Integration of Multi-Criteria Decision-Making in Heritage Building Information Management

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Abstract: This paper proposes a theoretical framework that integrates Heritage Building Information Management (HBIM) with Multi-Criteria Decision-Making (MCDM) techniques, to improve decision-making processes in the field of heritage conservation. The proposed framework employs the detailed semantic and geometric data provided by HBIM to evaluate and prioritize conservation strategies based on multiple criteria, including historical significance, architectural integrity, economic viability, social relevance, and environmental impact. The combination of both methodologies has the potential to not only technically improve heritage conservation but also facilitate informed and transparent decision-making processes by allowing stakeholder participation, balancing competing priorities, and achieving sustainable conservation outcomes. This study lays the foundation for a comprehensive, dynamic, and adaptive decision-making workflow that addresses the complicated challenges of heritage conservation.

Keywords: HBIM, MCDM, decision-making, heritage preservation

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1 Introduction

Heritage sites hold significant value in terms of history, education, and science, as they provide insight into human ingenuity, craftsmanship, and cultural integrity. Heritage conservation is increasingly regarded as a component of sustainable development [1], in alignment with the principles of the circular economy. This is achieved through the responsible conservation and adaptation of historic structures, which entails maintaining their physical integrity and ensuring the preservation of their cultural and historical significance. In comparison to new construction, heritage conservation often has a lower environmental impact [2].

Effective heritage conservation necessitates a multidisciplinary approach that engages various stakeholders [2], [3], including conservationists, architects, historians, and the local community [4]. This collaborative process must consider historical, cultural, social, and environmental factors while navigating uncertainties and balancing competing interests to achieve long-term conservation goals [5],

[6]. However, decision-making in this context is often constrained by the complexity and diversity of the factors involved.

This paper explores the integration of Heritage Building Information Management (HBIM) [7] and Multi-Criteria Decision-Making (MCDM) techniques to enhance decision-making processes in heritage conservation. While HBIM offers a dynamic representation of historic buildings, MCDM provides the tools to evaluate different conservation strategies based on various criteria. This integration creates a comprehensive framework to optimize heritage conservation decisions, facilitate collaboration between stakeholders, and promote transparency in the decision-making process.

2 State-of-the-Art

The conservation of historic buildings has traditionally been approached through a process of option prioritization and efficient resource allocation, with a reliance on expert judgment and qualitative assessments. However, in recent years, there has been a growing interest in the integration of quantitative approaches, such as MCDM [8], which is seen as offering the potential to systematize and streamline the decision-making process [9].

MCDM techniques have been employed in various fields, including engineering, environmental science, and public policy, for the evaluation of alternatives based on multiple criteria [8]. In the field of heritage conservation, MCDM has been employed to evaluate the significance of historic buildings, select adaptive reuse options, and assess the impact of interventions [9]. Studies have demonstrated the efficacy of MCDM in facilitating transparent and informed decision-making, balancing competing objectives, and promoting stakeholder involvement [2], [4].

In the construction industry, Building Information Modeling (BIM) has become a cornerstone for improving project outcomes through enhanced visualization, collaboration, and data management. However, as the scope of BIM has expanded to encompass a broader range of functions, many in the field now refer to it as Building Information Management [10]. Recent developments in integrating MCDM with BIM [11] have further facilitated decision-making processes in construction activities, risk management, and sustainability assessment [6]. The evolution of BIM towards HBIM, specifically tailored for heritage buildings, has opened new avenues for applying MCDM to heritage conservation. HBIM models provide a digital representation of historic buildings, capturing both their physical and historical attributes [1], [3], [5], [11], which can be analyzed using MCDM techniques to evaluate conservation alternatives.

The integration of MCDM with HBIM is still in its early stages, with most existing research focusing on limited applications. Studies have highlighted the benefits of this integration, including the assessment of the sustainability of rehabilitation interventions with an emphasis on environmental, economic, and social criteria [3], as well as the ranking of retrofit alternatives for heritage buildings with a focus on economic and functional aspects [12]. However, these approaches concentrate on a narrow set of criteria and very specific decision-making scenarios and do not address the management of data complexity within the HBIM models. Despite promising developments, further research is required to

address the challenges of integrating MCDM with HBIM, particularly concerning data management, criteria selection, and stakeholder engagement.

3 MCDM and HBIM Approach

In the field of historic preservation, decision-makers must reconcile the competing demands of historic integrity with modern functionality and sustainability. Integrating MCDM techniques with HBIM offers a holistic approach to preserving cultural heritage and adapting it for contemporary use. When making decisions related to historic heritage, it is essential to consider multiple factors. MCDM provides a structured framework for evaluating and prioritizing these factors.

In the context of MCDM applied to heritage buildings, a series of decisions must be made, i.e., the selection of alternative uses, the prioritization of renovation efforts, the assessment of significance, the evaluation of solutions, the estimation of service life, and the choice of contractors. These decisions are guided by several criteria dimensions, such as:

- Historic [3], [9], [13]: The distinctive stories, uniqueness, and historical significance of the building, including its heritage and archaeological value, period details, and construction techniques.
- Architectural [4], [9], [13]: The visual appearance and unique design, which serve to highlight the artistic and architectural significance and authenticity of the building.
- Economic [2]–[4], [9]: Financial aspects, including funding opportunities, conservation costs, tourism potential, and long-term economic benefits.
- Social [2]–[4], [9], [13]: The relevance and utility of the building to the local community, including political considerations and its role in fostering community identity and cohesion.
- Cultural [2], [4], [9], [13]: The contribution of the building to the cultural heritage and identity of the community, with particular emphasis on its educational value, cultural significance, and the preservation of traditions and practices.
- Managerial [4], [9]: Administrative and logistical considerations, such as personnel management, spatial organization, storage needs, and urban planning.
- Technological [3], [4], [9]: The building's capacity to fulfill current requirements, including accessibility, fire safety, environmental controls, and protection from the natural elements.
- Structural [4], [9], [14]: The condition and stability of the physical structure of the building, including its integrity, load-bearing capacity, risk management, and signs of damage affecting its longevity.
- Environmental [2]–[4], [9]: The ecological impact of the building, with a focus on sustainability, energy efficiency, and the minimization of the environmental footprint of maintenance and occupancy.

- Functional [2], [4], [9]: The current usability of the building and its future adaptability, ensuring that it remains usable and relevant. This is achieved by taking into account the occupancy, practical use, and continuity of purpose.

The HBIM application can integrate MCDM criteria and methodologies into three-dimensional models [6] of heritage sites, facilitating stakeholder interaction. This digital representation collects comprehensive information about heritage buildings, including structural components and historical annotations, enabling MCDM analysis. Stakeholders can assign weights to the various criteria in real-time and directly compare renovation options within the HBIM model [6], with visual representations of each choice. HBIM also permits the simulation of various conservation scenarios, which are evaluated using MCDM to assist decision-makers in selecting sustainable options [14]. The interactive nature of HBIM involves stakeholders, with sensitivity analysis and expert validation ensuring alignment with real-world preferences and constraints.

4 Methodology

The HBIM and MCDM approach employs a structured, iterative process comprising distinct phases. These include the understanding of historic buildings, the collection of accurate data, and the application of decision-making techniques. This approach involves all stakeholders and ensures transparency and alignment with preservation goals and current needs. Figure 1 shows schematically the iterative decision-making process using the HBIM-MCDM approach.

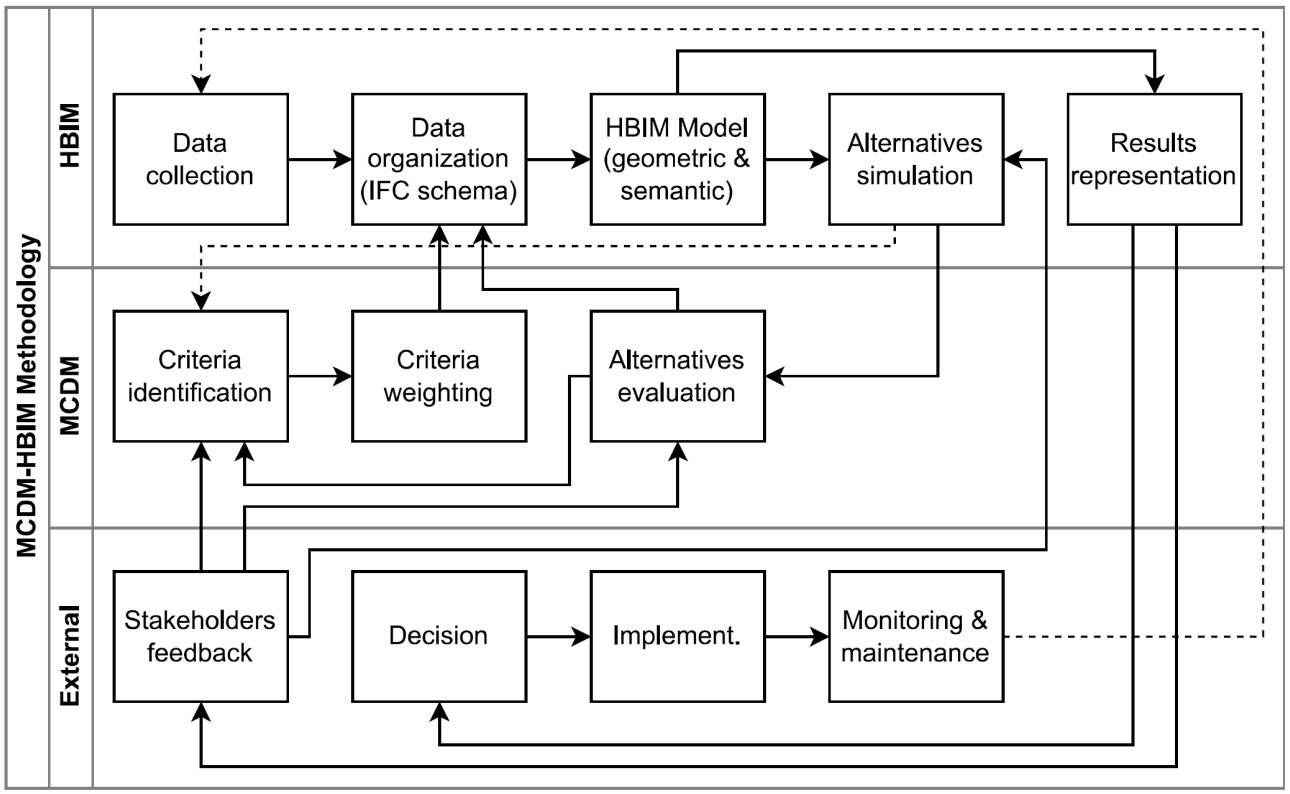

Figure 1: Methodology schema *(dashed lines are used when two arrows cross)*

4.1 Data Collection and HBIM Model Development

The initial phase of the process involves the collection of data essential to the development of the HBIM model. This includes historical research, on-site inspections, and materials analysis [1]. To gather the necessary data, various techniques are employed, such as the retrieval of historical documents, archival records, and previous surveys [14]; the use of laser scanning, photogrammetry, and manual measurements to conduct on-site inspections [11]; and the documentation of construction and restoration materials. Once the data has been collected, it is organized and integrated into the Industry Foundation Classes (IFC) schema defined by buildingSMART International (bSI) to create the HBIM model.

4.2 Criteria Identification and Weighting for MCDM

In parallel with the creation of the HBIM model, and having previously defined the final objectives of the decision to be made, a set of criteria for decision-making in heritage conservation is identified and classified into dimensions encompassing historic, architectural, economic, social, cultural, managerial, technological, structural, environmental, and functional considerations. Each criterion is assigned a weight that reflects its relative importance concerning the final objectives, determined by techniques such as stakeholder or expert consensus [6], [8].

4.3 Integration of MCDM Techniques with HBIM

The integration of MCDM techniques with the HBIM model involves several steps [4]. The first step is the assignment of criteria. This involves the incorporation of criteria and their respective weights into the HBIM model by associating them with specific elements and properties within the IFC schema. The second step is the simulation of alternatives. This is the use of the HBIM model to simulate various alternatives and evaluate their effects on the criteria [6]. The third step is the evaluation of alternatives. This is the application of MCDM techniques to rank the alternatives and calculate scores based on weighted criteria [6]. Finally, the fourth and final step is the integration of results. The alternative rankings are incorporated into the HBIM model by associating them with elements and properties within the IFC schema.

4.4 Decision Support

To facilitate decision-making, the results of the MCDM analysis are presented visually to stakeholders. This allows for the different scenarios, rankings, criteria scores, and key areas of interest to be displayed in the HBIM models. A feedback mechanism enables stakeholders to provide input on the scenarios, thereby refining the criteria, alternatives, or rankings iteratively.

4.5 Implementation and Monitoring

Once a decision has been made, the selected strategy is applied to the building, and the HBIM model serves as the central repository for ongoing monitoring and evaluation [11]. Regular updates of the HBIM model with new data from inspections, maintenance activities, and post-intervention evaluations ensure its effectiveness in long-term monitoring and support for future decision-making [1], [5], [14].

5 Discussion and Outlook

The HBIM and MCDM framework presents significant advantages, but its practical implementation is constrained by some key challenges. These include clustering and modeling decision factors, ensuring data accuracy, managing uncertainty, fostering effective communication and consensus among stakeholders, updating HBIM models, unifying decision-making processes into a cohesive system, and adapting users to new workflows.

Future research should prioritize a comprehensive understanding of stakeholder requirements and perspectives through qualitative interviews and content analysis. This understanding will inform the establishment of formal heritage conservation criteria.

Once these criteria have been clearly defined, they should be integrated, along with their weighting, into the HBIM model. This integration should ensure that the criteria are linked to relevant model elements and property sets (criteria groups). Following this, efforts should be directed towards optimizing the representation and regular updating of these criteria. In addition, defined responsibilities should be assigned to stakeholders, modelers, or collaborative teams.

It would be beneficial to explore intuitive and user-oriented methods for presenting and ranking alternatives within the HBIM model, considering whether MCDM processes should be conducted internally or externally. Establishing clear protocols for evaluating and ranking alternatives will enhance transparency and stakeholder engagement. An iterative workflow should be implemented to facilitate continuous updates, allowing the HBIM model to evolve in response to new data, changing requirements, and the outcomes of alternative evaluations.

Ultimately, the HBIM-MCDM framework must be validated through both theoretical and practical case studies to ensure it meets the necessary standards and effectively supports heritage conservation in real-world applications.

6 Conclusion

This approach shows the potential of integrating Heritage Building Information Management (HBIM) and Multi-Criteria Decision-Making (MCDM) techniques to enhance the preservation and adaptive reuse of historic buildings. By leveraging the digital modeling capabilities of HBIM and the structured decision-making processes of MCDM, stakeholders can achieve a more holistic and transparent approach to heritage conservation decision-making.

The integration of HBIM and MCDM addresses the multifaceted nature of heritage conservation by providing a framework that takes into account several factors, including historical significance, architectural integrity, economic viability, social relevance, and environmental impact. This approach facilitates informed decision-making, promotes stakeholder involvement, and ensures that conservation strategies are aligned with both contemporary needs and cultural heritage preservation.

Nevertheless, the successful implementation of this integrated approach necessitates the overcoming of several challenges. The accurate collection of data, effective communication among stakeholders,

and the management of complex technical processes are essential for the creation of reliable HBIM models and the execution of MCDM techniques. Furthermore, the implementation of continuous updates and long-term monitoring is necessary to maintain the relevance and accuracy of conservation strategies.

Future research should focus on further developing the integration of HBIM and MCDM. This can be achieved by developing uniform criteria for heritage conservation and exploring methods for data representation and stakeholder interaction. To this end, a case study on a listed building in Hamburg will be conducted. This will involve collaboration with various stakeholders to identify and prioritize conservation strategies, which will facilitate the validation and refinement of the framework in a real-world context.

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References

[1] F. Calcerano, S. Thravalou, L. Martinelli, K. Alexandrou, G. Artopoulos, and E. Gigliarelli, “Energy and environmental improvement of built heritage: HBIM simulation-based approach applied to nine mediterranean case-studies”, *Building Research & Information*, pp. 1–23, 2023. DOI: 10.1080/09613218.2023.2204417.

[2] Y. Li, L. Zhao, J. Huang, and A. Law, “Research Frameworks, Methodologies, and Assessment Methods Concerning the Adaptive Reuse of Architectural Heritage: A Review”, *Built Heritage*, vol. 5, no. 1, p. 6, 2021. DOI: 10.1186/s43238-021-00025-x.

[3] S. Santini, V. Borghese, and C. Baggio, “HBIM-based decision-making approach for sustainable diagnosis and conservation of historical timber structures”, *Sustainability*, vol. 15, no. 4, p. 3003, 2023. DOI: 10.3390/su15043003.

[4] B. O. Vehbi, K. Günçe, and A. Iranmanesh, “Multi-Criteria Assessment for Defining Compatible New Use: Old Administrative Hospital, Kyrenia, Cyprus”, *Sustainability*, vol. 13, no. 4, p. 1922, 2021. DOI: 10.3390/su13041922.

[5] P. Clini, C. Mariotti, R. Angeloni, and J. Muñoz Cádiz, “Architectural Heritage Digital Representations for Conservation Strategies”, in *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, 2024, pp. 111–118. DOI: 10.5194/isprs-archives-XLVIII-2-W4-2024-111-2024.

[6] S. Yarramsetty, M. Faheem, and S. K. Mvn, “An integrated approach to building planning using the multi-criteria decision method (MCDM) and BIM”, *International Journal of Sustainable Construction Engineering and Technology*, vol. 14, no. 4, pp. 49–63, 2024. DOI: 10.30880/ijscet.2023.14.04.005.

[7] M. Murphy, E. McGovern, and S. Pavia, “Historic Building Information Modelling (HBIM)”, *Structural Survey*, vol. 27, no. 4, pp. 311–327, 2009.

[8] H. Taherdoost and M. Madanchian, "Multi-criteria decision making (MCDM) methods and concepts", *Encyclopedia*, vol. 3, no. 1, pp. 77–87, 2023. DOI: 10.3390/encyclopedia3010006.

[9] R. R. Nadkarni and B. Puthuvayi, "A Comprehensive Literature Review of Multi-Criteria Decision Making Methods in Heritage Buildings", *Journal of Building Engineering*, vol. 32, p. 101 814, 2020. DOI: 10.1016/j.jobe.2020.101814.

[10] M. Bolpagni, "Building Information Modelling and Information Management", in *Industry 4.0 for the Built Environment* (Structural Integrity), M. Bolpagni, R. Gavina, and D. Ribeiro, editors, Structural Integrity. Cham: Springer International Publishing, 2022, vol. 20, pp. 29–54. DOI: 10.1007/978-3-030-82430-3_2.

[11] T. Tan, G. Mills, E. Papadonikolaki, and Z. Liu, "Combining Multi-Criteria Decision Making (MCDM) Methods with Building Information Modelling (BIM): A Review", *Automation in Construction*, vol. 121, p. 103 451, 2021. DOI: 10.1016/j.autcon.2020.103451.

[12] M. Pavlovskis, D. Migilinskas, J. Antucheviciene, and V. Kutut, "Ranking of Heritage Building Conversion Alternatives by Applying BIM and MCDM: A Case of Sapieha Palace in Vilnius", *Symmetry*, vol. 11, no. 8, p. 973, 2019. DOI: 10.3390/sym11080973.

[13] K. Bansal and P. Chhabra, "Values-based decision-making for conserving built heritage", in *2022 International Conference on Decision Aid Sciences and Applications (DASA)*, 2022, pp. 1770–1774. DOI: 10.1109/DASA54658.2022.9765068.

[14] N. Makoond, L. Pelà, and C. Molins, "A Risk Index for the Structural Diagnosis of Masonry Heritage (RISDiMaH)", *Construction and Building Materials*, vol. 284, p. 122 433, 2021. DOI: 10.1016/j.conbuildmat.2021.122433.