A collaborative GIS workflow for digital heritage documentation along the Sandakan heritage trail

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ABSTRACT The Sandakan Heritage Trail contains layered colonial and multi-ethnic histories, but deteriorating signboards, redevelopment pressures, and fragmented custodial documentation have reduced their accessibility. Digital technologies offer new possibilities for preserving interpretive materials, yet secondary cities typically face constraints in custodial capacity and archival continuity. This study develops a collaborative GIS workflow that integrates ArcGIS Field Maps, ArcGIS Survey123, ArcGIS Online, and ArcGIS StoryMaps in cooperation with municipal authorities, museum officers, and public universities. The workflow documents site locations, interpretive materials, and selected accessibility information, while a separate internal dataset captures evaluative walkability observations for municipal planning and future academic analysis. Archival referencing is used to situate signage within established historical sources without modifying narrative content. Preliminary implementation generated a geospatial inventory of interpretive boards and monuments, supported by photographs, coordinates, and provenance metadata. A prototype StoryMap was produced, combining narrative summaries, archival context, and route visualization. The digital consolidation made representational gaps particularly the dominance of colonial and missionary narratives and the absence of everyday local histories, more visible than when sites are viewed individually. The workflow demonstrates how a lightweight, collaborative GIS model can preserve dispersed heritage materials, clarify provenance, and enhance interpretive accessibility for educators, students, remote users, and individuals with mobility constraints. The outputs offer a transferable approach suitable for secondary cities with limited preservation resources and fragmented archival infrastructure.

KEYWORDS: Digital heritage; ArcGIS Online; Field Maps; Survey123; StoryMaps; Accessibility.
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TRANSACTIONS ON SCIENCE AND TECHNOLOGY

INTRODUCTION

Heritage trails function as interpretive frameworks that connect landmarks, memory, and identity within evolving urban environments, enabling visitors to apprehend historical continuity through spatial narrative (Boyd, 2017; Mat Nayan *et al*., 2021). In Sandakan, the Heritage Trail links sites associated with colonial administration, migrant communities, religious institutions, and early civic development, reflecting the town's transformation from a maritime trading center into a diverse multi-ethnic urban landscape. Although the Trail remains culturally significant, tropical weathering, redevelopment cycles, and fragmented custodial records have contributed to deteriorating signage and uneven public information, limiting the visibility and educational potential of its heritage assets.

Digital technologies now offer complementary pathways for strengthening documentation and interpretation. Geospatial tools, mobile data-collection platforms, and immersive visual media allow dispersed historical materials and physical signboards to be consolidated into integrated learning environments that support interpretation, preservation, and municipal planning (Angelidou & Stylianidis, 2020; Riganti, 2017). Whereas smart-heritage scholarship emphasizes the need for interoperable systems and institutional coordination (Angelidou & Stylianidis, 2020), digital-tourism research underscores how digital mediation can enhance transparency, interpretive clarity, and public engagement when responsibly implemented (Shehade & Stylianou-Lambert, 2020). These

perspectives collectively suggest that digital heritage initiatives should be framed not as isolated technical interventions but as part of wider institutional and communicative ecosystems.

At the same time, post-colonial and decolonial scholarships demonstrate that heritage documentation is never neutral. Conventional archival and interpretive practices frequently foreground colonial, state-centered, or elite narratives while obscuring vernacular histories, Indigenous presence, labor contributions, and everyday cultural landscapes (Chirikure *et al.*, 2015; Sham, 2015). Such representational imbalances shape not only what is documented but also what is rendered invisible. Although the ten recognized nodes of the Sandakan Heritage Trail do not explicitly include Indigenous cultural sites, they nonetheless sit within a broader historical landscape shaped by pre-war settlement patterns, maritime movement, and multi-ethnic community life. A responsible digital-heritage workflow must therefore pay attention to both presence and absence in the existing record, without altering, correcting, or adjudicating the official narratives presented on physical signboards.

The present initiative responds to these concerns by developing a collaborative GIS framework that integrates ArcGIS Field Maps, ArcGIS Survey123, ArcGIS Online, and ArcGIS StoryMaps. Participation from Sandakan Municipal Council (*Majlis Perbandaran Sandakan*), Sabah Museum Department Sandakan Branch (*Jabatan Muzium Sabah Cawangan Sandakan*), Sandakan Library (*Perpustakaan Sandakan*), and Universiti Malaysia Sabah ensures that documentation processes align with custodial knowledge and local conservation practice. The workflow distinguishes between an internal research dataset designed for municipal advisory and analytical purposes and a public-facing StoryMap intended for interpretive education, accessibility support, and virtual engagement.

Nationally, the project aligns with Malaysia's National Heritage Act 2005, which underscores coordinated stewardship of tangible and intangible heritage (Aziz & Noor, 2017; Henderson, 2012; Ugong, 2024). Internationally, UNESCO guidance emphasizes that heritage communication should be participatory, collaborative, transparent, and accessible, particularly in resource-constrained environments where documentation gaps are common (UNESCO, 2025). Within this context, digital documentation is approached not merely as a technical exercise but as an ethical and institutional undertaking that supports preservation, enhances public understanding, and provides continuity where physical artefacts remain vulnerable to loss (Poulopoulos & Wallace, 2022).

This study aims to develop a baseline digital archive of the Sandakan Heritage Trail through a collaborative GIS workflow. Its objectives are to document spatial locations and interpretive materials, incorporate selected visitor-relevant accessibility indicators, and produce a public-facing platform that enhances educational engagement while safeguarding evaluative walkability assessments for municipal use. The framework is designed to be transferable to other secondary cities with similar constraints in preservation resources, custodial capacity, and archival continuity.

LITERATURE REVIEW AND CONCEPTUAL BACKGROUND

Digital Transformation in Heritage Practice

Digital transformation has reshaped how cultural heritage is documented, interpreted, and communicated across urban contexts. Advances in Geographic Information Systems (GIS), mobile survey applications, cloud-based data environments, and immersive visual media now allow spatial, textual, and photographic information to be consolidated within integrated digital platforms. These tools support traceable documentation practices, enhance information visibility, and enable the

preservation of interpretive materials that are vulnerable to weathering or redevelopment pressures (Riganti, 2017; Shehade & Stylianou-Lambert, 2020).

In secondary cities where archival continuity is uneven, and conservation resources remain limited, digital environments help reduce fragmentation by centralizing dispersed historical sources and material artefacts. They also provide a means for educators, students, municipal staff, and remote users to access heritage information beyond the constraints of physical infrastructure. However, as Shehade & Stylianou-Lambert (2020) caution, the value of digital mediation does not lie in the technology itself but in the transparency of interpretive process and the critical framing that accompanies digital reproduction. In this perspective, digitization is not a substitute for custodial knowledge; it is an interpretive pathway that makes methods, limitations, and provenance legible to users.

Smart Heritage and Digital Urban Ecosystems

Situated within broader smart-city discourse, digital heritage is increasingly conceptualized as part of a wider urban information ecosystem. Angelidou and Stylianidis (2020) describe "smart heritage" as the adaptation of smart-city infrastructure for cultural management, emphasizing interoperability, efficient workflows, and cross-agency coordination. This framework insists that digital heritage initiatives must be institutionally anchored, rather than treated as stand-alone technical ventures.

Riganti's (2017) *smartheritage* agenda extends this argument by foregrounding governance, social inclusion, and community participation as prerequisites for sustainable digital innovation. Digital tools alone do not guarantee improved heritage outcomes; rather, they require collaborative structures that connect data management, interpretation, and long-term custodial responsibility. This study's multi-agency collaboration aligns directly with this strand of scholarship.

Post-Colonial and Decolonial Perspectives

Technological innovation cannot be disentangled from questions of representation, authority, and archival power. Post-colonial scholarship has shown that heritage practice frequently reproduces selective narratives shaped by colonial epistemologies, elite interests, and institutional priorities (Chirikure *et al.*, 2015). Sham (2015) argues that conservation policies often privilege monumental, colonial, or state-centric landscapes while marginalizing everyday cultural spaces, migrant histories, and vernacular memory.

Such representational silences are not accidental; they reflect deeper structural and historical forces. For digital-heritage projects, the challenge is not to "correct" existing narratives with alternative ones but to acknowledge the interpretive limits of what has historically been documented. By attending to both the presence of certain narratives and the absence of others, digital workflows can illuminate the unevenness of the historical record without imposing retrospective reinterpretation. This principle underpins the non-interventionist stance of the present study, which preserves signboard texts as they exist while making visible the gaps that accompany them.

Participation, Co-Creation, and Multi-Institutional Heritage Work

Heritage documentation increasingly draws on collaborative and co-creative methods that recognize the distributed nature of custodial knowledge. The PALIMPSEST project, for instance, illustrates how digital storytelling and art-based approaches enable communities to contribute meaningfully to heritage interpretation and representation (Mantzou *et al.*, 2023). At the governance

level, Malaysia's National Heritage Act 2005 underscores that sustainable heritage management requires coordinated stewardship among museums, municipalities, archival institutions, and other state bodies (Aziz and Noor, 2017). Henderson (2012) similarly argues that conservation work in Southeast Asia is strengthened when heritage professionals, tourism agencies, and local authorities collaborate rather than operate in isolation.

Ugong's (2024) findings further reinforce that community participation, institutional expertise, and state support function as mutually reinforcing pillars in successful conservation efforts. Collectively, these studies underline that digital-heritage initiatives require not only technological capacity but also shared decision-making structures that align with existing legal frameworks and institutional arrangements.

Authenticity, Interpretation, and Digital Mediation

Debates on authenticity have evolved considerably in the context of digital heritage. Shehade and Stylianou-Lambert (2020) argue that digital reproduction does not diminish authenticity; rather, it shifts authenticity towards transparency of process, documentation of method, and clarity about the interpretive choices involved. This approach frames authenticity as an epistemic quality, not a material one.

Hsu (2023), in his reconstruction of the Dutch Trading Post in Taiwan, demonstrates how 3-D modelling can critically engage with cultural loss by enabling users to reflect on what remains, what is absent, and what can only be approximated. Poulopoulos and Wallace (2022) note, however, that large-scale cultural-data infrastructures risk flattening local specificity unless metadata clarity, provenance, and custodial authorship are explicitly maintained.

Together, these perspectives position digital documentation as a hybrid practice: technical insofar as it records spatial and material data, and interpretive insofar as it must articulate context, limitations, and the conditions of its own production.

Sustainability, Governance, and Institutional Stewardship

Long-term sustainability in digital heritage depends not simply on technological adoption but on governance structures capable of maintaining, updating, and curating digital assets. Ugong (2024) illustrates how conservation efforts are most resilient when institutional capacity, community participation, and professional expertise are integrated. UNESCO's guidance on sustainable heritage communication similarly emphasizes participatory and collaborative governance, equitable access, and shared responsibility as foundations for responsible digital innovation (UNESCO, 2025).

Conceptual Framework for This Study

Synthesising the perspectives above, this study adopts a conceptual framework with two interconnected dimensions that guide both the documentation workflow and the structure of the resulting datasets.

Technological integration

This dimension refers to the use of Web GIS, mobile survey tools, and immersive media to document the spatial, visual, and interpretive characteristics of the Sandakan Heritage Trail in a coherent and metadata-rich format. Technological integration supports interoperability between Field Maps, Survey123, ArcGIS Online, and StoryMaps, enabling efficient consolidation of dispersed heritage materials. It also distinguishes between interpretive documentation intended for public dissemination and evaluative walkability data intended for research and municipal advisory work.

This dimension foregrounds reproducibility, accuracy, and the preservation of existing signboards, plaques, and narrative materials (Angelidou & Stylianidis, 2020; Riganti, 2017).

Collaborative governance

This dimension highlights multi-institutional cooperation among municipal authorities, museums, libraries, and the university in shaping responsible digital custodianship. Such collaboration ensures that digitised materials align with existing interpretive knowledge, conservation policy, and educational aims. It also establishes clear pathways for communicating evaluative findings to municipal partners while presenting interpretive information to public audiences through the StoryMap. This dimension aligns with national legislation, regional conservation practices, and UNESCO guidance on inclusive, participatory, and collaborative heritage management (Aziz & Noor, 2017; Henderson, 2012; Ugong, 2024; UNESCO, 2025).

These dimensions position digital documentation as both a technical and governance practice that preserves heritage interpretation while enabling extended analysis of walkability, accessibility, and user experience in a separate research trajectory.

MATERIALS AND METHOD

Study Area

The Sandakan Heritage Trail is an approximately 3.2 km walking route located in the urban core of Sandakan, Sabah. It links ten recognized heritage landmarks associated with colonial administration, migrant communities, religious institutions, and early civic development (Sabah Tourism Board, 2022). Established in 2003, the Trail remains a significant cultural asset; however, tropical weathering, redevelopment cycles, and inconsistent custodial documentation have resulted in partial loss of interpretive clarity and uneven public information.

This study develops a digital-heritage workflow aimed at consolidating spatial, interpretive, and accessibility information into a coherent geospatial archive. Collaboration with Universiti Malaysia Sabah, Sandakan Municipal Council, Sabah Museum Department Sandakan Branch, and Sandakan Library ensures that documentation processes align with local custodial practices and UNESCO's principles of collaborative, coordinated heritage management.

Research Design

The project adopts a collaborative digital-heritage framework derived from three interrelated domains. The first draws on the *smartheritage* agenda, which emphasizes institutional interoperability and inclusive governance (Riganti, 2017). The second is informed by smart-city cultural informatics, where digital tools facilitate coordinated custodial workflows across agencies (Angelidou & Stylianidis, 2020). The third incorporates UNESCO guidance on stakeholder engagement, transparency, and equitable access in heritage communication (UNESCO, 2025). Together, these domains provide the conceptual foundation for a workflow that integrates technological tools with collaborative custodial practice.

Rather than treating digitisation as a purely technical activity, the research design recognises digital documentation as both an interpretive and an ethical practice. The framework distinguishes between a research dataset, developed for municipal advisory purposes, and a public-facing StoryMap, designed for education, interpretation, and visitor preparedness. This separation reflects international best practice in responsible digital-heritage communication.

The workflow consists of four phases that correspond to the two dimensions of the study's conceptual framework: technological integration and collaborative governance. Phases 1 and 2 address data captured through geospatial and structured-observation tools, while Phases 3 and 4 address verification, custodial provenance, and public communication. Each phase is iterative, with outputs feeding into both the internal research dataset and the public-facing StoryMap. The following subsections describe each phase in detail.

Phase 1: Field mapping

ArcGIS Field Maps was used to document the spatial and visual characteristics of the Sandakan Heritage Trail. Each interpretive board, signboard, plaque, monument, or relevant feature was recorded using WGS 84 (EPSG:4326) coordinates, together with a timestamp, collector identity, site name, descriptive notes, and photographic documentation. GNSS metadata indicated a typical horizontal positional accuracy of approximately ±3 metres.

This phase prioritises reproducibility and transparent provenance. Physical materials are documented exactly as they appear on site to ensure that interpretive content remains accessible even if signboards deteriorate or are removed during redevelopment. This approach reflects the view that authenticity in digital heritage derives from clarity of method and the traceability of recorded information rather than from perfect material reproduction (Shehade and Stylianou-Lambert, 2020).

Phase 2: Structured data collection

ArcGIS Survey123 was used to document walkability, accessibility, and comfort conditions along the Sandakan Heritage Trail. The instrument consists of twenty-six single-select variables organised into six index groups addressing footpath quality, legibility and navigation, crossing safety, perceived safety, shade and comfort, and cultural experience. Each variable uses a 0–4 response scale and includes optional photograph and notes fields. Full item content is not included in this preliminary-results paper because the instrument is undergoing refinement for a separate walkability study. The Survey123 instrument serves two distinct functions within the project.

i) Visitor-relevant information for the public StoryMap

Only variables that assist visitor preparedness and basic accessibility awareness are included in the public StoryMap. These indicators relate directly to tourism experience and do not involve evaluative scoring. They include parking availability, the presence of inclusive access such as wheelchair or stroller-friendly routes, opening hours where applicable, and general entry conditions. These elements support itinerary planning without introducing technical assessments that fall outside the interpretive purpose of the StoryMap.

ii) Advisory data for municipal partners and academic analysis

The remaining Survey123 variables capture evaluative aspects of walkability, surface quality, safety, shading, navigation, and cultural-experience conditions. These indicators are analytical in nature and are used only for two restricted purposes: they support internal decision-making by Sandakan Municipal Council, and they provide a dataset for academic research on walkability and user experience along the Trail.

Because these indicators evaluate operational qualities rather than heritage interpretation, they are not published in the public StoryMap. They form part of the Internal Research Dataset, which will underpin a separate scholarly paper once extended data collection and analysis are complete. This distinction preserves the interpretive clarity of the public StoryMap while ensuring that

evaluative walkability findings are communicated appropriately to custodial agencies and retained for research purposes. The full instrument schema will be reported in detail in a separate methodological paper on walkability evaluation along the Trail.

Phase 3: Archival Cross-Referencing

Archival materials from Sandakan Library and interpretive insights from Sabah Museum Department Sandakan Branch were consulted to establish provenance and contextualize interpretive boards and monuments within the broader historical record. This non-interventionist process aims to clarify origins, dates, and narrative context without altering the content of physical signage. Through this cross-referencing process, the research team identifies where physical signage aligns with institutional or archival sources, documents gaps or ambiguities that require custodial attention, and preserves the interpretive provenance necessary for users to understand the evidential basis of the recorded information.

Where interpretive text from signboards, plaques, or institutional sources is used in the public StoryMap, it is reproduced as faithfully as possible in summary form. Verbatim transcriptions are preserved in the Internal Research Dataset so that the original wording and provenance remain traceable. This practice aligns with post-colonial scholarship that emphasises transparency about the conditions and limits of historical records while avoiding retrospective correction of established narratives (Chirikure *et al*., 2015; Sham, 2015).

Phase 4: Educational Dissemination

ArcGIS StoryMaps integrates digitised text, photographs, coordinates, and selected accessibility indicators into an interpretive platform designed for heritage education, tourism, and remote engagement. The StoryMap presents three interrelated categories of digitised heritage material: the ten official Trail locations, the interpretive boards associated with them, and monuments or plaques situated along or adjacent to the route. For each element, narrative summaries derived from physical signage or institutional sources are combined with geospatial route visualisation and photographic documentation.

The platform is designed to preserve existing interpretive materials, communicate Sandakan's historical landscape in a coherent visual format, and support virtual engagement for educators, students, remote users, and individuals facing mobility constraints. Panoramic photographs and 360-degree videos recorded using an Insta360 X5 are incorporated where appropriate. All images and 360-degree clips are stored in their native JPG and MP4 formats and linked to recorded coordinates within the UMS ArcGIS Online workspace, so that each visual record can be traced to a specific site. These recordings provide safe and inclusive access to locations with steep gradients, stairs, or other physical limitations.

The integration of these elements aligns with the project's separation between interpretive content presented publicly and evaluative walkability information retained internally for research and municipal advisory use.

Sampling and Coverage

Data collection began in September 2025 and remains ongoing. All ten officially recognised nodes of the Sandakan Heritage Trail have been documented, beginning at Masjid Jamik (the Town Mosque) and continuing through the William Pryer Monument, the Stairs with a Hundred Steps, and Agnes Keith's House. The route proceeds past the Remains of the Old Staircase, the Goddess of Mercy Chinese Temple (Kun Yam Temple), and St Michael's and All Angels' Church, before

reaching the Sam Sing Kung Chinese Temple, the Malaysia Fountain, and the Wisma Warisan and Sandakan Heritage Museum precinct.

These sites were recorded together with additional interpretive boards, plaques, architectural features, and historically significant markers along adjacent streets. Sampling prioritises complete spatial coverage of the Trail rather than selective emphasis on particular landmark categories, ensuring that the baseline archive captures both the official nodes and the dispersed interpretive features that shape the wider historical landscape. This approach supports the aim of producing a coherent geospatial record that reflects the full range of interpretive materials encountered along the route. Record counts per node currently range from one to five, depending on the number of associated boards and plaques.

Verification Procedures

Verification in this study applies only to historical and interpretive information drawn from physical signboards, plaques, and institutional sources. Contemporary walkability indicators captured in Survey123 are not subject to archival verification, since they represent real-time observational data rather than historical material.

Verification principles

The study follows three verification principles. First, provenance is prioritized over revision, whereby archival and institutional sources are used to confirm the origins, dates, and contextual references of interpretive materials without altering the content of physical signage or plaques. Second, the process adopts a flagging rather than filtering approach; any ambiguities, inconsistencies, or incomplete information identified during verification are recorded in the Internal Research Dataset for future custodial attention, and no modifications are made to the original materials. Third, all original wording is preserved within the internal dataset through verbatim transcription of signboards and plaques, while only curated summaries are presented in the public StoryMap to support readability and visitor orientation.

This approach aligns with digital-heritage scholarship that advocates transparency about the conditions and limitations of existing records, while preserving the historical form and interpretive shape of the documentation. It also maintains a clear distinction between heritage interpretation for public audiences and the more detailed archival record retained for research and custodial review.

Verification will be carried out by the research team in consultation with Sandakan Municipal Council, the Sandakan Heritage Trail Committee, Sabah Museum Department Sandakan Branch, and Sandakan Library. Verification applies only to historical and interpretive text drawn from signboards, plaques, and institutional sources, and does not apply to real-time observational variables.

Data Management and Curation

The study uses a dual-curation model that separates interpretive heritage content from operational walkability assessments, since each serves different audiences and purposes.

Internal research dataset

The Internal Research Dataset contains the full documentation collected through ArcGIS Field Maps and Survey123, including accessibility observations, walkability indices, safety assessments, shading information, and cultural-experience indicators. These data are analytical in nature and

were collected to support academic research, walkability evaluation, and advisory communication with Sandakan Municipal Council.

Because Survey123 indicators measure operational and experiential qualities of the Trail rather than heritage interpretation, they are not included in the public StoryMap. These indicators will instead be used in a separate academic paper on walkability and in reports prepared for municipal partners. The dataset is stored securely in the UMS ArcGIS Online environment and is shared only with municipal stakeholders and for future scholarly outputs.

Public StoryMap designed

The Public StoryMap is designed for heritage education, tourism, and public engagement. It therefore includes only interpretive text derived from signboards and institutional sources, photographs of sites and artefacts, coordinates and location descriptions, and selected visitor-relevant information such as parking availability and inclusive-access features.

These elements support visitor preparedness and interpretive clarity, which are central to the StoryMap's educational purpose. Operational and evaluative information from the Survey123 instrument is intentionally excluded because it does not form part of the Trail's heritage narrative and may distract from its interpretive and tourism functions.

Metadata maintained across both datasets include collector identity, documentation date, verification status, coordinate precision, and archival source. This ensures provenance, supports custodial transparency, and aligns with UNESCO's principles of responsible digital-heritage governance. The curated separation of datasets allows the StoryMap to focus on heritage interpretation while enabling the Internal Research Dataset to support walkability research and municipal advisory work.

Ethical and Legal Compliance

The study is non-invasive and complies with the Malaysian Code of Responsible Conduct in Research (MCRCR) and the National Heritage Act 2005. All field assistants provided verbal consent. Public dissemination through the ArcGIS StoryMaps platform follows UNESCO principles of equitable access, responsible representation, and clear separation between interpretive content and analytical data.

RESULTS AND DISCUSSION

Spatial Dataset and Documentation Logic

The spatial dataset produced through ArcGIS Field Maps provides a transparent and reproducible foundation for documenting the Sandakan Heritage Trail. All ten official nodes were recorded, together with additional interpretive boards, plaques, and historically relevant markers. The resulting inventory captures thirty (30) Field Maps records. All thirty (30) records contain complete coordination and photographic fields, and GNSS metadata indicates a typical horizontal accuracy of approximately ±3 meters. Archival cross-checking has been completed for the ten official Trail nodes and initiated for additional plaques and markers. These descriptive metrics indicate that the baseline archive is complete for the recognized nodes and sufficiently robust for the preliminary analysis presented here.

Figure 1 provides an example of this documentation, showing how the William Pryer Monument appears within the ArcGIS Online Map Viewer. The figure demonstrates how each record stores coordinates, photographs, timestamps, and collector details. This level of detail supports claims that the workflow produces auditable data suitable for long-term custodial reference. The figure also illustrates how the digital record preserves the existing interpretive landscape, including material condition, textual clarity, and spatial location.

Figure 1. Field Maps documentation of the William Pryer Monument interpretive signboard at Dataran MPS. The photograph and coordinates appear in the ArcGIS Online Map Viewer and form part of the ongoing geospatial inventory for the Sandakan Heritage Trail.

The dataset confirms that a lightweight geospatial workflow is sufficient to structure dispersed heritage materials in a way that can be maintained by multiple agencies. This directly supports the study's conceptual argument that technological integration must be paired with custodial clarity, since the data model is easy to adopt and update.

Interpretive Integration in StoryMaps

The ArcGIS StoryMap prototype integrates spatial data, photographs, interpretive text, and archival context into a single interface that supports both educational use and public engagement. Each site panel contains a narrative description that is derived from existing signage or from institutional interpretive sources, together with a photograph and an embedded map.

Figure 2, which presents a preliminary panel for Agnes Keith House, demonstrates how these elements come together. The figure shows how narrative content, site photography, and route information can be combined in a single visual frame. The panel provides clarity and coherence that may not always be available on weathered or fading physical signboards. It also allows users to understand the spatial relationship between different sites along the Trail, which strengthens interpretive continuity.

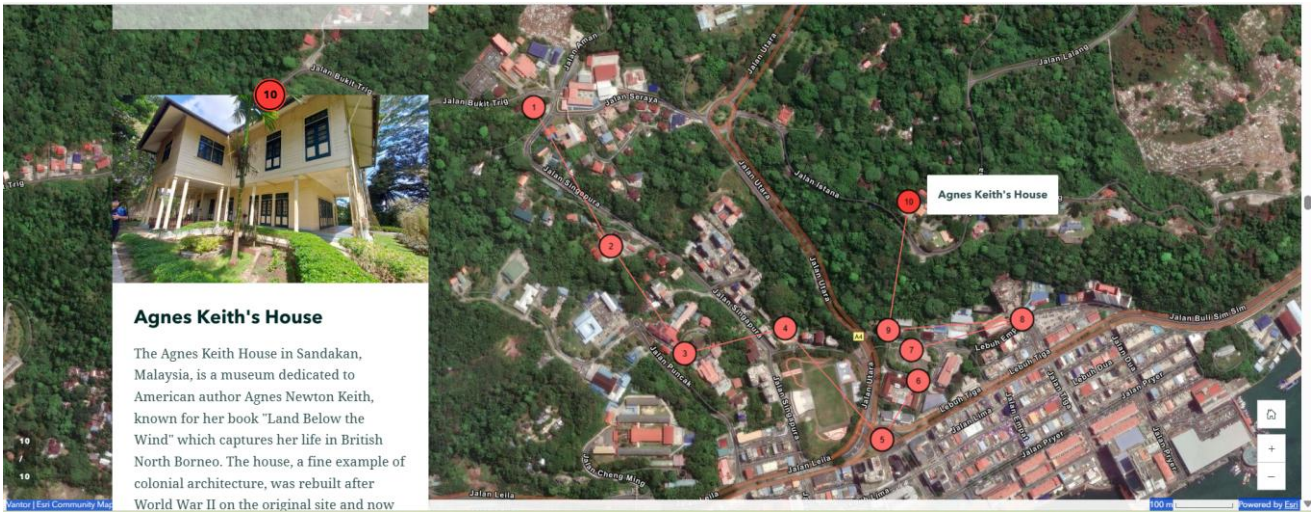

Figure 2. Draft StoryMap panel for Agnes Keith's House showing preliminary integration of narrative text, photographic documentation, and the geospatial route map.

A further example appears in Figure 3, which displays an early thematic grouping of religious heritage sites. This figure shows how StoryMaps can be used not only for sequential navigation but also for thematic interpretation. The grouping of Masjid Jamik As Sheikh Hasabollah At-Tohiri, the Goddess of Mercy Temple, Sam Sing Kung Temple, and St Michael's and All Angels' Church demonstrate the interface's flexibility. Such thematic arrangements allow researchers, heritage practitioners, and custodial agencies to highlight connections across faith traditions, architectural styles, and community histories.

Figure 3. Prototype list-style panel grouping religious heritage sites with accompanying descriptions and spatial markers. This layout is under development and will be expanded as documentation progresses.

A fourth example appears in Figure 4, which presents the North Friendship Window Plaque at St Michael's and All Angels' Church. The figure shows a high-resolution photograph of the plaque, its geolocated position, and the digitized wording derived directly from the physical inscription. This example illustrates how StoryMaps can preserve the text and visual details of plaques and signboards that may deteriorate over time. It also supports interpretive transparency by allowing users to compare the verbatim transcription with the original photograph, making the documentation process and provenance visible.

Figure 4. Example showing how the North Friendship Window Plaque is digitised in the StoryMap interface, with a photograph of the plaque, its transcribed text, and its geolocated position within the Sandakan Heritage Trail.

These four figures show how StoryMaps supports interpretive clarity, multimodal presentation, and accessible learning. They also demonstrate how digitization can preserve the physical form of heritage inscriptions while sitting them within a broader spatial narrative.

Analytical Interpretation of Preliminary Findings

The combined spatial dataset, interpretive panels, thematic clusters, and plaque transcriptions reveal that collaborative GIS can integrate spatial precision with interpretive coherence in a secondary-city context. Figure 1 confirms the reproducibility of spatial documentation by demonstrating consistent coordinate capture and photographic evidence. Figure 2 shows how the StoryMap format consolidates interpretive text and visual material in ways that enhance clarity and educational usability. Figure 3 illustrates the capacity of the platform to support thematic organisation, allowing users to explore cross-cutting relationships between sites. Figure 4 demonstrates how plaques and inscriptions can be preserved digitally with clear provenance, ensuring that material vulnerable to weathering remains accessible in stable archival form. Together, these findings indicate that the workflow is capable of producing a coherent and auditable digital-heritage record.

These examples support the study's conceptual framework, which emphasises technological integration and collaborative governance. The internal dataset provides detailed insight into site conditions and accessibility constraints. The public StoryMap enhances interpretive clarity, supports virtual navigation, and accommodates users who may face mobility challenges.

The distinction between the internal dataset and the public-facing platform is not only practical but also ethical. It prevents evaluative walkability information from being misinterpreted as public commentary, while still allowing municipal partners to make informed decisions about maintenance and accessibility planning.

Representational Gaps and Archival Silences

Although the primary aim of the study is to document and preserve existing interpretive materials, the process made visible several notable gaps in the heritage record. Many signboards emphasise colonial, missionary, and mercantile histories. In contrast, the everyday histories of local

communities, including long-established families and multi-ethnic working populations, are largely absent from formal signage.

These gaps become more apparent when the materials are digitised and viewed together within a single platform. The sequential and thematic layouts shown in Figures 2, 3, and 4 reveal patterns that are less visible when visiting the sites individually. The multimodal integration of site locations, interpretive boards, and plaques within the StoryMap reinforces this visibility by bringing dispersed materials into a coherent spatial and narrative structure. For each Trail site, digitised photographs, curated narrative summaries, and geolocated routes appear in a unified interface, while verbatim transcriptions are retained in the Internal Research Dataset to ensure custodial transparency.

This integrated view enables users to see not only what has been historically documented but also what remains unrecorded. This interpretive visibility aligns with the study's conceptual emphasis on documenting both presence and absence in the heritage record. The study does not alter physical narratives or supplement them with new interpretations. Instead, it records what is present and makes visible what is absent. This approach aligns with post-colonial scholarship that advocates transparency about archival silences rather than retrospective correction. The digital archive may support future efforts by custodial agencies or community groups to broaden the interpretive landscape of the Trail.

CONCLUSION

This study demonstrates that a collaborative digital-heritage workflow can consolidate dispersed interpretive materials, enhance spatial clarity, and support custodial collaboration for the Sandakan Heritage Trail. The workflow, which integrates ArcGIS Field Maps, ArcGIS Survey123, ArcGIS Online, and ArcGIS StoryMaps, produces documentation that is both methodologically transparent and institutionally relevant. The combination of spatial records, archival cross-referencing, thematic arrangement, and plaque transcription illustrates how digital tools can make the existing heritage landscape more accessible without altering any of the narratives inscribed on physical materials.

The four figures included in this study highlight different dimensions of this contribution. Figure 1 demonstrates the reproducibility and spatial precision of Field Maps documentation. Figure 2 illustrates how StoryMaps can consolidate photographs and interpretive text into a coherent and accessible format. Figure 3 shows the potential for thematic structuring that can support educational use and interpretive depth. Figure 4 demonstrates how plaques and inscriptions can be digitized to preserve material text and visual detail that may be vulnerable to weathering or physical loss. Together, these examples show how a multimodal digital workflow can integrate spatial, visual, and narrative elements into a unified platform that supports both public engagement and municipal stewardship.

The findings also reveal the unevenness of the existing heritage record. When the Trail's materials are viewed collectively in digital form, the selective visibility of certain historical narratives becomes more apparent. Colonial, missionary, and mercantile histories are well recorded, while the everyday experiences of long-established local communities remain largely absent from formal interpretation. The digital workflow does not revise or replace these narratives, but it makes visible the shape of the existing archive, including its silences. This approach reflects a commitment to interpretive transparency and to the ethical principles outlined in post-colonial and UNESCO literature on heritage communication.

The dual dataset structure enhances this transparency. The internal dataset contains walkability assessments and site-condition observations that can support municipal planning, while the public StoryMap provides interpretive and educational information without evaluative commentary. This distinction protects users from misinterpretation while allowing custodial partners to make informed decisions about accessibility, signage maintenance, and visitor management. Such a separation reflects best practice in responsible digital-heritage governance.

Although the present study is preliminary, it provides a transferable model for other secondary cities that face similar challenges of fragmented documentation, limited resources, and uneven custodial capacity. The workflow is lightweight enough to be adopted incrementally and robust enough to anchor long-term heritage management. Future work may expand the dataset, incorporate additional thematic layers, or deepen collaboration with local communities and archival institutions. Such expansions would allow the digital archive to grow as a living record that preserves what is present and draws attention to what remains undocumented.

In summary, the project shows that a coordinated digital-heritage workflow can support preservation, interpretation, and custodial communication in a context where physical materials are vulnerable and documentation is uneven. It contributes to the broader discourse on sustainable digital heritage by demonstrating how geospatial methods, collaborative governance, and interpretive transparency can be aligned to support inclusive and accessible heritage practice in Sandakan and beyond.

DATA AVAILABILITY STATEMENT

The spatial records, photographs, and observational data generated during this study are maintained within a secure ArcGIS Online workspace managed by Universiti Malaysia Sabah. Because the project is ongoing, full datasets are not yet publicly available. A simplified dataset that includes verified site names, coordinate locations, and non-sensitive image metadata will be deposited in the UMS Institutional Repository when the next project phase is completed. Researchers may request access to the full dataset from the corresponding author, subject to approval from Sandakan Municipal Council, Sabah Museum Department Sandakan Branch, and Sandakan Library as relevant custodial agencies. Public-facing interpretive content will be accessible through the ArcGIS StoryMaps platform once the interface has undergone final verification.

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REFERENCES

[1] Angelidou, M. & Stylianidis, E. 2020. Cultural heritage in smart city environments: The update. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, 5(2), 957–964.

[2] Aziz, A. S. A. & Noor, N. A. M. 2017. Safeguarding intangible cultural heritage in Malaysia: A legal analysis on the National Heritage Act 2005. *The European Proceedings of Social and Behavioural Sciences*. Future Academy. pp 841–848.

[3] Boyd, S. W. 2017. Editorial: Heritage trails and tourism. *Journal of Heritage Tourism*, 12(5), 417–422.

[4] Chirikure, S., Mukwende, T. & Taruvinga, P. 2015. Post-colonial heritage conservation in Africa: Perspectives from drystone wall restorations at Khami World Heritage Site, Zimbabwe. *International Journal of Heritage Studies*, 22(2), 165–178.

[5] Henderson, J. C. 2012. Conserving heritage in South East Asia: Cases from Malaysia, Singapore and the Philippines. *Tourism Recreation Research*, 37(1), 47–55.

[6] Hsu, P. H. 2023. Reconstruction of the lost colonial architecture in the context of heritage tourism: Dutch Trading Post in Taiwan. *Built Heritage*, 7(1), 14–29.

[7] Mantzou, P., Bitsikas, X. & Floros, A. 2023. Enriching cultural heritage through the integration of art and digital technologies. *Social Sciences*, 12(11), 594–611.

[8] Mat Nayan, N., Jones, D. S., Ahmad, S. & Khamis, M. K. 2021. Exploring the built-environment: Heritage trails, values and perceptions. *IOP Conference Series: Earth and Environmental Science*, 881, 12009.

[9] Poulopoulos, V. & Wallace, M. 2022. Digital technologies and the role of data in cultural heritage: The past, the present, and the future. *Big Data and Cognitive Computing*, 6(3), 73–91.

[10] Riganti, P. 2017. Smart cities and heritage conservation: Developing a smartheritage agenda for sustainable inclusive communities. *Archnet-IJAR: International Journal of Architectural Research*, 11(3), 16–27.

[11] Sabah Tourism Board. 2022. *Sandakan Heritage Trail* (https://sabahtourism.com/destination/sandakan-heritage-trail/). Last accessed on 20 February 2025.

[12] Sham, D. H. M. 2015. *Heritage as resistance: Preservation and decolonisation in Southeast Asian cities.* PhD Thesis, University of London, United Kingdom.

[13] Shehade, M. & Stylianou-Lambert, T. 2020. Revisiting authenticity in the age of the digital transformation of cultural tourism. *In:* Katsoni, V. & Spyriadis, T. (Eds.), *Cultural and Tourism Innovation in the Digital Era*. Springer International Publishing. pp 3–16.

[14] Ugong, N. A. 2024. Sustainable cultural heritage management: A case study in Sarawak, Malaysia. *Journal of Cultural Heritage Management and Sustainable Development*, ahead-of-print. https://doi.org/10.1108/JCHMSD-04-2023-0036

[15] UNESCO. 2025. Guide 4: Engaging local communities and businesses. In: *UNESCO World Heritage Sustainable Tourism Online Toolkit.* UNESCO, Paris. (Available at https://whc.unesco.org/document/198410). Last accessed on 20 February 2025.