HBIM, AI and PMBOK: Integrated approaches to effective architectural heritage management

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ABSTRACT

This article focuses on the interaction between the Heritage Information Modeling (HBIM) methodology and Artificial Intelligence (AI) technology, emphasizing their impact on the design of innovative strategies for architectural heritage management. The main objective is to examine how this integration promotes a more comprehensive and refined approach to the management of this estate, resulting in more accurate and informed decisions. Based on the management concept outlined by the Project Management Body of Knowledge PMBOK (2021), based on groups of essential processes for the development of any project - planning, execution, monitoring and control, and closure, this study seeks to explore specific applications of HBIM in conjunction with various AI techniques, such as machine learning and computer vision. These techniques make it possible to detect patterns and recognize objects, respectively.

Through bibliographic research, case studies are identified that illustrate how this integration manifests itself in practical applications. These studies range from the preservation of historical data and information to the management of this data throughout the life cycle of structures. These applications support decisions, enable predictive maintenance, risk analysis, and simulations. The main objective of this article is to contribute to stimulate the development of new technologies and methodologies that drive innovative discoveries and applications in the field of architectural heritage. A more sustainable approach to managing this legacy is sought, aiming to reduce damage and improve conservation efficiency. Although the importance of the application of emerging technologies in wealth management is recognized as a paradigm shift with several benefits, it is important to highlight the existence of a scientific knowledge gap in this field, which motivated the conception of this article.

Keywords: Emerging Technologies, Architectural Heritage, Innovative Strategies, New Paradigms, Management.

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INTRODUCTION

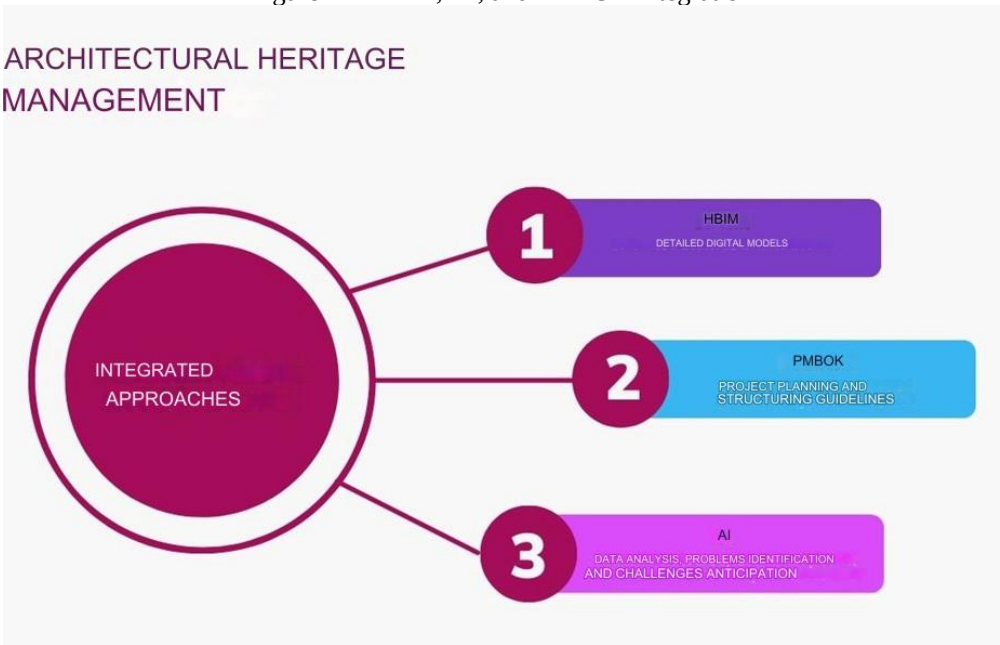
Architectural heritage management is undergoing a significant transformation with the introduction and integration of advanced methodologies and innovative technologies, such as HBIM, AI, and the application of Project Management Body of Knowledge (PMBOK) principles. This convergence represents not only a breakthrough, but a watershed in the management of this historical and cultural legacy

Preserving, protecting, and promoting the cultural and historical heritage of buildings and architectural structures is essential. However, managing these heritage sites presents unique challenges due to the ancient construction systems, the diversity of materials, and the different construction pathologies present in historic buildings. The need to adapt these structures to new uses and specific standards further increases the complexity of this process (ANTONIAZZI, 2015).

Despite its crucial importance, the management of architectural heritage still lacks adequate deepening (JORDAN-PALOMAR et al., 2018), reflected in the scarcity of publications on the subject, indicating a vast field to be explored in the knowledge of this area (JORDAN-PALOMAR et al., 2018).

The introduction of artificial intelligence in architectural conservation is gradually paving the way for new and promising ways of knowing, protecting and valuing the existing built heritage. In this scenario, HBIM has emerged as a crucial methodology in the management of architectural heritage due to its unique ability to offer a detailed, comprehensive, and accurate view of historical structures (BRUMANA et al., 2018).

Figure 1 – HBIM, AI, and PMBOK integration



Source: The author(2024)

Figure 1 illustrates the integration between the HBIM Methodology, AI and the principles outlined by the PMBOK representing a comprehensive approach to the preservation and conservation of old buildings and structures, taking into account their particularities and specific needs. This article seeks to explore how this integration can promote a more effective and sustainable management of architectural heritage, presenting the objective of reducing damage and enhancing the conservation of these historical treasures.

THEORETICAL BACKGROUND

HBIM

HBIM has played a key role in the management of architectural heritage, offering a wide range of practical applications that have revolutionized the way these cultural assets are documented, maintained, and preserved. One of the key practical applications of HBIM in architectural heritage management is the creation of detailed and accurate digital models of historic structures. These three-dimensional models not only capture the physical characteristics of buildings, but also incorporate information about materials, construction methods, construction phases, and changes over time (WOODWARD; HEESOM, 2020). This thorough documentation is essential for the proper preservation and conservation of heritage, as it provides a solid basis for the management of interventions and maintenance (JORDAN-PALOMAR et al., 2018).

Thus, HBIM allows for a thorough analysis of the current condition of historical structures. Integrated analysis tools help identify areas of deterioration, structural hazards, and maintenance needs, allowing the implementation of preventive measures for long-term conservation. In addition, continuous monitoring through HBIM assists in the early detection of any changes or damages, enabling a quick and efficient response (RIMKUS; CUPERSCHMID, 2023).

The role in the planning of interventions is also highlighted. The models generated by HBIM allow you to simulate different scenarios of restoration, renovation or interventions, making it easier to visualize the results even before the physical implementation. This helps in making informed decisions and choosing the best preservation strategies, minimizing potential risks or adverse impacts (SILVA, 2021).

In this context, HBIM also plays a crucial role in the management of information related to architectural heritage. By centralizing detailed data in a digital model, it simplifies the access and dissemination of information to various actors involved in the process, such as conservators, architects, engineers, government officials, and the public. This significantly improves communication and collaboration between stakeholders, facilitating discussions, analysis, and shared decisions (COSTA et al., 2021).

In addition to technical applications, HBIM is also a powerful tool for educating and sensitizing the public about the importance of architectural heritage. It offers the possibility of creating immersive and interactive experiences, allowing people to virtually explore historic buildings, understand their evolution over time, and value their cultural heritage. This contributes to raising awareness about the need for preservation and conservation of these assets.(SIOUNTRI; ANAGNOSTOPOULOS, 2023a).

PMBOK

The Project Management Body of Knowledge (PMBOK) represents a methodology that offers widely recognized practices and guidelines for project management. Integrated with architectural heritage management, combining Information Modeling for Historic Building (HBIM) and Artificial Intelligence (AI), the PMBOK becomes an essential tool for success in the conservation and preservation of historic structures (RIMKUS; CUPERSCHMID, 2023).

In the Project Initiation phase, the PMBOK assists in defining the scope, objectives and requirements of the project for the preservation of architectural heritage (DEINYFFER MARANGONI; CESAR ZILLI, 2019). HBIM plays a crucial role in creating detailed digital models of historic structures, while AI contributes to data analysis and the identification of patterns essential to understanding conservation needs (TOLENTINO, 2016).

In Project Planning, the PMBOK provides guidelines for structuring and planning activities (DEINYFFER MARANGONI; CESAR ZILLI, 2019). The integration of HBIM and AI enables a more accurate analysis of historical data, identifying critical areas that require specific attention during preservation, according to PMBOK guidelines. In the Project Execution and Control phase, HBIM monitors the progress of conservation activities, providing valuable information for decision-making (DEINYFFER MARANGONI; CESAR ZILLI, 2019). AI can automate processes, such as data analysis and structural problem detection, ensuring more efficient execution, as the PMBOK suggests. In the Project Closure phase, the PMBOK guides final processes and documentation (DEINYFFER MARANGONI; CESAR ZILLI, 2019). Here, HBIM can record interventions carried out, creating a detailed digital history of the preserved structure, while AI contributes to the analysis of the results obtained and feedback for future preservations, aligning with the PMBOK's closure practices (PMI, 2021) (AL-JABRI, 2017),.

Fridgeirsson et al. (2023) conducted Qualitative Research on the Impact of Artificial Intelligence on Schedules, Costs, and Knowledge Areas in Risk Management, as defined by the PMBOK.® They identified these areas as the most susceptible to the effects of AI development. Results from this study indicate that AI can have a significant impact on project management by automating tasks, optimizing resource allocation, and offering data-driven insights. Potential to

improve decision-making, risk analysis, and project forecasting, resulting in increased efficiency, cost reduction, and better overall results. AI's ability to analyze historical project data to predict future outcomes makes it easier to allocate resources and manage risk. Within the scope of project communication and documentation, AI finds application in Natural Language Processing (NLP), allowing sentiment analysis and identification of possible problems or conflicts. In addition, AI-powered chatbots can update on project progress, answer frequently asked questions, and assist staff, promoting more effective communication and reducing administrative tasks. It is worth noting that chatbots can also play a role in project management education, exemplifying numerous possibilities for improving project management through AI (FRIDGEIRSSON et al., 2021).

Based on this understanding, it can be seen that the integration of PMBOK with HBIM and AI offers a holistic and structured approach to architectural heritage management, providing powerful tools to ensure effectiveness, accuracy and sustainability in preservation actions, respecting best project management practices.

ARTIFICIAL INTELLIGENCE INTEGRATED WITH HBIM

AI, a branch of computer science that seeks to replicate human cognitive processes such as learning, reasoning, pattern identification, and decision-making, offers comprehensive applications to optimize the efficiency and accuracy of architectural heritage interventions is becoming increasingly popular (SOUSA et al., 2023). The integration between Artificial Intelligence (AI) and Information Modeling for Historic Building (HBIM) represents an innovative approach to enhance the conservation, analysis, and maintenance of historic architectural structures (BIENVENIDO-HUERTAS et al., 2020).

For example, when preserving a historic cathedral, the integration of AI and HBIM allows for the collection of an extensive database containing structural details, material information, maintenance history, records of previous analyses, and even three-dimensional representations of the building. Through AI algorithms such as machine learning, HBIM processes this extensive data to identify patterns of deterioration over time. This includes analyses of the condition of materials, such as stone, wood, or mortar, identifying areas susceptible to deterioration due to climatic conditions or specific environmental actions (VAIENTI et al., 2023). Additionally, AI can be trained to recognize visual patterns in digital images or three-dimensional models of the structure, identifying cracks, surface wear, or variations in texture that indicate structural problems (SIOUNTRI; ANAGNOSTOPOULOS, 2023b).

The integration of AI and HBIM not only identifies problem areas, such as cracks or corrosion spots, but also offers insights into the underlying causes of these issues (PALMA, 2019).

In the field of architectural heritage management, AI performs essential functions such as data analysis and diagnostics, predictive maintenance, data management, and documentation, as well as enabling modeling and simulation to predict the outcomes of planned interventions, contributing to informed decision-making on the best approaches for restoration or conservation.(CROCE et al., 2023)

EXAMPLES OF USING AI-INTEGRATED HBIM

Recent developments in the field of artificial intelligence (AI), and more specifically in the field of deep learning (DL), have shown a gradual contribution to the study of the typological evolution of buildings, especially those of cultural heritage. An example of this is the research conducted by Siountry et al. (2023), which presents a deep learning-based method for classifying modern Athenian architecture (since 1830). The method uses the YOLO algorithm, which is capable of classifying objects in images and videos with high accuracy and speed. This algorithm is widely used in computer vision tasks, such as the classification of buildings in satellite images and the automatic analysis of building images, classifying them according to specific characteristics, such as architectural style (Siountry et al).

Deep learning (DL) is a subfield of artificial intelligence and machine learning that employs algorithms known as neural networks. To date, DL has been applied in several fields, including speech recognition, computer vision, machine translation, among others. However, due to its architecture and the ability to perform procedures almost autonomously, DL can be applied in several sectors beyond those initially explored (FIGUEIREDO et al., 2022)

The opportunities provided by Artificial Intelligence (AI) in the preservation of architectural heritage on a global scale are vast and highly impactful. From identifying problems early to conducting predictive simulations, this technology is substantially redefining the understanding, protection, and conservation of historical and cultural legacies for future generations.

The convergence between AI and HBIM in the preservation of architectural heritage represents a promising advance, evidenced by examples highlighted below that involve the preservation of historic structures, creation of detailed digital models, advanced diagnostics, and predictive maintenance (Siountry et al., 2023).

PRESERVATION OF HISTORIC STRUCTURES

Colosseum, Rome (Italy): The preservation of historic structures has found in the combination of HBIM and AI a powerful tool for safeguarding notable monuments, such as the Colosseum in Rome, Italy. The use of these advanced technologies allowed for a thorough and detailed mapping of this impressive structure. The application of Historical Building Information Modeling (HBIM) made

it possible to create a highly accurate digital model of the Colosseum, capturing every architectural and historical detail. This model serves as a robust data foundation for the implementation of Artificial Intelligence (AI). AI, by analyzing the data provided by HBIM, plays a key role in identifying areas that are susceptible to wear and tear, structural damage, or degradation. With sophisticated algorithms, the AI is able to recognize patterns and anomalies that may not be immediately noticeable, allowing for a comprehensive and thorough analysis of the Colosseum's condition over time. In addition, AI acts as an ally in the process of guiding restorative interventions. By providing valuable insights and grounded in accurate data, this technology assists experts in making informed decisions about the best practices and strategies to adopt to preserve and restore the Colosseum while maintaining its authenticity and historical integrity. This innovative approach, which unites the power of HBIM and AI, represents not only a breakthrough in the preservation of the Colosseum, but also demonstrates the potential of these technologies to protect and conserve other historical monuments around the world. (GIOVAMPAOLA, 2021).

DETAILED DIGITAL MODEL:

Peru's Machu Picchu, one of the world's most iconic archaeological sites, is benefiting from the innovative combination of HBIM and AI to safeguard its heritage. HBIM plays a crucial role in creating a detailed digital model of this ancient Inca city, capturing not only its monumental architecture but also the site's complex topography. AI, in turn, is applied to thoroughly analyze this data coming from HBIM. This technological junction allows for a continuous analysis of the structure of Machu Picchu, enabling the detection of subtle changes in topography or potential damage to structures. The AI, armed with advanced algorithms, is able to identify anomalies that may indicate gradual erosion of the terrain or structural instability, offering a preemptive view of problems that may arise. AI's predictive ability is crucial for anticipating issues related to erosion, wear and tear, or potential structural hazards, allowing corrective measures to be implemented before problems worsen. This proactive approach is essential for the long-term preservation of Machu Picchu, ensuring its protection from damage that could compromise its authenticity and historical beauty. In this way, the integration between HBIM and AI not only offers a detailed view of the structure, but also plays a key role in the conservation and prevention of damage at one of the most iconic and precious sites in world history. This exemplary use of these technologies illustrates how the combination of historical knowledge and technological innovation can protect and preserve cultural heritage for future generations (LASAPONARA et al., 2022).

ADVANCED PROBLEM DIAGNOSIS:

Petra Ancient City, Jordan: The use of HBIM allows for the creation of detailed and accurate digital models of the complex structures in Petra, capturing its unique architecture and the intrinsic history of the site. This process provides a solid foundation of data for the implementation of AI, which performs advanced analytics. AI, when analyzing the data obtained by HBIM, plays a vital role in identifying areas susceptible to deterioration. Using sophisticated algorithms, the AI is able to detect patterns of degradation, identify areas with potential structural damage or signs of deterioration, and provide a comprehensive view of the current state of Petra's structures. This integration between HBIM and AI not only helps in the early identification of problems but also plays a crucial role in planning conservation strategies. By providing accurate data and grounded insights, this technology supports conservation experts in devising customized preservation plans and implementing strategic interventions to protect and maintain the integrity of the ancient city of Petra. Thus, the combined application of HBIM with AI in the ancient city of Petra represents a remarkable example of how the union between technology and historical knowledge can be fundamental to the preservation of an important archaeological site. This innovative approach offers an advanced diagnosis of the problems faced by historic structures and establishes valuable guidelines to ensure the conservation of this heritage for future generations (GOUSSOUS, 2020).

PREDICTIVE MAINTENANCE:

Great Wall of China: The convergence of Artificial Intelligence (AI) Systems with Historical Building Information Modeling (HBIM) is employed to identify patterns of deterioration, so as to predict areas of potential risk along the length of the Great Wall of China, identifying signs of degradation, and enabling the implementation of appropriate maintenance measures. This integration allows for the anticipation of problems and the proactive implementation of preventive conservation measures, ensuring the continued protection of this significant historical structure (ZHANG; ZOU, 2022).

METHODOLOGY

This study aimed to examine the impact of the integration between HBIM, IA and PMBOK on architectural heritage management. In addition, we sought to analyze the role of this integration in the design of innovative strategies for heritage management, to investigate the practical applications of HBIM in conjunction with AI techniques, such as Machine Learning and computer vision, and to identify and analyze case studies that exemplify the practical application of this integration in real scenarios of heritage preservation and management.

Figure 1 – Methodology

Source: The author(2024)

Figure 2 illustrates the research methodology that involved a comprehensive Literature Review, with a survey and review of specialized literature on HBIM, AI, architectural heritage management, historic preservation and project management methodologies (with a focus on the PMBOK). Case studies, scientific articles, books, journals, conferences and reports that address the integration between HBIM and AI in wealth management were identified and analyzed, using databases such as Web of Science and Google Scholar.

The research also included the identification of relevant case studies illustrating the integration of HBIM and AI into practical applications in architectural heritage management.

Finally, at the conclusion of the study, the main findings were reiterated, pointing out perspectives for future directions for the field. In addition, ethical frameworks have been made, such as the preservation of historical and cultural authenticity, data privacy, and responsibility in the disclosure of sensitive information.

FINAL THOUGHTS

The integration of HBIM, AI, and PMBOK in architectural heritage management can be a comprehensive and effective approach in Project Planning and Management, Utilization of Artificial Intelligence with HBIM, and Project and Data Management. In the initial phase of Project Planning and Management aimed at preserving architectural heritage, HBIM plays a crucial role in assisting in the creation of detailed digital models of historic structures. The PMBOK, in turn, offers guidelines

for the planning and structuring of these projects. AI can be employed to analyze historical data, identify problem areas, and anticipate future conservation challenges.

During the Project Execution and Control stage, HBIM proves to be valuable in monitoring the evolution of conservation activities. Meanwhile, AI can automate repetitive tasks, such as analyzing data or detecting spoilage patterns. In the Project Closure phase, the PMBOK outlines the processes to finalize and document the project, with HBIM being instrumental in recording all interventions carried out, creating a detailed digital history of the preserved structure.

The use of Artificial Intelligence in HBIM in Data Analysis and Diagnostics can process large volumes of data collected by HBIM to identify deterioration patterns, anticipate future problems, and offer detailed insights into the structural condition. AI can even predict the need for preventive maintenance based on predictive analytics, which is crucial for preserving architectural heritage. In addition, AI enables Computer Vision and Natural Language Processing, techniques that help in the visual identification of damage and the analysis of historical documents to extract relevant information.

In Project and Data Management, one can use the PMBOK guidelines to manage the preservation project, combining them with HBIM's tools and AI capabilities for analysis and informed decision-making. In Documentation and Organization, HBIM can be used to catalog data, and AI, along with PMBOK guidelines, can structure the documentation process to keep a detailed record of interventions. Thus, the integration of HBIM, Artificial Intelligence, and PMBOK can provide a more holistic and efficient management of architectural heritage, combining technology, project management practices, and detailed analysis to preserve these historic structures effectively.

Given this context, it can be said that the integration between HBIM and Artificial Intelligence points to a future in which the preservation of historical architectural heritage will be more precise, efficient and carefully aligned with the cultural and historical demands of local communities. The advancement of AI algorithms presents the potential for more accurate and advanced analytics, deepening the understanding of the data collected by HBIM. This will enable a more detailed and thorough interpretation of historical structural information. In addition, the increasing automation of repetitive tasks, such as processing data and identifying patterns, tends to optimize the team's efforts. With this, professionals will be able to focus on more complex analyses and strategic interventions for heritage preservation. The integration between HBIM and AI can expand to include other emerging technologies, such as Augmented Reality (AR) or Virtual Reality (VR). This combination will allow for a more immersive experience in understanding and visualizing historic buildings, providing new methods of analysis and preservation.

However, it is critical to consider ethical issues such as data privacy, historical authenticity, and local community involvement. The evolution of these technologies must be guided by ethics and

sustainability, ensuring that the preservation of architectural heritage is carried out responsibly and in line with the cultural and historical needs of local communities. In summary, the integration between HBIM and Artificial Intelligence points to a future in which the preservation of historical architectural heritage will be more accurate, efficient, and carefully aligned with the cultural and historical demands of local communities.

REFERENCES

1. Al-Jabi, S. (2017). Alignment framework between building information modeling processes and the PMBOK® Guide construction extension processes in construction projects. *Middlesex University London School of Science and Technology*. Retrieved from <file:///C:/Users/Carla/Downloads/ALIGNMENT_FRAMEWORK_BETWEEN_BUILDING_INF.pdf>.

2. Antoniazzi, T. H. (2015). Gestão em obras de restauração no patrimônio edificado. *UFRJ/PROARQ/Programa de Pós-graduação em Arquitetura*. Retrieved from <http://objdig.ufrj.br/21/teses/833202.pdf>.

3. Bienvenido-Huertas, D., Nieto-Julián, J. E., Moyano, J. J., et al. (2020). Implementing artificial intelligence in H-BIM using the J48 algorithm to manage historic buildings. *International Journal of Architectural Heritage, 14*(8), 1148–1160.

4. Brumana, R., Della Torre, S., Previtali, M., et al. (2018). Generative HBIM modelling to embody complexity (LOD, LOG, LOA, LOI): Surveying, preservation, site intervention—the Basilica di Collemaggio (L'Aquila). *Applied Geomatics, 10*(4), 545–567.

5. Costa, H. E., Souza, Baldessim M. P., Guilherme Quinilato, et al. (2021). Modelagem BIM para o registro digital do patrimônio arquitetônico moderno, *6*, Retrieved from <https://periodicos.ufrn.br/revprojetar/article/view/21331>.

6. Croce, V., Caroti, G., Piemonte, A., et al. (2023). H-BIM and artificial intelligence: Classification of architectural heritage for semi-automatic scan-to-BIM reconstruction. *Sensors, 23*(5), 2497.

7. Deinyffer Marangoni, Q., Cesar Zilli, J. (2019). Management of projects in organizational management: Application of the foundations of the PMBOK in a business association. *Faculdade Novo Milenio, 12*.

8. Figueiredo, B., Martins, J. P., Granja, J., et al. (Eds.). (2022). *4o Congresso Português de 'Building Information Modelling' vol. 2 - ptBIM*. UMinho Editora. Retrieved from <https://ebooks.uminho.pt/index.php/uminho/catalog/book/77>.

9. Fridgeirsson, T. V., Ingason, H. T., Jonasson, H. I., et al. (2023). A qualitative study on artificial intelligence and its impact on the project schedule, cost and risk management knowledge areas as presented in PMBOK®. *Applied Sciences, 13*(19), 11081.

10. Giovampaola, I. D. (2021). SyPEAH: The WebAPP system for protection and education to archaeological heritage in the Parco Archeologico del Colosseo. *Geosciences, 11*(6), 246.

11. Goussous, J. S. (2020). Artificial intelligence-based restoration: The case of Petra. *Civil Engineering and Architecture, 8*(6), 1350–1358.

12. Jordan-Palomar, I., Tzortzopoulos, P., García-Valldecabres, J., et al. (2018). Protocol to manage heritage-building interventions using heritage building information modelling (HBIM). *Sustainability, 10*(4), 908.

13. Lasaponara, R., Abate, N., Fattore, C., et al. (2022). Open big earth observation data and artificial intelligence for the study and preservation of UNESCO natural and cultural heritage: The case of Machu Picchu. In M. Ziółkowski, N. Masini, & J. M. Bastante (Eds.), *Machu Picchu in

Context* (pp. 239–264). Springer International Publishing. Retrieved from <https://link.springer.com/10.1007/978-3-030-92766-0_6>.

14. Palma, V. (2019). Towards deep learning for architecture: A monument recognition mobile app. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XLII-2/W9*, 551–556.

15. Project Management Institute. (2021). *A Guide to the Project Management Body of Knowledge and the Standard for Project Management* (7th ed.). Project Management Institute.

16. Rimkus, C. M. F., Cuperschmid, A. R. (2024). Gestão do escopo em projetos de intervenção do patrimônio arquitetônico: Integração das boas práticas do PMBOK com o manual de elaboração de projetos de preservação do patrimônio cultural e o contexto HBIM. *Caderno Pedagógico, 20*(8), 3309–3338. Retrieved from https://ojs.studiespublicacoes.com.br/ojs/index.php/cadped/article/view/1825.

17. Silva, R., Carvalho, M. (2022). Revisão da literatura da integração BIM IA na construção civil. In B. Figueiredo, J. P. Martins, J. Granja, et al. (Eds.), *4o Congresso Português de 'Building Information Modelling' vol. 2 - ptBIM* (pp. 39–49). Universidade do Minho Editora. Retrieved from <https://ebooks.uminho.pt/index.php/uminho/catalog/view/77/133/1567-1>.

18. Silva, W. D., Afonso, M. L., Silva, C. D. (2023). Gerenciamento de projetos: Viajando com os princípios e domínios de desempenho do PMBOK 7. Atena Editora. Retrieved from <https://atenaeditora.com.br/catalogo/ebook/gerenciamento-de-projetos-viajando-com-os-principios-e-dominios-de-desempenho-do-pmbok-7>.

19. Siountri, K., Anagnostopoulos, C. N. (2023). The classification of cultural heritage buildings in Athens using deep learning techniques. *Heritage, 6*(4), 3673–3705. Retrieved from https://www.mdpi.com/2571-9408/6/4/195.

20. Sousa, J. J., Lin, J., Wang, Q., et al. (2023). Using machine learning and satellite data from multiple sources to analyze mining, water management, and preservation of cultural heritage. *Geospatial Information Science*. Retrieved from https://www.osti.gov/pages/bib

lio/1992398-using-machine-learning-satellite-data-from-multiple-sources-analyze-mining-water-management-preservation-cultural-heritage.

21. Tolentino, M. M. A. (2016). A utilização do HBIM na documentação, na gestão e na preservação do Patrimônio Arquitetônico. *SIGraDi 2016, XX Congress of the Iberoamerican Society of Digital Graphics*, Buenos Aires, Argentina. Retrieved from <http://www.proceedings.blucher.com.br/article-details/24842>.

22. Vaienti, B., Petitpierre, R., Di Lenardo, I., et al. (2023). Machine-learning-enhanced procedural modeling for 4D historical cities reconstruction. *Remote Sensing, 15*(13), 3352. Retrieved from https://www.mdpi.com/2072-4292/15/13/3352.

23. Woodward, A., Heesom, D. (2020). Implementing HBIM on conservation of heritage projects: Lessons from renovation case studies. *International Journal of Building Pathology and Adaptation, 39*(1), 96–114. Retrieved from https://wlv.openrepository.com/handle/2436/622902.

24. Zhang, F., Chan, Albert P. C., Darko, A., et al. (2022). Integrated applications of building information modeling and artificial intelligence techniques in the AEC/FM industry.

Automation in Construction, 139, 104289. Retrieved from https://www.researchgate.net/publication/360153277_Integrated_applications_of_Building_Information_Modeling_and_Artificial_Intelligence_techniques_in_the_AECFM_industry.