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Applying Digital Twin Technology for Heritage Conservation and Sustainable Tourism Development in Vietnam: A Theoretical Framework and Implementation Roadmap

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Abstract: This study proposes a theoretical framework and a strategic roadmap for applying Digital Twin technology to address the dual challenges of heritage conservation and sustainable tourism development in Vietnam. Utilizing a systematic literature review and qualitative case study analysis, the research demonstrates that current heritage digitization efforts in Vietnam primarily result in static 3D models, lacking the real-time data connectivity and simulation capabilities that are core elements of a true Digital Twin. Grounded in the theoretical foundations of the Socio-technical systems (STS) theory and the technology acceptance model (TAM), the study develops an integrated conceptual model. This model elucidates the relationship among technological, organizational and social factors in the deployment of Digital Twin technology. It suggests that the successful application of the Digital Twin can advance proactive conservation and sustainable tourism goals, aligning with the principles of UNESCO and UNWTO. Finally, the research proposes a detailed roadmap for the 2025–2035 period, along with specific policy implications, aimed at fostering a sustainable digital ecosystem for Vietnam's cultural heritage.

Keywords: Digital Twin, Cultural heritage, Sustainable tourism, Heritage digitization, Technology acceptance model, Socio-technical systems, Vietnam.

1. Introduction

Vietnam possesses a vast and rich repository of tangible and intangible cultural heritage, which serves as a strategic asset that shapes national identity and acts as a core driver for the tourism economy. With over 41,000 inventoried relics and scenic spots, including eight UNESCO-recognised World cultural and natural heritage sites (UNESCO, 1972, this heritage is not merely a source of national pride but also a crucial economic resource (Throsby, 2003). These heritage sites attract millions of tourists annually, generating substantial revenue and promoting socio-economic development in local areas (De-Miguel-Molina et al., 2021). A prime example is My Son Sanctuary, which welcomed 380,000 visitors and generated a revenue of 60.3 billion VND in 2023 alone, underscoring the immense appeal and economic value of the heritage.

However, this invaluable heritage treasure is facing increasing dual pressure. Firstly, there are environmental and temporal challenges, including the impacts of climate change, pollution and the natural aging process of materials (D'Amico et al., 2019). Secondly, the challenge posed by overtourism leads to physical wear and tear, infrastructure overload and a diminished visitor experience (UNWTO, 2005). In this context, the solution of digital transformation, particularly the application of Digital Twin technology, emerges as a groundbreaking approach. A Digital Twin, defined as a dynamic, real-time updated digital replica of a physical object or system, enables the simulation, analysis, forecasting and optimisation of the real object's operations (Grieves & Vickers, 2017; El Saddik, 2018). In the field of heritage and tourism, this technology offers immense potential: from accurate preservation and restoration of heritage (Bruno et al., 2018), real-time risk monitoring (such as humidity, temperature and cracks) to managing tourist flows (Yovcheva et al., 2014), creating virtual touring experiences (TomDieck & Jung, 2017) and planning for crisis response scenarios.

Although the potential of Digital Twin has been acknowledged and applied globally in smart city and heritage management, its application in Vietnam remains at a nascent stage. Existing studies are often fragmented, primarily focusing on mere 3D digitisation aspects without fully leveraging the interactive, analytical and predictive capabilities of a complete Digital Twin system. Crucially, Vietnam lacks a comprehensive theoretical framework to guide the implementation of Digital Twin to simultaneously serve conservation goals and foster sustainable tourism. Furthermore, the absence of a systematic implementation roadmap, tailored to the domestic institutional context, resources and technological infrastructure, is the most significant obstacle.

To address this gap, the study is conducted with three main objectives:

1. To analyze the current state of digital technology application in heritage conservation in Vietnam and identify the gaps in relation to a complete Digital Twin model.
2. To develop an integrated theoretical framework to rationalize the factors influencing the adoption of Digital Twin technology in the field of heritage conservation and sustainable tourism development.
3. To propose a strategic deployment model, including specific phases, prerequisites (in terms of policy, technology and human resources), key stakeholders and evaluation metrics, to assist management agencies and operating units in applying Digital Twin technology effectively and practically.

To achieve these objectives, the study will answer the following research questions:

RQ_1: What is the current status and maturity level of heritage digitization projects in Vietnam compared to the standards of Digital Twin technology?

RQ_2: Which theoretical frameworks can be employed to explain the factors influencing the successful adoption and implementation of Digital Twin for heritage conservation and sustainable tourism?

RQ_3: What is a suitable strategic model and roadmap for Vietnam to effectively apply Digital Twin technology in this sector?

In terms of academic contribution, this research offers a novel theoretical model for studying the intersection between digital technology and heritage science. On a practical level, the paper provides a guiding manual that gives policymakers, heritage site management boards and tourism enterprises a clear vision and concrete steps to harness the power of Digital Twin, aiming for the goal of sustainable development for Vietnam's heritage and tourism sectors.

2. Theoretical Framework

2.1. Digital Twin (DT) technology for heritage conservation and sustainable tourism development

The concept of the Digital Twin (DT), although originally rooted in NASA (Allen, 2021), was systemized by Michael Grieves (2002) through three core components: a physical product in real space, a virtual product in virtual space and the data connection linking these two entities. Subsequent scholarly perspectives have expanded this definition, viewing DT as a unique replica that reflects the entire lifecycle of its physical counterpart (R. Stark et al., 2019), achieved through the convergence of the physical and virtual products (Schleich et al., 2017) and the continuous, real-time data transmission (Glaessgen & Stargel, 2012). A crucial academic classification was offered by Kritzinger et al. (2018) who clearly distinguished three levels of integration: Digital model, Digital shadow and Digital twin, based on the degree of automation and the directionality of the data flow.

Structurally, the operation of DT rests on three main facets (Attaran, 2017): data acquisition, modelling and application. Underlying technologies include the Internet of Things (IoT) (Researchandmarkets, 2022), which uses sensors for real-time data collection; Cloud Computing for storage and computational capacity (Shu et al., 2016); Artificial Intelligence (AI) to provide advanced analysis, prediction and recommendations (Hou, 2020), (Xie et al., 2021); and Extended Reality (XR) to create digital representations and immersive interactions (B. Marr, 2019).

The core functions of Digital Twins (DT) in the academic literature encompass the capability to predict system responses, enable continuous monitoring of operating conditions to support proactive decision-making and facilitate the simulation of physical processes (virtual experimentation) (Attaran, 2017). The predictive analytics function allows organizations to transition from reactive to predictive maintenance, optimizing schedules and minimizing downtime (Iliuță et al., 2024; Borghesani, 2025). DT supports comprehensive asset lifecycle management (Senthilkumar, 2025) and optimizes system performance through continuous feedback loops (Yao et al., 2023). Furthermore, the technology serves as a repository of operational knowledge (Son et al., 2022), aiding training and organizational memory retention, while also being an essential tool for simulation-based decision support (Iliuță et al., 2024).

In the field of heritage conservation (Shabani et al., 2020), DT provides advanced tools for damage prediction and restoration support, with geometric surveying and 3D modeling being pivotal initial steps. The technology addresses both endogenous and exogenous risks in heritage management (Angjeliu et al., 2020; Shabani, Hosamo et al., 2021). Case studies such as the Notre Dame Cathedral project (digital preservation) and research on ancient architecture in Asia (utilizing BIM and LiDAR) have confirmed the feasibility of DT in archaeological research and the conservation of deteriorating structures (Rosa, 2022; Wang et al., 2022; Tan et al., 2022). By integrating IoT and AI, DT can monitor environmental conditions and provide early detection of degradation signs (Murali, 2025). For natural heritage, DT accelerates the understanding of natural processes and ecosystems (Dawn et al., 2023).

In the realm of tourism, despite the lack of a definitive theoretical consensus, the Digital Twin (DT) is commonly conceptualized as an accurate digital replica of a destination, functioning as a multifaceted platform that supports smart tourism destinations (Rahmadian, 2023). This technology enables the management and monitoring of performance data, visitor flow and potential threats (Litavniece et al., 2023), thereby facilitating the prediction of system responses (Cureton et al., 2021; Ford et al., 2020; White et al., 2021). Practical applications include mitigating congestion in crowded areas (e.g., in Kyoto) (Akira Yoshii, 2025) and supporting the prediction of and response to natural disasters such as floods (Xiang et al., 2021; Riaz et al., 2023) by providing data-driven and precise predictive analysis (Ahmed et al., 2023). DT also offers advanced methodologies for monitoring the environment and ecosystems (Tzachor et al., 2023), allowing for scenario testing and the connection of models at a broad scale (Buhalis et al., 2023).

From a managerial perspective, the DT optimizes infrastructure, transport and public services, thereby fostering novel (Raes et al., 2022) and differentiated (Deren et al., 2021) destination management models. DT implementation allows for personalized marketing campaigns (e.g., in Málaga) and enhances accessibility for visitors. This technology facilitates the transition toward smart city governance models (Deng et al., 2021), increasing citizen engagement and improving evidence-based decision-making (Dembski, 2020; White, 2021; TwinUp, 2025). Nevertheless, DT deployment introduces significant challenges regarding cybersecurity and privacy (Tyagi, 2023), necessitating integrated solutions such as blockchain to ensure secure and transparent data management. Overall, the DT empowers stakeholders to make informed decisions that promote sustainable tourism development (Notcha et al., 2019).

To comprehensively analyze the application of a complex technology like the Digital Twin within the specialized domain of cultural heritage, this study constructs an integrated theoretical framework based on two main pillars: Socio-Technical Systems (STS) theory and the Technology Acceptance Model (TAM).

2.2. Socio-Technical systems (STS) theory

Socio-Technical Systems (STS) theory is an approach to organizational design and technology management, which originated from the pioneering studies conducted by the Tavistock Institute in London in the 1950s (Trist & Bamforth, 1951). The core premise of STS is that any organizational system comprises two independent yet intimately related subsystems: the technical subsystem (encompassing technology, machinery, processes and tasks) and the social subsystem (comprising people, skills, relationships, organizational structure and culture) (Trist, 1981). The theory posits that optimizing only one subsystem will lead to suboptimal overall performance. Instead, STS emphasizes the principle of "joint optimization," requiring design and management efforts to simultaneously optimize both the technical and social aspects to achieve maximum effectiveness and sustainability (Cherns, 1976; Mumford, 2006).

The application of this theory to the context of deploying Digital Twin technology for heritage preservation and sustainable tourism development in Vietnam is particularly relevant, as this endeavor is not merely a technical challenge but a complex socio-technical intervention. Adopting the STS lens allows for the analysis of a holistic system where technology and human/organizational factors mutually support each other.

In the context of this study, the technical subsystem encompasses the entire infrastructure and processes of the Digital Twin. These components include: data acquisition technologies (3D scanners, drones, IoT sensors); modeling and simulation platforms (3D software, AI algorithms); user interfaces (AR/VR applications, management dashboards); and data infrastructure (cloud storage, cybersecurity) (Baxter & Sommerville, 2011). A well-designed technical system ensures the model's accuracy, interoperability and reliability.

The social subsystem encompasses all human, organizational and institutional elements related to the use and management of the Digital Twin system. This is a critical factor determining the acceptance and sustainable success of the technology. The core components include: (1) Stakeholders: These comprise state management agencies (e.g., the Ministry of Culture, Sports and Tourism, local relic management boards), Decision-makers and Policymakers. Scientists/Conservationists serve as professional users, requiring precise data for research and conservation interventions. Local communities, living around the heritage sites, may participate in tourism processes and are directly affected by policies. Tourism enterprises are travel companies exploiting tourism products (including virtual tourism) and finally, tourists are the end-users experiencing AR/VR products. As argued by (Mumford, 2006), organizational structure and work processes must be clearly defined to show how Digital Twin technology is integrated into existing heritage management workflows, who is responsible for data updating and who has access to which data. (2) Skills and Competencies: This involves the digital literacy (Manzuch, Z., 2017) of heritage managers and the community (Huvila, I., 2018) required to use and leverage the new technology. (3) Institutions and Policies: This covers the legal framework regarding the ownership of digital heritage data (Borecká, A., 2021), the standards for digital conservation (UNESCO, 2015) and policies on sharing the economic benefits from digital tourism with the community (De-Miguel-Molina, B., Santamarina-Campos, V., De-Miguel-Molina, M., & Segarra-Oña, M., 2021). (4) Culture and Values: This relates to the public's attitude toward the "digitization" of heritage; ethical considerations in historical representation (Rodríguez-Echavarria, K., & Pires, I. M., 2020); and respect for the authenticity of the heritage (Cameron, F., 2010).

"Therefore, the biggest challenge is not the technical construction of a perfect Digital Twin, but the establishment of a system that is fit-for-context in Vietnam. The Socio-Technical System (STS) theoretical framework suggests that a successful roadmap must focus on 'joint optimization' through four key principles. Firstly, the technological design must be human-centered (Cherns, 1976), for example, prioritizing practical risk alert features over merely focusing on Virtual Reality (VR) experiences. Secondly, active stakeholder involvement, particularly from local communities and heritage experts, is crucial during the design process to ensure the social system (acceptance, skills) co-evolves with the technical system (Geels, 2004). Thirdly, there must be co-development between policy and technology, ensuring regulations (such as revenue distribution from virtual tourism) are established to support conservation and livelihood goals. Finally, both the technical and social systems must possess adaptability and a capacity for learning, allowing for iterative adjustments (Trist, 1981).

By employing the STS theory as an analytical lens, this study moves beyond a "technology-centric" approach. Instead, it proposes a holistic implementation roadmap where the success of the Digital Twin is measured not solely by its technical accuracy, but also by its ability to empower stakeholders, enhance management capacity and make a substantive contribution to the goals of sustainable tourism development and heritage preservation in Vietnam."

2.3. Technology acceptance model (TAM)

The Technology acceptance model (TAM), developed by Davis (1989) based on the Theory of reasoned action (Fishbein & Ajzen, 1975), stands as one of the most influential theoretical frameworks in information systems research, designed to predict and explain why users accept or reject a new technology. TAM posits that the behavioral intention (BI) to use a system is primarily determined by two core beliefs: (1) Perceived usefulness (PU), which is the degree to which a user believes that using the technology will enhance their job performance and (2) Perceived ease of use (PEOU), which is the degree to which a person believes that using the system will be free of effort (Davis, 1989). The original model also suggests that PEOU has a positive impact on PU and both factors influence intention, which is a direct precursor to actual system usage (Davis, Bagozzi, & Warshaw, 1989).

The success of the implementation roadmap for applying the Digital Twin (DT) in heritage conservation and sustainable tourism in Vietnam is contingent not merely upon technical perfection but, fundamentally, on the actual adoption by key stakeholders. The Technology Acceptance Model (TAM) offers a robust diagnostic lens to explore the barriers and drivers of technology adoption from the perspective of heterogeneous user groups, primarily comprising heritage managers/conservation experts and tourists.

For managers and experts, Perceived Usefulness (PU) is manifested in the potential for enhanced decision-making (e.g., risk prediction, conservation optimization), while Perceived Ease of Use (PEOU) relates to the intuitiveness of the management interface. Conversely, for tourists, PU is interpreted as the enhancement of the travel experience (e.g., via AR/VR applications) and PEOU is associated with the seamlessness, easy installation and interactivity of the application.

However, the classic TAM is often deemed overly parsimonious. Extended versions, such as TAM 2 (Venkatesh & Davis, 2000) and the Unified theory of acceptance and use of technology (UTAUT) (Venkatesh et al., 2003), incorporate critical external variables. For the present research context, key contextual factors necessitating integration include: User digital competence (influencing PEOU), Social influence (opinions from colleagues or online reviews) (TomDieck & Jung, 2017), Facilitating conditions (such as the quality of Wi-Fi/4G infrastructure at heritage sites and technical support) (Venkatesh et al., 2003) and Cultural and experiential values (such as perceived authenticity and personal innovativeness) (TomDieck & Jung, 2017).

By quantitatively measuring these variables, this research can precisely identify the barriers to be overcome (e.g., the need for specialized training for staff, or interface improvement for tourists), thereby ensuring the Digital Twin system achieves high acceptance and is effectively operationalized.

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3. Research methodology

To achieve the stipulated objectives, this research adopts a mixed-methods research approach, integrating both qualitative and quantitative methodologies. The research design is structured as a Multi-phase sequential design, comprising three principal stages, each corresponding to a research objective: Phase 1 (Qualitative – exploratory) to construct the theoretical framework, followed by Phase 2 (Quantitative – survey) for empirical validation and concluding with Phase 3 (Qualitative – validation/consensus) to establish and gain consensus on the proposed roadmap.

Table 1. Stages of research

Stage	Primary objective & (Research questions)	Methodology	Data collection	Data analysis	Deliverables
Phase 1: Status analysis & Preliminary theoretical framework development	(1) Current State Analysis & Gap identification. (2) Development a preliminary integrated theoretical framework. (RQ1, RQ2)	Qualitative research (exploratory)	Lterature review; Case study analysis (3-4 heritage sites); Semi-structured expert interviews (n ≈15-20).	Thematic analysis. Data coding (using NVivo).	Detailed report on current state & Technological gaps. Preliminary theoretical framework (Identifying influencing factors).
Phase 2: Survey and validation	(1) Broad-scale measurement of digital maturity. (2) Validation of theoretical factors. (RQ1, RQ2)	Quantitative research (survey)	Survey administration n ≈150 managers and experts.)	Descriptive statistics (Mean, SD).	Quantitative data on the level of digital maturity. The clusters of influencing factors have been empirically examined.
Phase 3: Development & Validation of the roadmap	(3) Proposed model and strategic implementation roadmap. (RQ3)	Qualitative consensus research	Development of a draft roadmap (based on Phases 1 and 2). Delphi technique (2-3 rounds) with the expert group. (n ≈ 15-20).	Descriptive statistics (Median and IQR) for consensus assessment. Content analysis of qualitative input.	The strategic deployment model and roadmap have been validated and refined.

Source: Developed by the authors

Phase 1: an exploratory qualitative research stage, will be conducted to analyze the current state and develop a preliminary theoretical framework (addressing RQ1 and RQ2). Data will be collected through an in-depth literature review (encompassing academic publications), multiple case studies (Yin, 2018) at 3-4 key heritage sites and semi-structured interviews (Patton, 2015) with approximately 15-20 experts (including policymakers, site managers and technology specialists). This qualitative data will be coded and thematically analyzed (Braun & Clarke, 2006) using NVivo software to identify technology "gaps" and influencing theoretical factors.

Phase 2: Quantitative research (designed to measure and confirm the findings from Phase 1 on a larger sample, addressing RQ1 and RQ2). A structured questionnaire survey (Fowler, 2014) will be administered to a convenience non-probability sample (Saunders et al., 2019) of approximately 150 heritage managers and researchers.

Phase 3: Returning to a qualitative approach, will focus on developing and validating the implementation model (addressing RQ3). Based on the synthesized results from Phases 1 and 2, a draft strategic roadmap (including phases, prerequisites and KPIs) will be constructed. This roadmap will then be refined and validated using the Delphi technique (2-3 rounds) with the core expert group involved in Phase 1 (Linstone & Turoff, 1975). Consensus analysis (using Median and IQR) and qualitative feedback will be used to finalize the deliverable (von der Gracht, 2012).

The overall validity of the study is significantly enhanced through the use of triangulation (Denzin, 1978), specifically methodological triangulation (combining qualitative and quantitative methods) and data triangulation (combining literature, interviews and surveys) (Creswell & Plano Clark, 2018).

Proposed research model

Building upon the established theoretical framework and to systematically address the research objectives, this study proposes an integrated theoretical framework for the implementation of Digital Twin technology in the domain of heritage preservation and sustainable tourism development. This model, illustrated in [Figure 1], links the foundational elements (inputs), the adoption process (process) and the targeted results (outcomes) of Digital Twin application.

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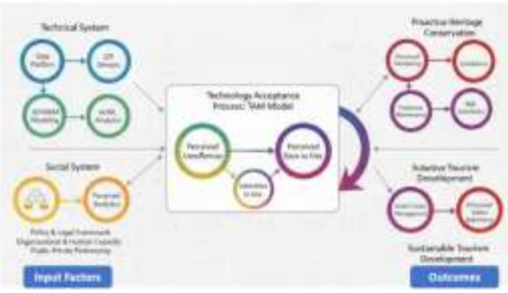

Figure 1: Conceptual research model. Source: Authors' proposal

The model is structured into three primary components:

Input factors: Framed through the lens of the Socio-Technical Systems (STS) theory (Trist, 1981), these factors are prerequisites for the system's success.

- *Technical system:* Comprising the core technological elements of a complete Digital Twin, which include: the data platform and interoperability capabilities; IoT sensors for real-time data acquisition (D'Amico et al., 2019); 3D/HBIM modeling technologies to generate the digital replica (Murphy et al., 2009; Logothetis et al., 2021) and AI/ML analytics capabilities for predictive purposes.

- *Social system:* Encompassing the organizational and institutional enabling factors, this system includes: a clear policy and legal framework; organizational and human capacity regarded as part of "facilitating conditions" (Venkatesh et al., 2003) and effective public-private partnership (PPP) mechanisms to mobilize resources (Throsby, 2003).

Technology acceptance process: Based on the technology acceptance model (TAM) (Davis, 1989), this stage serves as an intermediary, elucidating how stakeholders (managers, experts, tourists) perceive and adopt the technology. The readiness of the socio technical system (STS) inputs is hypothesized to positively influence perceived ease of use (PEU), defined as the degree to which the Digital Twin system is perceived as user-friendly and accessible. Perceived usefulness (PU) refers to the stakeholders' belief that the Digital Twin will provide tangible benefits for conservation efforts or the tourism experience (TomDieck & Jung, 2017). These two perceptions collectively drive the intention to use (IU), which is the decision to practically apply the technology (Davis, 1989).

Outcomes: These represent the ultimate goals of the study, activated by the successful utilization of the Digital Twin. They encompass applications for conservation, restoration and experience enhancement (Bruno et al., 2018), including:

+ *Proactive heritage conservation:* Shifting the management paradigm from reactive repair to proactive prevention, evidenced by: Structural health monitoring in real-time (D'Amico et al., 2019); Predictive maintenance (Koutoupis et al., 2021) and Risk simulation (e.g., assessing the impact of climate change, disasters).

+ *Sustainable tourism development:* Data-driven optimization of tourism activities, adhering to the pillars of sustainability (UNWTO, 2005), including: Smart crowd management (Yovcheva et al., 2014); Enhanced visitor experience through AR/VR technologies (TomDieck & Jung, 2017) and operational optimization at the destination.

This model posits the central hypothesis that: The readiness and maturity of both the technical and social systems (Inputs) will positively impact the perceived usefulness and ease of use of the Digital Twin technology (Process), thereby fostering the intention to use and ultimately realizing the goals of proactive conservation and sustainable tourism (Outcomes).

4. Analysis and discussion

4.1 The current state of heritage digitalization in Vietnam: Achievements, limitations and technological gaps

a. National policy framework and achievements

The Vietnamese government has demonstrated strong vision and commitment in applying digital technology to the heritage sector. Decision No. 2026/QD-TTg, which approved the "Program on digitalization of Vietnamese cultural heritage for the 2021-2030 period," is the clearest evidence of this. This program is not merely a policy directive but also sets forth specific and ambitious objectives. These include targets for coverage, requiring that 100% of UNESCO-inscribed heritage, 100% of special national relics and 100% of national treasures be digitized and deployed on digital platforms (Government of Vietnam, 2021); establishing a unified National Cultural Heritage Database System based on digital technology, with the capacity for data linkage and sharing (Manzuch, 2017); and developing human resources, with 100% of specialized personnel in the sector being trained and updated on knowledge and skills regarding digital transformation (Huvila, 2018).

Furthermore, other initiatives such such as the "Digital transformation program for the culture, sports and tourism sector," have contributed to creating a favorable policy environment, promoting digitalization projects nationwide. In practice, many localities and agencies have actively implemented digitalization projects, achieving notable initial results, exemplified by:

The complex of Hue monuments: As one of the pioneering entities, the Hue monuments conservation center has collaborated with international partners such as CyArk and Seagate to conduct 3D digitalization of major structures, including the Tomb of Tu Duc, An Dinh palace and most recently, the Dien Thai Hoa (Thái Hòa Palace). Modern technologies such as unmanned aerial vehicles (drones), terrestrial laser scanning (LiDAR) and photogrammetry techniques have been applied to generate high-accuracy 3D models for the purposes of archiving, research and promotion. Interactive visitor applications, such as VR3D virtual reality experiences and QR Code scanning, have also been deployed.

Hoi An ancient town: Facing the formidable challenge of preserving a vibrant, living urban heritage, Hoi An has launched the "Hoi An metaverse" project. This initiative provides a virtual reality (VR360) website, allowing global users to explore the old quarter's space through 360-degree perspectives and 3D models, complete with bilingual vietnamese-english narrations, thereby extensively promoting Hoi An's image.

My Son sanctuary: This World heritage site has also been digitized via a VR360 virtual reality website, integrating virtual narration and, notably, placing a 3D model of its digital museum onto a global map 3D platform.

b. Technological limitations and gaps

While the aforementioned projects represent commendable efforts, a more in-depth analysis from a technological and strategic perspective reveals substantial limitations and a significant gap.

Regarding limitations: (1). Lack of implementation depth: Even in locations where digitization has been implemented, the level remains simplistic. For instance, at the My Son Sanctuary, the digitization of Cham cultural artifacts is still at a fundamental level, lacking detailed elaboration. (2). Data fragmentation: A significant challenge is the fragmented state of data, which lacks common standards. This fragmentation poses difficulties for integration and the development of a unified national database system, as set out in the objectives. (3). Cost and human resource barriers: The initial investment costs for hardware, software, and system maintenance are substantial. Furthermore, the shortage of human resources possessing interdisciplinary expertise (e.g., conservation, information technology, data science) constitutes an inherent weakness. (4). Undeveloped legal framework: Issues related to cybersecurity, heritage data security, and particularly digital copyright for digitized products, remain challenges that necessitate a clear legal framework for resolution.

The technological gap: between "digital models" and "digital twins"

While these projects represent commendable efforts, a deeper technological analysis reveals a significant gap. The majority of current projects in Vietnam are primarily focused on creating visualization products and virtual tours. These initiatives generate visually appealing and engaging "Digitized Models" or "Virtual Worlds."

However, these are static records or virtual spaces, lacking the two core elements that constitute a true Digital Twin: bi-directional, real-time data connectivity and simulation and predictive capabilities. The current 3D models of Tu Duc Mausoleum or the 360-degree tours of Hoi An, for instance, are not connected to sensors that reflect the actual condition of the structures (e.g., wood moisture levels, wall inclination). Furthermore, they currently lack the capacity to simulate deterioration scenarios or forecast environmental impacts.

This gap indicates that Vietnam is still in the nascent stages of application and requires a significant leap in both mindset and technology to fully exploit the potential of Digital Twins, transitioning from tools for storage and promotion to instruments for proactive and intelligent management.

Table 1: Comparative analysis of major heritage digitalization projects in Vietnam

Heritage site	Project/Activity name	Key technologies	Primary objectives	Real-time Data integration	Predictive/ Simulation capability	Maturity level
Complex of Hue monuments	3D digitization of Tu Duc tomb, An Dinh palace, Thai Hoa palace	LiDAR, photogrammetry, drone, VR/AR	Documentation archiving, preservatio, Promotion, enhancing visitor experience	No	No	Digital model / Interactive experience
Hội An ancient town	Hội An metaverse	360-degree photography, 3D modeling, VR360	Tourism promotion, creation of virtual tours	No	No	Virtual tour
Mỹ Sơn sanctuary	Digitalization using Virtual reality technology	VR360, 3D modeling, 3D map	Tourism promotion, enhanced experience, support for preservation work	No	No	Virtual tour / Digital museum

Source: Compiled by the authors

The table of analysis has systematized and clarified the current technological gap. It visually demonstrates that existing projects, despite utilizing high-end technology for initial data acquisition, ultimately conclude at the level of visualization. The absence of real-time data connectivity and predictive analytical capabilities constitutes the primary impediment preventing these models from evolving into proactive and intelligent management tools. This precisely identifies the focal point for future strategic efforts.

4.2. A comprehensive Digital Twin application model for Vietnamese heritage: Practical scenarios

To bridge the current technological void, Vietnam must transition from generating static models to establishing dynamic and predictive Digital Twins. The following are specific, feasible application scenarios, formulated based on successful international precedents and the practical requirements of Vietnamese heritage sites. They embody a transformation in management philosophy—shifting from post-damage reaction to proactive risk prediction and prevention.

The overall architecture of the system is structured into three main blocks, operating on a Cloud-based platform and simultaneously governed by overarching common policies and comprehensive information security measures.

The first block is the *System Layer* (Platform & Infrastructure), which serves as the technical Cloud infrastructure foundation (including firewalls, VPCs, servers) and provides core development technologies such as Interfaces (HTML5, ReactJs), Applications (Java, Spring), Databases (SQL/NoSQL) and BI Reporting. This layer offers advantages in terms of flexible scalability, cost optimization and big data processing power (AI/ML).

The second block is the *Application Layer* (Digital Twin Core). This is the central hub that delivers the business functionalities and functional software of the Digital Twin, encompassing the intuitive operational platform, 3D/GIS models connected to IoT/AIS data, integrated data sources (tourism, monitoring) and the central database.

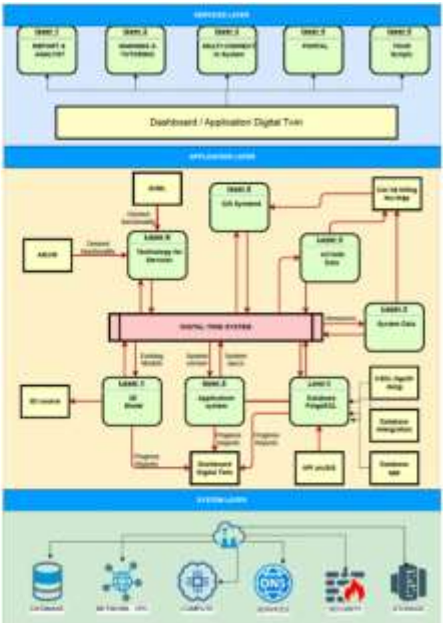

Figure 2: A proposed operational framework for World Heritage tourism in Vietnam. Source: The authors.

Finally, the *Services block* (User Interaction) is the end-user interface layer, providing utilities for users (such as VR/AR experiences) and administrators (early warning, data monitoring). The entire system utilizes APIs and web-based platform applications for communication and data sharing between layers.

4.3. Digital Twin implementation roadmap in Vietnam, 2025-2035

To realize the aforementioned application model, Vietnam requires a strategic, long-term roadmap with clear phase demarcation, based on a thorough analysis of existing barriers and opportunities.

Table 3: Strategic roadmap for Digital Twin application in Vietnamese heritage, 2025-2035

Phase	Timeline	Primary objectives	Key actions	Main stakeholders	Key performance indicators (KPIs)
1: Fudation &Pilot	2025–2027	Establishing the legal framework, standards and technological validation.	Issuing national standards for Digital heritage data. Implementing 1–2 pilot cultural heritage Digital Twin (DT) projects. training 50–100 core specialists.	Ministry of Culture, Sports and Tourism (MoCST), Ministry of Science and Technology (MoST), Management Boards of pilot heritage sites.	National Standard on Heritage Building Information Modeling (HBIM) promulgated. 1–2 CHDTs operating stably, providing real-time data.
2: Scaling & Platform	2028–2031	Scaling up the DT model and developing the national data platform.	Deploying DTs for 3–5 key heritage sites. Developing the first version of the National Heritage data platform.	MoST, Heritage site management boards, Technology enterprises.	3–5 critical heritage sites managed using DT. National data platform operational, integrating data from various projects.
3: Integration & Ecosystem	2032–2035	Inter-sectoral data integration and fostering the digital service ecosystem.	Interconnecting the national heritage data platform with other national databases. Opening APIs for third-party access. Organizing hackathon competitions.	MoST, Ministry of Finance, Enterprises, Research institutes, Community.	At least 10 innovative third-party applications/services developed. Heritage data utilized in tourism and urban planning.

Source: Compiled by the authors

5. Key policy and action recommendations

For the successful implementation of the Digital Twin roadmap, a synchronous coordination among stakeholders is essential, focusing on the following specific tasks:

+ For the Government and the Ministry of Culture, Sports and Tourism (MoCST):

- Complete the legal framework: This includes finalizing specific standards (regarding data, sensor technology, management procedures) and clarifying regulations on data ownership, sharing and commercialization to attract private investment.
- Develop public private partnership (PPP) incentive policies: Establish attractive incentive mechanisms (tax breaks, credit lines) to encourage leading technology enterprises to participate in Digital Heritage Twin (DHT) projects, especially by applying the PPP model in the culture and tourism sectors.

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- Strategic investment in human resources: Recognizing human resources as a critical factor, it is necessary to develop training programs in collaboration with universities and research institutes to upskill management staff on new technologies such as IoT, AI and DHT.

+ For Heritage management boards:

- Internal capacity building: Establish a core team (or expert group) for digital transformation to effectively collaborate with technology partners and develop a suitable, distinct DHT roadmap for each heritage site.

- Promote collaboration and research: Strengthen close cooperation with research institutes and technology companies (such as VR360, FPT Software, etc.) to pilot applications, thereby facilitating technology absorption and risk-sharing.

- Community integration: Employ community based participatory research (CBPR) methods. Engaging local residents (artisans, knowledge holders) will ensure that the Digital Twin system is not only technically accurate but also accurately reflects the cultural and social values of the community.

Conclusion

The application of Digital Twin technology is a critical strategic imperative for heritage preservation and sustainable tourism development in Vietnam. This technology facilitates Vietnam's transition from a static digitalization model to an intelligent, predictive heritage management system, aligning with the principles of UNESCO and UNWTO and simultaneously addressing the conflict between conservation and development. However, its implementation faces significant challenges concerning finance, human resources and the legal framework. Success mandates a clear strategic roadmap (e.g., the 2025-2035 action framework) and, critically, the establishment of a new strategic mindset in heritage management. It necessitates close collaboration among administrators, scientists, engineers and the community, coupled with a long-term investment commitment, to both preserve the past and build a sustainable digital future, thereby transforming cultural heritage into a vital resource for national prosperity.

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