

Integrating Smart City Technologies in Urban Heritage Conservation: A Sustainable Revitalisation Framework for Malaysian Cities

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ABSTRACT

This study examines the integration of smart city technologies into the conservation and sustainable revitalisation of urban heritage areas in Malaysia. Focusing on the The United Nations Educational, Scientific and Cultural Organisation (UNESCO) World Heritage cities of George Town in Penang and Malacca, the research addresses the persistent challenge of balancing modernisation pressures with the protection of cultural significance and historical identity. A mixed methods design was adopted, comprising a stakeholder survey of 120 residents, business operators, visitors, and heritage professionals, 15 semi structured interviews with heritage managers, local authority officials, and community leaders, and field-based observations conducted within the two historic precincts. Quantitative data were analysed using descriptive statistics, while qualitative data were thematically coded with QSR NVivo (NVivo) software to identify institutional, social, and technological patterns. The findings indicate that digital tools such as Geographic Information Systems, Internet of Things (IoT) sensors, and mobile heritage applications are gradually complementing traditional conservation practices by enhancing heritage monitoring, curatorial accuracy, and visitor interpretation. Stakeholders acknowledged the potential of these technologies to improve decision making and strengthen community engagement, although overall public awareness and digital literacy remain moderate. Technical skill gaps, fragmented governance structures, and concerns regarding authenticity were identified as ongoing barriers to effective implementation. In response, the study proposes a Sustainable Heritage Revitalisation

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Framework that integrates four (4) interdependent components, namely Preservation, Digitalisation, Community Engagement, and Governance Integration, to guide heritage rich cities in strategically deploying smart technologies. This framework addresses a critical gap in existing smart city models, which frequently underemphasise cultural heritage as a core dimension of urban innovation. The study offers practical guidance for policymakers, planners, and heritage practitioners seeking to align technological innovation with conservation imperatives and community values. It contributes to Malaysia's national smart city agenda and to global efforts under Sustainable Development Goal 11.4 by demonstrating how culturally attuned smart technologies can advance inclusive, resilient, and sustainable urban revitalisation.

INTRODUCTION

Urban heritage areas face a persistent dual challenge: preserving historical and cultural assets while adapting to the imperatives of modern urban development. Rapid urbanisation, intensified tourism, and globalisation exert significant pressures on the integrity, authenticity, and social fabric of historic environments (UNESCO, 2011; Smith & Waterton, 2021). These tensions are particularly acute in historic Asian cities, where economic growth and infrastructural expansion frequently clash with conservation priorities. Similar dynamics are evident in several Association of Southeast Asian Nations (ASEAN) heritage cities such as Hoi An in Vietnam, where rapid tourism growth has strained conservation capacity; Chiang Mai in Thailand, where heritage zoning conflicts with commercial redevelopment pressures; and Singapore's Chinatown, which demonstrates the challenges of balancing digital innovation with the preservation of cultural identity. These examples underscore the shared regional struggle of integrating development demands with heritage conservation.

In parallel, the rise of smart city paradigms has introduced digital technologies, data analytics, and networked infrastructures that promise to enhance urban governance, sustainability, and citizen engagement (Meijer & Bolivar, 2015). Core technologies such as (IoT) sensors, Geographic Information Systems (GIS), augmented reality (AR), and artificial intelligence (AI) have been successfully deployed in various urban sectors to improve operational efficiency and service delivery. ASEAN cities have similarly begun experimenting with such tools. For example, Luang Prabang has piloted digital visitor management systems to regulate tourist flows, while Singapore has developed 3D digital twin models to support heritage documentation and conservation planning. However, despite these promising initiatives, the systematic integration of digital technologies into heritage conservation frameworks remains fragmented and under-theorised. Projects often remain limited to pilot stages without sustained institutional commitment (Luo et al., 2024; Tousi et al., 2025).

Globally, the integration of smart technologies in heritage contexts has produced mixed outcomes. In Barcelona, heritage GIS platforms have improved asset management but face challenges in cross-departmental data integration. Kyoto's digital heritage mapping demonstrates community-led innovation, yet sustainability is threatened by inconsistent funding cycles. Similarly, Amsterdam's heritage sensor network enhances structural monitoring but raises concerns related to authenticity and over-technologisation. In ASEAN cities, digital initiatives often lack long-term financial and governance support. Collectively, these examples illustrate a broader international gap. Although digital tools can support preservation and interpretation, their long-term success depends on strong governance structures, cultural sensitivity, and active participation from local stakeholders (Song & Selim, 2022).

In Malaysia, the significance of urban cultural heritage is clearly evident in George Town and Malacca, both of which were inscribed as UNESCO World Heritage Sites in 2008 for their multicultural legacies and historic built environments. The post-inscription period generated substantial growth in heritage tourism and contributed to the local economy. However, this growth also intensified the risks of gentrification, uncontrolled development, and the erosion of cultural authenticity (Khoo & Chang, 2021). Policy mechanisms such as conservation zoning and building height controls have been implemented, but enforcement is inconsistent. As a result, piecemeal development has continued to threaten the integrity of heritage areas. These challenges mirror those faced in many ASEAN heritage cities, where urban growth pressures often compete with conservation priorities.

Malaysia's Smart City Framework 2019–2025 (Kementerian Perumahan dan Kerajaan Tempatan, 2019) and various city-level blueprints place strong emphasis on mobility, environmental management, and public service delivery. In contrast, heritage has received limited focus within these national and local strategies. Nonetheless, several promising initiatives exist. George Town's Integrated Heritage Database System (IHDS), a GIS-based inventory, facilitates real-time monitoring of building conditions and supports evidence-based decision-making. In Malacca, a planned Smart Heritage Tourism application incorporating chatbots and AR visualisations aims to diversify tourist flows, enrich interpretive experiences, and promote cultural dissemination. Although these efforts show potential, they remain isolated and are not yet embedded within a cohesive governance framework that supports long-term heritage management.

This divergence between smart city governance, which often focuses on infrastructure efficiency and economic competitiveness, and heritage conservation practice, which prioritises regulatory protection and material restoration, highlights the need for a more integrative approach. Drawing on Smart Governance Theory (Meijer & Bolivar, 2015), Stakeholder Theory (Freeman, 1984), and Place Identity Theory (Relph, 1976), this study argues that sustainable revitalisation of heritage areas requires the convergence of technological capability, inclusive governance, and cultural stewardship. This perspective aligns with The United Nations Educational, Scientific and Cultural Organisation (UNESCO)'s Historic Urban Landscape (HUL) approach, which emphasises the integration of heritage protection into broader urban, social, and economic planning frameworks. Accordingly, this study pursues three main objectives: (1) to identify the types of smart city technologies currently applied or planned in the heritage areas of George Town and Malacca; (2) to examine how stakeholders perceive the benefits and challenges of integrating these technologies within conservation practice; and (3) to develop an integrative Sustainable Revitalisation Framework that links preservation, digitalisation, community engagement, and governance to guide the effective implementation of smart technologies in heritage-rich Malaysian cities.

This study makes three key contributions. First, it provides a comparative analysis of two (2) Malaysian UNESCO cities, offering empirical insights into how smart city technologies are being applied in heritage contexts. Second, it examines stakeholder perceptions to identify both the enabling factors and barriers to technological integration. Third, it proposes a Sustainable Revitalisation Framework for Smart Heritage Cities, integrating four interdependent pillars—Preservation, Digitalisation, Community Engagement, and Governance Integration—thereby bridging the conceptual and operational gap between smart city agendas and heritage conservation practice. Guided by these aims, the research addresses the following questions:

- (i) RQ1: What smart city technologies are currently being applied (or planned) in George Town and Malacca's heritage areas, and for what purposes?
- (ii) RQ2: How do these technologies contribute to, or hinder, the sustainable conservation and revitalisation of urban heritage, according to stakeholders?

- (iii) RQ3: What framework can be formulated to integrate smart city technologies into urban heritage conservation efforts in Malaysian cities, ensuring both heritage preservation and urban sustainability?

To address these gaps, this study focuses on the UNESCO World Heritage cities of George Town in Penang and Malacca in southern Malaysia, two (2) of the nation's most historically significant urban centres. Both cities present contrasting yet complementary heritage landscapes: George Town characterised by its multicultural living heritage, dense shophouse typologies, and community-driven conservation networks, and Malacca shaped by centuries of layered colonial influences and a tourism-intensive economy. Their differing governance structures, conservation challenges, and emerging digital initiatives make them ideal comparative cases for examining how smart city technologies can support sustainable heritage revitalisation. Accordingly, this study investigates the types of smart technologies currently applied or planned in these heritage areas, how stakeholders perceive their benefits and challenges, and how an integrative framework may guide more effective adoption. These aims provide the foundation for the research questions and the proposed Sustainable Revitalisation Framework for Smart Heritage Cities.

LITERATURE REVIEW AND CONCEPTUAL FRAMEWORK

Urban Heritage Conservation and Sustainable Revitalisation

Urban heritage conservation is increasingly recognised as more than the static preservation of tangible and intangible assets; it is a dynamic process of adaptive revitalisation that sustains cultural continuity, reinforces local identity, and stimulates economic vitality through tourism and creative industries. In contemporary discourse, sustainable revitalisation reframes heritage as a catalyst for liveability, social cohesion, and climate-resilient urbanism, aligning with global sustainability goals (UNESCO, 2011; Smith & Waterton, 2021). The Historic Urban Landscape (HUL) approach offers a holistic, place-based methodology that situates heritage within integrated urban management systems, acknowledging environmental, socio-economic, and cultural dimensions. HUL explicitly rejects “museification” which refers to the reduction of heritage to static museum pieces, and instead advocates for heritage cities as living and evolving entities embedded in contemporary urban life.

However, this ideal is often challenged by market forces and development pressures. In Malaysia, George Town and Malacca, both UNESCO World Heritage Sites, face escalating land values, rapid tourism growth, and the displacement of local communities. Rising costs and gentrification threaten socio-cultural diversity, while inconsistent regulatory enforcement allows inappropriate alterations or demolitions (Khoo & Chang, 2021). This mirrors global patterns in cities such as Hoi An in Vietnam and Dubrovnik in Croatia, where over tourism and speculative real estate activities have strained conservation systems (Gravari-Barbas & Guinand, 2022). Sustainable revitalisation therefore requires integrative and multi-sectoral planning that aligns heritage protection with housing, mobility, climate adaptation, and economic diversification (Bullen & Love, 2011; Licciardi & Amirtahmasebi, 2022). Equally critical is inclusive governance, which empowers communities as co-stewards rather than passive recipients and embeds multi-stakeholder collaboration into decision-making to ensure that heritage retains social relevance and intergenerational value.

Smart City Technologies and Their Relevance to Heritage

The smart city paradigm applies digital infrastructure, data analytics, and networked systems to improve operational efficiency, sustainability, and citizen participation (Meijer & Bolívar, 2015). While

historically oriented toward mobility, energy, and public safety, these technologies are increasingly relevant to heritage management, offering tools for documentation, monitoring, interpretation, and engagement (Luo et al., 2024). Key applications include:

- (i) GIS and 3D Mapping — enabling precise documentation, layered spatial analysis, and scenario modelling. In George Town, the Integrated Heritage Database System (IHDS) integrates geospatial layers for heritage building condition monitoring. Similar initiatives in Amsterdam and Florence support vulnerability mapping and disaster preparedness (Rodgers & van Oers, 2011).
- (ii) IoT Sensors — monitoring microclimate, vibration, and structural stress in real time. Pilot deployments in George Town mirror systems in Barcelona’s Gothic Quarter, where predictive analytics inform preventive maintenance (Tousi et al., 2025).
- (iii) Mobile Applications and AR/VR — enriching interpretation and dispersing visitor flows. Malacca’s proposed Smart Heritage Tourism App parallels AR projects in Kyoto and Singapore’s Chinatown, enhancing storytelling while managing overtourism (Jiang et al., 2023).
- (iv) Digital Participation Platforms — enabling community reporting of alterations, sharing oral histories, and curating collective memory. The *Map My Heritage* platform in the UK illustrates the potential for youth engagement and open heritage data sharing. (Avci & Akyol, 2023)

The emerging concept of smart heritage encapsulates this convergence, where technological innovation is balanced with cultural sensitivity, participatory design, and authenticity safeguards (Song & Selim, 2022). Yet, concerns persist: digitalisation may widen the digital divide, risk over-commercialisation, or prioritise “spectacle” over substance if not grounded in scholarly rigor (Bobic & Akhavan, 2025).

Fragmentation in the Literature

Despite promising pilots, the scholarly and policy discourse remains fragmented. Urban technology research often prioritises infrastructure optimisation and economic competitiveness, sidelining cultural heritage (Tousi et al., 2025). Conversely, heritage studies have been cautious in adopting digital tools, focusing primarily on regulatory frameworks and material conservation. This siloed scholarship has resulted in missed opportunities for cross-pollination, particularly in governance integration, interoperability, and community-driven innovation.

Addressing this fragmentation requires synthesising insights from multiple theoretical lenses:

- (i) Smart Urbanism: examines how digital infrastructures reshape urban governance, power relations, and spatial practices.
- (ii) Critical Heritage Studies: foregrounds heritage as a social construct, shaped by contestation, identity, and community agency.
- (iii) Stakeholder Theory: emphasises balanced engagement among government, private sector, Non-governmental Organisations (NGOs), and community actors.

- (iv) Place Identity Theory: explains how emotional attachment to place influences conservation behaviours and public support.

By integrating these perspectives, a more holistic smart heritage governance framework can be developed by one that recognises heritage not just as a spatial asset but as a socio-technical system embedded in the cultural fabric.

Conceptual Framework

Building on this synthesis, we propose the Sustainable Revitalisation Framework for Smart Heritage Cities. (Figure 1), structured around four mutually reinforcing pillars:



Fig. 1. Sustainable Revitalisation Framework Integrating Smart Technologies into Urban Heritage Conservation.

Source: Authors (2025)

- (i) Heritage Preservation: Protecting tangible and intangible assets using digital tools that support authenticity and integrity, e.g., structural health monitoring and digital twin modelling.
- (ii) Digitalisation (Smart Infrastructure): Deploying interoperable, context-appropriate systems (GIS, IoT, AR, and VR) with open data standards to integrate heritage into wider urban management systems.
- (iii) Community Engagement: Leveraging participatory apps, co-design processes, and digital literacy programmes to ensure inclusivity and shared stewardship.
- (iv) Governance Integration: Embedding smart heritage initiatives into statutory planning, inter-agency coordination, and sustainable financing models such as Public-private partnership.

This configuration reflects a systems-thinking approach: digitalisation strengthens preservation and engagement; engaged communities advocate for governance reform; strong governance sustains technological interventions. This cyclical relationship aligns with UNESCO's HUL methodology and extends it by embedding smart city governance principles into heritage policy.

METHODOLOGY

This study employed a mixed-methods comparative case study design to examine the integration of smart technologies within urban heritage environments. Given the exploratory, interdisciplinary, and context-dependent nature of the research questions, a case study approach was deemed appropriate for capturing the complexity, institutional dynamics, and socio-cultural specificities inherent in heritage governance and digital transformation. The historic city centres of Malacca and George Town in Penang, were selected as primary cases due to their national and international significance as UNESCO World Heritage Sites, as well as their early experimentation with smart city initiatives in heritage precincts. Examining two sites enabled both in-depth contextual analysis and cross-case comparison, thus strengthening analytical robustness and enhancing the transferability of insights.

The research design integrated quantitative and qualitative components through three data collection strategies: stakeholder surveys, semi-structured interviews, and field-based observation supported by document analysis.

Stakeholder Survey (Quantitative Component)

A structured questionnaire was administered to stakeholders in both cities to examine perceptions, awareness, and experiences related to digital tools in heritage management. The target population included residents, business operators, visitors, and heritage professionals located within the core heritage zones. Stratified random sampling was employed to ensure representation across stakeholder categories in each city. A total of 120 valid responses were obtained, comprising 60 from George Town and 60 from Malacca.

The questionnaire included Likert-scale items measuring attitudes towards smart heritage technologies (e.g., perceived benefits for conservation, concerns about authenticity and over-digitalisation), prior usage of digital applications, and socio-demographic characteristics. Given the exploratory orientation, the sample size ($N = 120$) is appropriate for generating indicative patterns and identifying emergent themes without aiming for population-level generalisability. Summary statistics for respondent demographics and key variables are presented in Table 1.

Semi-Structured Interviews (Qualitative Component)

To obtain deeper insights into institutional perspectives, governance challenges, and technological adoption processes, 15 semi-structured interviews were conducted with key informants (eight (8) in George Town and seven (7) in Malacca). Participants included:

- (i) Heritage site managers (e.g., George Town World Heritage Incorporated, Malacca Museums Corporation)
- (ii) Local authority officials overseeing smart city initiatives
- (iii) Urban planners and conservation professionals
- (iv) Local historians, cultural practitioners, and community heritage leaders

An interview protocol guided discussions on current conservation practices, existing or planned digital initiatives, organisational constraints, and perceived opportunities for integrating smart technologies. Interviews were conducted between March and October 2024, either in person or via video conferencing.

and each session lasted approximately 45 to 60 minutes. With informed consent, all interviews were audio-recorded and transcribed verbatim for thematic analysis.

Field Observation and Document Analysis

Fieldwork was undertaken in both cities to observe on-the-ground conditions of digital and heritage infrastructure. Observations focused on the presence and functioning of technologies such as GIS-linked informational kiosks, Closed-Circuit Television (CCTV) networks, Quick Response (QR)-coded interpretive signage, and visitor information systems. Researchers also documented the physical condition of heritage structures, tourist movement patterns, and interactions with any observable digital tools. Photographs, field notes, and site sketches were collected to support the triangulation of findings.

Document analysis supplemented empirical observations. Key policy and planning documents—including the George Town Special Area Plan, the Malacca Structure Plan, and the Smart Melaka Blueprint 2035—were reviewed to identify strategic priorities, planned interventions, and institutional commitments. Additional sources such as press releases, government reports, official portals, and reputable media articles (e.g., Esri Malaysia's press announcement regarding George Town's GIS system) were examined to verify claims about implemented or proposed digital initiatives.

Analytical Approach and Triangulation

A triangulated analytical strategy was applied to synthesise insights from the various data streams. Survey data provided descriptive patterns reflecting general attitudes and stakeholder experiences. Interview transcripts were coded thematically to uncover deeper drivers, constraints, and governance dynamics influencing technology adoption. Field observations and documentary evidence were used to validate stakeholder claims, identify implementation gaps, and contextualise differences between stated policies and on-ground realities.

By integrating quantitative breadth with qualitative depth, the study ensures a comprehensive and methodologically rigorous examination of smart heritage practices in Malaysia's two (2) major heritage cities. This multi-source triangulation enhances the credibility, dependability, and confirmability of the findings, consistent with established qualitative and mixed-methods research standards.

DATA ANALYSIS

Quantitative Analysis

Survey data were analysed using descriptive statistical techniques to identify overall patterns in stakeholder perceptions, levels of awareness, and experiences with smart heritage technologies. Initial comparisons were conducted between respondents in George Town and Malacca; however, because response patterns were largely consistent across both sites, aggregate results are presented to enhance interpretability. Key indicators included the proportion of respondents who agreed with statements on the perceived usefulness of digital tools, levels of confidence in technology enhanced heritage management, and awareness or utilisation of specific applications such as digital mapping platforms or mobile heritage guides.

Cross tabulations were performed to explore variations across demographic groups, such as age, residency status, and stakeholder category. These comparisons provided insights into whether certain

groups, for example younger respondents or heritage professionals, exhibited higher receptivity toward advanced tools such as augmented or virtual reality. Given the sample size and the exploratory purpose of the study, the analysis prioritised pattern recognition rather than causal inference, and no inferential statistical tests were applied.

Qualitative Analysis

Qualitative data obtained from semi structured interviews and open-ended survey responses were analysed using thematic analysis. All interview transcripts were uploaded into QSR NVivo 12 (NVivo) to support systematic coding and conceptual categorisation. An initial set of codes was developed based on the interview guide and included categories such as existing smart initiatives, perceived benefits, operational challenges, and recommendations for improvement. Through iterative reading, additional inductive codes emerged. These included themes related to data governance, training needs, community scepticism, and enhanced tourist engagement through digital tools.

These subthemes were then organised into broader analytical categories that reflected the four components of the proposed framework, namely Preservation, Digitalisation, Community Engagement, and Governance Integration. Instances that referenced specific technologies or ongoing projects such as heritage GIS systems, QR code trails, or proposed mobile applications were coded separately to construct a consolidated inventory of digital initiatives in each city. To enhance the reliability of interpretation, two researchers independently coded a subset of transcripts and reconciled discrepancies through discussion until agreement was reached.

Triangulation

Triangulation across survey results, interview data, field observations, and documentary sources strengthened the validity and credibility of the findings. When interviewees referenced particular technologies or challenges, for example the effectiveness of the GIS Heritage Database in George Town or gaps in internet connectivity in certain heritage clusters, these claims were corroborated with survey responses, field observations, or relevant policy documents. This multi-source approach supported cross verification of evidence, reduced the risk of single source bias, and contributed to a more comprehensive understanding of how smart technologies interact with heritage conservation practices.

Ethical Considerations

Ethical procedures were carefully observed throughout the research process. Ethical approval was granted by the University Research Ethics Committee. All participants were informed of the purpose of the study, provided voluntary consent, and were assured of confidentiality. Survey responses were collected anonymously, and interviewees are identified only through generic descriptors such as “heritage official in Malacca” or “community representative in George Town” in order to protect their identities. All data were stored securely and used solely for academic purposes.

Table 1. Profile of Survey Respondents (N = 120) (Equal Samples from George Town and Malacca)

Characteristic	Categories / Distribution
City	George Town – 60 respondents (50%); Malacca – 60 (50%)
Gender	Male – 55%; Female – 45%
Age Group	18–29 years – 30%; 30–49 years – 50%; 50 and above – 20%

Role in Heritage Area	Local resident – 40%; Business owner – 15%; Tourist – 30%; Heritage official/NGO – 15%
Education Level	Secondary or below – 20%; Tertiary (college/university) – 80%

Source: Authors (2025)

The sample included a mix of stakeholders reflecting the social makeup of the areas. In George Town, many local respondents were long-time residents of the inner city, whereas in Malacca a number of respondents were domestic tourists. The education level skewed high likely because those interested in the topic were more willing to participate.

RESULTS

This section presents the principal findings from both case studies and is structured around three areas of analysis: current smart technology initiatives implemented in the heritage zones of George Town and Malacca, stakeholder perceptions regarding the benefits and challenges of these technologies, and the broader outcomes associated with sustainable heritage revitalisation, including shifts in governance practices and community responses. Quantitative survey results are interpreted alongside qualitative insights in order to create a coherent and multidimensional understanding of the two cities. All findings are discussed with reference to the four components of the study's conceptual framework, namely Preservation, Digitalisation, Community Engagement, and Governance Integration. The evidence collected from both sites indicates that a variety of smart city technologies are now being used, or are in advanced stages of planning, to support heritage conservation and management. These initiatives illustrate a gradual yet notable shift towards digital innovation within UNESCO-recognised historic environments. They also reflect wider international trends that emphasise data-informed monitoring, participatory digital platforms, and enhanced interpretive experiences for residents and visitors. Table 2 summarises the key initiatives identified in each city, outlining their primary functions, stages of implementation, and governance arrangements. Taken together, these examples provide a comparative view of how George Town and Malacca are beginning to incorporate smart technologies into their heritage strategies, albeit with differing priorities and levels of maturity.

Table 2. Notable Smart City Technology Initiatives for Heritage Conservation in George Town and Malacca

Initiative / Tool	Description	Implementation Status & Governance
GIS Heritage Database System (George Town)	An integrated geospatial database cataloguing heritage buildings and sites, incorporating map-based inventories and real-time updates via mobile devices. Supports monitoring of structural conditions, renovation tracking, and impact assessment of surrounding developments. Also maps cultural events to link spatial and socio-cultural data.	Operational since 2015, managed by George Town World Heritage Incorporated (GTWHI) in collaboration with local authorities. Continuously updated; public access available via a web portal for selected datasets.
Smart Heritage Tourism App (Malacca)	Mobile platform under development to deliver site information, thematic trails, and interactive AR/VR experiences. Incorporates AI chatbots for visitor queries, aiming to enhance cultural interpretation and disperse tourist flows beyond high-traffic sites.	Planned/in development (as of 2024), spearheaded by the Melaka State Government. Prototype launch anticipated in 2025, integrated within the broader Melaka Super App ecosystem.
IoT Structural Monitoring (George Town)	Pilot deployment of IoT sensors on select heritage structures (e.g., century-old shophouses, religious buildings) to monitor vibration, humidity, and temperature. Automated alerts trigger conservation	Pilot stage since 2023, initiated by Penang City Council in partnership with a local university. Early data collection ongoing; expansion contingent on pilot outcomes.

	officer interventions when readings exceed safety thresholds, enabling predictive maintenance.	
Digital Crowd-Engagement Platforms (Both cities)	Online tools to involve the public in heritage management. In George Town, GTWHI's portal enables citizens to report site issues or share historical narratives. In Malacca, social media surveys were used to co-design the Smart Heritage Tourism App's content.	Ongoing. George Town's reporting portal has been active since 2019 with growing uptake. Malacca's digital outreach in 2024 generated substantial public input, influencing app features (as acknowledged by officials).

Source: Authors (2025)

The initiatives reveal differentiated strategies between the two cities: George Town exhibits a data-centric and monitoring-oriented approach, while Malacca's current trajectory emphasises visitor experience and engagement-driven innovation. Both, however, incorporate elements of participatory governance, suggesting a convergence towards community-informed digital heritage management.

Table 2, George Town has been proactive in deploying a GIS-based heritage management system: indicating an early embrace of digital tools for preservation. This system has reportedly improved inter-agency coordination and monitoring – one official noted that “for the first time, we have a single source of truth for heritage data”. Meanwhile, Malacca is catching up by focusing on tourism-oriented technology (the planned app), which aligns with its heavy tourism economy. Both cities are experimenting with IoT and digital engagement, though on a smaller scale. Notably, some initiatives (like community reporting) are relatively low-cost and leverage social media rather than sophisticated new systems.

Stakeholder Perceptions: Benefits and Challenges

The survey and interviews shed light on how different stakeholders perceive the impact of smart technologies on heritage conservation. Overall, sentiment was cautiously optimistic. A majority of survey respondents (approximately 85%) agreed that digital tools can enhance heritage preservation efforts by providing better information and early warnings. Likewise, around 80% felt that AR or VR applications could enrich the heritage tourism experience by bringing history to life in engaging ways. These findings suggest a broad openness to integrating technology, countering the notion that heritage stakeholders are universally technophobic.

Benefits and Challenges of Smart Technology in Heritage Management

The analysis of interview and document data revealed both perceived benefits and critical challenges associated with the integration of smart city technologies in the heritage contexts of George Town and Malacca. The findings are grouped into four(4) primary benefits and four recurrent challenges, reflecting the multi-dimensional impact of digital interventions on conservation practice, governance, and socio-economic outcomes.

- (i) **Data-Driven Decision-Making:** Planners and conservation officers emphasised the value of evidence-based policy formulation enabled by geospatial databases, sensor networks, and digital records. For example, GIS-based mapping of building conditions in George Town enabled municipal authorities to identify clusters of at-risk heritage structures, allowing targeted allocation of conservation grants and enforcement actions. As one (1) planner observed, technology provides ‘patterns and priorities’ rather than reliance on anecdotal complaints. The availability of longitudinal datasets further supports monitoring of physical changes, aiding in the detection of unauthorised alterations and evaluation of conservation interventions.

- (ii) **Enhanced Monitoring and Emergency Response:** The pilot deployment of IoT structural monitoring systems demonstrated significant potential for proactive risk management. In one reported instance, unusual vibrations detected in a century-old shophouse during nearby construction prompted immediate intervention and temporary suspension of piling activities. Similarly, the integration of CCTV surveillance into city-wide security systems was credited by law enforcement with reducing vandalism and artefact theft, albeit accompanied by initial community concerns over privacy.
- (iii) **Public Engagement and Heritage Education:** Interactive and visually engaging digital tools—particularly (AR) overlays and online reporting portals—were identified as effective in broadening citizen participation and fostering intergenerational engagement. The AR-enabled mural interpretation in George Town significantly increased online sharing and stimulated public interest in site histories. Digital platforms such as the GTWHI reporting site lowered participation barriers, enabling residents who might not attend physical consultations to report heritage issues online, often leading to more rapid enforcement responses.
- (iv) **Tourism Management and Economic Stimulation:** In Malacca, tourism stakeholders perceived smart applications and digital guides as tools to enhance visitor experience and stimulate economic activity. AR or VR features are anticipated to attract technology-oriented tourists, potentially increasing visit duration and expenditure. Additionally, digital heritage initiatives were reported to create opportunities for local technology start-ups and creative industries, aligning with the concept of culturally sustainable innovation where heritage functions as a catalyst for the creative economy.

Challenges

- (i) **Limited Awareness and Digital Literacy:** Low adoption rates for heritage-related mobile applications indicated gaps in public awareness and digital literacy. Several respondents noted insufficient promotional campaigns at launch and observed that older residents often lacked access to or comfort with smartphone technology. This suggests a need for complementary offline engagement strategies such as community workshops or public information kiosks.
- (ii) **Resource and Maintenance Constraints:** Financial and technical sustainability emerged as persistent concerns. Respondents questioned the availability of long-term funding for system updates, database maintenance, and hardware replacement. The GIS system in George Town initially relied on external technical support, highlighting the necessity of building local technical capacity. Continuous data updating, particularly field surveys of building conditions, was also cited as labour-intensive, with staffing shortages limiting operational effectiveness.
- (iii) **Data Integration and Inter-Agency Coordination:** Stakeholders highlighted the absence of interoperable governance frameworks to link heritage datasets with broader urban systems such as planning approvals, smart mobility, or tourism promotion platforms. This fragmentation was viewed as a missed opportunity for cross-sectoral benefits (e.g., linking parking management systems to heritage-sensitive zones). Respondents consistently emphasised that institutional collaboration posed greater challenges than technology deployment itself.

- (iv) **Concerns Regarding Authenticity and Over-Reliance on Technology:** A minority of heritage specialists cautioned that digital tools should not overshadow the tangible and human dimensions of heritage practice. Overemphasis on technologically driven experiences, without scholarly rigour, risks trivialising historical narratives. Concerns were also raised about the potential neglect of physical archives or traditional interpretation methods, underscoring the principle that technology should serve as an enabler rather than a substitute for core conservation practices.

SYNTHESIS

Despite these structural and operational constraints, the trajectories observed in both George Town and Malacca indicate a gradual but measurable shift towards integrating digital solutions in ways that remain anchored to heritage values and local socio-cultural contexts. The findings demonstrate that successful smart heritage transitions rely on the coherent interplay of the four pillars of the proposed framework. Preservation emerges as the normative anchor, requiring that any technological intervention safeguard authenticity, material continuity, and place identity. Digitalisation functions as an enabler, most effective when deployed selectively to enhance documentation, interpretation, and environmental monitoring rather than imposing technology for its own sake. Community engagement remains the social driver, ensuring inclusivity, knowledge sharing, and local ownership in decision-making processes. Governance provides the institutional scaffolding, where leadership continuity, regulatory clarity, and cross-agency coordination shape long-term implementation capacity. Collectively, these insights reinforce the need for a people-centred and context-sensitive smart heritage ecosystem, one (1) grounded in skilled human capital, empowered communities, and accountable governance structures. Such an ecosystem ensures that digital innovations are not merely technological upgrades but instruments that support sustainable conservation, socio-cultural resilience, and equitable urban development.

CONCLUSION

This study set out to examine how smart city technologies can be meaningfully integrated into urban heritage conservation in Malaysia, focusing on the UNESCO World Heritage cities of George Town and Malacca. The empirical findings reveal that although both cities have begun adopting digital tools such as GIS inventories, IoT-based monitoring systems, and interactive mobile applications, the integration of these technologies remains fragmented, uneven, and often driven by isolated pilot initiatives rather than long-term institutional strategy. Despite these constraints, stakeholders acknowledged the potential of digitalisation to enhance heritage monitoring, improve information flows, strengthen community participation, and support more informed decision-making processes. A key contribution of this study lies in demonstrating that technology alone does not drive successful heritage revitalisation. Instead, sustainable outcomes emerge from the synergistic interaction of four interdependent pillars: Preservation, Digitalisation, Community Engagement, and Governance Integration. Preservation provides the normative anchor that safeguards cultural significance and authenticity. Digitalisation acts as a strategic catalyst that enhances documentation, analysis, and interpretation when deployed in ways that respect local contexts. Community engagement ensures that heritage management remains socially grounded, inclusive, and reflective of local knowledge systems. Governance integration supplies the institutional alignment, policy coherence, and financial continuity required to sustain technological innovation over time.

Based on these insights, this study introduces the Sustainable Revitalisation Framework for Smart Heritage Cities, which conceptually bridges the longstanding divide between smart city agendas and

heritage conservation practice. The framework advances existing scholarship by reconciling socio-technical, cultural, and governance dimensions that are typically treated in isolation. It extends the UNESCO (HUL) approach by embedding digital infrastructures and participatory mechanisms into heritage policy design. It also contributes to debates on smart urbanism by demonstrating how technological interventions must be culturally sensitive, community informed, and institutionally embedded to produce meaningful outcomes. The findings offer several policy implications. Urban authorities should prioritise interoperable digital systems that integrate heritage data with planning, mobility, and tourism platforms. Investments in digital capacity building are essential, particularly for local heritage officers and community groups who will be the long-term custodians of these technologies. Equally important is the need for sustained governance structures, including cross-agency committees, data sharing protocols, and public-private partnerships, to ensure that digital innovation is not confined to short-term pilot projects. These policy directions are particularly relevant for rapidly urbanising ASEAN heritage cities facing similar pressures of over tourism, commercialisation, and cultural homogenisation.

This study is not without limitations. Its focus on two (2) Malaysian cities provides depth but limits generalisability across diverse ASEAN contexts. Future research could adopt comparative or longitudinal designs to examine how institutional capacity, cultural norms, and technological maturity shape the evolution of smart heritage initiatives. Integrating economic analyses, such as cost-benefit modelling or assessments of the impacts of digital tourism tools, would also deepen understanding of the tangible outcomes of digitalisation in heritage management. In conclusion, this study underscores that the future of heritage conservation in Malaysia, and in many heritage-rich cities across the Global South, depends on embracing a people centred and governance led model of digital transformation. Smart technologies, when strategically aligned with preservation values, community aspirations, and coherent governance systems, can serve as powerful instruments for sustaining cultural identity, enhancing urban resilience, and advancing inclusive and culturally sensitive smart city development. The Sustainable Revitalisation Framework proposed here provides a workable pathway for embedding such innovation, positioning Malaysian heritage cities at the forefront of regional and global discussions on smart heritage governance.

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CONFLICT OF INTEREST STATEMENT

The authors declare that there are no conflicts of interest, financial or otherwise, that could have influenced the conduct or outcomes of this research. All procedures and analyses were undertaken independently, without any commercial or institutional interests that could be construed as potential sources of bias.

AUTHORS' CONTRIBUTIONS

Muhammad Hafiz Abd Razak led the research conceptualisation and framework development. Designed the methodology and instruments, oversaw data collection coordination, wrote the original manuscript draft, and managed project administration, including stakeholder engagement and grant reporting. Nor Suzylah Sohaiimi co-led data collection in George Town and Malacca, handled qualitative data curation and

transcription, assisted in structuring the findings section, and reviewed multiple manuscript drafts for clarity and coherence. Sharif Shofirun Sharif Ali conducted formal analysis of survey and interview data, developed figures and visual data representations, and participated in comparative review of international literature on smart heritage. Reviewed final manuscript with focus on analytical accuracy. Mohd Rizal Safar contributed to the validation of research instruments and triangulation of findings. Provided expertise in public policy analysis and contextualised the findings within the broader governance framework. Reviewed the manuscript, ensuring alignment with Malaysian planning policies. Inoue Tomo contributed to theoretical framing and comparative analysis with Japanese smart heritage approaches. Led the international literature review section, identified emerging models in Asia-Pacific, and advised on cross-cultural interpretations and applications.

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