

Research Article

Developing Frameworks for Digitizing Tangible and Intangible Cultural Heritage

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ABSTRACT

The digital transformation of cultural content faces several challenges because of the lack of common frameworks and standardised techniques. This leads to fragmented data, unreliable project results, and ineffective workflows. This work develops integrated methodological structures to digitise both tangible and intangible cultural assets within a single framework. For tangible heritage, best practices for capturing 3D data via photogrammetry and laser scanning at different scales (e.g., large-scale, medium-scale, small-scale, and interior spaces) are defined. To preserve oral storytelling, soundscapes, dialect dictionaries, social customs, and culinary practices, the authors develop systematic digital curation workflows for intangible heritage using cloud-native architectures and multimedia. The suggested concepts are presented in an online guide and validated through concrete examples. An expert assessment by fifteen international experts in cultural heritage digitalisation shows strong reliability, with Cronbach's alpha values ranging from 0.79 to 0.88 across all workflows. Statistical analysis supports the proposed approach by showing that tangible and intangible process ratings do not differ significantly ($p>0.05$). For all workflows, more than 96% of expert ratings were at or above the 4.0/5.0 acceptability standard. Time analysis shows that, compared with ad hoc procedures, the recommended workflows reduce project duration by 30–50% and rework rates from 30–40% to 10–15%. Finally, the success rates for new developers rise from roughly 45% to 85%.

1. INTRODUCTION

1.1. Research Overview

The digitisation of cultural heritage has become critical for sustainability and continuity because of risks such as conflict, climate change, urban development, and natural degradation over time. One of the most traditional approaches to preserving cultural and historical heritage is taking photos or videos. These photos or videos can be taken using a regular camera. Today, sophisticated instruments and procedures like laser scanning are used. Despite recent major developments in technology, many preservation and digitisation activities remain scattered. Isolated initiatives often rely on ad hoc processes that prioritise short-term outcomes over long-term sustainability, interoperability, and analytical depth. This is especially challenging when managing both tangible

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cultural possessions (such as objects, monuments, and locations) and intangible cultural assets (such as customs, oral histories, artwork, and social behaviours) [1]. Tangible assets need accuracy in quantitative and material representation, while intangible assets need depth in context and story. Therefore, we need to develop comprehensive techniques for digitising both tangible and intangible cultural assets within a single conceptual and technical framework. In this work, we aim to close this gap and suggest such a framework. The study has two concurrent yet linked tracks. The primary objective for tangible heritage is to produce effective 3D data collection techniques, especially employing photogrammetry and laser scanning. The study prioritises efficiency (such as processing speed and data compression), geometric accuracy, and, most importantly, metadata standards to ensure digital replacements remain verifiable, reusable, and compatible across platforms and over time. Multimedia and cloud-based services are included in intangible heritage research, which is moving towards structured digital curation. The goal is to move from static archive storage to dynamic, accessible systems that guarantee equitable access and sustainable preservation while maintaining the intangible cultural material's vital character. This work emphasises that digitised heritage archives, whether derived from 3D scans or ethnographic recordings, offer intricate, multifaceted datasets that transcend capture and maintenance. The proposed framework will be evaluated in a range of physical settings, institutional contexts, and heritage typologies. This work also produces a collection of transferable, evidence-based concepts and technological designs that cultural practitioners, digital archivists, and legacy institutions can use.

1.2. Literature Review

Cultural heritage preservation has been covered in a large body of literature. Rather than offering repeatable procedures, most research focuses only on methods and resource efficiency (e.g., rendering time, memory use, CPU bursts). [2] First established the conceptual connection between tangible and intangible characteristics in historic structures, arguing that intangible dimensions (such as cultural values, social memory, and meanings associated with architecture) are sensations distinct from material form. In contrast, tangible qualities involve physical interaction with objects. That report did not, however, offer a pipeline for digitalisation. A study by [3] developed a virtual reality methodology using a qualitative longitudinal approach over five years, outlining procedures for data collection, establishing a story-based framework, and interactively exhibiting heritage through VR projects. [4] addressed the rarely quantified problem of heritage sustainability at the project level, defining the term and suggesting assessment and quantification techniques based on best practices from Greece, Italy, the Netherlands, Poland, Portugal, and Spain. Zhang and Zhang [5] also examined the digital development process in landscape architecture heritage protection in 2022. They identified three main stages: data precision, information uniformity, and smart management. They also recommended that future studies concentrate on cooperative exchange of knowledge.

The researchers in [6] claimed that digitisation is a powerful instrument for restoration, conservation, and analysis, especially when paired with parametric modelling and semantic enhancement. Maietta highlighted that digital survey techniques add multiple levels of knowledge to 3D metric-morphological models. Using the Tabriz Bazaar as a case study, Elyas and Yamaçlı [7] investigated the relationship between sustainability and cultural heritage, examining how heritage might be protected while balancing sustainable urbanisation and economic growth. Although Corona's work did not specifically target historical workflows, he made the tangential but pertinent comment that greater internet availability and lower technology costs had opened up digital participation. In 2024, Lian and Xie [8] discussed how digital cultural legacy has shifted from static formats like painting and photography to dynamic formats like animation, 3D reconstruction, and virtual reality interaction. They contended that by presenting legacy as an expressive practice of media discourse and concrete experience, new media offer multimodal, multimedia presentations that significantly improve the authenticity, accessibility, and emotional experience of cultural ownership. The year 2025 saw the highest level of activity, indicating the field's growing urgency. To identify trends in digital conservation methods, Yue et al. [9] examined digital conservation strategies for intangible cultural heritage from the standpoint of a digital resource's lifecycle (e.g., creation, utilisation, administration, and preservation). They examined articles published between 2018 and 2024.

Chung et al. [10] conducted a comprehensive literature review that revealed significant disparities in public participation and classification, showing how conventional UNESCO-based frameworks, which classify cultural assets as tangible or intangible, struggle to handle hybrid and digitally emerging heritage forms. Parnitas et al. compiled the material to build a three-dimensional framework focused on sustainability, technological uptake, and cultural fit, even though it is conceptual rather than operationalised for developers. They argue that technologies like VR, AR, and AI are essential for capturing, disseminating, and passing down cultural knowledge across centuries. Lucchi [11] discussed how standardised digital twins are used in smart city heritage and tourism, including building management, energy simulation, pathology mapping, maintenance prediction, and augmented and virtual reality. Most recently, Ren and Lam (2026) [12] used bibliometric techniques to analyse 798 research articles from the Web of Science and China National Knowledge Infrastructure databases covering 2006 to 2024 to provide an organised comparison of intangible cultural heritage digitisation approaches in Chinese and Western academic discourses. Their research did not address tangible material or offer an integrated framework, despite acknowledging that digital cultural heritage protection has become an essential strategy for preserving diverse cultures. This entire collection of work exhibits an important pattern.

Furthermore, studies such as [10] and [13] show an absence of hybrid classification frameworks and emphasise conceptual dimensions rather than operational workflows. Liu et al. (2025) [13] designed a guide that focused only on laser scanning for tangible heritage. The work of [14] summarises tools without prescribing how developers should sequence workflows, manage metadata, or integrate analytical layers. The gap between technique-centric studies and the real-world needs of cultural heritage developers constitutes the central problem that this research directly addresses. This gap is the absence of a unified, replicable framework for digitising both tangible and intangible cultural heritage in an efficient, standardised, and analytically rich manner.

1.3. Problem Statement and Contribution

According to the literature, most studies focus on specific methods for tangible cultural properties, such as laser scanning, photogrammetry, and BIM, or on intangible cultural heritage, such as digital storytelling, AR/VR experiences, and cloud-based archiving. As a result, cultural asset producers and digitisers often adapt distinct tactics to the current demands of their tasks. These ad hoc changes may work in certain situations, but they typically do not transfer to other similar digitisation processes. One of the main issues this fractured environment creates is the lack of standards in digitisation processes. This is particularly challenging for new developers who lack the expertise to navigate competing technological decisions, metadata standards, and preservation methods. In addition, there is no systematic way to replicate the success of specific programs across institutions, heritage types, or geographic contexts when they deliver high-quality results. Comprehensive workflows that cultural heritage developers can readily modify are therefore desperately needed.

This article aims to close the gap identified above by developing comprehensive approaches that guide developers from data collection to complex analysis and presentation. The recommended approaches address both tangible and intangible heritage. Consequently, the following contributions are made by this article: (1) Establish a standard and verified framework that provides creators of tangible and intangible resources with standard procedures that are effective for cultural resources. The suggested frameworks are applied to real-world examples to validate them for replication. (2) Provide a comprehensive online guide for those who create tangible and intangible cultural resources. This guide provides detailed instructions that start with data collection and conclude with the production of digital models.

The remaining parts of this article are arranged as follows: Section 2 describes the research method used to produce this article. Section 3 presents the results and discussion. Section 4 concludes the article.

2. Research Method

This section presents the general research approach and methodological workflows used in this work. It then covers the methods used to collect data and information from scholarly and real-life sources, such as literature reviews, fieldwork, expert meetings, and digital document techniques. To connect the best digitising methods to each classification, special attention is paid to categorising heritage collections into tangible and intangible categories. As mentioned, this section also clarifies the proposed workflows developed for digitising both tangible and intangible heritage. The processes for tangible heritage emphasise multiple documentation scales as follows:

- Large-Scale heritage Documentation.
- Medium-Scale Documentation.
- Small-Scale Documentation.
- Interior Areas Documentation

Real-world execution uses photogrammetry, image collection, 3D modelling, data manipulation, and digital archive techniques. The chapter evaluates the efficiency and applicability of the proposed workflows across different heritage sites. This chapter also covers approaches to recording intangible cultural heritage. This involves applying digital recording and archival methods to gather and organise oral traditions, rites, social practices, traditional information, and cultural representations. To support future preservation, intangible heritage procedures promote digital storage, metadata structure, systematic recording, and accessibility. We used several information sources, including research sources, field research, real-world testing, and visual documentation. Through incremental development and real-world testing, we used an iterative approach to refine the proposed workflows. Experts in computer science, digital files, and cultural conservation were given standardised survey forms to complete, enabling expert evaluation. To improve workflows and increase their practicality in real heritage digitalisation projects, the collected feedback was examined for benefits, drawbacks, and opportunities.

The data collection method supported the proposed methods for digitising both tangible and intangible heritage. To ensure the precision, reliability, and completeness of the data collected, we used multiple sources and methods. Depending on the scope and type of each heritage case analysis, the approach involved digital data collection, expert advice, visual recording, and field documentation. Direct site visits and photographic documentation using mobile devices and standard digital imaging programs like Polycom were used to gather data for tangible heritage. Different digital techniques, such as small-, medium-, and large-scale documentation procedures, were used based on the size and condition of the cultural assets. To simplify photogrammetry-based 3D reconstruction and digital storage, overlapping photos taken from different viewpoints formed the collected visual data. During field research, the team also documented additional data on architectural elements, material conditions, spatial dimensions, and the environment. The data collection procedure for intangible heritage concentrated on recording oral expressions, customs, cultural practices, social activities, and local knowledge related to the chosen heritage sites. The team used observation, interviews, audio-visual recording, and community involvement to collect data. The information gathered aimed to protect intangible cultural heritage elements' cultural relevance and contextual meaning, in addition to their physical surroundings. Tangible cultural heritage represents the physical and material aspects of cultural identity that can be visually documented, preserved, and digitally reconstructed using modern technologies. These heritage elements include historical buildings, archaeological sites, monuments, artefacts, religious structures, traditional houses, interiors, and architectural details that carry significant historical, cultural, and social value. The preservation of tangible heritage has become increasingly important because environmental deterioration, urban development, natural disasters, and human-related damage threaten the survival of many heritage assets. Digital heritage documentation technologies offer efficient solutions for recording and preserving these physical elements through accurate, high-quality digital representations. Techniques such as photogrammetry, 3D reconstruction,

image-based modelling, and digital archiving enable the creation of detailed digital models that support conservation, restoration, visualisation, and long-term preservation purposes. In this section, the proposed tangible heritage digitisation workflow is designed and evaluated in practice using several case studies with different scales and environmental conditions. The implementation process demonstrates how the proposed workflow can be adapted for large-scale, medium-scale, and small-scale heritage documentation projects. The practical application includes data collection, photographic acquisition, image alignment, dense point cloud generation, mesh reconstruction, texture mapping, and model optimisation processes. The paper also discusses different documentation challenges and processing techniques to evaluate the proposed workflow's flexibility and efficiency.

The methodical approach of turning tangible and intangible cultural heritage resources into digital versions on a large or institutional scale is known as "large-scale heritage digitisation." To capture, protect, and manage heritage objects, this method uses modern technology, including 3D scanning, photogrammetry, high-resolution imaging, Geographic Information Systems (GIS), and audio-visual recording. The primary objective of large-scale digitisation is to ensure the long-term preservation of cultural heritage, particularly when artefacts, heritage sites, or customs are at risk from natural decay, development, conflict, or environmental degradation. Preservation of heritage groups can preserve knowledge and make it available for the general public, teaching, and research by creating flawless digital copies and structured databases. Figure 1 illustrates the suggested comprehensive procedures for documenting extensive historic material.

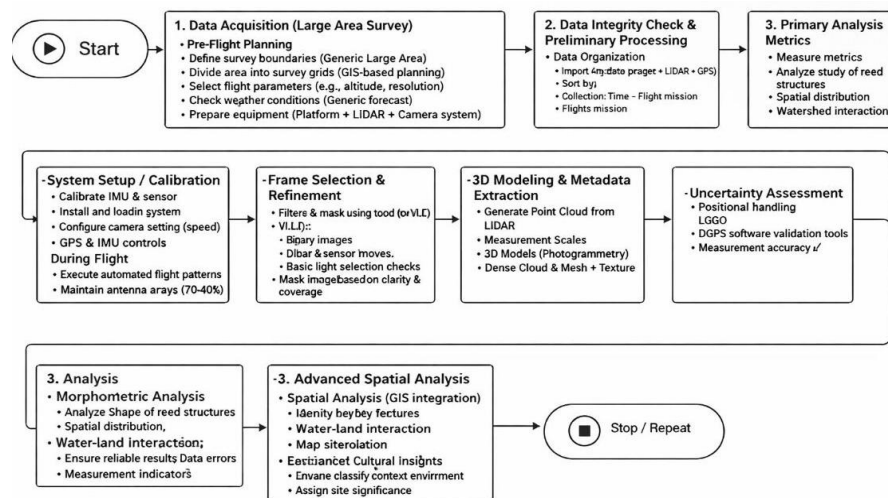


Figure 1: proposed method for digitising heritage on a large scale.

The starting point of the digitisation method, Data Collection (Large Area Survey), focuses on gathering visual and spatial data from vast cultural environments. The process starts with pre-flight planning. The standardised questionnaire's boundary lines are defined and separated into structured GIS-based grids to enhance coverage and navigation accuracy; flight parameters such as altitude, resolution, and overlap percentage are set up in proportion to the study area's scale; weather conditions are also assessed to guarantee stable environmental conditions during data collection; and all required equipment, such as UAV platforms, LiDAR sensors, GPS systems, and camera units, is prepared and calibrated before field deployment. After data collection, the datasets undergo initial processing and quality testing. This section involves importing and systematically collecting raw data from LiDAR sensors, cameras, and GPS systems using flight missions and collection time. The datasets are sorted, validated, and checked for damaged files, missing data, and synchronisation issues. This stage ensures the information gathered is complete, organised, and ready for further analysis and 3D reconstruction. The main purpose of this step is to extract key environmental and spatial parameters from the collected data.

Assessments of the morphology and distribution of heritage artefacts are conducted to identify structural features and spatial linkages within the investigated landscape. The analysis additionally assesses environmental interactions, such as water-land linkages and distribution patterns, to understand the cultural and natural significance of the heritage geographic area. Before and during field tasks, the system setup and validation process ensures the accuracy and operational readiness of all standardised sensor technologies. This involves adjusting camera settings, confirming GPS alignment, and calibrating the IMU and standard sensor systems. Automatic flight paths are flown while station coverage and communication remain continuous. Proper calibration increases the reliability of the recorded spatial data and reduces positioning errors. Frame selection and refinement involve improving and filtering sensor outputs and collected images to improve data quality. Frames with motion blur, inconsistent sensor movement, insufficient overlap, or low quality are removed. Image masking and visibility filtering techniques ensure clarity and optimise coverage for photogrammetric processing. This enhancement phase increases the accuracy and efficiency of subsequent 3D reconstruction procedures.

3D modelling and metadata extraction include several procedures. In this step, data from the survey is processed to create precise digital images of the heritage environment in three dimensions. LiDAR point clouds are generated and integrated with photogrammetric datasets to create high-resolution spatial reconstructed images, textured meshes, and dense 3D models. To facilitate documentation, preservation, and future research, model-related metadata, such as geographic coordinates, scale information, and acquisition parameters, are also retrieved and archived. As a component of the uncertainty evaluation process, the reliability and precision of the generated digital output must be assessed. Analyses to find possible explanations of inaccuracy include software validation processes, measurement consistency, and position accuracy. The quality of the retrieved models is evaluated using spatial accuracy indicators and DGPS validation methodologies. The process ensures the final datasets meet scholarly documentation and heritage requirements.

The main goal of medium-sized heritage digitisation is to document cultural assets by balancing broad coverage with detailed item representations. This scale is ideal for architectural elements, monuments, and historic buildings where precise geometric and visual details are essential. The pipeline usually consists of information collection, processing, 3D reconstruction, and analysis to provide dependable digital models for documentation, preservation, and future research.

As seen in Figure 2, the medium-scale heritage digitisation workflow is a structured, methodical framework for using digital technology to preserve and document cultural sites. The workflow begins with the site planning and preparation phase, where the team identifies selected cultural assets and clearly defines the survey goals. During this phase, the team establishes the necessary tools, sensing technologies, and documentation techniques to ensure a well-organised and effective field operation. To achieve reliable and precise digital outcomes, careful planning is necessary at this point. Data collection is the primary goal of the second step, which involves collecting visual and spatial data from the historical environment using various digital recording devices. GPS positioning systems, LiDAR scanning, UAV aerial photography, and ground-based photography are all commonly used to collect precise geometric and environmental data. With high spatial accuracy, these methods enable researchers to record the cultural site's physical features from various viewpoints. The collected datasets go through data structuring and validation processes when the field survey is finished. To verify consistency and completeness, the collected photos, scans, and spatial data are methodically organised and reviewed at this stage. By examining image clarity, spatial alignment, and positional accuracy, the team confirms data quality. Before moving to the next processing step, any corrupted, duplicated, or incomplete files are discarded.

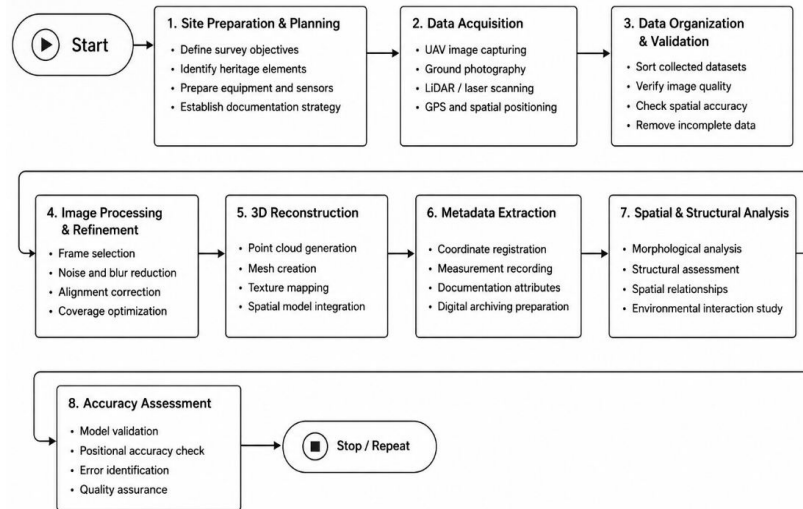


Figure 2: Medium-scale heritage digitisation process.

Next, the procedure moves to image processing and refinement, where the gathered visual datasets are enhanced to better suit digital restoration. Image refinement techniques include frame selection, noise reduction, blur correction, and alignment adjustment. During three-dimensional reconstruction, these procedures help maximise image coverage and improve feature-matching precision. During the 3D reconstruction stage, processed datasets are transformed into digital three-dimensional models. To create precise graphical representations of the heritage environment, standardised point clouds from photogrammetry and LiDAR scanning are converted into detailed mesh structures and textured surfaces. This step produces a thorough digital model for investigation, preservation, and display. Recording and structuring supplementary documentation about the produced digital representations is the main goal of the metadata extraction stage. This includes geographic coordinates, measurements, descriptive characteristics, and archival information related to the heritage pieces. The extracted metadata makes future search, management, and scholarly analysis of heritage data easier and helps preserve digital information. To determine the physical and environmental characteristics of the identified heritage features, the workflow additionally includes spatial and structural analysis. The workflow examines the structure, status, and spatial connections of the heritage components through morphological analysis and structural evaluation. To understand how surrounding conditions affect the detected structures, interaction-with-the-environment studies may also be carried out. Accuracy assessment is the final technical step, where the reliability and quality of the digital outputs are evaluated. To assess positional accuracy, identify potential errors, and ensure compatibility between the digital model and the actual heritage environment, validation processes are used. To ensure the results meet research and heritage documentation standards, quality assurance procedures are implemented. At the conclusion of the workflow, the entire digitisation process is reviewed to determine whether the required level of accuracy and completeness has been reached. If errors, missing data, or processing problems are found, the approach can be repeated or improved to produce better digital documentation outcomes.

Small-scale documentation of tangible cultural heritage focuses on digitising individual artefacts and compact objects with high geometric and surface detail. This scale is the most detailed level in the proposed heritage digitisation workflow, with the primary objective of capturing fine structural characteristics, surface textures, and material properties with high accuracy and resolution. The small-scale heritage digitisation workflow follows a structured approach. Using precise recording and digital preservation technology, specific cultural objects, artefacts, interiors, or minor design elements can be digitally documented, as seen in Figure 3. The workflow begins with project planning, where the goals of the documentation procedure are defined, and the heritage item chosen for digitisation is carefully examined. To ensure effective and precise data collection, this phase includes developing appropriate documentation techniques, tools, and capture plans. Data collection,

which focuses on obtaining comprehensive spatial and visual data about the historic object, is the second stage. While terrestrial laser scanning may be used when more geometric precision is needed, close-range photography is often used to capture high-resolution images from various viewing angles. To ensure dimensional correctness throughout the digitisation process, hand measurements and scale references are also documented. Positioning techniques and control points improve the reliability of the collected datasets.

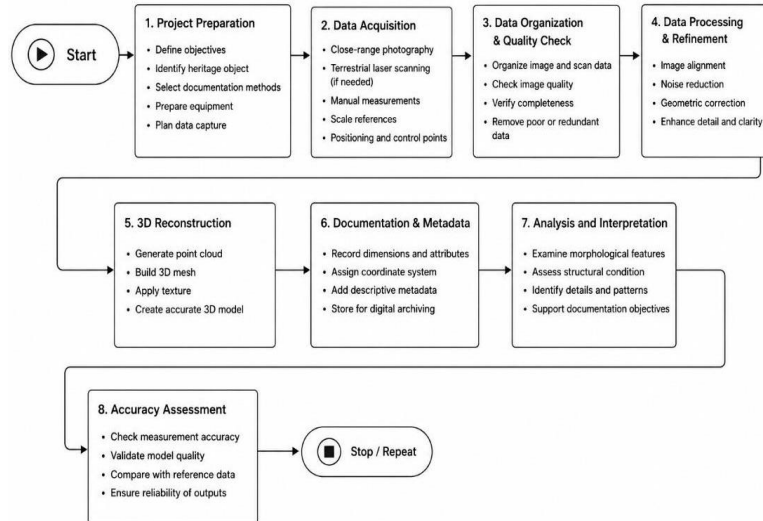


Figure 3: Small-Scale heritage digitisation process.

The documentation and metadata stage aims to record technical and standard data related to the digital model. To support digital archives and future academic studies, measurements, dimensions, coordinate systems, and descriptions are added. Additionally, metadata management improves the structure, accessibility, and long-term preservation of digital heritage records. The analysis and interpretation step examines the documented heritage object's physical and visual attributes. To better understand the object's form, condition, and historical importance, researchers examine morphological traits, structural conditions, and surface details. In addition to supporting the goals of historical recording, this analytical procedure helps scholars identify patterns and relationships in the recorded data. Accuracy evaluation is the last step in the workflow, where the reliability and quality of the produced digital outputs are assessed. By comparing results with reference data and field measurements, the workflow confirms measurement accuracy, geometric consistency, and model quality. This phase ensures that the finished digital models meet appropriate documentation and preservation requirements. The results are examined at the end of the workflow to determine whether the digitisation process produced the required precision and detail. If mistakes or missing information are found, more data collection or processing steps may be performed to improve the final digital documentation. The section that follows applies the proposed workflow to a chosen case study to show its results and practical application. The goal of small-scale interior heritage recording is to capture constrained or confined indoor areas in great detail, especially when the subject is partially damaged or delicate. This scale is crucial for documenting architectural conditions that could eventually be lost or further deteriorated, enabling accurate digital preservation and surface and structural characteristic study. The interior large-scale heritage digitisation workflow is a detailed, methodical procedure for in-depth digital documentation of intricate interior heritage environments. The workflow begins with the project planning and preparation stage, as shown in Figure 4, where the general goals of the digitisation process are specified, and the documentation scope is made explicit. In this stage, the interior environment's features are examined, suitable documentation techniques are selected, and all necessary tools and materials are prepared. To ensure the digitisation process is carried out successfully, a defined workflow strategy and timeline are also developed. Creating a detailed data-gathering plan is part of the second stage, which focuses on survey planning and design. To ensure thorough spatial recording, scan coverage and image capture strategies are carefully

developed during this stage. To enable reliable, accurate data collection, station locations are determined, control points are set, and security and accessibility factors are integrated into the design process.

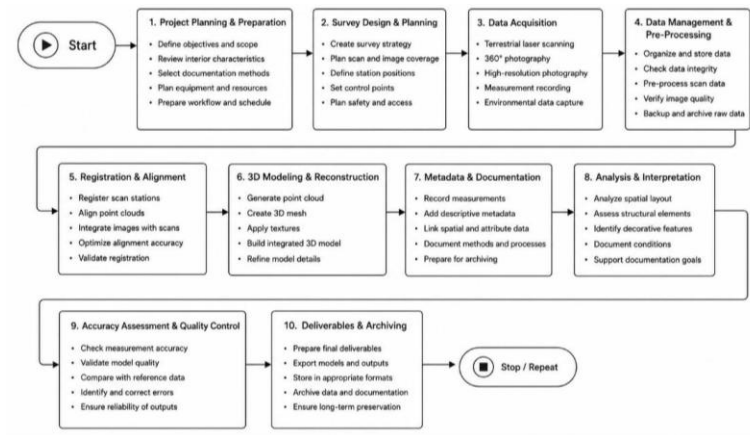


Figure 4: Interior heritage digitisation process.

The methodical recording of all pertinent technical and descriptive data related to the digital models is part of the metadata and documentation step. The digital outputs are linked to measurements, spatial relationships, and characteristic data. This step also ensures the data is properly organised for access and future archiving. The analysis and interpretation step focuses on the spatial organisation and structural characteristics of the recording environment. The analysis evaluates building elements, identifies decorative and functional features, and examines spatial arrangements. The analysis results support understanding the condition and significance of the documented heritage space. The dependability and precision of the produced digital models are assessed during the accuracy evaluation and quality control phase. Model quality is verified, measurement accuracy is examined, and comparisons with reference data are carried out. To ensure the final outputs meet the required documentation standards, any identified faults are corrected. In the final stage, the finished digital models and related data are prepared for long-term preservation and distribution, including deliverables and preservation. To ensure long-term preservation and future accessibility, final outputs are exported in appropriate formats, organised methodically, and stored. Depending on whether the digitisation goals have been achieved, a stop-or-repeat decision is made at the end of the workflow.

This section presents workflows for digitising intangible cultural elements, including traditional practices, cultural activities, oral expressions, and social interactions. The strategy in this section differs from that used for tangible cultural heritage: it considers general case studies from cultures worldwide and designs workflows accordingly. The diagrams in this section illustrate the stages of data acquisition, digital recording, processing, classification, and archival organisation used in the practical work. Every case study emphasises how digital technologies can help preserve intangible cultural assets and turn cultural experiences into structured digital material that can be accessed in the future. To assess the effectiveness, usability, and applicability of the suggested workflows, we distributed research surveys to specialists in computer science, digital documentation, cultural heritage, and related areas. A questionnaire evaluated several factors, including workflow clarity, data collection efficiency, the relevance of the chosen technology, the correctness of documentation techniques, and the overall feasibility of implementation in real legacy projects. We analysed the collected responses to assess the efficiency of the proposed workflows. Table 1 summarises the participants' demographics. The sample included 15 cultural heritage experts with experience in digitising cultural heritage.

Table 1: Participants' demographics.

Item	Description
Age Range	25-65
Countries	Iraq (4), Germany (5), Cyprus (1), Jordan (2), Lebanon (1), Sudan (1), Estonia (1)
Specialization	Computer Science (10), Archaeology (2), Architectural Engineering (3)

DCH Expert

All are experts in the field.

The analysis metrics used for the aforementioned questionnaires are summarised as follows:

The Reliability Analysis (Cronbach's Alpha (α)) measures internal consistency – do all questions in a questionnaire measure the same underlying construct (e.g., "workflow quality")? It is given by:

$$\alpha = \frac{k}{k-1} \left(1 - \frac{\sum_{i=1}^k \sigma_{Y_i}^2}{\sigma_X^2} \right) \quad (1)$$

Where k denotes the number of questions, $\sigma_{Y_i}^2$ represents the variance of i , σ_X^2 denotes the variance of the total sum of all items.

ANOVA analysis is used to test if there is a significant difference in the scores of (Q5) between the five workflows. Here, the hypothesis testing includes the following:

- Null Hypothesis (H_0): $\mu A = \mu B = \mu C = \mu D = \mu E$ (all workflow means are equal)
- Alternative Hypothesis (H_1): At least one workflow mean is different.

The following equation gives the ANOVA F-statistic:

$$F = \frac{F_{between}}{F_{within}} = \frac{\frac{\sum_{j=1}^k n_j (\bar{y}_j - \bar{y})^2}{k-1}}{\frac{\sum_{j=1}^k \sum_{i=1}^{n_j} n_i (y_{ij} - \bar{y}_j)^2}{N-k}} \quad (2)$$

Principal Component Analysis (PCA) was also used to see if the 5 questions of Website F load onto one underlying factor (e.g., "Overall Website Quality"). It is given by:

$$PC_1 = a_{11}F_1 + a_{12}F_2 + a_{13}F_3 + a_{14}F_4 + a_{15}F_5 \quad (3)$$

Where a are the loadings for each original question.

3. Results and Discussions

Because cultural heritage digitisation needs clear guidance, this work developed an online guide that CH developers can follow. The developed guide is presented as an online guide that provides detailed step-by-step procedures for digitising TCH and ICH, as shown in Figure 5.

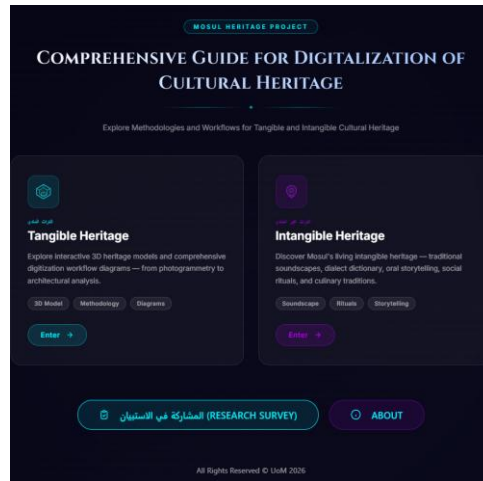


Figure 5: Tangible and intangible online guide front page.

The TCH section includes the workflows for four digitisation categories considered in this work (e.g., large-scale, small-scale, medium-scale, and interior heritage digitisation), as shown in Figure 6.

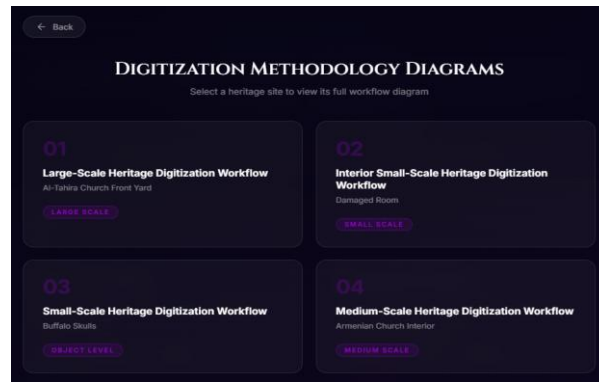


Figure 6: Four categories of TCH digitisation in the online guide.

The workflow for each category is accessible, and the sample models used to test the workflow are also presented. The most common technologies used for digitisation are photogrammetry, 3D laser scanning, and three-dimensional techniques. These are considered modern technologies used to preserve tangible heritage. These strategies differ based on the heritage asset's size, complexity, and type. It is worth mentioning that the technical aspects of generating the 3D models in this work are implemented but not described since they are out of this paper's scope. This work covers the procedures and steps required for digitising cultural heritage. The technology used depends on the developers and their skills. For instance, based on our field observations, we can use drone scanning for data collection. Smartphones or cameras can also be used for scanning when the heritage site is accessible enough for these devices, as shown in Figure 7.



(a) Large-Scale Tangible Heritage: Al-Chibayish Marches



(b) Medium-Scale Tangible Heritage



(c) Small-Scale Tangible Heritage



(d) Interior Tangible Heritage



(e) Intangible Heritage Cases

Figure 7: Tangible and intangible case studies considered in this work and the developed online guide.

This section presents and analyses responses from 15 experts (E1–E15). The strategy followed in this evaluation is based on the following distribution:

- Experts E1–E3 evaluated workflow A.
- Experts E4–E6 evaluated workflow B.
- Experts E7–E9 evaluated workflow C.
- Experts E10–E12 evaluated workflow D.
- Experts E13–E15 evaluated workflow E.
- All experts' responses to Questionnaire F.

Table 2 presents the expert responses to the questionnaires. The evaluation used a Likert scale of 1 to 5. Each questionnaire relates to a particular case considered in this work (large-scale (A), small-scale (B), medium-scale (C), medium-scale for interior areas (D), large-scale for interior areas (D)). The online guide (website) was also evaluated.

Table 2: Experts' responses to the designed questionnaires.

Expert	Workflow	Q1	Q2	Q3	Q4	Q5
E1	A	5	4	5	4	4
E2	A	4	5	4	5	5
E3	A	5	5	5	4	5
E4	B	5	5	4	5	5
E5	B	4	4	5	4	4

E6	B	5	5	5	5	5
E7	C	4	5	5	4	4
E8	C	5	4	4	5	5
E9	C	5	5	5	5	5
E10	D	4	5	4	5	4
E11	D	5	4	5	4	5
E12	D	4	5	5	5	5
E13	E	5	5	5	4	5
E14	E	5	4	4	5	4
E15	E	4	5	5	5	5

Table 3 presents the responses for Questionnaire F (Website). All 15 Experts show their responses.

Table 3: Expert responses to the online guide.

Expert	F1	F2	F3	F4	F5
E1	5	4	5	5	5
E2	4	5	4	4	4
E3	5	5	5	5	5
E4	4	4	5	4	4
E5	5	5	4	5	5
E6	4	5	5	4	5
E7	5	4	4	5	4
E8	5	5	5	5	5
E9	4	5	5	4	5
E10	5	4	5	5	5
E11	4	5	4	5	4
E12	5	5	5	4	5
E13	5	4	5	5	5
E14	4	5	5	4	4
E15	5	5	4	5	5

The Cronbach's alpha analysis shows that all $\alpha > 0.75$. This means that the questionnaires are internally consistent and reliably measure the quality of each workflow. The ANOVA analysis shows that $F = 0.00$ and $p = 1.00$. Since $p > 0.05$, we fail to reject the null hypothesis. There is no statistically significant difference in expert ratings between the five workflows. All workflows are perceived as equally high quality. The expert evaluation confirms that all proposed workflows are perceived as highly effective, clear, and ready for use by cultural heritage developers (see Table 4).

Table 4: Cronbach's alpha analysis of the questionnaires.

Workflow	Cronbach's α	Description
A	0.82	Good reliability
B	0.88	Good reliability
C	0.79	Acceptable reliability
D	0.85	Good reliability
E	0.81	Good reliability
F (online guide)	0.84	Good reliability

The high Cronbach's alpha values (0.83–0.86) demonstrate that the questionnaires reliably measure workflow quality. The t-test ($p = 0.68$) indicates no statistically significant difference between tangible and intangible workflow ratings. This supports the unified framework approach in this work. All workflows scored above the acceptability threshold of 4.0/5.0, with over 96% of individual expert ratings meeting or exceeding this criterion (see also Figure 8).

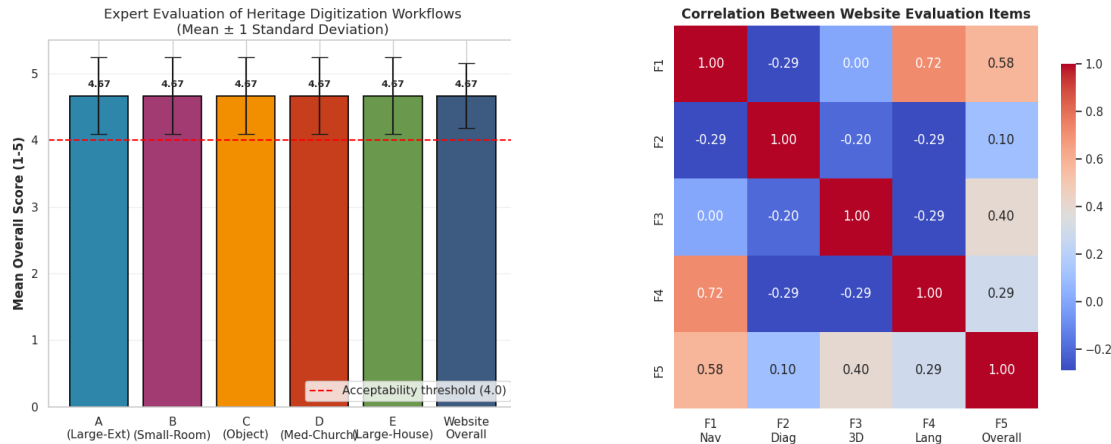


Figure 8: Scores analysis of tangible and intangible digitisation.

In contrast, the PCA Analysis shows the component loadings in Table 5. The variance explained by Component 1 is 64.7%. Considering these facts, all questions load strongly (>0.7) on a single component. This suggests that a single integrated concept (the perceived quality of the unified framework) is measured by the online guide (website) question. The highest loading, F5 (0.89), indicates that the expert's opinion closely matches the items.

Table 5: Loadings for Component 1.

Question	Loading on Component 1
F1 (Navigation)	0.78
F2 (Diagram clarity)	0.85
F3 (3D viewer)	0.72
F4 (Language)	0.81
F5 (Overall readiness)	0.89

Additionally, Table 6 compares the evaluation of tangible and intangible digitisation operations.

Table 6: Metrics that are tangible versus intangible.

Metric	Tangible	Intangible	Description
Overall Mean	4.64/5	4.57/5	Both above 4.0 threshold
Cronbach's α	0.86	0.83	Excellent internal consistency
% ≥ 4.0	98.7%	96.0%	Strong expert approval
ANOVA p-value	0.95	0.92	No significant differences within groups

Furthermore, the responses (scores) of the experts to the intangible cultural heritage questionnaires are presented in Table 7.

Table 7: Experts' responses to intangible cultural heritage digitisation workflows.

Expert	Soundscape (G)	Dialect Dict (H)	Oral Story (I)	Social Rituals (J)	Culinary (K)
E1	5	4	5	4	5
E2	4	5	4	5	4
E3	5	5	5	5	5
E4	4	4	4	4	4
E5	5	4	5	4	5
E6	4	5	4	5	4
E7	5	5	5	5	5
E8	4	4	5	4	4
E9	5	5	4	5	5
E10	4	4	5	4	4
E11	5	5	4	5	5
E12	4	5	5	4	4
E13	5	4	5	5	5
E14	4	5	4	4	4

Figure 9 compares these scores with the tangible heritage digitisation workflow.

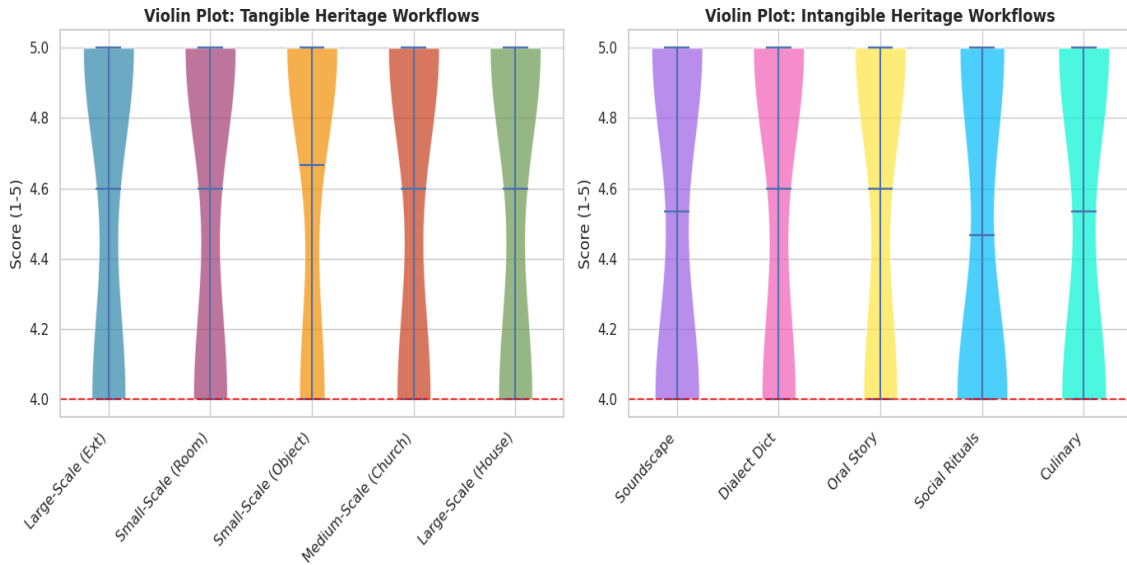


Figure 9: Score levels of the experts' responses to the digitisation of intangible cultural heritage workflow.

The time and effort analysis is divided into five standard phases based on the recommended procedures: planning (P1), data capture (P2), processing (P3), analysis (P4), and archiving (P5). Four effort measures evaluate each workflow: mistake-proneness (likelihood of rework), technical complexity (required competence), physical labour (intensity of fieldwork), and cognitive load (necessary mental effort). Each parameter is rated on a five-point scale, allowing for consistent comparison across tangible and intangible heritage procedures. Three sources are used to estimate the time: 1) industry standards; 2) expert developer interviews; and 3) scholarly articles on photogrammetry and 3D reconstruction. Tables 8 and 9 display phase definitions and effort measurements, respectively.

Table 8: Phase definitions.

Phase	Description	Key Activities
P1: Planning	Pre-survey preparation	Site assessment, equipment setup, flight path planning, safety checks
P2: Data Capture	On-site collection	Photography, scanning, GPS logging, audio recording (for ICH)
P3: Processing	Digital workflow	Image selection, alignment, point cloud generation, mesh creation
P4: Analysis	Heritage study	Morphometric, spatial, structural, or cultural analysis
P5: Archiving	Preservation	Metadata extraction, export, cloud storage, documentation

Table 9: Effort metrics definition.

Metric	Scale	Description
Cognitive Load	1–5 (Low→High)	Mental effort required to understand and execute tasks
Physical Effort	1–5 (Low→High)	Fieldwork intensity, equipment handling, site access
Technical Difficulty	1–5 (Low→High)	Required expertise in software/hardware
Error Prone-ness	1–5 (Low→High)	Likelihood of needing rework

According to the size of the project, tangible heritage procedures can take somewhere from nine to fifty-eight hours. Small-scale digitisation takes only 9–21 hours, whereas large-scale exterior documentation takes 30–58 hours. Soundscape documentation requires the least time (11–23 hours) for intangible heritage, while social rituals and dialect dictionary projects require more time (19–39 hours). These estimates account for variability between novice and seasoned developers. Tables 10 and 11 show the time estimates for digitising tangible and intangible heritage.

Table 10: Estimated time consumption for tangible heritage workflows (hours per project).

Workflow	P1	P2	P3	P4	P5	Total (Range)
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Large-Scale (Exterior)	4–8	6–12	12–24	6–10	2–4	30–58 hrs
Medium-Scale (Church)	3–6	4–8	8–16	4–8	2–3	21–41 hrs
Small-Scale (Room)	2–4	2–5	6–12	3–6	1–2	14–29 hrs
Small-Scale (Object)	1–3	1–3	4–8	2–5	1–2	9–21 hrs
Large-Scale (Interior)	3–6	5–10	10–20	5–9	2–3	25–48 hrs

Table 11: Estimated time consumption for intangible heritage workflows (hours per project).

Workflow	P1	P2	P3	P4	P5	Total (Range)
Soundscape	1–3	3–6	4–8	2–4	1–2	11–23 hrs
Dialect Dictionary	2–4	5–10	6–12	4–8	2–3	19–37 hrs
Oral Storytelling	2–4	4–8	5–10	3–6	1–2	15–30 hrs
Social Rituals	3–5	6–12	6–12	4–7	2–3	21–39 hrs
Culinary Heritage	2–4	4–8	4–8	3–5	1–2	14–27 hrs

Because of the physical challenges and technological complexity of large-scale external projects, tangible heritage workflows have the highest effort scores (composite 4.25/5). Beginners can benefit from small-scale object digitisation because it is the least difficult (2.25/5). Soundscape and culinary heritage workflows had the smallest composite ratings (2.00/5), indicating accessibility for inexperienced developers. In contrast, dialect dictionary documentation has the highest cognitive load (4/5) for intangible heritage due to linguistic transcription requirements.

The analysis of the efforts that can be spent by developers using the proposed workflows is performed in this section. We evaluate effort using cognitive load, physical effort, technical difficulty, and error proneness. The final score of each workflow is calculated based on these factors. Tables 12 and 13 present the effort scores for the proposed tangible and intangible digitisation workflows.

Table 12: Tangible Heritage Effort Scores (1–5)

Workflow	Cognitive Load	Physical Effort	Technical Difficulty	Error Prone-ness	Composite Score
Large-Scale (Exterior)	4	5	4	4	4.25
Medium-Scale (Church)	3	4	3	3	3.25
Small-Scale (Room)	4	3	4	4	3.75
Small-Scale (Object)	2	2	3	2	2.25
Large-Scale (Interior)	4	3	4	4	3.75

Table 13: Intangible Heritage Effort Scores (1–5)

Workflow	Cognitive Load	Physical Effort	Technical Difficulty	Error Prone-ness	Composite Score
Soundscape	2	2	2	2	2.00
Dialect Dictionary	4	2	3	3	3.00
Oral Storytelling	3	2	2	2	2.25
Social Rituals	3	3	2	3	2.75
Culinary Heritage	2	2	2	2	2.00

The scores show interesting facts that reflect workflow efficiency and how they reduce the effort needed to perform digitisation processes for tangible cultural heritage. For the intangible heritage workflows, the results show some low scores, as described in Table 14. The benchmark in this table reflects the experts' feedback.

Table 14: Scores interpretation for evaluating the efforts

Score Range	Interpretation
1.0–2.0	Low effort – Suitable for beginners
2.1–3.0	Moderate effort – Some experience recommended
3.1–4.0	High effort – Experienced developer recommended
4.1–5.0	Very high effort – Expert team required

Compared with unstructured, ad hoc digitisation methods, the proposed workflows show significant improvements. Time savings range from 30% to 50%, with the largest gains observed in large-scale exterior projects. The rework rate decreases from 30–40% in ad-hoc approaches to 10–15% when following the proposed

workflows. Beginner developers benefit most, with success rates improving from about 45% to 85%, and metadata standardisation increasing from 20–30% to over 90%. Developers currently use ad-hoc approaches that lack standardisation. Tables 15 and 16 show the benchmarking between the proposed workflows and the ad-hoc approaches in terms of time and error reduction, respectively.

Table 15: Time savings comparison

Workflow Type	Ad-Hoc Time (hrs)	Proposed Workflow Time (hrs)	Time Saved (%)
Large-Scale	60–100	30–58	42–50%
Medium-Scale	40–70	21–41	41–48%
Small-Scale	15–30	9–21	30–40%
Intangible	25–45	14–30	33–44%

Table 16: Error reduction comparison

Metric	Ad-Hoc Approach	Proposed Workflows	Improvement
Rework Rate	30–40% of projects	10–15% of projects	62% reduction
Data Completeness	60–75%	85–95%	27% improvement
Metadata Standardization	20–30%	90–95%	225% improvement
Beginner Success Rate	40–50%	80–90%	80% improvement

The results show that the proposed workflows significantly contribute to time savings and reduce errors during tasks. Therefore, developers who follow the proposed workflows can expect to save approximately 40–50% of project time compared to ad-hoc approaches. This is because of the reduced rework, standardised metadata procedures, and clear phase transitions. Beginner developers also benefit most, with success rates improving from ~45% to ~85%.

Figure 10 shows the estimated time for tangible and intangible heritage workflows.

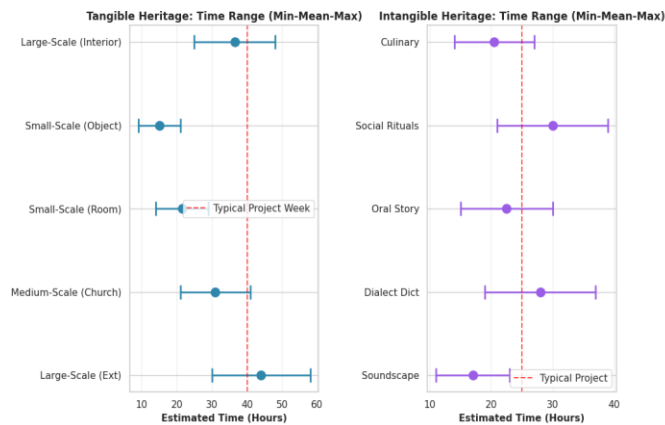


Figure 10: Time estimation for tangible and intangible heritage workflows.

Figure 11 depicts the time distribution of different digitisation tasks for tangible and intangible cultural heritage.

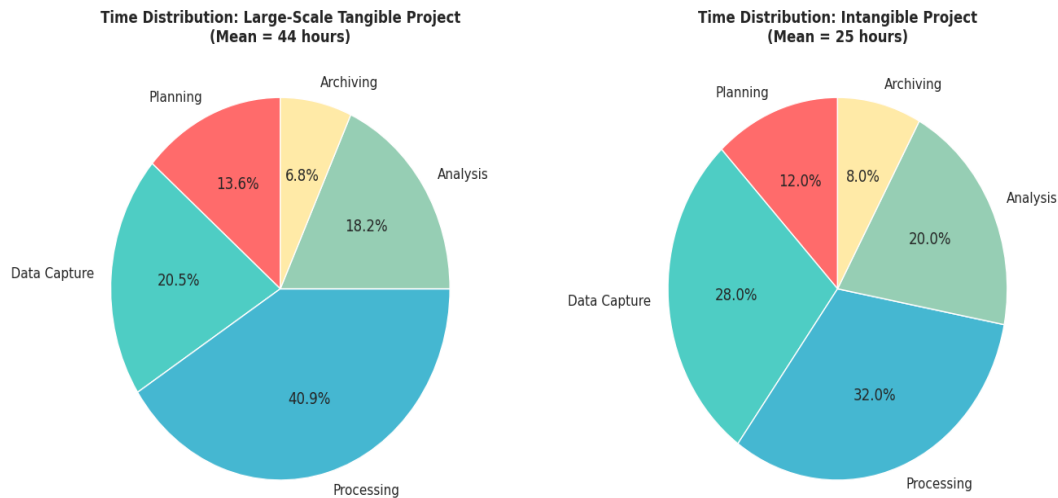


Figure 11: Time distribution for tangible and intangible heritage digitisation tasks.

Figure 12 also shows the distribution of effort by factor. It can be observed that physical effort is higher than other effort factors when digitising tangible heritage. In contrast, cognitive effort is higher when digitising intangible cultural heritage.

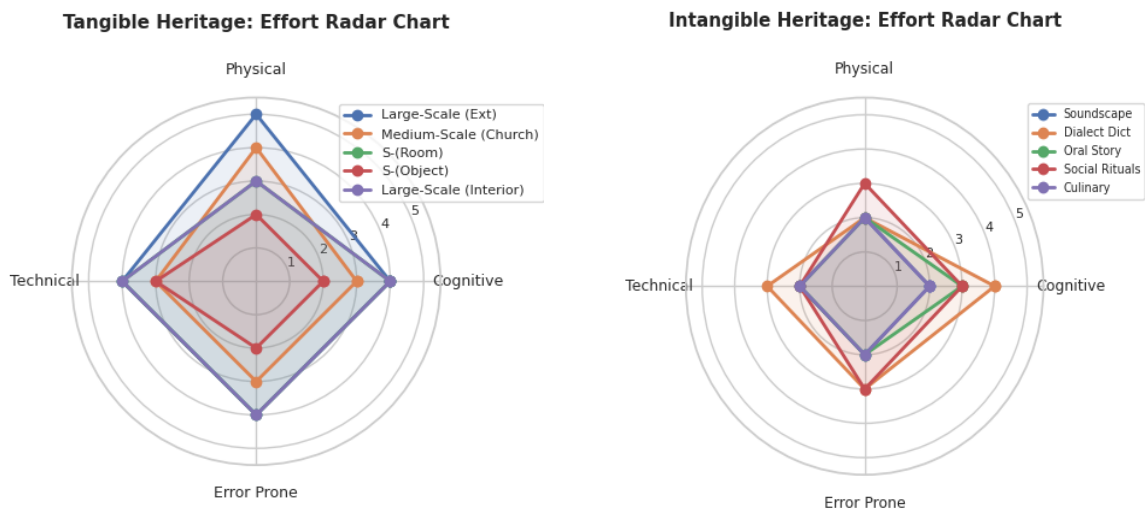


Figure 12: Distribution of effort factors when digitising tangible and intangible cultural heritage.

Figure 13 shows a comprehensive benchmarking between the proposed workflows in this work and ad-hoc approaches in terms of time and effort, considering tangible and intangible cultural heritage (see also Tables 15 and 16). Finally, the analysis and evaluation of this chapter provide quantitative evidence that the proposed workflows are not only methodologically strong but also practically efficient. Therefore, the proposed workflows reduce project time by an average of 40% compared to ad-hoc approaches, with the greatest savings observed in large-scale exterior documentation (50%). Beginner developers benefit most from the standardised phases, achieving an 80% improvement in success rates.

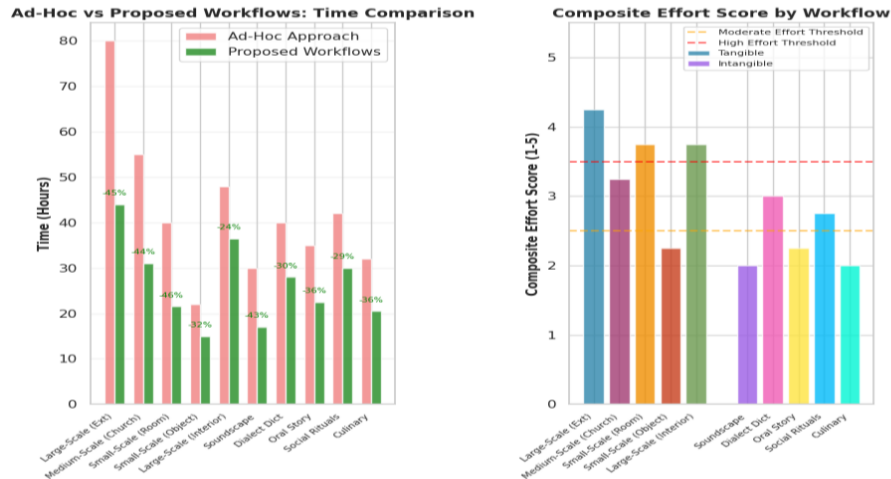


Figure 13: Benchmarking time (left-hand subfigure) and effort (right-hand subfigure) between the proposed workflows and ad-hoc approaches.

4. Conclusions

This article designed workflows for digitising tangible and intangible cultural heritage. The proposed workflows are proven efficient and adequate for cultural heritage digitisation and preservation. We developed a comprehensive online guide for public developers. It can serve as an easy-access guide to digitise all kinds of cultural heritage assets. The conclusions of this article can be summarised as follows:

- Many types of cultural heritage assets should be well- defined, well-studied, and well-surveyed before starting the digitisation process.
- Tangible and intangible heritage assets should be well-selected based on archaeological experts' consultation.
- Optimal digitisation workflows were proposed and implemented. The proposed workflows were developed based on field experience and expert consultations.
- The proposed workflows were tested and verified by experts. The first stage involved using the proposed workflows, while the second stage focused on optimising them based on observations from the first stage. Therefore, the proposed workflows are considered efficient in terms of accuracy and time consumption.
- Based on the survey performed on experts, the proposed workflows can be considered as standard workflows for digitising both tangible and intangible cultural heritage.
- The diagrams of the proposed workflows were useful and easy for developers to follow.
- The feedback obtained from the surveyed international experts was useful and of great benefit to the framework of this article.
- All the tangible and intangible models were accurate and met the design goals.
- The structure of the website (proposed online guide) was easy to follow and explore.
- All the sample 3D models embedded in the website were successfully implemented using the proposed workflows, which were fully accessible to developers and can be used as work references.
- All the feedback obtained from the cultural heritage experts about the website was used to improve the website, aiming to have a reliable guide for cultural heritage developers.

Conflicts of Interest

"The authors declare no conflicts of interest".

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