR2.

Learning experience (MesC3d) has the most representative link with knowledge and expertise (BR4). In a list of 32 risks identified in the literature and experts' opinion, the highest-ranked risk "lack of BIM knowledge" was the greatest barrier to BIM implementation presented by [11]. Professionals with limited knowledge and expertise related to BIM led to cultural resistance and technical and interoperability issues, which can hinder BIM implementation and experience achievement [62].



	MesC1a	MesC1b	MesC2a	MesC2b	MesC3a	MesC3b	MesC3c	MesC3d
BR1	12	8	8	9	21	5	4	15
BR2	22	17	10	10	32	7	4	16
BR3	20	13	9	9	24	7	3	13
BR4	19	15	11	10	27	7	4	20
BR5	7	7	9	8	10	6	2	8
BR6	11	5	6	7	13	7	3	8
BR7	9	6	6	7	13	6	5	8
BR8	13	9	5	6	10	5	3	9
BR9	6	5	7	7	8	5	2	7
BR10	11	9	8	8	17	5	2	12
BR11	9	8	7	7	16	6	2	10
BR12	3	4	2	2	6	3	0	3
BR13	4	3	2	2	5	2	0	3
BR14	14	8	9	11	17	7	5	13
BR15	3	3	2	2	5	2	1	4
BR16	13	9	10	10	22	7	4	14

Figure 6 - Factors that affect the project performance X Risks associated with BIM

CONCLUSION

This article contributed to the literature with an in-depth analysis of 107 articles dealing with BIM implementation risk that answer the two research questions (RQs) proposed. The first research question explores the core topics in the literature of BIM related to risk, pointing out the three most frequently mentioned risks: technological interface among programs, interoperability issues, and inadequate knowledge or expertise. Second, the relation between BIM risks and project success dimensions are explored in the literature, particularly with Project Efficiency. Finally, insights pinpoint the positive association between the BIM critical success factors and the risks associated with BIM, particularly in the design phase.

This paper presents certain inherent limitations to the literature review method. First, the sample demonstrates limitations related to the search strategy, including selecting WoS databases, search strings, and logical operators adopted. Therefore, we may lose some relevant studies. The screening phases can show some bias related to the researcher's interpretation of the exclusion criteria.

For future research, an in-depth study of the relationship between BIM-related risks and project performance through quantitative research approaches. Besides, there is a new room for future research on the relationship between BIM-related risk and critical success factors, particularly in the design phase.

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A REVIEW EXPLORING BIM CRITICAL SUCCESS FACTORS AND BIM IMPLEMENTATION PHASES