DOI: 10.23968/2500-0055-2024-9-3-15-26

BIM IMPLEMENTATION FOR HERITAGE RENOVATION THROUGHOUT PROJECT LIFECYCLE: CURRENT USE, BENEFITS, AND BARRIERS

Bani Feriel Brahmi*, Souad Sassi-Boudemagh

AVMF laboratory, University of Constantine 3 Salah Boubnider, Constantine, Algeria

*Corresponding author's email: feriel.brahmi@univ-constantine3.dz

Abstract
Introduction: Building Information Modeling (BIM) has garnered significant attention due to advancements in sophisticated technologies and methods. However, a comprehensive review of the existing literature indicates a lack of research exploring the application of BIM in managing the entire intervention design and renovation processes from a broader system perspective. The **purpose of the study** was to fill this gap by identifying and evaluating the current utilization, benefits, and barriers associated with implementing BIM in the lifecycle of renovation projects. The study **methodology** is based on conducting 31 structured interviews with experienced professionals who have employed BIM in their project deliveries. The **results** reveal that the primary benefits of BIM adoption, in descending order of importance, pertain to improved collective understanding of design intent, lower risk and better predictability of outcomes, better-designed and performing buildings, more accurate project documentation, and increased accuracy of the cost estimate. However, there are several prominent barriers: project budget, complexity of modeling historic structures, cost to hire BIM professionals, and the lack of BIM knowledge. The findings will advance BIM adoption for heritage renovation and enable project stakeholders to focus on realizing the benefits and potential uses of lifecycle BIM, while also addressing the critical challenges discussed in this study.

Keywords: BIM implementation; heritage renovation; BIM benefits; BIM barriers.

Introduction

The renovation of heritage buildings holds great potential for preserving a sense of identity and continuity for future generations in a rapidly changing world. Today, the renovation of heritage buildings serves as a revitalization avenue to promote sustainability and safeguard the buildings' significance and values (Fouseki and Cassar, 2014). Moreover, it brings about economic growth, as well as social, cultural, and environmental benefits to urban communities (Tweed and Sutherland, 2007).

Undertaking renovation projects involves managing significant complexity, which includes handling multiple stakeholders and addressing various renovation objectives and criteria, especially when the building remains in use (Buser and Carlsson, 2016; Kamari et al., 2019a). There is a need to explore and select among a large number of renovation alternatives and approaches available in the market, considering the attitudes and behavior of the building occupants (Kamari et al., 2019b; Lidelöw et al., 2019). Complexity increases during the early design phases, and significant changes may occur due to the unavailability of original structural information or unforeseen construction conditions identified late, resulting in project time and cost overruns (Roy and Kalidindi, 2017).

Information technology (IT) is widely discussed in the context of the emergence of large, ambitious, and complex projects in the architecture, engineering, construction, and operations (AECO) industry. This is driven by new sustainability requirements that necessitate regular and efficient information exchange among project participants and stakeholders throughout the project lifecycle (Oesterreich and Teuteberg, 2016). Currently, IT has become an increasingly vital tool across all industries, uncovering untapped value potential. The AECO sector is also experiencing transformation with the advent of the Fourth Industrial Revolution, known as Industry 4.0 (Lasi et al., 2014). The digitization and automation of construction, often referred to as Construction 4.0, are leading to changes in product and supply chain management (Dallasega et al., 2018). It is a major enabler of productivity improvements, along with sophisticated and integrated design and construction, through the adoption of innovative and disruptive technologies, including BIM (Oesterreich and Teuteberg, 2016).

BIM has emerged as a catalyst for paradigm change and has become an industry standard in the AECO sector by automating and manipulating data at different project lifecycle stages (Farnsworth et al., 2015; Kelly and Ilozor, 2019). In the context

For citations: Brahmi, B. F., Sassi-Boudemagh, S. (2024). BIM implementation for heritage renovation throughout project lifecycle: current use, benefits, and barriers. Architecture and Engineering, No 3 (9), pp. 15–26. DOI: 10.23968/2500-0055-2024-9-3-15-26.

of heritage renovation, BIM has garnered significant interest for its technological advancements and methodological developments, such as 3D laser scanning and photogrammetry. As a digital delivery method, BIM revolutionizes the information management of the renovation process by storing interrelated semantic information, which facilitates the dissemination of intangible values of a building throughout its lifecycle (Angelini et al., 2017).

While existing literature has extensively explored the potential benefits of BIM in digital building documentation (Pocobelli et al., 2018), there is a notable lack of research focusing on the use of BIM for managing entire intervention design and renovation processes, including the generation and evaluation of various design alternatives. Furthermore, most studies have relied on single-case analyses, with few adopting a broader systemic perspective. Therefore, this study aims to fill this gap by identifying and assessing the current utilization of BIM in renovation projects' lifecycle, examining the benefits gained, and identifying the barriers encountered.

Background

The BIM adoption process may differ between new and existing buildings due to variations in information availability, the quality of building information, and functionality requirements. The majority of research has focused on exploring the potential benefits of employing BIM for digital building documentation (Pocobelli et al., 2018). BIM generates a digital model for the preservation process because of its ability to store interrelated semantic information, promoting the dissemination of a building's intangible values during its lifecycle (Angelini et al., 2017). BIM offers efficient and accurate remote presentation, analysis, and documentation of the structure, surpassing previous survey techniques (Gigliarelli et al., 2017). However, the effectiveness of BIM is subject to broader discussions due to the challenges related to the high effort required for modeling/converting captured building data into semantic BIM objects (López et al., 2018). The variety and complexity of heritage building components may not be represented in current typical BIM software libraries, and also depend on the level of detail required to perform engineering and design analyses (López et al., 2018; Pocobelli et al., 2018). Brahmi et al. (2022) suggested integrating other emerging technologies within BIM and seeking innovative solutions to overcome this issue. They also recommended developing, upgrading, and adjusting BIM simulation software to accurately represent the conditions of heritage buildings and enable accurate environmental simulations within BIM modeling (Brahmi et al., 2022).

Simeone et al. (2014) investigated the potential impact of BIM in heritage renovations to improve specialists' collaboration and knowledge management. The authors concluded that BIM models, like those used in new construction projects, ensure the availability, accessibility, consistency, and coordination of all knowledge related to a historical artifact and shared by different actors involved in investigation/conservation processes. This promotes decision-making on the development of relevant interventions (Simeone et al., 2014). However, only a few research studies have investigated the generation and evaluation of various design alternatives in heritage renovation using BIM.

Heritage buildings have a very high energy demand, as well as a very low indoor climate standard (Tomšič et al., 2017). For example, 35 % of buildings in the European Union are more than 50 years old, and nearly 75 % of the building stock (including heritage buildings) are energy inefficient (European Commission, 2019). The same statistics demonstrate that renovating existing buildings can lead to significant energy savings, as it could reduce total EU energy consumption by 5–6 % and CO_2 emissions by around 5 %. Conversely, only about 1 % of the building stock is renovated each year. In this regard, the design team must address the increasing energy demand and indoor environmental requirements while also considering architectural aspects and qualities in developing appropriate renovation scenarios (design options).

Brahmi et al. (2022) revealed that BIM enables design teams to conduct faster, complex analyses and rapid assessments of energy simulations through BIM coordination with energy models, to produce a full virtual construction model. In their research, Žurić et al. (2022) focused on the "historical value" when integrating HBIM into GBC historic building certification. The implementation process focuses on interoperability and data preservation, using the open standard (IFC). However, there is limited research effort to integrate Life Cycle Assessment (LCA) with BIM and manage the environmental performance of renovation projects, along with the lack of a "cradle-to-grave" comprehensive BIM-based environmental sustainability simulation tool (Wong and Zhou, 2015). Similarly, current cloud computing technology and Big Data management are not sufficiently addressed within the green BIM tool (Wong and Zhou, 2015).

Recent studies propose methodologies for linking Heritage BIM with various technologies and digital simulations, such as Building Performance Simulation (BPS) and computational design (Gigliarelli et al., 2017). However, these studies also highlight the lack of open-source platforms for Heritage BIM, limited interoperability between different software environments (such as gbXML files or IFC files) (Cheng et al., 2015; Gigliarelli et al., 2017), and the need for integration with facilities management technologies (Kassem et al., 2015). Furthermore, only a few published prototypes with limited usage demonstrate markedly different BIM requirements in these projects (Angelini et al., 2017; Edwards, 2017). Despite the rapid developments and dissemination of standards, further research is necessary to automate processes and adapt BIM to the specific requirements of existing buildings (Volk et al., 2014).

Methods

To achieve the research objectives, a series of structured online interviews were conducted between January 2, 2022, and March 15, 2022. A total of 31 experienced professionals involved in heritage renovation projects that utilized BIM participated in the interviews. The inclusion criteria ensured that all interviewees had more than 10 years of professional experience and possessed the necessary knowledge of BIM within the heritage sector. The majority of interviewees, primarily from Canada and the United States, had diverse organizational backgrounds. This included architectural firms (54.84 %), followed by construction firms (16.13 %), engineering firms (12.9 %), academic staff (6.45 %), and three respondents from owners, facility managers, and construction management. The sample size of 31 interviewees, while not exhaustive, was chosen to provide a variety of perspectives within the constraints of the study. The selection was made purposefully to capture a representative sample and effectively address the research questions, reflecting the actual perceptions, complexities, and widespread use of BIM practices in heritage renovations.

Within their respective organizations, the respondents reported having such roles as BIM specialists (32.26 %), historic preservation consultants (25.81 %), project managers (22.58 %), and directors (19.35 %). Additionally, 67.74 % of the participants stated that they were members of various local or international organizations committed to heritage preservation.

The interview questionnaire consisted of 20 structured questions divided into two major parts: I) Current use and benefits of BIM in heritage renovation throughout the project lifecycle, and II) Barriers to using BIM in heritage renovation throughout the project lifecycle. The interview questions were initially based on a study conducted by Feng et al. (2014) and were later modified and adapted to specifically investigate BIM implementation in the context of heritage renovation. The interviewees were asked to select and rank the identified benefits and barriers of BIM implementation using a five-point Likert-type scale. The responses were then used to measure the significance of each item using the statistical method of mean score (M).

Results and Discussion

This section presents the findings obtained from the interviews conducted during the study and provides a comprehensive discussion of the results. The results are organized into two main parts: I) Current use and benefits of BIM in heritage renovation throughout the project lifecycle, and II) Barriers to BIM implementation in heritage renovation throughout the project lifecycle.

1. Current use and benefits of BIM in heritage renovation throughout the project lifecycle

The results of the interviews indicate that a significant majority of the respondents (75 %) have recent experience with BIM, specifically within the past five years, as BIM was utilized in the completion of their renovation projects. This suggests that the respondents possess relevant and up-to-date knowledge and expertise, making their responses representative and reliable.

As shown in Fig. 1, Autodesk Revit is the most commonly used BIM software in heritage renovation, with up to two-thirds of respondents (21 responses) reporting its use in their projects. This finding aligns with previous research in the literature, supporting the prevalence of Autodesk Revit in the field of heritage renovation (Logothetis et al., 2015; López et al., 2018). The popularity of Autodesk Revit can be attributed to its robust capabilities and widespread adoption within the industry. The respondents mentioned other BIM software platforms in addition to Autodesk Revit. Navisworks™ was mentioned by 11 respondents, indicating its usage for tasks such as clash detection and project coordination. Graphisoft ArchiCAD was mentioned by 5 respondents, followed by Tekla Structures with 2 mentions, and Bentley Systems Architecture and VICO Constructor with 1 mention each. These software platforms provide specialized features and functionalities that cater to specific project requirements or user preferences.

Fig. 2 highlights the leadership role of architects in the BIM coordination process for completed renovation projects. In the majority of cases (58 %), architects took the lead in BIM coordination. This finding aligns with the common practice in which architects assume the role of lead designers in construction projects, overseeing the overall design and coordination of various disciplines. The architect's involvement in BIM coordination reflects their crucial role in managing collaborative efforts and ensuring effective communication among project stakeholders.

During the interviews, the respondents were asked to indicate the BIM applications utilized in their renovation projects from a list of 15 identified applications (Fig. 3). Subsequently, they were asked to rank the benefits of these BIM applications on a 5-point Likert scale (1 — not beneficial at all, 2 — slightly beneficial, 3 — moderately beneficial, 4 — very beneficial, and 5 — extremely beneficial) (Fig. 4).

As anticipated and consistent with previous research findings (Gigliarelli et al., 2017;

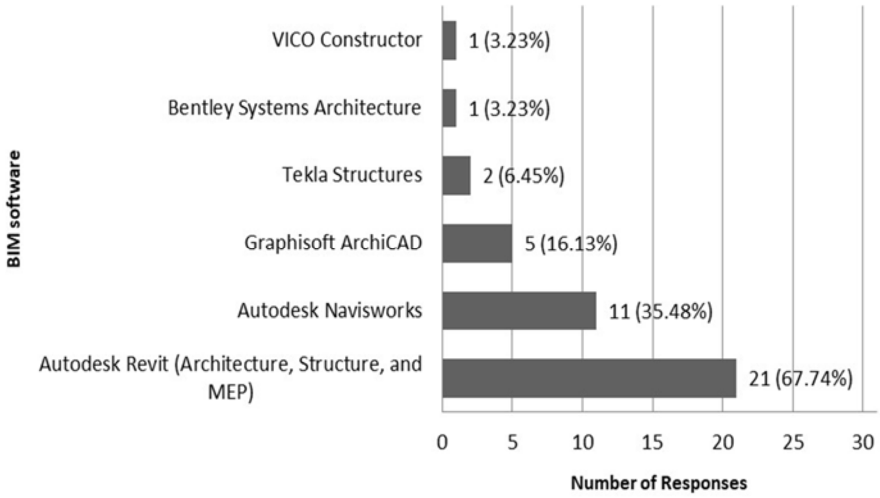

Fig. 1. BIM software packages used in heritage renovation projects

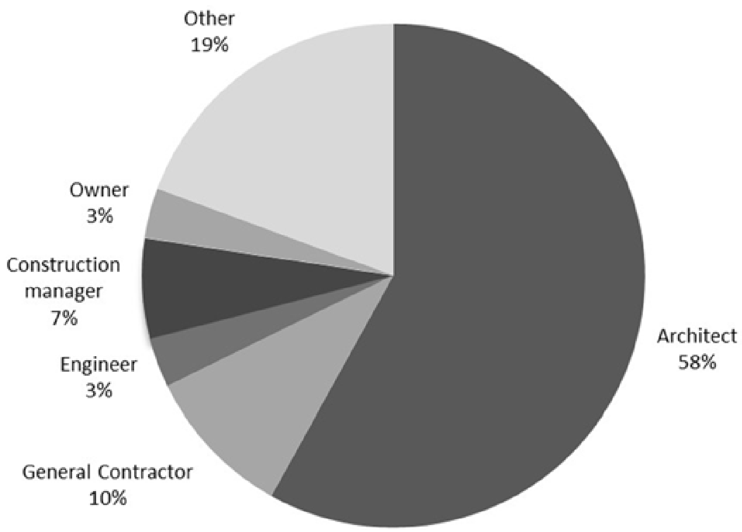

Fig. 2. BIM leadership

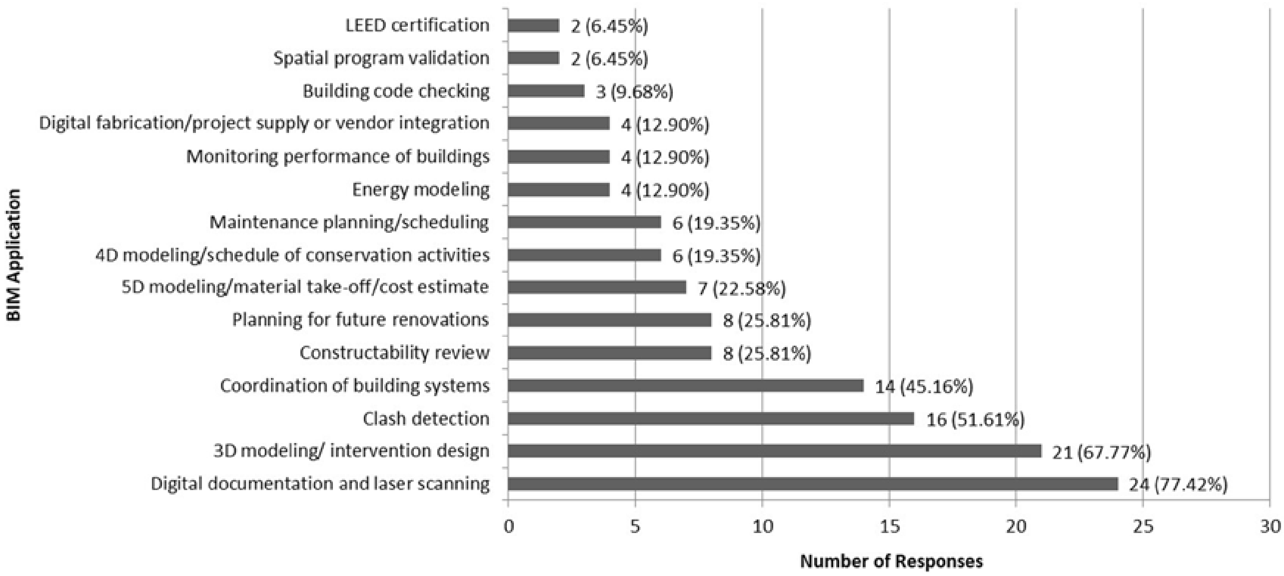

Fig. 3. Extent of current usage of various BIM applications in heritage renovation projects

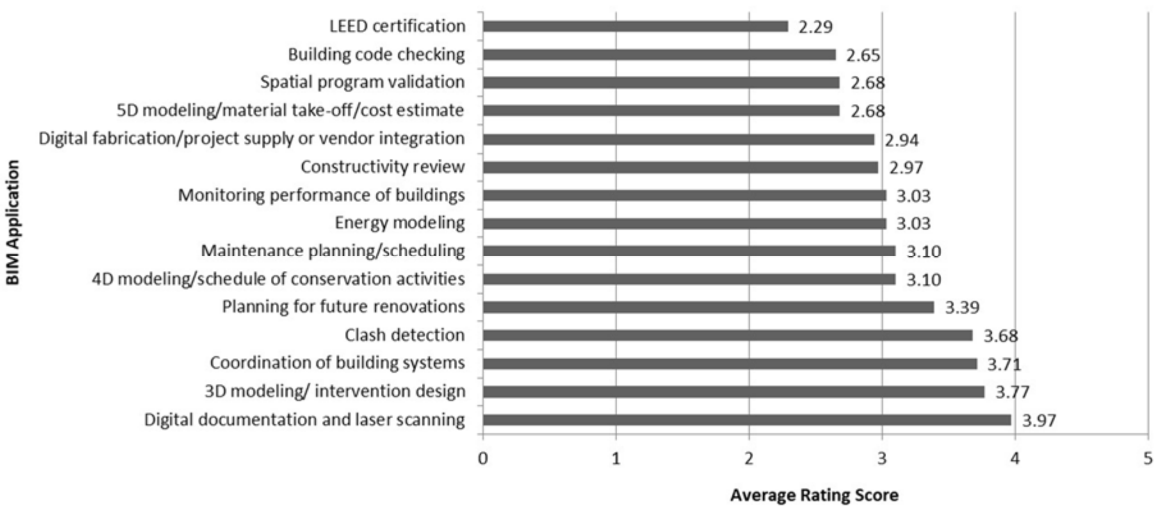

Fig. 4. Benefits of using BIM applications in heritage renovation projects

Pocobelli et al., 2018), the most commonly used BIM application in renovation projects is digital documentation and laser scanning, with 24 respondents reporting its use. Furthermore, this application is considered the most beneficial for renovation projects, with an average score of 3.97. These findings are supported by several studies (Angelini et al., 2017; Gigliarelli et al., 2017; López et al., 2018; Pocobelli et al., 2018).

Surprisingly, the results indicate significant developments and changes in BIM practices in recent years, which vary from project to project. The use of BIM has expanded to encompass more diverse and multifaceted applications, notably 3D modeling and intervention design (21 responses), clash detection (16 responses), and building systems coordination (14 responses). These applications were highly ranked for their perceived benefits in renovation projects, following digital documentation and laser scanning. The respondents recognized the value of 3D modeling and intervention design (average score: 3.77), as it allows for enhanced visualization and understanding of design intent. Building systems coordination (average score: 3.77) emerged as another crucial aspect, facilitating the effective integration and collaboration between different subsystems within the project. Clash detection (average score: 3.68), on the other hand, helps identify and resolve conflicts or clashes between various building elements or systems, enhancing efficiency and reducing rework.

The findings emphasize BIM's ability to foster teamwork and support collaborative, multilevel, and iterative processes. It provides a platform for evaluating alternative design options and value engineering, enabling stakeholders to explore different possibilities and negotiate connections and interfaces between subsystems. This collaborative approach can lead to optimized designs, improved performance, and enhanced decision-making throughout the project lifecycle.

The results highlight the growing recognition and utilization of BIM's capabilities beyond traditional applications, such as documentation and scanning. The expanding use of BIM in areas such as 3D modeling, clash detection, and building systems coordination highlights its potential to enhance efficiency, coordination, and collaboration in renovation projects. This finding aligns with the idea that BIM supports a more integrated and collaborative approach to design and construction, enabling stakeholders to leverage its benefits and overcome project complexities (Migilinskas et al., 2013).

In contrast, certain BIM applications remain largely unexplored in the context of heritage renovation, including energy modeling (4 responses), building code checking (3 responses), spatial program validation (2 responses), and LEED certification (2 responses). Additionally, the last BIM applications, along with 5D modeling/cost estimation, ranked as the least beneficial, likely due to their limited usage in renovations. Pocobelli et al. (2018) argued for the inclusion of tools such as rule-based code checking within BIM platforms. This inclusion would facilitate coordination and standardization of policies and controls related to environmental/energy performance and historic preservation codes, as well as the automation of the Leadership in Energy and Environmental Design (LEED) process for green building certification (Pocobelli et al., 2018).

Overall, the findings indicate that there is room for further exploration and utilization of specific BIM applications in the context of heritage renovation. By incorporating them, stakeholders in heritage renovation projects can potentially enhance project outcomes, improve environmental performance, and ensure compliance with relevant regulations and certifications.

The results of the interview questionnaire, which assessed the rating of a list of 21 identified benefits achieved through BIM utilization in renovation projects, are presented in Fig. 5. The mean (M) values range from the lowest mean score of M = 2.58 for “Individual participant productivity” to the highest mean value of M = 3.90 for “Improved collective understanding of design intent”. To determine the significance of each factor, the study adopted a scale interval grading similar to the approach utilized by Olawumi et al. (2018). The grading scale is as follows: “not important” (M < 1.50), “somewhat important” (1.51 ≤ M ≤ 2.50), “important” (2.51 ≤ M ≤ 3.50), “very important” (3.51 ≤ M ≤ 4.50), and “extremely important” (M ≥ 4.51). This scale helps categorize the level of importance attributed to each benefit (Fig. 5).

Heritage renovation is a complex and sensitive approach, characterized by a high level of risk and uncertainty (Roy and Kalidindi, 2017). The results of this study demonstrate that shifting to BIM offers an effective approach to address this challenge. The five most significant benefits of BIM implementation are: improved collective understanding of design intent, lower risk and better predictability of outcomes, better-designed and performing buildings, more accurate project documentation, and increased accuracy of the cost estimate (with mean values of 3.90, 3.71, 3.61, 3.58, and 3.52, respectively). It is important to note that none of the identified benefits scored higher than 4.50, nor 2.50 or lower (Fig. 5). Therefore, these 21 benefits can be categorized as significant advantages that demonstrate the usefulness of BIM in improving the effectiveness and efficiency of heritage renovation projects, while also highlighting opportunities to further maximize BIM benefits in such projects.

Fig. 6 illustrates the contribution of BIM to improved performance across different project phases. The reviewees reported that BIM is most likely to contribute to improved performance during the construction document phase (20 responses) and the design development phase (19 responses). In contrast, the use of BIM is perceived to have a lesser contribution during the post-construction operation phase (Fig. 6), which aligns with existing literature indicating that BIM adoption in this phase is not yet well-established (Kassem et al., 2015).

El-adaway et al. (2017) suggested that improving the performance of the construction industry should start with the contract and organizational aspects. In line with this perspective, the respondents in this study were asked to rate the frequency and benefits achieved through the use of different project delivery methods within BIM, using a five-point Likert-type scale (Fig. 7). The results indicate that BIM is most often used in the design-bid-build delivery method, which is likely the most widely employed approach. The construction management and design-build methods follow it. Nevertheless, the respondents perceived that BIM implementation is highly beneficial for projects delivered using the construction management method (with an average score of M = 3.55), more so than for design-bid-build (M = 3.48). This perception is likely due to the collaborative requirements between parties in the construction management method, as this approach typically involves more collaboration and coordination among the project stakeholders. The shift towards BIM in construction necessitates

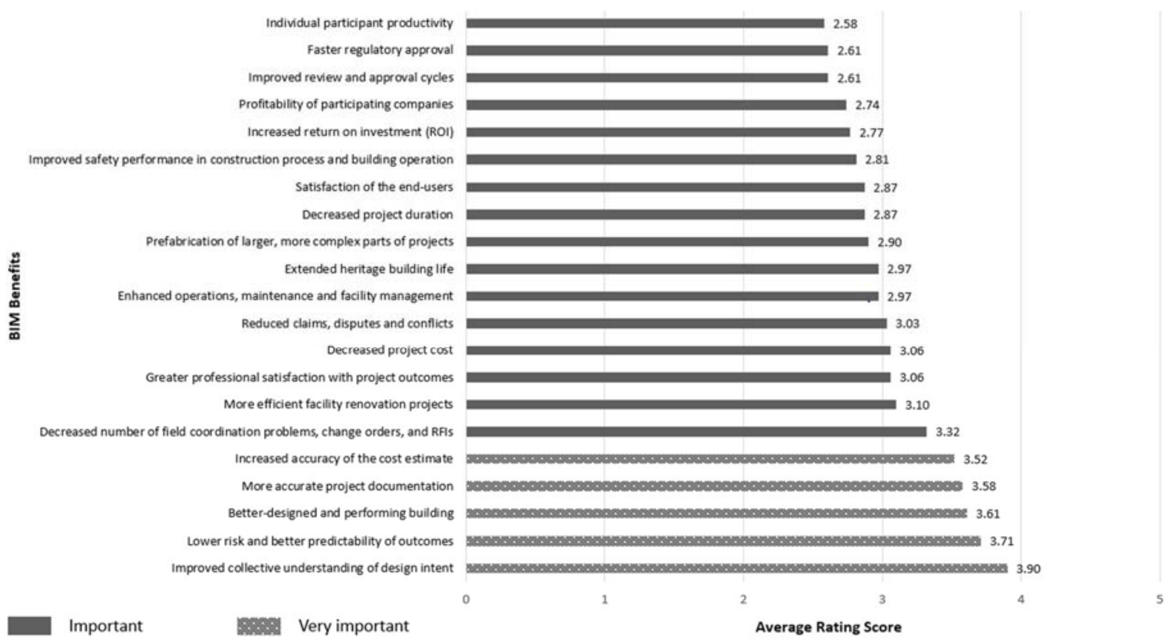

Fig. 5. Summary of BIM benefits

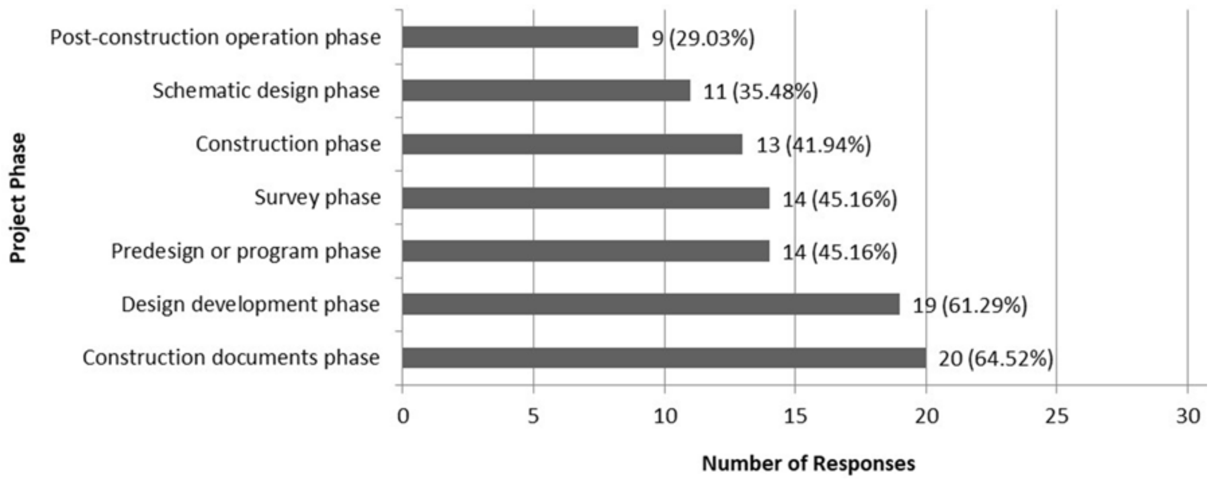

Fig. 6. BIM's contribution to improved performance in different project phases

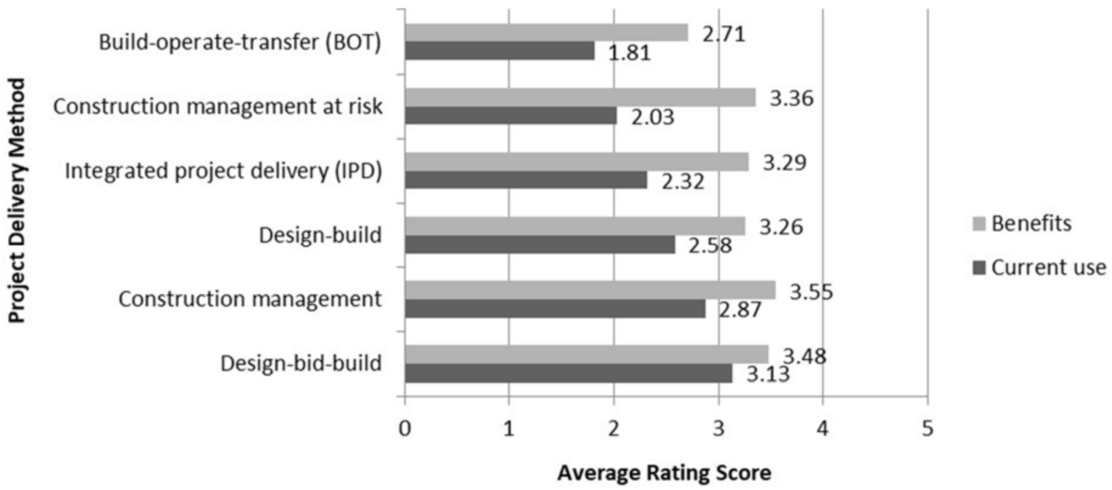

Fig. 7. Current use and benefits of BIM within different project delivery methods

a change in contractual arrangements, as the fragmentation of traditional approaches and fights for individual benefits contradict the collaborative atmosphere required for successful BIM implementation (Migilinskas et al., 2013).

2. Barriers to BIM implementation in heritage renovation throughout the project lifecycle

To identify and prioritize the barriers that hinder BIM implementation in renovation projects, the respondents were asked to rank a list of 17 identified barriers using a five-point Likert-type scale (Fig. 8). The same scale interval grading utilized in the previous section (for BIM benefits) was applied to determine the significance of each barrier: "not important" ($M < 1.50$), "somewhat important" ($1.51 \leq M \leq 2.50$), "important" ($2.51 \leq M \leq 3.50$), "very important" ($3.51 \leq M \leq 4.50$), and "extremely important" ($M \geq 4.51$).

The mean values (M) for the barriers range from the lowest mean score of M = 2.74 for "Project is too complex" to the highest mean value of M = 3.71 for "Project budget". Similar to the benefits analysis, the scale interval grading was used to determine the significance of each barrier. Notably, all 17 factors fall within the categories of "important" and "very important" barriers that require the attention and consideration of project stakeholders to ensure the full implementation of BIM in heritage renovation. The most significant barriers pertained to the project budget, complexity of modeling historic structures, cost of hiring BIM professionals, and lack of (H)BIM knowledge, with mean values of 3.71, 3.61, 3.58 and 3.55, respectively.

The respondents highlighted project budget and financial constraints as major barriers to BIM implementation. This suggests that the cost of incorporating BIM technologies and processes in heritage renovation projects may exceed the allocated budget or may not be adequately considered during project planning. As mentioned in the literature, the results highlight that the respondents recognize the complexity involved in modeling historic structures using BIM. Heritage buildings often possess unique architectural features, intricate designs, and

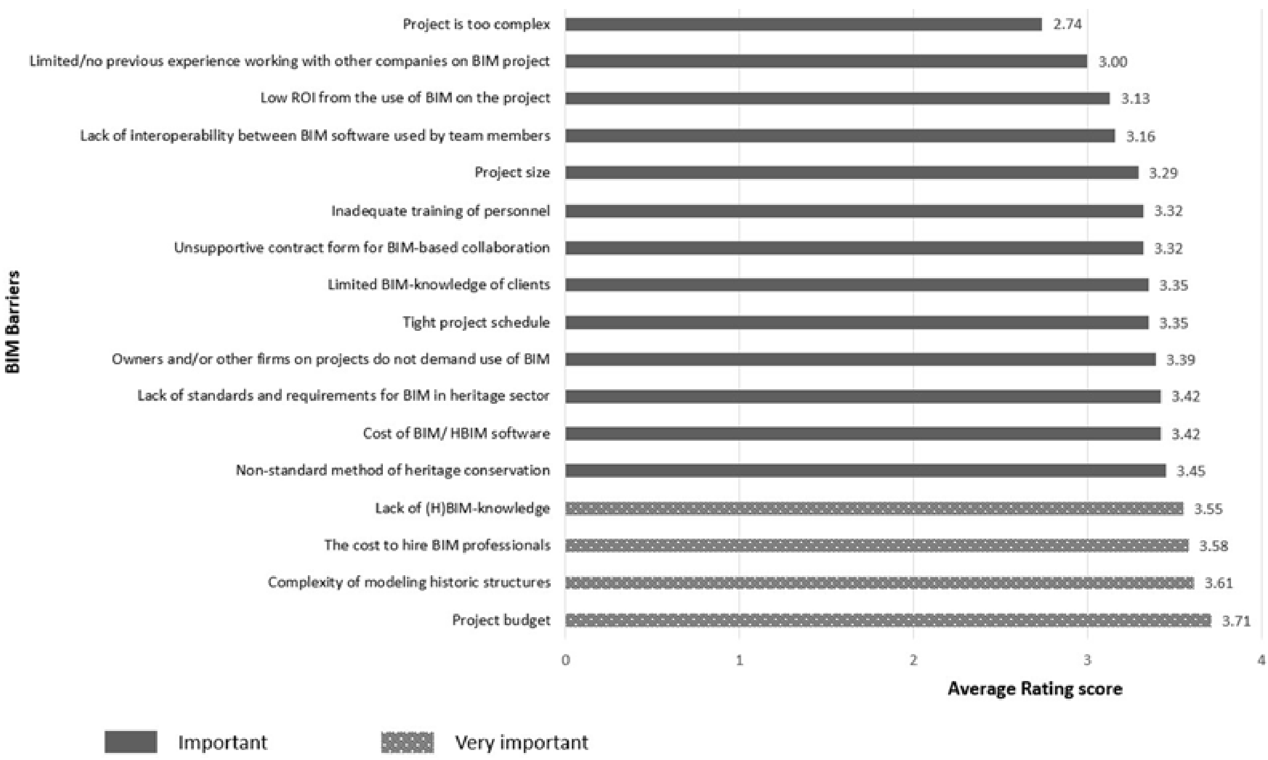

Fig. 8. Summary of BIM barriers in descending order of significance

unconventional construction techniques, which can pose challenges when developing accurate and detailed digital models. Furthermore, the respondents perceive a lack of knowledge and understanding of BIM and heritage-specific BIM (HBIM) as barriers to successful implementation. This implies that stakeholders involved in heritage renovation projects may not have sufficient knowledge of BIM processes, methodologies, or the specific considerations required for managing heritage projects.

Recommendations for future improvements

To overcome these barriers and maximize the potential of BIM in heritage renovation, the following practical recommendations and strategies are suggested:

- Mandate BIM adoption in contracts: Owners and developers of heritage projects should include clauses mandating the use of BIM in contracts. In this regard, almost all respondents (90 %) confirm the importance of property owners' mandating of the use of BIM to encourage its implementation on heritage sites. Here, the client plays a complex role as a change agent, using their power and influence to drive change among project participants (Lindblad, 2019).
- Combining methodologies, techniques, and software: Explore the integration of different methodologies, techniques, and software to open up new possibilities for enhancing BIM applications to attain sustainability and high-performance outcomes. The advancement of digitalization in the construction industry, including the adoption of Industry 4.0 practices, provides a foundation for benchmarking the effects of digital technologies.
- Financial support and incentives: Seek financial support from federal governments and encourage clients to provide incentives for interdisciplinary cooperation, especially for experts from construction companies. This could involve setting up venture capital funds to support the growth of innovative startups and facilitate their collaboration with developers and contractors in implementing BIM for heritage projects.
- Involvement of heritage governmental bodies: Involve heritage governmental bodies during the design phase to ensure that their expertise and perspectives are incorporated into the BIM implementation process.
- Education and training opportunities: Launching more education and training opportunities, especially for the heritage preservation community and project managers, to help them become digitally adept.
- Encourage academic research: Encourage further academic research on the subject of BIM in heritage renovation and support the publication of papers in this field to advance knowledge and understanding.
- Adapt organizational and business structures: Select organizational and business structures that align with the characteristics of sustainable renovation and are best suited to the capabilities and needs of project participants for the efficient implementation of heritage projects.

- Develop new contracts and legal frameworks: Create and develop new contracts and legal frameworks that foster collaboration and enable the full realization of benefits from BIM utilization.

By implementing these recommendations, stakeholders can overcome barriers and enhance the effective implementation of BIM in heritage renovation projects.

Conclusions

This research aims to identify and assess the current use, benefits gained, and barriers encountered in implementing BIM for heritage renovation. To achieve this objective, 31 structured online interviews were conducted with experienced professionals in the field. The study makes a new contribution by investigating BIM implementation throughout the entire lifecycle of heritage projects.

The results reveal that the primary benefits of BIM adoption, in descending order of importance, pertain to improved collective understanding of design intent, lower risk and better predictability of outcomes, better-designed and performing buildings, more accurate project documentation, and increased accuracy of the cost estimate. Conversely, the most significant barriers are project budget limitations, the complexity of modeling historic structures, the cost of hiring BIM professionals, and the lack of (H)BIM knowledge.

The results also indicate a significant and unexpected shift in BIM practices in recent years, revealing varied usage patterns across different projects. The usage of BIM has expanded to encompass more multifaceted applications, such as clash detection and building system coordination. However, there is untapped potential for BIM use in areas such as energy modeling, LEED certification, building code checking, 5D modeling/cost estimation, and spatial program validation. These areas need to be explored to address multiple criteria, project complexity, and values. In doing so, experiences from new and existing buildings can serve as a benchmark for evaluating the effects of BIM in sustainable heritage renovation.

A significant limitation of this study is the data collection process, which relied on the willingness of participants. The sample size of interviews was limited, which may restrict the comprehensive investigation of BIM implementation regarding its complexity and widespread use. However, the findings contribute to advancing BIM adoption in heritage renovation and provide guidance to project stakeholders on maximizing the benefits of BIM throughout the project lifecycle while addressing critical challenges. Future research efforts could involve conducting quantitative studies with a larger pool of participants to explore and compare BIM experiences from different stakeholders' perspectives, in order to further validate and generalize the results.

References

Angelini, M. G., Baiocchi, V., Costantino, D., and Garzia, F. (2017). *Scan to BIM for 3D reconstruction of the Papal Basilica of Saint Francis in Assisi in Italy.* [online] Available at: https://www.sanfrancescoassisi.org/fondazione/ita/pdf/2017-Scan-to-BIM.pdf [Date accessed January 13, 2022].

Brahmi, B. F., Sassi Boudemagh, S., Kitouni, I., and Kamari, A. (2022). IPD and BIM-focussed methodology in renovation of heritage buildings. *Construction Management and Economics*, Vol. 40, Issue 3, pp. 186–206. DOI: 10.1080/01446193.2021.1933557.

Buser, M. and Carlsson, V. (2016). What you see is not what you get: single-family house renovation and energy retrofit seen through the lens of sociomateriality. *Construction Management and Economics*, Vol. 35, Issue 5, pp. 276–287. DOI: 10.1080/01446193.2016.1250929.

Cheng, H.M, Yang W.B, & Yen, Y.N. (2015). BIM applied in historical building documentation and refurbishing. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, XL-5/W7, 85–90.

Dallasega, P., Rauch, E., and Linder, C. (2018). Industry 4.0 as an enabler of proximity for construction supply chains: A systematic literature review. *Computers in Industry*, Vol. 99, pp. 205–225. DOI: 10.1016/j.compind.2018.03.039.

Edwards, J. (2017). It's BIM – but not as we know it! In: Arayici, Y., Counsell, J., Mahdjoubi, L., Nagy, G., Hawas, S., and Dweidar, K. (eds.) (2017). *Heritage building information modeling*. New York: Routledge, pp. 6–14.

El-adaway, I., Abotaleb, I., and Eteifa, S. (2017). Framework for multiparty relational contracting. *Journal of Legal Affairs and Dispute Resolution in Engineering and Construction*, Vol. 9, Issue 3, 04517018-1–04517018-19. DOI: 10.1061/(ASCE)LA.1943-4170.0000238.

European Commission. (2019). Energy performance of buildings directive. [online] Available at: https://ec.europa.eu/energy/topics/energy-efficiency/energy-efficient-buildings/energy- performance-buildings-directive_en [Date accessed December 09, 2020].

Farnsworth, C. B., Beveridge, S., Miller, K. R., and Christofferson, J. P. (2015). Application, advantages, and methods associated with using BIM in commercial construction. *International Journal of Construction Education and Research*, Vol. 11, Issue 3, pp. 218–236. DOI: 10.1080/15578771.2013.865683.

Feng, L. Olbina, S., and Issa, R. (2014). Implementation of Building Information Modeling (BIM) on K-12 educational facility projects in Florida. In: Sulbaran, T. (ed.). *50th ASC Annual International Conference Proceedings*. March 26–28, 2014, Virginia Tech, Virginia.

Fouseki, K. and Cassar, M. (2014). Energy efficiency in heritage buildings — future challenges and research needs. *The Historic Environment: Policy & Practice*, Vol. 5, Issue 2, pp. 95–100. DOI: 10.1179/1756750514Z.00000000058.

Gigliarelli, E., Calcerano, F., and Cessari. L. (2017). Heritage BIM, numerical simulation and decision support systems: an integrated approach for historical buildings retrofit. *Energy Procedia*, Vol. 133, pp. 135–144. DOI: 10.1016/j.egypro.2017.09.379.

Kamari, A., Jensen, S. R., Corrao, R., and Kirkegaard, P. H. (2019a). A holistic multi-methodology for sustainable renovation. *International Journal of Strategic Property Management*, Vol. 23, No. 1, pp. 50–64. DOI: 10.3846/ijspm.2019.6375.

Kamari, A., Schultz, C. P. L., and Kirkegaard, P. H. (2019b). Constraint-based renovation design support through the renovation domain model. *Automation in Construction*, Vol. 104, pp. 265–280. DOI: 10.1016/j.autcon.2019.04.023.

Kassem, M., Kelly, G., Dawood, N., Serginson, M., and Lockley, S. (2015). BIM in facilities management applications: a case study of a large university complex. *Built Environment Project and Asset Management*, Vol. 5, No. 3, pp. 261–277. DOI: 10.1108/BEPAM-02-2014-0011.

Kelly, D. and Ilozor, B. (2019). A quantitative study of the relationship between project performance and BIM use on commercial construction projects in the USA. *International Journal of Construction Education and Research,* Vol. 15, Issue 1, pp. 3–18. DOI: 10.1080/15578771.2016.1202355.

Lasi, H., Kemper, H.-G., Fettke, P., Feld, T., and Hoffmann, M. (2014). Industry 4.0. *Business & Information Systems Engineering*, Vol. 6, Issue 4, pp. 239–242. DOI: 10.1007/s12599-014-0334-4.

Lidelöw, S., Örn, T., Luciani, A., and Rizzo, A. (2019). Energy-efficiency measures for heritage buildings: A literature review. *Sustainable Cities and Society*, Vol. 45, pp. 231–242. DOI: 10.1016/j.scs.2018.09.029.

Lindblad, H. (2019). Black boxing BIM: the public client's strategy in BIM implementation. *Construction Management and Economics*, Vol. 37, Issue 1, pp. 1–12. DOI: 10.1080/01446193.2018.1472385.

Logothetis, S., Delinasiou, A., and Stylianidis, E. (2015). Building Information Modelling for cultural heritage: a review. In: Yen, Y.-N., Weng, K.-H., and Cheng, H.-M. (eds.). *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, Vol. II-5/W3. 25th International CIPA Symposium 2015, 31 August – 04 September 2015, Taipei, Taiwan, pp. 177–183. DOI: 10.5194/isprsannals-II-5-W3-177-2015.

López, F. J., Lerones, P. M., Llamas, J., Gómez-García-Bermejo, J., and Zalama, E. (2018). A review of heritage building information modeling (H-BIM). *Multimodal Technologies and Interaction*, Vol. 2, No. 2, 21. DOI: 10.3390/mti2020021.

Migilinskas, D., Popov, V., Juocevicius, V., and Ustinovichius, L. (2013). The benefits, obstacles and problems of practical BIM implementation. *Procedia Engineering*, Vol. 57, pp. 767–774. DOI: 10.1016/j.proeng.2013.04.097.

Oesterreich, T. D. and Teuteberg, F. (2016). Understanding the implications of digitisation and automation in the context of Industry 4.0: A triangulation approach and elements of a research agenda for the construction industry. *Computers in Industry*, Vol. 83, pp. 121–39. DOI: 10.1016/j.compind.2016.09.006.

Olawumi, T. O., Chan, D. W. M., Wong, J. K. W., and Chan, A. P. C. (2018). Barriers to the integration of BIM and sustainability practices in construction projects: A Delphi survey of international experts. *Journal of Building Engineering*, Vol. 20, pp. 60–71. DOI: 10.1016/j.jobe.2018.06.017.

Pocobelli, D. P., Boehm, J., Bryan, P., Still, J., and Grau-Bové, J. (2018). BIM for heritage science: a review. *Heritage Science*, Vol. 6, 30. DOI: 10.1186/s40494-018-0191-4.

Roy, D., and Kalidindi, S. N. (2017). Critical challenges in management of heritage conservation projects in India. *Journal of Cultural Heritage Management and Sustainable Development*, Vol. 7, No. 3, pp. 290–307. DOI: 10.1108/JCHMSD-03-2017-0012.

Simeone, D., Cursi, S., Toldo, I., and Carrara, G. (2014). BIM and knowledge management for building heritage. In: *Proceedings of ACADIA 14*, October 23–25, 2014, Los Angeles, California, USA, pp. 681–690.

Tomšič, M., Mirtič, M., Šijanec Zavrl, M., and Rakušček, A. (2017). Energy renovation of cultural heritage buildings “by the book”. *Procedia Environmental Sciences*, Vol. 38, pp. 212–219. DOI: 10.1016/j.proenv.2017.03.108.

Tweed, C. and Sutherland, M. (2007). Built cultural heritage and sustainable urban development. *Landscape and Urban Planning*, Vol. 83, Issue 1, pp. 62–69. DOI: 10.1016/j.landurbplan.2007.05.008.

Volk, R., Stengel, J., and Schultmann, F. (2014). Building Information Modeling (BIM) for existing buildings — literature review and future needs. *Automation in Construction*, Vol. 38, pp. 109–127. DOI: 10.1016/j.autcon.2013.10.023.

Wong, J. K. W. and Zhou, J. (2015). Enhancing environmental sustainability over building life cycles through green BIM: a review. *Automation in Construction*, Vol. 57, pp. 156–165. DOI: 10.1016/j.autcon.2015.06.003.

Žurić, J., Zichi, A., and Azenha, M. (2022). Integrating HBIM and sustainability certification: A pilot study using GBC historic building certification. *International Journal of Architectural Heritage*, Vol. 17, Issue 9, pp. 1464–1483. DOI: 10.1080/15583058.2022.2042623.

ВНЕДРЕНИЕ BIM ПРИ РЕКОНСТРУКЦИИ ОБЪЕКТОВ КУЛЬТУРНОГО НАСЛЕДИЯ НА ПРОТЯЖЕНИИ ВСЕГО ЖИЗНЕННОГО ЦИКЛА ПРОЕКТА: ТЕКУЩЕЕ ИСПОЛЬЗОВАНИЕ, ПРЕИМУЩЕСТВА И ПРЕПЯТСТВИЯ

Бани Фериэль Брахми*, Суад Сасси-Будемах

Лаборатория AVMF, Университет Константины 3 Салах Бубнидер, Константина, Алжир

*E-mail: feriel.brahmi@univ-constantine3.dz

Аннотация
Введение: информационное моделирование зданий (BIM) привлекает значительное внимание благодаря развитию сложных технологий и методик. Однако всесторонний обзор имеющихся литературных источников свидетельствует об отсутствии исследований в области применения BIM в управлении процессами проектирования и реконструкции с более широкой системной точки зрения. **Цель исследования** — восполнить этот пробел путем выявления и оценки текущего использования, преимуществ и препятствий, связанных с внедрением BIM на протяжении всего жизненного цикла проектов реконструкции. **Методология** исследования основана на проведении 31 структурированного интервью с опытными специалистами, использовавшими BIM в своих проектах. **Результаты** показывают, что основными преимуществами внедрения BIM в порядке убывания важности являются улучшение коллективного понимания проектного замысла, снижение рисков и повышение прогнозируемости результатов, более качественное проектирование и улучшенные эксплуатационные характеристики зданий, более точная проектная документация и повышение точности смет. Однако существует и ряд существенных препятствий: бюджет проекта, сложность моделирования исторических сооружений, стоимость найма BIM-специалистов и отсутствие знаний в области BIM. Полученные результаты могут способствовать внедрению BIM при реконструкции объектов культурного наследия и позволят участникам проекта сосредоточиться на реализации преимуществ и потенциальных возможностей использования BIM на протяжении всего жизненного цикла проекта, а также на решении важнейших задач, рассмотренных в данном исследовании.

Ключевые слова: внедрение BIM; реконструкция объектов культурного наследия; преимущества BIM; препятствия в BIM.