Forcael, E., Castro, A., Bedwell, F., Casanova, E., Orozco, F. & Moreno, F. (2023). Barriers to BIM implementation in bridge construction: a case study. *Proceedings of the 31st Annual Conference of the International Group for Lean Construction (IGLC31),* 128–139. doi.org/10.24928/2023/0211

BARRIERS TO BIM IMPLEMENTATION IN BRIDGE CONSTRUCTION: A CASE STUDY

Eric Forcael[1], Alonso Castro[2], Francisco Bedwell[3], Euro Casanova[4], Francisco Orozco[5], and Francisco Moreno[6]

ABSTRACT

The purpose of this research was to find the barriers that hinder the implementation of BIM in bridge projects (BrIM). This was done by a bibliographic analysis and the application of an evaluation tool to a case study, corresponding to a Chilean road project with an important number of bridges. Based on the literature, twenty-three barriers were found, which were then validated through the application of the survey to the case study, resulting the main barriers: "Interoperability problems between different BIM software", and "Differences between BIM for buildings and BIM for bridges". Then, a risk analysis was run, concluding that the barriers in bridge projects cause high levels of impact when implementing BIM. Thus, this research may help project and engineering managers to have a first approximation to the most recurring barriers in BrIM and how to rank them according to their impact. Finally, for future research, the findings of this study can be extended to other complex projects —such as bridges— but with different levels of uncertainty, that allow finding new barriers or confirm those found here.

KEYWORDS

BIM, management, bridges, barriers, Chile.

INTRODUCTION

CONTEXT

Since the first industrial revolution, the impact of new technologies has been of utmost importance to obtain better results in the highly competitive areas that have characterized the construction industry. In this way, factors such as resistance to change, and lack of training, financing or knowledge have jeopardized the advancement of new technologies. Building Information Modeling (BIM) has been part of this reality, facing barriers in its implementation. Thus, this methodology has caused a great impact on construction projects, bringing a new way to develop them in each stage (pre-design, operation, maintenance, among others).

This has led to an increase in the number of BIM users, along with government programs for its progressive implementation in different institutions. In this scenario, countries such as Chile, through its Ministry of Public Works, have promoted initiatives to increase the use of

[1] Associate Professor, Department of Civil and Environmental Engineering, Universidad del Bío-Bío, Concepción, Chile, eforcael@ubiobio.cl, orcid.org/0000-0002-3036-4329

[2] Research Assistant, Department of Civil and Environmental Engineering, Universidad del Bío-Bío, Concepción, Chile, alonso.castro1501@alumnos.ubiobio.cl

[3] BIM Manager, BIMORE, Santiago, Chile, fbedwell@bimore.cl

[4] Assistant Professor, Department of Civil and Environmental Engineering, Universidad del Bío-Bío, Concepción, Chile, ecasanova@ubiobio.cl, orcid.org/0000-0002-1701-0550

[5] Professor, College of Engineering, Universidad Panamericana, Guadalajara, Mexico, forozco@up.edu.mx, orcid.org/0000-0003-2409-1026

[6] Professor, College of Engineering, Universidad Panamericana, Guadalajara, Mexico, fmorenoa@up.edu.mx, orcid.org/0000-0003-4058-9350

BIM methodologies in all their infrastructure projects, where the case study considered in this research (a major road project located in southern Chile), is a good example to show this effort.

THE PROBLEM, SCOPE, AND OBJECTIVES OF THE INVESTIGATION

This research consisted of an exhaustive literature search to determine the main barriers to BIM implementation, which were then ratified through the application of an evaluation instrument to various stakeholders belonging to the Ruta Nahuelbuta project, a major road project located in southern Chile. This allowed answering the following questions: what are the most relevant barriers to the implementation of BIM in bridges, what is the probability of these barriers occurring, and what level of severity will these events have in the development of the project?

The general objective of this research was to determine the barriers that limit the implementation of BIM methodology in bridge construction projects, from which the following specific objectives are derived: to determine the barriers to be studied based on an exhaustive literature review; to validate the barriers previously found in the literature, through an evaluative tool; to analyze quantitatively and qualitatively the results obtained.

ACADEMIC BACKGROUND

The necessary information for this research was gathered through a literature review on the fundamentals, vocabulary, and key concepts related to Bridge Information Modeling (BrIM).

BRIDGE INFORMATION MODELING (BRIM)

First, bridge information modeling (BrIM) is essentially BIM applied to bridge projects (Maire & Brinckerhoff, 2012). On the other hand, Cho *et al.* (2009), establish that BrIM corresponds to a 3D concept for design, construction, maintenance, and operation, where the system displays data that allows its use in real-time as conditions change throughout the life cycle of a bridge.

Additionally, Gaitá & Gómez (2014) defined this concept as a set of systems, methods, and digital storage media used to generate the information model of a bridge, which allows combining the information associated with the design and construction from several disciplines.

There are some differences between BIM and BrIM, which according to Bartholomew *et al.* (2015) correspond mainly to a geometric difference since buildings are developed on a rectangular grid system, while bridges are defined with curved or straight horizontal alignments, vertical slopes, elevations, and superelevations. Another difference is the number of specialties since the number of disciplines and trades in buildings is significantly higher than in bridges.

SOME OTHER ASPECTS OF BRIM

Chronologically speaking, Heikkilä (2001) started by determining the content of bridge information models, their technical guidelines and promoting the use of 3D models in Finland. Later, Shirole *et al.* (2009) summarized the main problems and challenges when implementing BrIM in the construction industry. Subsequently, Shim *et al.* (2011) worked on an informative scheme to avoid possible interoperability problems between bridge design and construction processes. Then, Marzouk & Hisham (2012) present a methodology to use BrIM as a tool to estimate costs, who later in 2014 present another cost estimation methodology but adding the estimation of a work schedule for the construction phase (Marzouk & Hisham, 2014). Bartholomew *et al.* (2015) studied alternative BrIM standards and a method for exchanging information modeling data. Meanwhile, Kasireddy & Akinci (2015) analyzed a case study to demonstrate the benefits and challenges of implementing BrIM for bridge life cycle inspection. Other authors, such as Markiz & Jrade (2019) conducted research to demonstrate the feasibility of integrating a support system with the use of BrIM, and overcome subjectivity in decision-making. Finally, Zheng & Xu (2020) conducted risk analyses on the implementation of BrIM.

CASE STUDY

PROJECT DESCRIPTION

The interurban road infrastructure project considered as a case study is called "Improvement of the Nahuelbuta Route", which search for improving connectivity and maximize economic and social benefits of people by reducing transport costs and accidents. This project entailed the improvement and widening of an existing dual carriageway running between two important cities located in southern Chile. It is a public-private partnership (PPP) project, under a modality of Build-Operate-Transfer (BOT), reaching a budget of US$254 million and a road concession period of 35 years (2 years for administrative and project procedures, 3 years for construction and 30 years for operation under a toll mechanism). The project includes an extension of 55 km of dual carriageway, with 17 low-grade intersections, 30 at-grade intersections, 3 toll plazas, 78 bus stops, 2 viewpoints, 2 railroad crossings, 23 pedestrian walkways, 32 km of service roads, 21 km of bicycle lanes, 1 control area, and 15 bridges of different characteristics.

SOFTWARE AND WORKFLOW USED

As for the software used in the project, the architecture and engineering specialties used *Revit* as an information modeling tool for obtaining plans, modeling structures, and calculating the amount of work. *Tekla structures* was used for the modeling of steel reinforcement of bridges.

For the geometric design of road works, *Istram* was used, which is an application specialized in the design of civil engineering projects. On the other hand, it was necessary to use *Autodesk BIM 360* as a cloud platform, to upload, visualize and manage the project models of different specialties and subspecialties. Also, *Naviswork* was used for the compilation and simultaneous review of models, which was able to identify and resolve discrepancies in project coordination.

Finally, *BIMcollab* is a virtual platform for communication and control of the project, through functions such as reporting discrepancies in 3D modeling to the responsible user, sending images of modeling problems, generating reports with the dates on which errors were detected and solved, and thus facilitating review by the client and external users.

METHODOLOGY

BIBLIOGRAPHIC RESEARCH TO DEFINE BARRIERS TO BRIM IMPLEMENTATION

To define the main barriers encountered in the literature when implementing BIM in bridges, an extensive literature review was carried out using the Systematic Literature Review (SLR) method, which is a way of evaluating and interpreting all available research so that it is relevant to a particular research question in a thematic area or phenomenon of interest (Kitchenham, 2004). On this basis, an analysis of the selected documents was then carried out to identify the most frequent barriers and, therefore, the most important according to several authors.

BIBLIOGRAPHIC COMPILATION

At this stage, it was necessary to develop a search protocol, compile a database and make the bibliographic selection, as follows:

Search protocol development

First, the methods proposed by Kitchenham (2004) and Borrego *et al.* (2014) were implemented. In particular, the main filters used were keywords and research questions, among other criteria established in the development of this stage, such as: reading the abstract, title, and internal references of the documents. *Google Scholar* was used as a search engine to retrieve academic content (papers, books, theses, etc.). The keywords used were *barrier*, *building information modeling*, *challenged*, BIM, *bridge information modeling*, BrIM, *construction,* and *risk*.

Database

The search yielded more than 500 bibliographic items, where the vast majority of them came from journals such as *Automation in construction*, *Building and Environment,* and *Journal of Construction Engineering and Management*.

Bibliographic selection

Here, the aforementioned filters were used to select the material, reducing the information to be analyzed to less than 20%. Then, we proceeded to read the content and determine which texts contributed information to the study, obtaining about one hundred documents. Finally, the references of each research were reviewed in search of the most relevant material.

DESIGN AND APPLICATION OF AN EVALUATIVE TOOL

As evaluation tool, a survey was chosen (through the *SurveyMonkey*™) since it is a widely used method and easy to distribute. The survey was applied to stakeholders belonging to the Nahuelbuta Society (owner of the project used here as a case study), and divided into 3 sections:

- Basic information on the respondents (years of experience and specialty).
- Assignment of the probability, between 0 and 100%, of an event, occurring and the level of severity, also between 0 and 100%, it would have on the project. It should be noted that the probability of occurrence was quantified according to the following ranges: very unlikely = 0-20%; unlikely = 21-40%; expected = 41-60%; likely = 61-80%, and very likely = 81-100%. In the case of severity, the ranges were: insignificant = 0-20%; minor = 21-40%; moderate = 41-60%; significant = 61-80%, and disaster = 81-100%.
- Application of a survey to case study stakeholders on the main barriers to the application of BIM in bridge projects.

RESULT ANALYSIS

Based on the results obtained from the surveys, we then proceeded to analyze these results, to construct a ranking of the barriers that impact the most on the implementation of BIM in bridges and a probability-severity matrix associated with this categorization of barriers**.**

BIBLIOMETRIC ANALYSIS

After applying the respective filters, 64 documents were obtained from the literature selection. The purpose of this stage was to distinguish the material according to its origin, year of publication, and the number of cited times. Then, a content analysis was carried out to match the documents that mentioned the same barrier when implementing BIM in a bridge project.

Main sources of information and countries

Out of the 64 documents selected, 46 were journal articles (71.8%); 16 came from conferences (25%) and 2 were theses and 1 survey (3.2%). Most of the research cited comes from five countries. In first place is the United Kingdom with 16%, followed by the United States with 13%; in third place is Hong Kong with 9%, and finally China and Spain, both with 6%.

BARRIERS TO BIM IN BRIDGE PROJECTS

Twenty-three barriers were established, which are listed below and then corroborated through an exhaustive literature review, which results are shown in Table 1. Although the number of barriers to be analyzed may seem to be high, other similar studies have been effective in drawing conclusions from large number of variables (Forcael et al., 2018; Sun et al., 2017):

1) **Need to train a greater number of BIM users:** The number of users trained to work with BIM is limited, and the consequence of this is the difficulty of its implementation.

2) **Ambiguity about the intellectual property of modeling:** Due to the collaborative nature of the BIM methodology, issues related to the intellectual property of the modeling emerge.
3) **Cost associated with the implementation of the software:** BIM works with multiple software, along with the purchase of equipment (hardware) and training courses.
4) **Ambiguity regarding the chain of legal liability:** New obligations for BIM professionals related to work scopes, roles, and responsibilities in case of errors or miscoordinations.
5) **Resistance to change the way a project is built:** Resistance to change due to work culture, lack of commitment and innovation, or the idea that the current way of working is sufficient.
6) **Low use of standards for the description of BIM objects and coding systems:** A BIM standard grants information regarding possible uses, benefits, technical glossary, etc., where the idealistic holy grail of BIM has been to create a common language for builders.
7) **Low demand for the use of BIM by the client/manager:** The lack of demand is due to the lack of knowledge of the program or the client's perception (since his/her requirements are met with conventional tools, he/she considers the implementation of BIM unnecessary).
8) **Interoperability problems between different BIM software:** Fragmentation between participants in each project phase can be caused by the diversity of software and can contribute to the interoperability problems, because of the diversity of software formats.
9) **Lack of knowledge of the benefits of implementing BIM:** The low number of studies of the BIM impact on the projects has caused uncertainty among senior executives and clients.
10) **Time and/or cost for training personnel in the software:** The difficulty of handling the software results in a slow learning pace, bringing a high investment of time and cost.
11) **BIM is still little known and/or complex to use:** BIM is described by users as "rigid" due to the specific order of actions to coordinate the diverse software, along with an "unfriendly" interface, which makes self-learning difficult, made worse due to constant software updates.
12) **Low collaboration among Project participants using BIM:** The "fragmented nature" of the construction field causes the main obstacles of peer-to-peer input.
13) **Lack of government intervention in massive BIM use:** Low participation of the government as a change agent. For BIM to become widespread, the role of the State is essential, through subsidies, courses, or promotion of public projects that require its use.
14) **Low support from managers and decision-makers in the implementation of BIM:** The support offered by top management is a relevant element to implementing BIM in the construction industry, through the necessary investments for training in this methodology.
15) **Lack of experience or expertise in BIM use:** Due to the low number of regulated BIM users, there is a lack of experience, causing difficulties in the implementation.
16) **Limited existence of BIM protocols:** The launch of protocols in the scheduling phase is crucial to ensure consistency in the information and formatting styles for BIM implementation, if not, it increases the occurrence of mishaps.
17) **Changes in workflows within and between projects:** Because of the collaborative nature of BIM, it is important to give way to radical changes in the workflow. These changes are not entirely linear but produce feedback loops between BIM specialties.
18) **Limited access to a stable connection to servers for storing and coordinating information:** There was no stable internet service or hardware (*IT infrastructure*) with the necessary capabilities to be efficiently connected to external or internal servers.
19) **Cybersecurity risk:** Cybersecurity becomes a major threat when an unauthorized user or hacker get access to a BIM project. In addition, confidential information, such as electronic signatures on documents, can be easily forged or replicated, creating authenticity doubts.
20) **Need for a BIM manager in projects:** Because information models are shared among users, it is crucial to hire an employee who updates the BIM data with accuracy.

21) **Low availability of specialized BIM software for bridges:** It is caused due to the low availability of specialized software that has specific “families” for the modeling of bridges.
22) **Difficulty in making updates to bridge models on-site:** When wanting to perform on-site inspections of a bridge to update the information of its real conditions, a lack of flexibility to represent and exchange information parametrically has been found.
23) **Differences between BIM for buildings and BIM for bridges:** The differences that contrast BIM and BrIM lie in the procedure for modeling the parts of each project, since, in general, roadway elements must be adapted to the geometry of the terrain.

Table 1: Barriers found in the literature

Barriers / Authors	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
(Ahmad et al., 2018)		•				•		•	•	•									•				
(Ahmed & Hosque, 2018)								•			•												
(Ahmed et al., 2014)						•	•		•	•	•	•		•	•			•					
(Ahn et al., 2016)				•				•			•		•				•						
(Al-btoush & Haron, 2017)					•												•						
(Arshad et al., 2019)		•		•		•		•								•			•				
(Azhar et al., 2015)	•	•	•	•		•		•		•		•				•				•			
(Bartholomew et al., 2015)																							•
(Chan et al., 2019)	•	•	•		•	•		•				•		•	•								
(Chiu & Lai, 2020)	•						•			•	•	•	•	•									
(Costin et al., 2018)			•	•	•	•		•															
(Dayan et al., 2022)					•			•					•					•		•		•	
(Forcael et al., 2020)								•				•						•					
(Gaitá & Gómez, 2014)																					•		
(Gerrish et al., 2017)						•					•												
(Kasireddy & Akinci, 2015)																					•	•	
(Kiani et al., 2015)		•			•				•		•												
(Maire & Brinckerhoff, 2012)																					•		
(Marefat et al., 2018)					•		•				•	•			•	•							
(McGuire et al., 2016)				•			•	•													•		
(Mehran, 2016)		•		•				•	•					•	•	•							
(Migilinskas et al., 2013)			•							•		•		•									
(Ng & Lai, 2016)			•				•		•		•	•	•					•					
(Porwal & Hewage, 2013)		•		•																			
(Saieg et al., 2018)	•		•					•															
(Saka & Chan, 2020)					•	•	•		•		•		•	•									
(Seyis, 2019)		•								•		•			•					•			
(Ullah et al., 2019)		•	•		•	•	•	•	•				•	•	•	•							
(Vass & Gustavsson, 2017)													•				•						
(Zhao et al., 2018)	•	•	•		•			•				•			•	•			•				

CASE STUDY EVALUATION OF THE BARRIERS FOUND IN THE LITERATURE

To evaluate the impact of the barriers found in the literature, an evaluation instrument (survey) was applied to a group of 17 professionals belonging to the case study described above. This survey consisted of two parts: questions associated with the probability of occurrence of an event (in this case a barrier), and questions related to the severity that could cause the occurrence of such an event. Based on the results of both indicators (probability and severity), the impact caused by the existence of barriers in the implementation of BIM in bridges was calculated.

For the validation of the evaluation instrument applied, it is necessary to ensure its understanding and whether its design is self-explanatory (Forcael et al., 2022). For the present study, eminent practitioners and researchers reviewed the survey and made relevant comments to improve its comprehensibility, repeating the process until the survey was fully refined.

Once the data was processed, Cronbach's alpha coefficient (α) was calculated to evaluate the reliability of the survey, ensuring the survey's objectivity. This value was calculated with equation 1, where K is the number of questions, V_i is the sum of the variances of each question and V_t is the variance of the total results of the respondents.

$$\alpha = \frac{K}{K-1}\left(\frac{\sum_{i=1}^{K} V_i}{V_T}\right) \tag{1}$$

Along with the validation of the interview described above, according to Oppenheim (2000), a pilot interview was also applied to measure and calibrate the interviewee's response time and ensure that the questions were explicit and did not confuse the interviewee. Thus, for the survey applied, Cronbach's alpha values obtained were 0.869 for questions related to probability and 0.909 for questions associated with severity, values with a more than acceptable reliability according to Doloi (2008). The response rate of the applied instrument reached 47%, which is considered satisfactory as it exceeds the minimum value suggested by Fellows & Liu (2015). The survey is available on request from the authors. The sample consisted of architects, builders, civil engineers, BIM managers, and BIM coordinators, whose profiles are shown in Table 2.

Table 2: Respondent profile.

Labor sector	Private	50%
	Public and Private	50%
Professional Career	Architect	25%
	Civil Engineer	50%
	Builder	13%
	Other	13%
Current area of work	Construction	13%
	BIM Management	25%
	Engineering	63%
Work experience	5 - 10 years	25%
	10 - 20 years	13%
	+20 years	63%
Experience with BIM	0 - 2 years	25%
	2 - 5 years	25%
	5 - 10 years	38%
	+10 years	13%
BIM knowledge level	Self-acquired knowledge	38%
	Training	38%
	Masters in BIM	25%

IMPACT ANALYSIS OF THE BARRIERS PRESENT IN BIM FOR BRIDGE PROJECTS

Calculation of indexes

The methodology proposed by Akogbe *et al.* (2013) was used to calculate the indexes, which allows the factors to be classified in terms of impact, using probability and severity responses:

- Probability index (P.I.): represents the probability of occurrence of an event, with values between 0% and 100%, and calculated with equation 2.

$$I.P = \frac{\sum_0^{100} a_i * n_i}{N} \tag{2}$$

Where a_i represents the value assigned to each answer (0%, the impossibility; and 100%, the certainty); n_i represents the frequency of each answer, and N is the total number of answers.

- Severity index (S.I.): represents the severity of an event on the project if it were to occur, ranging from 0% (no severity) to 100% (total severity), calculated with equation 3.

$$I.S = \frac{\sum_0^{100} b_i * n_i}{N} \tag{3}$$

Where b_i represents the value assigned to each response (where 0% is no impact and 100% is high impact); n_i represents the frequency of each response and N is the total number of responses.

- Impact Index (I.I.): impact of an event based on the probability of occurrence and its severity, classifying the barriers according to their risk for the project and calculated with equation 4.

$$I.P\ x\ I.S = I.I \tag{4}$$

Impact Index Ranking

Table 3 shows the results from the evaluation tool, which are broken down into the probability index (P.I.), the severity index (S.I.), and based on these two indicators, the impact index (I.I.).

Table 3: Impact factors ranking.

Barrier	P.I.	P.I. Ranking	S.I.	S.I. Ranking	I.I.	I.I. Ranking
8. Interoperability issues between different BIM software.	85%	3	87%	4	74%	1
23. Differences between BIM for buildings and BIM for bridges.	86%	2	80%	6	69%	2
16. Limited existence of BIM protocols.	72%	10	82%	5	59%	3
15. Lack of experience or expertise in BIM use.	76%	7	76%	7	58%	4
17. Changes in workflows within and between projects.	81%	4	64%	13	52%	5
21. Availability of specialized BIM software for bridges.	56%	16	92%	1	52%	6
6. Low use of standards for BIM object description and coding systems.	78%	6	64%	12	50%	7
12. Low collaboration between project participants using BIM.	74%	9	66%	11	49%	8
5. Resistance to change the way a project is built.	78%	5	61%	14	48%	9
19. Cybersecurity risks.	52%	19	90%	2	46%	10
3. Cost associated with software implementation.	76%	8	59%	17	45%	11
22. Difficulty in making updates to bridge models on-site.	46%	21	88%	3	41%	12
1. Need to train a greater number of BIM users.	61%	15	67%	10	41%	13
9. Lack of knowledge of the benefits of implementing BIM.	70%	11	58%	20	41%	14
2. Ambiguity about the intellectual property of modeling.	66%	13	58%	19	38%	15
4. Ambiguity regarding the chain of legal liability.	69%	12	53%	22	37%	16
7. Low demand for the use of BIM by the client/manager.	64%	14	54%	21	35%	17
11. BIM is still little known and/or complex to use.	48%	20	70%	9	33%	18
14. Low support from managers and decision-makers in the implementation of BIM.	55%	17	60%	16	33%	19
10. Time and/or cost for staff training on the software.	52%	18	61%	15	32%	20
18. Limited access to a stable connection to servers for storing and coordinating information.	40%	23	76%	8	30%	21
13. Lack of government intervention in massive BIM use.	41%	22	59%	18	24%	22
20. Need for a BIM manager on projects.	90%	1	25%	23	22%	23

It can be seen that the “Need for a BIM manager on projects” is the barrier with the highest probability of occurrence according to the respondents (90%), followed by “Differences between BIM for buildings and BIM for bridges” (86%), and in third place “Interoperability problems between different BIM software” (85%). In terms of severity, the factor with the highest index was “Availability of specialized BIM software for bridges” (92%), followed by “Cybersecurity risks” (90%) and “Difficulty in making updates to bridge models on-site” (88%).

The impact index (I.I.), as previously explained, is related to the two previous indexes, and provides an overview of the impact of the barriers on the project. The first is “Interoperability problems between different BIM software” (74%), which is not surprising, since it is in the top five of the previously ranked indexes. Next are “Differences between BIM for buildings and BIM for bridges” (69%), “Limited existence of BIM protocols” (59%), “Lack of experience or expertise in the use of BIM” (58%), and “Changes in workflows within and between projects” (52%). In this research, any barrier that exceeded the median I.I. was classified as relevant. Thus, the P.I. and S.I. of the barriers mentioned in the classification by I.I. have values that meet this criterion, except for “Changes in workflows within and between projects”.

Probability-severity matrix

Figure 1 shows a probability-severity matrix, which was used to determine the impact zone in which each barrier is located. The impact categories range from very low (lower left zone), to very high (upper right zone). The matrix design is based on the research of Dumbravă & Vladut-Severian (2013). It is seen that most of the factors are in the very high and high impact zone.

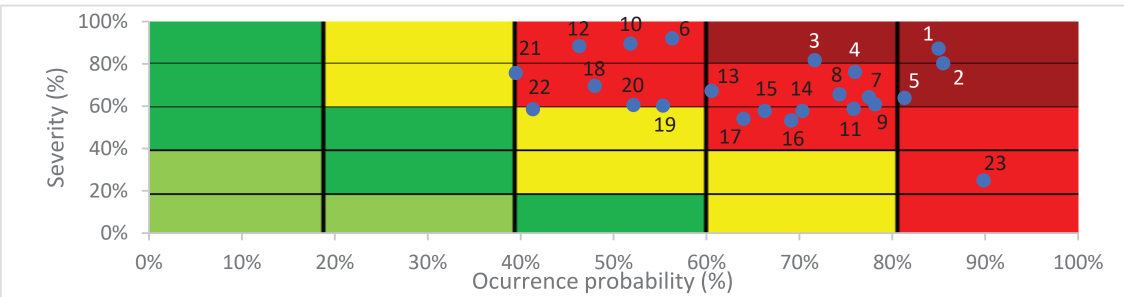

Figure 1: Probability v/s severity matrix

CONCLUSIONS

In terms of contributions for practice, this research may help project and engineering managers to have a first approximation to the most recurring barriers in BrIM and how to rank them according to their impact. Despite the findings of this study are based on survey responses from BrIM projects, they can be extended to complex projects with different levels of uncertainty.

As found, this research shows that “Interoperability issues between different BIM software”, “Differences between BIM for buildings and BIM for bridges”, “Limited existence of BIM protocols”, “Lack of experience or expertise in the use of BIM”, and “Changes in workflows within and between projects” are the main barriers to implement BIM in bridges. Therefore, a project manager should pay attention to the existence of BIM protocols for bridges and to count on professionals with proved BIM experience. From a technical point of view, it is relevant to focus on interoperability between BIM software packages and the main differences found when using BIM for bridges instead of BIM for buildings. Finally, the last barrier found —related to changes in workflows within and between projects—, accounts for the importance of having competent managers to coordinate the whole project properly.

The only factor unique to bridge projects was the “Differences between BIM for buildings and BIM for bridges”. It is also important to mention the close relationship between the barriers “Interoperability problems between different BIM software” and “Limited existence of BIM protocols”, as they may allow writing a guide for interoperability between software to be used. Finally, in terms of risk, as most of the barriers were grouped in the upper right corner of the probability-severity graph, i.e., high probability of occurrence and high severity levels, it was possible to confirm that the barriers present in bridge projects generate high levels of impact when implementing BIM. Because of the exploratory nature of this study, for future research it is recommended to consider a larger number of interviewed professionals belonging to multiple bridge projects, which could provide other barriers or confirm those found in this study.

REFERENCES

Ahmad, Z., Thaheem, M. J., & Maqsoom, A. (2018). Building information modeling as a risk transformer: An evolutionary insight into the project uncertainty. *Automation in Construction*, *92*(March 2017), 103–119. https://doi.org/10.1016/j.autcon.2018.03.032

Ahmed, Shakil, & Hosque, I. (2018). Barriers to Implement Building Information Modeling (BIM) to Construction Industry: A Review. *Journal of System and Management Sciences*, *8*(1), 45–60.

Ahmed, Sherif, Emam, H., & Farrell, P. (2014). Barriers to BIM/4D implementation in Qatar. *The First International Conference Ot the CIB Middle East & North Africa Network CIB-MENA 2014*, 533–547.

Ahn, Y. H., Kwak, Y. H., & Suk, S. J. (2016). Contractors' Transformation Strategies for Adopting Building Information Modeling. *Journal of Management in Engineering*, *32*(1). https://doi.org/10.1061/(ASCE)ME.1943-5479.0000390

Akogbe, R.-K. T. M., Feng, X., & Zhou, J. (2013). Importance and ranking evaluation of delay factors for development construction projects in Benin. *KSCE Journal of Civil Engineering*, *17*(6), 1213–1222. https://doi.org/10.1007/s12205-013-0446-2

Al-btoush, M. A. K. A., & Haron, A. T. (2017). Barriers and challenges of building information modelling implementation in Jordanian construction industry. *Global Journal of Engineering Science and Research Management*, *4*(9), 9–20. https://doi.org/10.5281/zenodo.888559

Arshad, M. F., Thaheem, M. J., Nasir, A. R., & Malik, M. S. A. (2019). Contractual Risks of Building Information Modeling: Toward a Standardized Legal Framework for Design-Bid-Build Projects. *Journal of Construction Engineering and Management*, *145*(4), 1–13. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001617

Azhar, S., Khalfan, M., & Maqsood, T. (2015). Building information modelling (BIM): now and beyond. *Construction Economics and Building*, *12*(4), 15–28. https://doi.org/10.5130/AJCEB.v12i4.3032

Bartholomew, M., Blasen, B., & Koc, A. (2015). Bridge Information Modeling (BrIM) Using Open Parametric Objects. In *Us Departament of Transportation* (Vol. 1).

Borrego, M., Foster, M. J., & Froyd, J. E. (2014). Systematic Literature Reviews in Engineering Education and Other Developing Interdisciplinary Fields. *Journal of Engineering Education*, *103*(1), 45–76. https://doi.org/10.1002/jee.20038

Chan, D. W. M., Olawumi, T. O., & Ho, A. M. L. (2019). Perceived benefits of and barriers to Building Information Modelling (BIM) implementation in construction: The case of Hong Kong. *Journal of Building Engineering*, *25*(February), 100764. https://doi.org/10.1016/j.jobe.2019.100764

Chiu, W. Y. B., & Lai, J. H. K. (2020). Building information modelling for building services engineering: benefits, barriers and conducive measures. *Engineering, Construction and Architectural Management*, *27*(9), 2221–2252. https://doi.org/10.1108/ECAM-10-2018-0460

Cho, A., Chen, S. S., & Shirolé, A. M. (2009). Ten Minutes With The Godfathers of Bridge Information Modeling. *ENR.Com*, 12–13.

Costin, A., Adibfar, A., Hu, H., & Chen, S. S. (2018). Building Information Modeling (BIM) for transportation infrastructure – Literature review, applications, challenges, and recommendations. *Automation in Construction*, *94*, 257–281. https://doi.org/10.1016/j.autcon.2018.07.001

Dayan, V., Chileshe, N., & Hassanli, R. (2022). A Scoping Review of Information-Modeling Development in Bridge Management Systems. *Journal of Construction Engineering and Management*, *148*(9), 03122006. https://doi.org/10.1061/(ASCE)CO.1943-7862.0002340

Doloi, H. (2008). Analysing the novated design and construct contract from the client's, design team's and contractor's perspectives. *Construction Management and Economics*, *26*(11), 1181–1196. https://doi.org/10.1080/01446190802512359

Dumbravă, V., & Vladut-Severian, I. (2013). Using Probability – Impact Matrix in Analysis and Risk Assessment Projects. *Journal of Knowledge Management, Economics and Information Technology*, *42*(December), 76–96.

Fellows, R., & Liu, A. (2015). Research Methods for Construction. In *Journal of Chemical Information and Modeling* (Vol. 53, Issue 9, p. 302).

Forcael, E., Martínez-Rocamora, A., Sepúlveda-Morales, J., García-Alvarado, R., Nope-Bernal, A., & Leighton, F. (2020). Behavior and Performance of BIM Users in a Collaborative Work Environment. *Applied Sciences*, *10*(6), 2199. https://doi.org/10.3390/app10062199

Forcael, E., Morales, H., Agdas, D., Rodríguez, C., & León, C. (2018). Risk Identification in the Chilean Tunneling Industry. *Engineering Management Journal*, *30*(3), 203–215. https://doi.org/10.1080/10429247.2018.1484266

Forcael, E., Puentes, C., García-Alvarado, R., Opazo-Vega, A., Soto-Muñoz, J., & Moroni, G. (2022). Profile Characterization of Building Information Modeling Users. *Buildings*, *13*(1), 60. https://doi.org/10.3390/buildings13010060

Gaitá, J., & Gómez, A. (2014). Uso de la metodología BrIM (bridge information modeling) como herramineta para la planificación de la construccion de un puente de concreto en Colombia. *Ciencia e Ingeniería Neogranadina*, *24*(2), 145–156.

Gerrish, T., Ruikar, K., Cook, M., Johnson, M., Phillip, M., & Lowry, C. (2017). BIM application to building energy performance visualisation and management: Challenges and potential. *Energy and Buildings*, *144*, 218–228. https://doi.org/10.1016/j.enbuild.2017.03.032

Heikkilä, R. (2001). *National Guidelines for Bridge Information Modeling and Automation*.

Kasireddy, V., & Akinci, B. (2015). Challenges in generation of as-is bridge information model: A case study. *32nd International Symposium on Automation and Robotics in Construction and Mining: Connected to the Future, Proceedings*. https://doi.org/10.22260/isarc2015/0037

Kiani, I., Sadeghifam, A. N., Ghomi, S. K., Kadir, A., & Marsono, B. (2015). Barriers to Implementation of Building Information Modeling in Scheduling and Planning Phase in Iran. *Australian Journal of Basic and Applied Sciences*, *9*(5), 91–97.

Kitchenham, B. (2004). Procedures for Performing Systematic Literature Reviews. *Joint Technical Report, Keele University TR/SE-0401 and NICTA TR-0400011T.1*, 33.

Maire, F., & Brinckerhoff, P. (2012). *Bridge Information Modeling: Opportunities, Limitations, and Spanning the Chasm with Current Tools*.

Marefat, A., Toosi, H., & Mahmoudi Hasankhanlo, R. (2018). A BIM approach for construction safety : applications , barriers and solutions. *Engineering, Construction and Architectural Management*, *26*(9). https://doi.org/https://doi.org/10.1108/ECAM-01-2017-0011

Markiz, N., & Jrade, A. (2019). Integrating an expert system with BrIMS, cost estimation, and linear scheduling at conceptual design stage of bridge projects. *International Journal of Construction Management*, *0*(0), 1–16. https://doi.org/10.1080/15623599.2019.1661572

Marzouk, M., & Hisham, M. (2012). Applications of Building Information Modeling in Cost Estimation of Infrastructure Bridges. *International Journal of 3-D Information Modeling*, *1*(2), 17–29. https://doi.org/10.4018/ij3dim.2012040102

Marzouk, M., & Hisham, M. (2014). Implementing earned value management using bridge information modeling. *KSCE Journal of Civil Engineering*, *18*(5), 1302–1313. https://doi.org/10.1007/s12205-014-0455-9

McGuire, B., Atadero, R., Clevenger, C., & Ozbek, M. (2016). Bridge Information Modeling for Inspection and Evaluation. *Journal of Bridge Engineering*, *21*(4), 04015076. https://doi.org/10.1061/(ASCE)BE.1943-5592.0000850

Mehran, D. (2016). Exploring the Adoption of BIM in the UAE construction industry for AEC firms. *Procedia Engineering*, *145*, 1110–1118. https://doi.org/10.1016/j.proeng.2016.04.144

Migilinskas, D., Popov, V., Juocevicius, V., & Ustinovichius, L. (2013). The Benefits, Obstacles and Problems of Practical Bim Implementation. *Procedia Engineering*, *57*, 767–774. https://doi.org/10.1016/j.proeng.2013.04.097

Ng, R. T. H., & Lai, J. H. K. (2016). Implementing building information modelling in building services engineering in Hong Kong : a focus group study. *The 7th Greater Pearl River Delta Conference on Building Operation and Maintenance*, *1*, 119–130.

Oppenheim, A. (2000). *Questionnaire Design, Interviewing and Attitude Measurement* (2nd ed.). Continuum.

Porwal, A., & Hewage, K. N. (2013). Building Information Modeling (BIM) partnering framework for public construction projects. *Automation in Construction*, *31*, 204–214. https://doi.org/10.1016/j.autcon.2012.12.004

Saieg, P., Sotelino, E. D., Nascimento, D., & Caiado, R. G. G. (2018). Interactions of Building Information Modeling, Lean and Sustainability on the Architectural, Engineering and Construction industry: A systematic review. *Journal of Cleaner Production*, *174*, 788–806. https://doi.org/10.1016/j.jclepro.2017.11.030

Saka, A. B., & Chan, D. W. M. (2020). Profound barriers to building information modelling (BIM) adoption in construction small and medium-sized enterprises (SMEs). *Construction Innovation*, *20*(2), 261–284. https://doi.org/10.1108/CI-09-2019-0087

Seyis, S. (2019). Pros and Cons of Using Building Information Modeling in the AEC Industry. *Journal of Construction Engineering and Management*, *145*(8), 04019046. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001681

Shim, C. S., Yun, N. R., & Song, H. H. (2011). Application of 3D Bridge Information Modeling to Design and Construction of Bridges. *Procedia Engineering*, *14*, 95–99. https://doi.org/10.1016/j.proeng.2011.07.010

Shirole, A. M., Riordan, T. J., Chen, S. S., Gao, Q., Hu, H., & Puckett, J. A. (2009). BrIM for project delivery and the life-cycle: state of the art. *Bridge Structures*, *5*(4), 173–187. https://doi.org/10.1080/15732480903143003

Sun, C., Jiang, S., Skibniewski, M. J., Man, Q., & Shen, L. (2017). A literature review of the factors limiting the application of BIM in the construction industry. *Technological and Economic Development of Economy*, *23*(5), 764–779. https://doi.org/10.3846/20294913.2015.1087071

Ullah, K., Lill, I., & Witt, E. (2019). An Overview of BIM Adoption in the Construction Industry: Benefits and Barriers. In I. Lill & E. Witt (Eds.), *Emerald Reach Proceedings Series - 10th Nordic Conference on Construction Economics and Organization, Volume 2* (pp. 297–303). Emerald Group Publishing Limited. https://doi.org/10.1108/S2516-285320190000002052

Vass, S., & Gustavsson, T. K. (2017). Challenges when implementing BIM for industry change. *Construction Management and Economics*, *35*(10), 597–610. https://doi.org/10.1080/01446193.2017.1314519

Zhao, X., Wu, P., & Wang, X. (2018). Risk paths in BIM adoption: empirical study of China. *Engineering, Construction and Architectural Management*, *25*(9), 1170–1187. https://doi.org/10.1108/ECAM-08-2017-0169

Zheng, Y., & Xu, C. (2020). Application of BIM in Bridge Engineering and Its Risk Analysis. *IOP Conference Series: Earth and Environmental Science*, *526*, 012223. https://doi.org/10.1088/1755-1315/526/1/012223