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Integration of virtual reality and heritage BIM for the preservation of buried cultural heritage Temples in Yogyakarta

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ABSTRACT

This research is based on the phenomenon of the discovery of temple artifacts as cultural heritage, which are often found in the Yogyakarta region at a depth of approximately 2 to 7 meters from the surface, with the location of the discovery varying from rice fields, settlements, to areas that have been planned in the master plan for development. This condition causes problems in the form of incompleteness in the restoration process, due to limitations in space, resources, and connectivity with the surrounding area context. On the other hand, various countries have proven the success of the application of digital technology in supporting the preservation of cultural heritage, but in Indonesia, especially in the case of buried temples, its application is still limited. This study aims to reveal the role of digital technology, specifically virtual reality (VR) applications, in supporting cultural heritage preservation efforts in the case of buried temples in Yogyakarta. The research method uses a qualitative approach with an architectural case study, which combines literature review, field observation, and interpretive analysis of the potential use of VR and Heritage BIM integration in the context of preservation. The research results show that VR and HBIM technology play a significant role in presenting three-dimensional visual representations that are able to strengthen public understanding, education, and immersive experiences, so that the preservation of buried temple cultural heritage can be realized in a more meaningful, sustainable, and adaptive manner to the challenges of modern development.

Introduction

The discovery of buried temple artifacts has been widely found in the southern region of Mount Merapi, Yogyakarta. Based on mapping data, several sites have been restored and designated as core zones protected by boundary fences to prevent the intervention of new construction. However, some sites exhibit conditions of incomplete restoration, thereby creating challenges in the preservation of cultural heritage.

One example is the Palgading Site, which has been known since the era of the Dutch East Indies administration. This site once underwent reconstruction involving the construction of a Buddha-style stupa. Astronomically, the site is located at the coordinates 7°43’33” South Latitude and 110°24’38” East Longitude, covering an area of approximately one hectare in the middle of the residential area of Palgading Hamlet, Sinduharjo, Ngaglik, Sleman, Special Region of Yogyakarta. The most recent excavation, conducted in 2008, discovered two temple structures and a stupa as part of a complementary temple complex. The latest restoration, completed in 2016, managed to reconstruct the stupa structure up to 80%; however, the restoration process has not yet been fully completed (Sismanto and Nau 2009).

Another example is Morangan Temple, which was discovered in 1884 in Morangan Hamlet, Sindumartani Village, Ngemplak, Sleman. The temple was found in a collapsed condition at a depth of 2.5 meters below the ground surface, located on the bank of the Gendol River, which originates on the slopes of Mount Merapi and is frequently traversed by cold lahar flows during heavy rainfall. The Morangan Temple complex consists of two structures: a main temple measuring approximately 8 x 8 meters and a perwara temple measuring 4 x 4 meters. This temple is a Hindu heritage from the 9th century CE. The condition of the site to this day remains unorganized, and the restoration process has not yet been comprehensively carried out (Kiswiranti 2018).

Another site is Kadisoka Temple, which was discovered in 2000 by sand miners in Kadisoka Hamlet, Purwomartani Village, Kalasan, Sleman. The temple's architectural artifacts, measuring 6.9 x 6.5 meters, are located at a depth of 2.5 meters below the ground surface in the secondary sediment area of the Kuning River. This temple dates back to the Hindu Mataram era; however, its restoration remains far from complete, and most of the structural components have not yet been fully reconstructed (Kusumayudha et al. 2019).

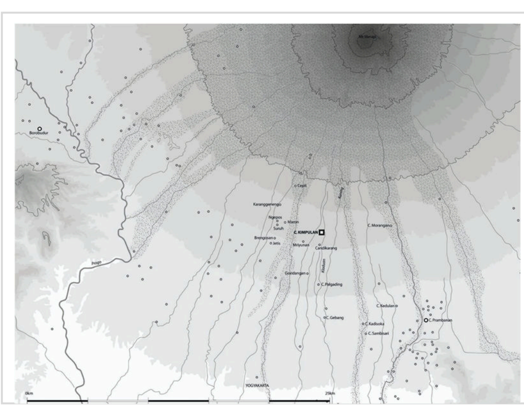

Figure 1. Map of the distribution of temple artifact locations on the southern slopes of Mount Merapi, Yogyakarta (Panca Putra et al. 2019)

The phenomenon of incomplete restoration demands new approaches to cultural heritage preservation. One of the innovations that has begun to be applied in architectural planning and conservation practices is the use of digital technologies such as Heritage Building Information Modeling (H-BIM) and, in particular, Virtual Reality (VR). VR technology enables the creation of immersive experiences that can visualize the original condition of temple sites, support reconstruction simulations, and enhance public education and engagement in an interactive manner. Meanwhile, H-BIM offers significant potential through a more holistic and sustainable approach, allowing for three-dimensional modeling that not only represents the physical structure but also integrates historical, architectural, and archaeological data (Nguyen et al. 2023).

As an accurate documentation platform, H-BIM has the capability to visualize the restoration process, plan sustainable development, and establish a comprehensive database accessible to various stakeholders, including archaeologists, architects, conservators, and governmental agencies. The integration of H-BIM and VR provides opportunities for managing cultural heritage in a more comprehensive manner, maximizing reconstruction accuracy, supporting decision-making processes, and enhancing both the educational value and the public experience of archaeological sites.

Based on the above phenomena, this research is designed to address two main problems:

1) What are the factors that hinder the preservation process of buried temples, resulting in the incomplete restoration of these sites?
2) How can digital technologies such as Heritage Building Information Modeling (H-BIM) and particularly Virtual Reality (VR) contribute to the preservation and restoration of buried temples in ways that are more meaningful, educational, and sustainable?

Accordingly, this study aims to explore the application of digital technologies, specifically H-BIM and VR, as innovative strategies to support the comprehensive, accurate, and sustainable preservation of buried temples in Yogyakarta.

Literature review

The phenomenon of buried temple discoveries in the southern slopes of Mount Merapi demonstrates the diversity of conditions and challenges in cultural heritage preservation. Several temples that have been excavated such as Sambisari Temple and Kedulan Temple although already restored, still face ongoing difficulties in physical recovery and integration with their surrounding environments. The incomplete restoration processes stem from multiple factors, including limited resources, modern construction interventions, and challenges in documenting existing site conditions. These cases highlight the need for a more holistic and systematic preservation approach, one that goes beyond physical reconstruction to include documentation, data management, and stakeholder collaboration (Ciptahening, Nugroho, and Phienwej 2019).

The case of Kimpulan Temple in Yogyakarta demonstrates a unique and successful example of buried temple preservation, serving as a best practice for similar sites. The restoration of Kimpulan Temple was carried out in full integration with the architectural design of the Library and Museum Building of the Islamic University of Indonesia (UII), allowing the physical conservation of the temple to coexist harmoniously with the development of a new modern structure. This integration maintained the temple's historical, symbolic, and architectural values while offering the public an educational experience through interaction with the museum and library spaces. The uniqueness of this approach establishes Kimpulan Temple as a crucial reference for future buried temple conservation projects, showcasing how contemporary architectural strategies can support heritage sustainability without compromising the integrity of the original structure (Panca Putra et al. 2019; Ahmad Saifudin Mutaqi and Wijaya 2023).

In this context, digital technologies have begun to emerge as innovative solutions for heritage conservation. One prominent approach is Heritage Building Information Modeling (H-BIM), which enables three-dimensional modeling that not only represents physical structures but also integrates historical, architectural, and archaeological data. H-BIM provides a comprehensive and accurate database for documentation, restoration visualization, sustainable development planning, and information access for various stakeholders, including archaeologists, architects, conservators, and government bodies. Thus, H-BIM facilitates a holistic, adaptive, and sustainable preservation framework.

Furthermore, the application of Virtual Reality (VR), Virtual Production Labs (VPL), and Extended Reality (XR) in various international heritage sites has demonstrated the effectiveness of digital technologies in cultural preservation. Case studies such as the Notre Dame Cathedral in Paris, the Caetani Castle Site in Rome, and the Pompeii ruins in Italy utilize these technologies for accurate documentation, reconstruction simulation, public education, and immersive experiences that deepen public understanding of heritage sites. These approaches allow for dynamic information management, more precise decision-making, and interactive engagement between the public and stakeholders (Elbaz, Kamel, and Abdelmohsen 2020; Banfi et al. 2022).

Although several buried temples in Yogyakarta have undergone partial restoration and some digital technologies have been applied, previous research shows that the integration of VR and H-BIM in local temple conservation remains extremely limited. This presents a significant research gap: the lack of comprehensive digital technology utilization to support documentation, simulation, education, and management of buried temples in a sustainable and holistic manner. Therefore, this research aims to explore the application of VR and H-BIM as innovative strategies to enhance restoration accuracy, public engagement, and the long-term sustainability of cultural heritage management.

Methods

This study employs a qualitative, case study–based approach to explore the role of architectural design and digital technology in supporting the preservation of buried temples. The primary focus of the research is directed toward Kimpulan Temple, which has been successfully restored through an integrated design approach alongside the architectural planning of the Library and Museum Building of the Islamic University of Indonesia (UII) a unique best practice that serves as a valuable reference for the preservation of other buried temples. The selection of Kimpulan Temple as the main case study is based on its distinctiveness and success in maintaining historical, symbolic, and architectural values while seamlessly coexisting with a modern structure. Meanwhile, other sites such as Sambisari Temple and Kedulan Temple are used as comparative cases to examine the potential applicability of similar architectural and technological strategies in different contexts (Salura and Clarissa 2024).

The research data were collected through field observations focusing on the temple's physical condition, its integration with modern architecture, and the surrounding environmental context. These were supported by digital documentation consisting of photographs, sketches, and three-dimensional modeling using Heritage Building Information Modeling (H-BIM) and Virtual Reality (VR) visualization, both to represent the existing conditions and to simulate the restoration process. Furthermore, semi-structured interviews were conducted with the project architect, conservators, museum managers, and local stakeholders to obtain in-depth perspectives regarding the restoration process, encountered challenges, and technology integration strategies. The study also reinforces its findings through a literature review encompassing the practice of buried-temple preservation in Indonesia, the utilization of H-BIM and VR in international cases, and theoretical frameworks on architectural and cultural heritage preservation (Bosco et al. 2019).

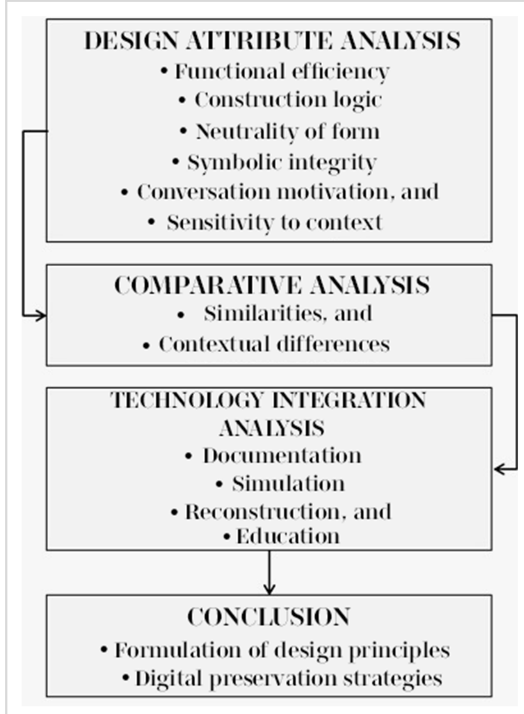

Figure 2. Analysis method

Data analysis was carried out through qualitative descriptive and comparative methods in several stages. First, design attribute analysis was employed to evaluate the success of Kimpulan Temple's restoration based on six indicators: functional efficiency, construction logic, formal neutrality, symbolic integrity, conservation motivation, and contextual sensitivity. Second, a comparative study was conducted to identify similarities and differences between Kimpulan Temple and other temples concerning the application of architectural strategies and digital technologies. Third, technological integration analysis assessed the contribution of H-BIM and VR in supporting documentation, simulation, public education, and decision-making processes. The outcomes of these analyses were synthesized to formulate design principles, restoration strategies, and technology integration frameworks that can be adopted for the sustainable preservation of buried temples.

By emphasizing the success of Kimpulan Temple as a case study, this research not only describes existing best practices but also constructs a broader and more applicable strategic framework, providing significant contributions to the development of cultural heritage preservation practices in Indonesia.

Results and discussion

Virtual Reality (VR) occupies a strategic and multidimensional role in cultural heritage preservation, particularly concerning temples that are buried or physically fragile. This discussion begins by exploring the contribution of VR in digital documentation and preservation, which has transformed the paradigms of conservation and analysis for buried temples. The case studies focus on several temples Palgading, Morangan, and Kadisoka Temples, which have not yet undergone adequate restoration, and Sambisari and Kedulan Temples in the Kalasan area, which have completed core-zone restoration. As a best practice, the preservation of Kimpulan Temple serves as a central example due to its integrated implementation between heritage conservation and the architectural planning of UII's Library and Museum Building. Furthermore, VR's role is discussed in the context of opening new dimensions for cultural heritage reconstruction and interpretation. Based on this framework, this paper aims to examine the pivotal role of digital technology particularly Heritage Building Information Modeling (H-BIM) and VR in supporting the preservation of buried temple heritage.

1. Digital preservation

Digital preservation through Virtual Reality (VR) technology not only creates an accurate digital recreation of temples using LiDAR and photogrammetry to capture every minute detail but also reveals buried or collapsed sections through the integration of archaeological data, thus presenting a complete reconstruction that cannot be directly observed. The main goal of digital preservation is to create the most accurate and detailed digital record or clone of a cultural heritage object. For buried temples, this is particularly critical due to their fragile and incomplete physical condition (Prasad, Sehgal, and Ghiya 2024).

a. Addressing physical vulnerability

In the context of still-buried temples which often possess unstable structural conditions conventional excavation presents an inherent paradox: the process of physical exposure itself may accelerate deterioration due to direct environmental exposure. Here, the crucial role of Virtual Reality (VR) as a form of "digital insurance" finds its most fundamental relevance. This mechanism operates through a multilayered process. Before excavation begins, aerial LiDAR scanning is employed to generate a Digital Elevation Model (DEM) that identifies structural anomalies and serves as a valuable initial digital blueprint. During excavation, each phase and layer is meticulously documented through photogrammetry or laser scanning, producing a permanent four-dimensional (4D) record encompassing both spatial and temporal dimensions. This approach ensures that if an architectural fragment or delicate relief is damaged during excavation, its digital preservation in perfect condition remains available for analysis, reconstruction, or restoration in the future.

The principle of "digital insurance" is not only defensive (preventing data loss) but also opens up opportunities for reconstruction and interpretation that were previously impossible. The successful restoration of Kimpulan Temple exemplifies this best practice, demonstrating the maximal use of digital data. The excavation of Kimpulan Temple, constrained within a limited area due to the concurrent construction of the UII Library Building, required extremely precise and rapid documentation. The photogrammetric and scanning data collected during the excavation not only served as archival material but also became the foundation for creating an immersive VR reconstruction. Through the VR model, archaeologists and the public can experience the temple within a more comprehensive context visualizing it both in its partially buried and restored conditions, as well as in a hypothetical complete reconstruction. This capability introduces a new interpretative dimension, allowing simulations of how sunlight would illuminate reliefs at specific hours or how the temple's proportions relate to its surrounding landscape, which has now drastically changed.

Thus, the case of Kimpulan Temple illustrates the evolution of VR's role from serving merely as "digital insurance" to functioning as a "virtual laboratory" for analysis, reconstruction, and dissemination. This approach transforms the preservation paradigm from physical-reactive (post-damage) to digital-proactive, ensuring that cultural heritage can be preserved, studied, and experienced within a permanent digital space, transcending physical fragility and temporal constraints.

b. Comprehensive status quo capture

Virtual Reality (VR) provides comprehensive capture capabilities by integrating multiple data types beyond mere visual elements. A key challenge for partially buried temples such as Morangan and Kadisoka Temples lies in the inaccessibility of crucial structural information still embedded underground. VR overcomes this limitation by functioning as an integrative platform that processes and visualizes geophysical data such as Ground-Penetrating Radar (GPR) and geomagnetic surveys, successfully implemented in the study of Kedulan Temple into intuitive 3D models. These subsurfac data can then be represented as semi-transparent layers within the VR environment, allowing archaeologists to virtually “see” and analyze floor plans, deep foundations, or corridors still buried beneath the surface. This capability enables comprehensive structural understanding and forms the basis for more targeted and low-risk physical excavation planning.

Moreover, VR-based digital preservation extends beyond the temple structure itself. It enables detailed recording of the surrounding landscape context, including topography, nearby watercourses, and spatial relationships with other sites that may have undergone significant change. Reconstructing this broader geographical and archaeological context is vital to address fundamental questions regarding site placement and environmental interaction in the past. For instance, Morangan Temple, now situated amid dense residential areas, poses severe challenges for contextual analysis. Through VR reconstruction, the temple’s past landscape can be digitally re-modeled, offering new insights into its original spatial logic knowledge that would be impossible to derive from the current site conditions.

Consequently, the integration of surface and subsurface data within VR not only overcomes excavation barriers but also restores the lost spatio-temporal dimensions of buried temples. This approach transforms such temples from isolated artifacts into components of a broader cultural and environmental network, enabling holistic archaeological interpretation and long-term preservation strategies.

c. Creating a dynamic, Query-able archive

Beyond static documentation, VR-based digital preservation establishes a dynamic, queryable archive that accommodates the iterative and ongoing nature of archaeological research. Unlike passive 3D models, this system transforms the temple model into a living spatial interface. Within the VR environment, every element from a single stone block to a specific relief panel can be linked to a comprehensive metadata database. As demonstrated in the Kimpulan Temple project, this function allows researchers to click on an object within the VR model and instantly access detailed information such as stone type, exact find coordinates, in-situ condition photographs, and laboratory analysis results. This transformation converts the visual model into an integrated scientific data repository. The integration can even be extended following Kimpulan’s best practice by linking the temple’s H-BIM model with the BIM model of the UII Library and Museum Building, creating a complete digital asset management system.

Furthermore, this dynamic aspect is enhanced by temporal comparison functions. Since each excavation and restoration phase such as those at Sambisari and Kedulan Temples can be documented within its own VR model, researchers can overlay or toggle between models from different periods (e.g., pre-, during-, and post-restoration). This feature serves as a powerful monitoring tool for tracking material degradation, assessing conservation effectiveness, and re-evaluating archaeological interpretations as new findings emerge. Thus, VR evolves from a visualization tool into a living archive that actively records the “life” of an archaeological site.

The combination of metadata querying and temporal analysis provides a foundation for a more transparent and scientifically accountable preservation approach. Every restoration decision can be traced back to its raw data, and reinterpretations can be visually and empirically tested against all documentation phases. Ultimately, VR becomes the backbone of a sustainable cultural heritage knowledge management system, particularly suited for the complexity of buried temples whose understanding continuously evolves through ongoing research.

d. Foundation for hypothetical reconstruction

An accurate digital preservation model serves as an indispensable factual foundation for hypothetical reconstruction, especially for temples existing as ruins with most components missing. In the case of Kimpulan Temple, before any speculation or interpretation regarding its original form can be proposed, a spatially precise and verifiable dataset recording the site's actual condition must be established. Within the VR framework, this need is addressed through the implementation of two complementary modes: "Preservation Mode" and "Reconstruction Mode."

"Preservation Mode" presents a model strictly bound to existing material evidence, depicting the status quo with all its imperfections and deterioration. This model serves as the single source of truth. Based on this foundation, "Reconstruction Mode" is developed, visualizing hypotheses proposed by archaeologists and experts about the temple's original form, including its roof, decorative elements, and full proportions that no longer exist. This clear distinction is crucial for maintaining scientific integrity. The accuracy of preservation data ensures that reconstructed elements remain anchored to verified physical evidence, enabling clear differentiation between documented facts and speculative interpretation at every analytical stage.

The convergence between the queryable dynamic archive and dual-mode reconstruction transforms VR from a supportive tool into a virtual laboratory for hypothesis testing. Researchers can not only view the final reconstruction but also click on specific sections to access the archaeological evidence such as recovered fragments or comparative analogies from other temples underpinning each interpretation. This capability fosters transparent, data-driven academic discourse in which multiple reconstruction scenarios can be visually compared and evaluated for plausibility on a solid evidential basis. Consequently, VR not only preserves the fragile physical form of the temple but also safeguards the intellectual process of uncovering its meaning and grandeur, ensuring that this interpretative journey itself becomes part of the documented heritage for future generations.

Based on the comprehensive discussion above, the application of Virtual Reality (VR) in buried-temple preservation is not merely compatible but forms a powerful synergy with Heritage Building Information Modeling (H-BIM)

The convergence of these technologies signifies an evolution from static architectural documentation toward the creation of a dynamic and intelligent "Digital Twin." This marks a significant methodological step in cultural heritage preservation. Its significance lies in how VR and H-BIM complement one another to establish a complete and cyclical preservation process (Liu, Zhang, and Osmani 2023):

- From data to structured information:

Heritage BIM as the Digital Backbone. Heritage Building Information Modeling (Heritage BIM) functions as the backbone for structured data. Laser scanning, photogrammetry, and geophysical survey data (e.g., Ground-Penetrating Radar, GPR) which underpin the VR model are integrated into the BIM platform. The result is not merely a visual 3D model but a centralized database containing geometric information, material properties, component relationships, and the damage status of each architectural element. A single "stone" within the model carries not only its form but also attributes such as rock type, level of degradation, and intervention history.

- From information to immersive and interactive analysis: The role of VR.

Virtual Reality (VR) becomes an invaluable interface in this framework. The data-rich BIM model can be streamed into a VR environment, transforming complex technical data into an immersive experience. Archaeologists, architects, and conservators can virtually "walk through" the buried temple, conduct detailed visual inspections as if on-site, and access embedded metadata simply by interacting with objects. This approach makes spatial analysis and architectural contextual understanding far more intuitive, bridging the gap between raw data and expert interpretation.

- Foundation for hypothesis and accountable conservation:

This synergy directly supports responsible hypothetical reconstruction. As previously discussed, the "Preservation Mode" in VR visualizes the BIM model containing as-built factual data. Meanwhile, "Reconstruction Mode" can be developed as an alternative design option within the same BIM model, based on these verified data. Every proposed reconstruction or restoration can be traced, documented, and virtually tested against the baseline data, ensuring scientific transparency and accountability.

Therefore, the integration of VR and Heritage BIM is not merely a modern technological application but constitutes a revolutionary digital preservation framework. This approach combines the precision of architectural data (BIM) with the human-centered visualization and exploration capabilities of VR, creating a system that preserves the past more effectively while empowering experts to understand, plan, and conserve architectural heritage with precision and insight previously unattainable. This marks a significant advancement toward more scientific, collaborative, and sustainable cultural heritage preservation.

2. The role of conservation and buried Temple analysis

The integration of digital technology, particularly VR and 3D modeling, has transformed the paradigm of conservation and analysis for buried temples. This approach is not only reactive but highly proactive and predictive, enabling smarter, safer, and data-driven interventions. The discussion focuses on four key areas: environmental simulation and risk analysis, monitoring of changes, visualization of complex archaeological data, and restoration planning and training (A. S. Mutaqi and Ardiyanto 2025).

a. Environmental simulation and risk analysis as the basis for proactive conservation

Once a buried temple is exposed, it immediately experiences stress from newly introduced environmental elements, such as rain, wind, temperature fluctuations, UV radiation, and surrounding soil pressure. To anticipate these negative impacts, an accurate 3D model of the temple serves as the foundation for advanced environmental simulation and risk analysis. In this context, the digital model can be imported into engineering software to conduct erosion and drainage simulations, which map rainfall flow over the structure to identify potential water accumulation points that may cause erosion or structural damage, thereby guiding conservators in designing effective drainage systems before actual damage occurs. Furthermore, Finite Element Analysis (FEA) can be applied to this 3D model to analyze pressure and stress on the temple structure. This analysis can answer critical questions regarding structural stability, such as the ability of a wall to withstand soil pressure after surrounding excavation or the resilience of the structure against seismic activity, thus serving as an indispensable safety guide for further excavation and consolidation processes.

b. Precision-based monitoring of change and damage

Damage to ancient temples is often gradual and subtle, making it difficult to detect through routine visual inspection. Digital technology offers a solution through precise temporal monitoring. By conducting periodic 3D scans (for example, every six months or annually), new VR models can be compared with previous ones with millimeter-level accuracy. Specialized software can automatically highlight areas experiencing displacement, widening cracks, or material loss, functioning as a powerful early warning system. Moreover, this approach can be enhanced through the integration of micro-environmental sensor data. Information on temperature and humidity from on-site sensors can be directly correlated with the 3D model, allowing researchers to analyze cause-and-effect relationships, such as the correlation between increased humidity and the emergence of biological growth (e.g., fungi) on specific areas of the temple.

c. Visualization and analysis of complex archaeological data in interactive 3D space

One of the main challenges in excavation a destructive process is the accurate recording of the spatial context of each find. Digital technology addresses this challenge by transforming complex data into interactive 3D visualizations. First, 3D stratigraphy visualization allows soil layers (stratigraphy), typically represented in confusing 2D diagrams, to be displayed as interactive 3D blocks within VR. This enables researchers to “walk through” temporal layers and understand the spatial context of artifact discoveries more intuitively. Second, artifact distribution mapping uses precise 3D coordinates of each find (such as pottery or bones) to display them as colored point clouds within the VR model. These distribution patterns can reveal specific activity areas, distinguishing, for example, ritual zones from residential zones. Third, this technology facilitates the digital reconstruction of complex artifacts, such as reassembling jars broken into hundreds of pieces. Each fragment can be scanned and digitally manipulated in VR, simplifying the highly intricate “puzzle assembly” process in three dimensions.

d. Planning and training for restoration in a safe and controlled virtual environment

Restoring collapsed temples involves complex and high-risk decisions. Digital technology offers a safe platform for planning and training restoration interventions before physical execution. Through digital restoration simulations, conservators can test various scenarios of reassembling stone blocks virtually within VR. They can manipulate virtual components to find the most stable configuration consistent with archaeological evidence, thereby saving time, cost, and, most importantly, minimizing the risk of errors that could damage the original artifacts. Furthermore, VR serves as an exceptionally effective virtual training tool for conservation technicians. In a safe and controlled environment, they can practice complex procedures, such as handling large stones or applying consolidating materials, without risking damage to the original cultural heritage objects, while simultaneously enhancing their competence before field implementation.

3. Reconstruction, contextualization, and interpretation through Virtual Reality

Beyond the goals of documentation and conservation, Virtual Reality (VR) opens a new dimension in the reconstruction and interpretation of cultural heritage. This discussion explores VR’s role as a medium that not only restores the physical form of buried or collapsed temples but also revives historical context, activities, and narratives associated with them, while providing a platform to test and discuss various interpretative scenarios.

a. Digital restoration and hypothetical visualization to reawaken Past Grandeur

Facing temples that often remain only as ruins with faded colors, VR allows for digital restoration and evidence-based hypothetical visualization. This process involves virtually reassembling architectural components based on analysis of foundation patterns, support traces, and comparisons with contemporaneous temples, so that virtual stones can be returned to their presumed original positions. Furthermore, by utilizing evidence of pigment fossils or barely visible color traces, VR can reconstruct the temple’s original color schemes, present its potential bright and ornamented appearance, while correct the common perception of ancient monuments as monochrome or dull. It is crucial to emphasize that such reconstruction must be presented with scientific transparency. Therefore, the VR experience should ideally include a feature that allows users to switch between “Archaeological Evidence Mode” (displaying only physically verified elements) and “Interpretation Mode” (showing the full hypothetical reconstruction), thus clearly communicating the boundary between fact and interpretation.

b. Contextualization of environment and landscape to understand site selection

Understanding a temple is incomplete without its original landscape context, which may have changed drastically. VR plays a role in reconstructing past landscapes based on paleoecological data, such as pollen analysis, enabling visualization of a temple surrounded by primary forest, located at the edge of an ancient river, or as part of a lost settlement. This visualization is not merely aesthetic but serves as a crucial analytical tool for understanding the rationale behind site selection, whether driven by religious motivations (proximity to sacred water sources), strategic considerations (territorial control from elevation), or economic factors (access to trade routes). By placing the temple back into its historical setting, VR provides deep insights into the interactions between the monument and its natural and cultural environment.

c. Reviving activities and narratives for an immersive experience

Temples in their time were living spaces, not merely static stone structures. VR has the unique capacity to revive activities and narratives through simulations of daily life. This can be realized by introducing avatars performing ritual or economic activities, incorporating ambient sounds such as chants or flowing water to create atmosphere, and, importantly, making relief narratives interactive. Users can click on a relief scene to witness epic stories, such as the Ramayana, enacted as 3D animations around them. This approach transforms a passive experience into active exploration, enabling the public not only to see but also to feel the pulse of life that once inhabited the space.

d. Experimentation with various interpretative scenarios as an academic discussion tool

Given the nature of archaeological research, which often produces competing theories, VR serves as an ideal platform for experimentation with multiple interpretative scenarios. This technology allows researchers to construct and store several versions of reconstructions within one environment for example, comparing theories regarding roof shapes or the functions of specific spaces. The ability to switch among these models facilitates comparative visual and structural analysis, helping to evaluate the feasibility of each hypothesis. Consequently, VR becomes a powerful academic discussion tool, where theoretical debates move from abstract textual descriptions to concrete spatial visualizations, fostering collaboration and the refinement of interpretations collectively.

Significant research findings

1. VR acts as a multifunctional "Time Bridge." This technology is not merely a visualization tool but a versatile platform that bridges the past (temples at their peak), the present (buried or damaged condition), and the future (preservation efforts). Each role discussed forms an interconnected link in the preservation cycle.
2. Shift from reactive to proactive approaches. VR transforms the preservation paradigm from reactive (repairing after damage occurs) to proactive and even predictive. Through simulation and digital monitoring, threats to damage can be identified and mitigated before they actually impact the physical structure.
3. Data integration generating new understanding. VR's main strength lies in its ability to integrate diverse data types (LiDAR, photogrammetry, GPR data, excavation results, historical records) into a cohesive 3D spatial environment. This integration allows researchers to perceive relationships and patterns previously invisible in separate datasets, giving rise to new interpretations and insights.
4. Integrative approach between heritage BIM and Virtual Reality Creates Powerful Synergy. BIM acts as the digital backbone or single source of truth, storing geometric and related information in a structured manner, while VR functions as an immersive interface that transforms complex data into experiences that can be intuitively understood and analyzed by experts.

Implications

The research findings on the integration of Heritage BIM and VR for the preservation of buried temples carry profound implications across three primary levels. For cultural heritage conservation practice, this approach shifts the working paradigm from fragmented 2D document-based documentation toward an integrated 3D digital model-based approach, demanding the adoption of new workflow protocols and the enhancement of technologically literate human resources. This transformation simultaneously improves accountability and transparency, as every conservation decision can be traced within the BIM model, while VR facilitates the dissemination of the rationale for interventions to the public. At the academic level, interdisciplinary collaboration with computer science and data science will generate new research methodologies, while scholarly publication formats may evolve to include explorable digital models. However, the ease of reconstructing the past also stimulates deeper ethical and philosophical discussions concerning authenticity and the limits of historical interpretation. At the policy and public domain level, these findings underscore the urgency of developing national digital standards to ensure data interoperability, creating sustainable VR-based business models to support conservation funding, and strengthening public awareness and ownership by providing more immersive access to cultural heritage.

Recommendations

Based on the identified implications, several strategic recommendations are proposed. For researchers and academics, priority should be given to developing ethical guidelines for digital reconstruction that clearly distinguish between facts, interpretations, and speculation. Future research should focus on enhancing technical interoperability in workflows from 3D scanning to BIM and VR, as well as conducting comprehensive comparative studies to measure the cost-effectiveness and outcomes of this new approach relative to traditional methods. For cultural heritage management institutions, key recommendations include immediate investment in human resource training and digital infrastructure through pilot projects, the creation of a national digital cultural heritage data repository to prevent data loss and support long-term research, and the integration of 3D digital documentation and BIM requirements into standard operating procedures for all conservation projects. For policymakers, crucial steps include formulating national policies and standards for digital preservation, supporting strategic collaboration between ministries/agencies related to culture and technology, and leveraging VR/AR in cultural tourism strategies to reduce physical impact on fragile sites while enhancing educational value.

Conclusions

Overall, this study concludes that the integration of Heritage BIM and Virtual Reality represents not merely a technical modernization but a paradigmatic transformation in cultural heritage preservation. This approach establishes a holistic and sustainable cycle in which BIM functions as the digital backbone ensuring data accuracy and accountability, while VR serves as an immersive interface democratizing access and understanding. Its broad implications for conservation practice, research agendas, and policy frameworks highlight its revolutionary potential. Therefore, planned and collaborative adoption, as detailed in the recommendations, is a strategic imperative to ensure that vulnerable cultural heritage can be preserved, studied, and passed on to future generations with greater precision, clarity, and significance.

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