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AUGMENTED REALITY IN THE DIGITAL PRESERVATION OF CULTURAL HERITAGE: CASE STUDY IN POLAND

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Abstract

The integration of augmented reality (AR) technologies into heritage preservation is revolutionizing how to document, interpret, and engage with historical sites. This study presents an innovative approach that combines multiple data sources—including images, point clouds, and building information modelling models—into a cohesive digital framework. Using the Unity platform, the data are integrated to provide maintenance recommendations and renovation strategies tailored to the unique needs of cultural heritage. The results are deployed in AR environment for immersive exploration and practical application in a Polish case, highlighting the transformative potential of AR in the digital preservation of heritage buildings.

Introduction

As a vital component of human civilization, cultural heritage carries profound historical, cultural, and artistic significance, serving as a bridge between past and present (Zheng et al., 2024; Cao et al., 2019). As such, the preservation of heritage sites is not only a technical challenge but also a cultural and ethical imperative. However, many cultural heritage sites face growing threats from natural aging, environmental factors, and human activities, making their preservation an urgent and complex task (Kolivand et al., 2018; Lee et al., 2019).

Traditional methods of cultural heritage preservation have primarily focused on physical conservation, restoration, and documentation through photographs, drawings, and written records (Elabd et al., 2021). Manual methods cannot provide a preview of the potential outcomes of preservation or renovation efforts in advance. Moreover, such process- and labor-intensive approach often lack the effectiveness needed to achieve preservation goals (Rebec et al, 2022).

Among these, Building Information Modelling (BIM) has become a widely adopted tool that offers a structured, data-rich representation of heritage assets. By integrating geometric, material, and historical data, BIM enables in-depth analysis and supports more informed decision-making throughout the conservation process (Nagy & Ashraf, 2021; Jordan-Palomar et al., 2018). Building on this foundation, immersive technologies such as virtual reality (VR) and augmented reality (AR) have further enhanced the way users interact with heritage data. While VR has been widely used for storytelling and virtual reconstructions, AR offers unique benefits that make it especially suitable for practical, on-site applications. It enables professionals to visualize structural defects, explore renovation scenarios, and interact with building models in real time. In addition, AR environments can be used to train maintenance workers or conservation staff by simulating repair procedures directly on the heritage structure, thereby improving communication, reducing errors, and enhancing technical understanding.

Numerous studies have explored the application of AR in the cultural heritage domain, especially in education, tourism, and public engagement. For instance, Osello et al. (2018) reconstructed the heritage building by establishing the heritage BIM (HBIM) and provided the visualization of conservation practices and the renovation process in emergencies based on AR. Van Nguyen et al. (2022) developed AR models for the digital visualization of architectural heritage.

However, a common feature across much of this literature is the focus on visual appeal and historical storytelling, rather than on supporting the technical and strategic needs of preservation professionals. As highlighted by Poux et al. (2020) and Ribeiro et al. (2024), most AR applications in cultural heritage remain centered on passive user experience (e.g., viewing reconstructions, learning narratives), with little integration of diagnostic data, real-time monitoring, or renovation decision support. In other words, AR is often treated as a tool for interpretation rather than intervention. This highlights a critical research gap: how AR can be repositioned from a primarily communicative or educational medium to a functional platform for expert analysis and strategic preservation.

This study aims to address this gap by proposing and validating a digital framework that integrates AR with multi-source data to support informed decision-making in heritage building renovation. The framework is implemented in a real-world case study of a historical building in Poland, where the AR interface allows users to inspect structural conditions, explore different renovation scenarios, and receive maintenance recommendations directly within an immersive environment.

Brief literature review

AR has been widely applied in cultural heritage contexts, particularly in enhancing interpretation, visitor engagement, and tourism experiences. Many studies highlight AR's potential to make heritage sites more interactive, immersive, and accessible to the public. For instance, Chen (2024) explored how AR serves as an interpretive medium that enables users to better understand the historical significance of heritage buildings. By overlaying narratives, annotations, and visual reconstructions onto the physical environment, AR enriches the storytelling dimension of heritage preservation. Similarly, Panhale et al. (2023) examined the use of AR in co-creating visitor experiences in heritage settings, arguing that heritage suppliers often employ AR not for technical preservation, but for fostering emotional and narrative connections between the site and the audience.

This interpretive and experience-driven focus is further reflected in other works. Osello et al. (2018) used AR to visualize emergency conservation scenarios for public awareness. Van Nguyen et al. (2022) applied AR for digital visualization, while Marto and Gonçalves (2019) emphasized mobile AR as a tool to enhance museum visitors' learning experience. Across these studies, AR is primarily positioned as a visualization tool—aimed at tourists, learners, or general audiences—rather than a technical platform to support heritage professionals in diagnosis, analysis, or decision-making.

However, as Poux et al. (2020) and Ribeiro et al. (2024) point out, this one-dimensional use of AR overlooks its potential for practical applications such as simulation of renovation impacts and evaluation of preservation strategies. There is thus a clear research gap in the integration of AR with functional data and workflows to support expert users in making informed decisions about conservation and renovation.

Methodology

This study proposes a digital framework that integrates advanced technologies to support heritage preservation. By combining multi-source data with AR tool, the research develops and implements this framework to analyze, visualize, and provide actionable recommendations for the preservation and renovation of cultural heritage.

Framework overview

Figure 1 presents the overall framework, which consists of four steps: data acquisition, virtual environment development, AR scenario construction, and finally, practical application. In the first step, multi-source data such as images and point clouds are collected and processed to ensure accuracy and consistency. The second step focuses on developing a detailed virtual environment, integrating the processed data into a cohesive digital model. The AR scenario construction involves overlaying this digital model onto the physical environment, enabling real-time visualization and interaction. Finally, the practical application phase tests the framework's effectiveness in providing actionable insights for preservation and renovation efforts.

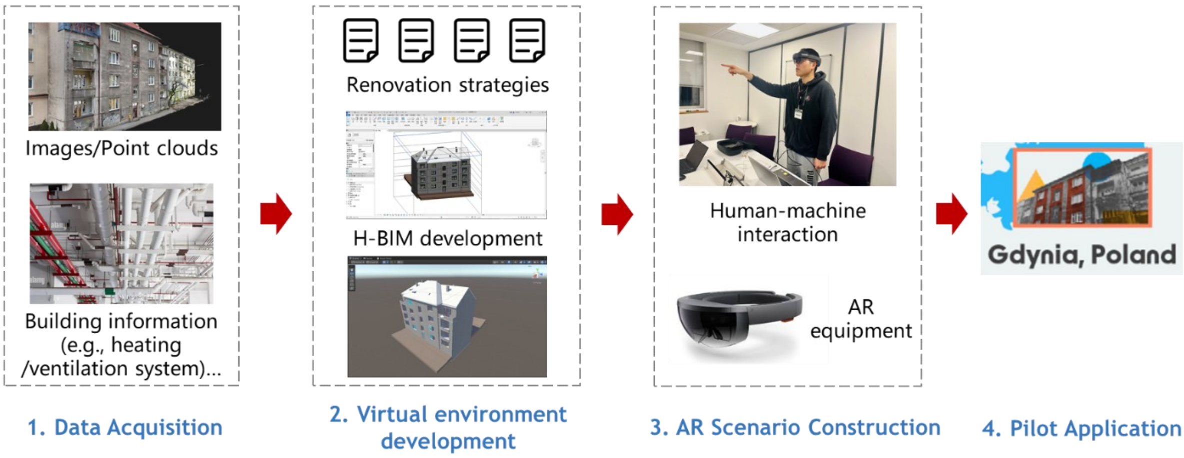


Figure 1: Overview of the digital framework

Data acquisition

The data acquisition phase serves as the foundation of the digital framework. In this study, specifically, images, point clouds, building information, and preservation and renovation information are collected. Building information, such as data of heating/ventilation system, sensor data, and building basic information (location, age, functions…), offer a holistic understanding of the building's condition.

Virtual environment development

After preprocessing the acquired data, the next step involves constructing a HBIM model in Revit software. The model serves as a digital representation of the heritage site, combining geometric, material, and structural information derived from images, point clouds, and existing documentation.

The HBIM model is then imported into a platform developed using the Unity engine (Li et al., 2021a; Li et al., 2021b). Both the structural model (.rvt file) and the attributes (.ifc file) are imported. Unity acts as the central hub for combining various data sources into a cohesive virtual environment. Moreover, the Unity platform supports real-time visualization and interaction with the heritage model, and the subsequent deployment of immersive AR applications.

AR scenario construction

The AR scenario construction phase focuses on creating an interactive augmented reality experience, leveraging the capabilities of Microsoft HoloLens 2 (Guo & Prabhakaran, 2024) and the Microsoft's Mixed Reality Toolkit (MRTK). The MRTK serves as a key framework for optimizing the AR application on the HoloLens 2, providing essential tools for spatial mapping and interaction design. The other technical tools used to create the AR environment is shown in figure 2.

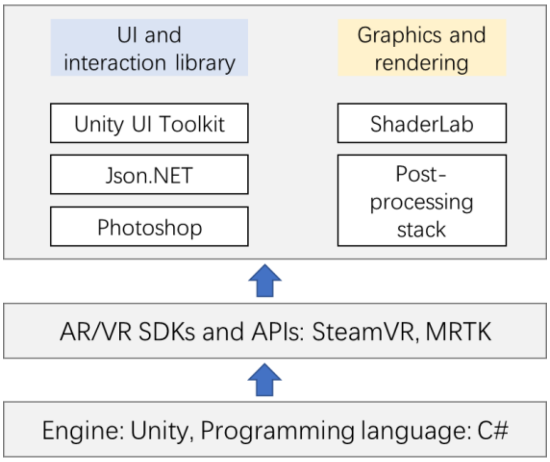


Figure 2: Technical tools used to create AR environment

Using MRTK's interaction tools, users can engage with the digital model through gestures commands. The interactive features also allow stakeholders to simulate and preview the outcomes of different preservation strategies, ensuring that decisions are informed by accurate, real-time visualizations.

Pilot application

To validate the proposed framework, a pilot application is conducted on a real-world heritage site to demonstrate its practical effectiveness. The selected site, which presented typical preservation challenges including structural aging and the need for careful renovation to maintain its historical authenticity, served as a testbed for applying the proposed methods.

The proposed framework is structured into three interconnected layers: the physical layer, data layer, and application layer. The physical layer includes the necessary hardware, such as Microsoft HoloLens 2 and sensors installed within the heritage building to monitor structural and environmental conditions. The data layer encompasses the multi-source data described earlier. Finally, the application layer delivers the platform's core functionality, providing services such as the visualization of preservation or renovation strategies. This layered structure ensures a seamless workflow, from data acquisition to actionable insights, supporting efficient and effective heritage preservation.

Case study

Site description

The heritage building in this study was constructed in 1928 in Poland. With the goal of environmental sustainability, it is important not only to renovate the buildings in order to minimize use of energy but also to focus on possible improvements of management systems. The challenge is how to find the most optimum renovation solution and check in which extent renewables can be applied in the building. Figure 3 illustrates the external surface conditions of the building.

Figure 3: The external surface of the building

Data acquisition

For this case study, images and point cloud data were obtained using a 3D laser scanner, which provided high-resolution spatial and geometric details of the building's external surfaces (as shown in Figure 2). Additionally, sensor data, such as environmental and structural monitoring information, was sourced from project partners who had installed the sensors within the building.

Virtual environment

In the virtual environment development phase, the building's digital model was first created in Revit. This model included both geometric information, such as the structure's dimensions and spatial layout, and attribute information, such as material specifications and structural properties. Once the HBIM model was finalized, it was exported from Revit and imported into the Unity platform. Figure 4 showcases the HBIM model in Unity.

Figure 4: The HBIM in the virtual environment

In Unity, a series of interactive functions were developed based on the imported HBIM model, including view navigation, visualization of point cloud data; inspection of structural defects, and different renovation scenarios. enabling users to visualize and compare different preservation strategies interactively.

(1) View navigation: Users can freely navigate and explore the building's digital model, switching between different perspectives and viewpoints. The platform offers four predefined views to facilitate easier navigation and examination of the building. These include the front view, side view, bird's-eye view, and interior view, allowing users to quickly switch between perspectives.

(2) Visualization of point cloud data: The platform includes the ability to overlay and inspect point cloud data alongside the HBIM model. This feature offers precise geometric and spatial information, enabling users to cross-reference the original scan data with the reconstructed digital model.

(3) Inspection of structural defects: The platform integrates real-time sensor data to dynamically display defects on the digital model. When users select the defect inspection interface, they can view detailed information about each defect, including its location, type, severity level, and corresponding maintenance recommendations.

For instance, as illustrated in Figure 5, a crack on the wall is highlighted in the model. By clicking on the crack, users can access its specific details, such as its location, type, severity level, and suggested repair and maintenance recommendations, as shown on the right side of Figure 5, including using a high-quality crack filler for sealant to prevent further expansion, applying a fiberglass mesh or plaster patch over the crack to improve durability, and repainting the surface with a weather-resistant coating to enhance protection.

Figure 5: Inspection of defects in the platform

(4) Renovation Scenarios:

The renovation scenarios are developed based on discussions with stakeholders to reflect their specific preservation needs. These scenarios are designed to visualize potential renovation strategies directly within the digital model, allowing users to assess and compare their outcomes interactively.

The platform includes three predefined renovation scenarios, including removing structural cracks, adding balconies, and removing graffiti from wall surfaces. For each renovation scenario, the platform provides a detailed description, along with visual comparisons of the building's condition before and after the renovation. Additionally, animations are included to demonstrate the renovation process step by step, helping users better understand the methods and impacts of each intervention.

For example, Figures 6 illustrates the changes before and after adding balconies, offering a clear visualization of the transformation.

(a) Before renovation

(b) After renovation

Figure 6: Renovation scenario of adding balconies to the structure

AR scenario development

The AR scenario is developed by connecting the virtual environment created in Unity with the hardware device, Microsoft HoloLens 2, using the MRTK. MRTK provides essential tools and resources to integrate the virtual model with the AR hardware, as mentioned in Figure 2, enabling seamless interaction between the user and the digital content.

During the configuration process, specific interaction settings are implemented, such as hand interaction and motion controller support, to allow intuitive and natural engagement with the AR environment. These configurations enable users to manipulate the model, explore different perspectives, and access detailed information about defects or renovation scenarios directly within the AR interface.

After wearing the HoloLens 2 device, users can engage with the model through simple hand gestures. For example, gestures such as tapping or pinching allow users to select specific elements, rotate the model, or zoom in on details like cracks or material textures.

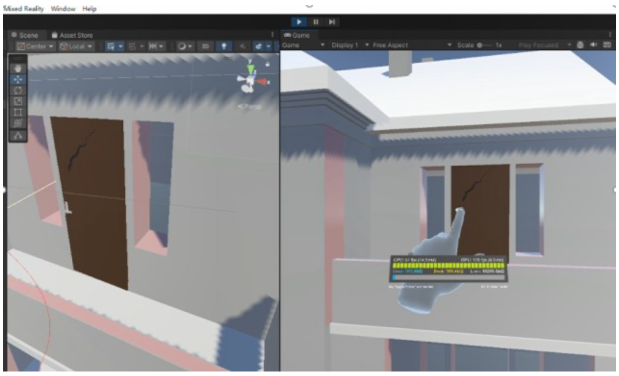


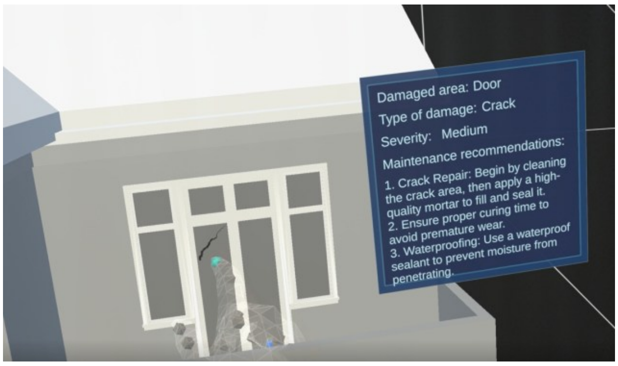
Figure 7: AR-based interaction with the digital model

Figure 7 illustrates how users can interact with the heritage model within the AR environment, showcasing both the virtual and real-world aspects of the AR scenario. The left side of the figure shows changes to the heritage model in the Scene view, demonstrating how modifications and interactions occur within the Unity platform. The right side of the figure, on the other hand, depicts the real-world AR interaction as seen through the HoloLens 2 device. This side highlights how users interact with the heritage model in real-time, merging the digital reconstruction with the physical environment.

AR application

The developed AR system was deployed using Microsoft HoloLens 2, enabling users to interact with the digital heritage model in a real-world environment. After wearing the headset, users are able to engage with the model through intuitive gesture-based commands. Basic interactions include rotating, scaling, and navigating around the model, offering users a spatial understanding of the building structure from multiple perspectives.

In addition to basic manipulation, the system supports interactive inspection of structural issues. Users can directly select visible cracks or defects within the AR environment to access corresponding maintenance strategies. As shown in Figure 8 (a), once a crack is selected, the system displays detailed information including defect type, severity level, and recommended repair methods. This feature provides clear and immediate guidance for maintenance planning and decision-making.



(a) Maintenance training

(b) Renovation scenario selection

Figure 8: Screenshots of AR application

Furthermore, the AR interface incorporates predefined renovation scenarios that allow users to explore and compare the visual impact of different interventions. By selecting a renovation option, users can observe the building's appearance before and after the proposed intervention. This real-time comparison, illustrated in Figure 8 (b), helps stakeholders intuitively evaluate the outcomes of alternative solutions. Such functionality supports informed decision-making by allowing users to better understand and discuss the implications of each renovation strategy.

Overall, the AR system enhances stakeholder participation by providing an intuitive and interactive platform for engaging with both maintenance and renovation processes. Beyond visualization, it delivers decision-relevant information—such as recommended repair strategies and renovation scenario-based comparisons—which supports clearer communication, shared understanding, and more informed decision-making. This functionality has demonstrated promising results in facilitating practical heritage conservation efforts.

Discussions

Validation of the study

To validate the effectiveness of the proposed framework, a questionnaire survey was conducted in collaboration with project partners. A forum was organized to facilitate discussions on the usability and functionality of the developed solution. The survey included a mix of open-ended and Yes/No questions, such as:

- "Are there any features or functions that you found confusing or hard to use?"
- "Does the tool provide all the necessary information?"
- "Is high-precision rendering of textures and details of heritage buildings required in AR?"
- "Do you need the AR interface to showcase the renovation process, such as the repainting of the wall?"
- "Does the user flow align with the expectations? Where do you see room for potential improvement?"
- "Will the visualization of all decorations of the building helpful for the building maintenance?"

By gathering feedback from participants and conducting online discussions and polls, the team was able to refine the framework based on their suggestions. A total of 25 individuals participated in the forum, with 19 of them actively responding to the questions. Each question received input from at least two or more participants, ensuring a diverse range of perspectives and feedback to guide the framework's improvement. The results showed that the majority of respondents found the current AR functionality comprehensive and agreed that the information presented was valuable for heritage preservation.

The results also revealed several interesting observations regarding the use of AR in heritage preservation. Participants generally expressed that a high level of detail in the model was not necessary. In fact, 100% of respondents agreed that it was unnecessary to include every decorative detail in the model, even if doing so would make it more closely resemble the real building. This feedback underscores a preference for models that prioritize functionality and clarity over hyper-realistic representations. Similarly, participants felt that it was not essential to display the entire renovation process within the AR environment. Instead, they emphasized the importance of focusing on key aspects that are most relevant to understanding and decision-making. All respondents unanimously agreed on the necessity of integrating real-time sensor data and actual photographs into the AR model. These elements were seen as crucial for providing accurate and actionable insights during preservation and renovation planning.

Additionally, some participants highlighted the value of providing training or guidance before engaging with the AR platform. They noted that an introduction to the system's functionalities and interaction methods would enhance usability and ensure that users can fully leverage its capabilities. This feedback points to the importance of designing user-friendly interfaces and offering adequate support to maximize the effectiveness of AR in heritage preservation.

Comparisons with existing literatures

Table 1 gives a brief comparison of this study with existing literatures.

Table 1: Brief comparisons with existing literatures

Reference	Work descriptions	Advantages of this study
Poux et al., 2020	VR-based reconstruction of heritage and visualization	-Integration of real-time data -Comprehensive renovation scenarios
Choi et al., 2024	A novel way to reconstruct scenarios	-Presentation of renovation scenarios and preservation information -Use of AR
Haydar et al., 2011	VR- and AR-based visualisation and interaction with reconstructed heritages	- Presentation of renovation scenarios and preservation information
Cao et al., 2019	Building resource library with digitalized virtual data	- Comprehensive renovation scenarios -Use of AR for interaction
Marto & Gonçalves, 2019	Developing AR for heritage based on mobile	- Presentation of renovation scenarios and preservation information

Compared to existing studies, this research stands out by integrating real-time sensor data into the AR environment, enabling dynamic monitoring of heritage sites. While many prior works focus on static visualization and reconstruction, this framework allows users to assess structural conditions and receive actionable insights in real time. This functionality bridges the gap between data collection and practical application, enhancing the preservation process.

Another notable advantage is the inclusion of comprehensive renovation scenarios. Unlike studies that often explore isolated aspects of renovation, this framework presents multiple scenarios within the AR environment, allowing users to compare outcomes directly. This approach provides a holistic understanding of preservation strategies, supporting more informed and collaborative decision-making among stakeholders.

Furthermore, the use of AR to enhance interaction with the digital model is a significant improvement over traditional visualization method. By enabling users to engage with the model through gestures and dynamic overlays, the framework creates an immersive and intuitive experience. This level of interactivity not only improves usability but also fosters deeper engagement with the preservation process, ensuring that the tool is practical and effective for real-world applications.

Limitations of this study

While this study demonstrates the potential of integrating AR and real-time data into heritage preservation, several limitations remain. The reliance on advanced hardware such as Microsoft HoloLens 2 may restrict the accessibility of the framework, particularly for resource-limited organizations or smaller heritage projects. Also, the framework depends heavily on the quality of input data, such as point clouds and sensor readings. Any inaccuracies or inconsistencies in the data can affect the reliability of the model and the effectiveness of the AR environment. While the framework provides predefined renovation scenarios, these options may not fully capture the complexity or specificity required for all heritage sites. Expanding the tool to include customizable scenarios and broader preservation needs would enhance its adaptability and practical value.

Another limitation lies in the modeling and representation of heritage data. Developing accurate BIM or IFC models for historical buildings is often challenging due to incomplete records, irregular geometries, and undocumented alterations. These complexities require significant manual effort and expert interpretation. Additionally, the current framework focuses primarily on spatial and sensor-based data, offering limited support for non-graphical information such as historical context, conservation guidelines, or material provenance. These qualitative elements are crucial for informed heritage management but are not easily visualized in AR. Future work should explore ways to embed semantic or narrative information—such as through linked databases or interactive annotations—to enhance the framework's interpretive and decision-making capabilities.

Conclusions

This study proposed a digital framework that integrates AR and real-time sensor data for heritage preservation, demonstrating its potential through a pilot application on a real-world case in Poland. By combining multi-source data with HBIM modeling, the framework offers a comprehensive approach to documenting, analyzing, and visualizing heritage sites. The use of AR, powered by Microsoft HoloLens 2 and MRTK, further enhances user interaction by allowing immersive exploration of defects and renovation scenarios in real time.

The framework addresses the research gap that the limited integration of AR with practical decision-making and preservation strategies for cultural heritages, particularly by leveraging AR for interactive and actionable solutions. These features not only support practical preservation and renovation efforts but also facilitate collaboration and informed decision-making among stakeholders. Feedback from validation surveys indicated that the tool is effective and user-friendly, with features like defect visualization and real-time data integration being particularly well-received.

Despite its achievements, the study also highlighted limitations, such as dependency on advanced hardware and the need for high-quality data inputs. Future research should focus on improving accessibility, refining customization options for renovation scenarios, and expanding the framework to address a wider range of preservation needs. Nevertheless, this study establishes a solid foundation for integrating digital technologies into heritage preservation, offering a scalable and innovative solution for safeguarding cultural heritage.

Acknowledgments

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References

Cao, D., Li, G., Zhu, W., Liu, Q., Bai S., & Li, X. (2019). Virtual reality technology applied in digitalization of cultural heritage. Cluster Computing, 22, 10063-10074.

Chen, D. (2024). The Interaction Between Architectural Heritage and the Public: Augmented Reality in Preservation Interpretation. In International Conference on Human-Computer Interaction (pp. 211-219). Cham: Springer Nature Switzerland.

Choi, J. W., Park, J. J., & Jun, H. J. (2024). An Interactive Virtual Reality Approach to Understanding Cultural Heritage Through Storyliving: A Case Study of Seoul City Wall (Hanyangdoseong) in South Korea. Applied Sciences, 14(23), 11348.

Elabd, N. M., Mansour, Y. M., & Khodier, L. M. (2021). Utilizing innovative technologies to achieve resilience in heritage buildings preservation. Developments in the built environment, 8, 100058.

Guo, H. J., & Prabhakaran, B. (2024, August). Improved Standard-Based Motion Parallax Measurement in Mixed Reality. In 2024 IEEE 7th International Conference on Multimedia Information Processing and Retrieval (MIPR) (pp. 148-154). IEEE.

Haydar, M., Roussel, D., Maïdi, M., Otmane, S., & Mallem, M. (2011). Virtual and augmented reality for cultural computing and heritage: a case study of virtual exploration of underwater archaeological sites (preprint). Virtual reality, 15, 311-327.

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

Kolivand, H., El Rhalibi, A., Sunar, M. S., & Saba, T. (2018). ReVitAge: Realistic virtual heritage taking shadows and sky illumination into account. Journal of Cultural Heritage, 32, 166-175.

Lee, J., Kim, J., Ahn, J., & Woo, W. (2019). Context-aware risk management for architectural heritage using historic building information modeling and virtual reality. Journal of Cultural Heritage, 38, 242-252.

Li, X. J., Ling, J. X., & Shen, Y. (2021b). Visual fatigue relief zone in an extra-long tunnel using virtual reality with wearable eeg-based devices. Journal of Central South University, 28(12), 3871-3881.

Li, X., Ling, J., Shen, Y., Lu, T., Feng, S., & Zhu, H. (2021a). The impact of CCT on driving safety in the normal and accident situation: A VR-based experimental study. Advanced Engineering Informatics, 50, 101379.

Marto, A., & Gonçalves, A. (2019). Mobile AR: User evaluation in a cultural heritage context. Applied Sciences, 9(24), 5454.

Nagy, G., & Ashraf, F. (2021). HBIM platform & smart sensing as a tool for monitoring and visualizing energy performance of heritage buildings. Developments in the Built Environment, 8, 100056.

Okanovic, V., Ivkovic-Kihic, I., Boskovic, D., Mijatovic, B., Prazina, I., Skaljo, E., & Rizvic, S. (2022). Interaction in extended reality applications for cultural heritage. Applied Sciences, 12(3), 1241.

Osello, A., Lucibello, G., & Morgagni, F. (2018). HBIM and virtual tools: A new chance to preserve architectural heritage. Buildings, 8(1), 12.

Panhale, T., Bryce, D., & Tsougkou, E. (2023). Augmented reality and experience co-creation in heritage settings. Journal of Marketing Management, 39(5-6), 470-497.

Poux, F., Valembois, Q., Mattes, C., Kobbelt, L., & Billen, R. (2020). Initial user-centered design of a virtual reality heritage system: Applications for digital tourism. Remote Sensing, 12(16), 2583.

Poux, F., Valembois, Q., Mattes, C., Kobbelt, L., & Billen, R. (2020). Initial user-centered design of a virtual reality heritage system: Applications for digital tourism. Remote Sensing, 12(16), 2583.

Rebec, K. M., Deanovič, B., & Oostwegel, L. (2022). Old buildings need new ideas: Holistic integration of conservation-restoration process data using Heritage Building Information Modelling. Journal of Cultural Heritage, 55, 30-42.

Ribeiro, M., Santos, J., Lobo, J., Araújo, S., Magalhães, L., & Adão, T. (2024, September). VR, AR, gamification and AI towards the next generation of systems supporting cultural heritage: addressing challenges of a museum context. In Proceedings of the 29th International ACM Conference on 3D Web Technology (pp. 1-10).

Van Nguyen, S., Le, S. T., Tran, M. K., & Tran, H. M. (2022). Reconstruction of 3D digital heritage objects for VR and AR applications. Journal of Information and Telecommunication, 6(3), 254-269.

Zheng, H., Chen, L., Hu, H., Wang, Y., & Wei, Y. (2024). Research on the Digital Preservation of Architectural Heritage Based on Virtual Reality Technology. Buildings, 14(5), 1436.

Zhong, H., Wang, L., & Zhang, H. (2021). The application of virtual reality technology in the digital preservation of cultural heritage. Computer Science and Information Systems, 18(2), 535-551.