Developing a Technology Selection Framework for Initial Data Acquisition for HBIM and Digital Twin Creation in Sri Lankan Heritage Sites:
A Case Study on Lankathilake Pilimage, Polonnaruwa

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Abstract

This research aims to develop and apply a structured technology selection framework for initial data acquisition for Heritage Building Information Modeling (HBIM) and Digital Twin creation in Sri Lankan heritage sites. The study addresses the challenge of selecting appropriate 3D documentation technologies by proposing a transparent and systematic decision-making process.

The study employs an Analytic Hierarchy Process (AHP) as its foundational framework. An AHP model was developed, defining a set of criteria (Cost, Geometric Accuracy, Texture Quality, Ground and Aerial Accessibility, Scale) and alternatives (various terrestrial and drone-based scanning and photogrammetry technologies). The framework's effectiveness was validated through a detailed case study of Lankathilake Pilimage, followed by hypothetical applications for four other representative heritage sites.

The AHP model successfully provided a ranked list of technology alternatives. For the Lankathilake Pilimage case study, the AHP results prioritized Drone Photogrammetry as the most suitable method, followed by Terrestrial Photogrammetry and then a combined Drone Lidar and Drone Photogrammetry approach. The application of the framework to other sites demonstrated how project-specific requirements, translated through pairwise comparisons, lead to different optimal technology choices.

The AHP framework provides a robust and repeatable methodology for selecting primary data acquisition technology. It effectively incorporates multiple, often conflicting, criteria to arrive at a data-driven decision. This framework is a valuable tool for heritage conservation professionals and researchers, offering a clear path forward for HBIM and Digital Twin projects in Sri Lanka.

1. Introduction

1.1 Context & Problem Statement

Figure 1 - Lankathilake Pilimage (Source - Author)

Sri Lanka is home to a vast and invaluable cultural heritage, including thousands of protected monuments and several UNESCO World Heritage Sites. This architectural legacy, however, faces escalating threats from environmental degradation and inadequate traditional documentation methods. Manual techniques, such as hand sketches and measured drawings, are often insufficient, labor-intensive, and result in fragmented data that lacks the detail required for modern conservation efforts. For example, a 2024 UNESCO report for the Rangiri Dambulla Cave Temple revealed that only 40% of the painted surfaces in Cave 2 have been manually documented, a striking illustration of the limitations of conventional methods. The advent of advanced digital technologies, including Heritage Building Information Modeling (HBIM) and Digital Twins, presents a transformative solution. These tools enable the detailed, accurate capture and analysis of heritage assets,

facilitating proactive preservation and long-term management. HBIM creates a comprehensive, semantically rich model for design and maintenance, while a Digital Twin provides a dynamic, real-time replica for continuous monitoring and predictive analysis.

Despite this potential, the adoption of these technologies in Sri Lanka is hindered by limited financial resources, a nascent digital infrastructure, and a lack of specific, context-aware guidelines for technology selection. Without a systematic framework, stakeholders struggle to make informed decisions, leading to inefficient resource allocation and a failure to fully leverage the benefits of digital preservation. This research addresses this critical void by developing a practical, context-specific framework to guide technology selection for initial data acquisition.

1.2 Research Aim and Objectives

The research aims to develop a practical technology selection framework for HBIM and Digital Twin creation in Sri Lankan heritage buildings. Objectives include:

- To develop a decision-making framework using the Analytic Hierarchy Process (AHP) to address the challenge of selecting appropriate 3D documentation technologies.
- To validate the effectiveness of the developed AHP framework through a detailed case study of the Lankathilake Pilimage site.
- To apply the framework to propose suitable technology choices for other representative heritage sites with varying characteristics.
- To discuss the key findings, acknowledge the limitations of the framework, and propose future narratives.

This will provide a vital guide for Sri Lankan heritage professionals and government bodies.

2. Literature Review

2.1 Evolution of Heritage Documentation Techniques

Sri Lanka has a rich archaeological heritage, primarily comprising ancient cities, monastic complexes, stupas, cave temples, and fortresses, spanning prehistoric to colonial periods (Archaeological Protected Monuments in Sri Lanka, 2025). The conservation and restoration of these diverse monuments, often situated in challenging terrains or featuring intricate details like ancient frescoes (see figure 2), greatly benefit from the application of modern digital technologies. Modern technologies yield accurate, detailed 3D models vital for conservation planning, assessing structural stability, and monitoring deterioration, all with minimal impact on fragile historical surfaces.
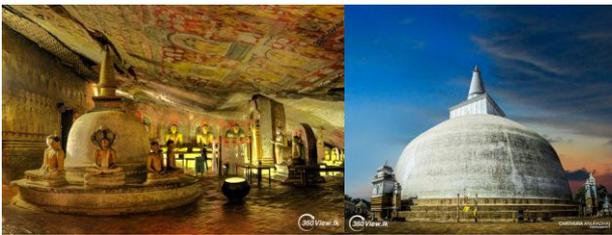

Figure 2 - Dambulla Cave temple & Ruwanweli seya
(Source – 360View.lk)

Heritage documentation has undergone a profound evolution, transitioning from traditional manual methods to sophisticated digital paradigms. Initially, documentation relied heavily on manual techniques such as hand sketches, measured drawings using tape measures and plumb bobs, and basic photographic records (Foka, 2022). These methods, while fundamental, were labor-intensive, time-consuming, and prone to inaccuracies and inconsistencies, often failing to capture the intricate geometries and structural complexities of historic buildings.

Figure 3 - Thivanka Pilimage Measured drawing and a Old Photograph of the exterior (Source - Author)

The mid-20th century saw the introduction of more precise methods like conventional surveying with theodolites and total stations, which significantly improved geometric accuracy (Foka, 2022). Architectural photogrammetry, initially relying on analogue cameras and stereoplotters, emerged as a non-contact method to derive measurements and 3D information from 2D photographs. This marked an early shift towards image-based documentation.

The advent of digital technologies in the late 20th and early 21st centuries catalyzed a transformative shift. Geographic Information Systems (GIS) and Remote Sensing (RS) provided powerful tools for spatial data management and analysis, enabling the mapping and monitoring of broader heritage landscapes (Foka, 2022). The true revolution, however, came with the proliferation of 3D digital documentation techniques.
Modern 3D data acquisition methods, primarily laser scanning (LiDAR) and digital photogrammetry, offer unparalleled levels

of detail, accuracy, and efficiency (Ahmad et al., 2021). These technologies enable the creation of comprehensive, metric archives of heritage assets, facilitating precise structural assessments, virtual reconstruction, and detailed restoration planning (Foka, 2022). The trend is now firmly towards integrating these digital techniques, often combining laser scanning for high geometric accuracy with photogrammetry for rich textural and color information, to create highly realistic and functionally intelligent 3D models (D'Amico et al., 2019). The international community, through bodies like CIPA, ICOMOS, ISPRS, and UNESCO, has played a crucial role in standardizing and promoting these advanced digital heritage practices, emphasizing their importance for long-term preservation and accessibility (Foka, 2022).

2.2 Challenges in 3D Digitization of Cultural Heritage

Despite the advancements, the field of 3D digitization of cultural heritage continues to face significant challenges. A pervasive issue is the lack of standardized protocols for data capture and processing, a concern highlighted in a 2022 study by the Network of European Museum Organisations (NEMO). The study points to the challenges of interoperability and data sustainability, which can result from disparate approaches to documentation. This lack of a unified framework complicates the sharing and long-term archival of digital heritage assets (NEMO, 2022). Beyond technical standardization, a central challenge lies in the decision-making process for technology selection. Project stakeholders must weigh a complex set of factors, including cost, available expertise, time constraints, and the specific characteristics of the heritage site. This multifaceted nature of the decision often leads to ad-hoc choices rather than a systematic evaluation, risking resource wastage and suboptimal data quality that can severely limit the utility of the final HBIM or Digital Twin.

2.3 3D mapping technologies as an Initial data acquisition method for HBIM and DT

3D mapping technologies are revolutionizing the field of heritage preservation by providing a robust initial data acquisition method for the creation of Historic Building Information Models (HBIM) and Digital Twins (DT). These technologies, including terrestrial and drone-based laser scanning and photogrammetry, capture complex geometric and visual data with unprecedented accuracy and detail. The resulting point clouds and textured meshes serve as the foundational geometric layer for an HBIM (Narayanan et al., 2022).
Beyond static representation, this data is crucial for creating dynamic Digital Twins, which integrate real-time sensor information to monitor the building's condition and performance over its lifecycle (Prakash et al., 2025). While these digital workflows offer significant benefits for conservation, documentation, and public engagement, they also present challenges, such as the lack of standardized practices and the complexity of technology selection, which this research aims to address (NEMO, 2022).
Choosing the right 3D mapping technology is crucial for a project's success. This decision directly impacts the accuracy and efficiency of the data collected, ensuring the final output meets the specific needs of the heritage preservation project.Making the wrong choice can lead to significant cost overruns and compromise the integrity of the final digital model. Therefore, a careful assessment of project requirements is essential before any data acquisition begins

Feature	LiDAR/ 3D Scanning	Photogrammetry	Combined Methods
Principle	Active: Laser pulses measure distance	Passive: Images triangulate 3D points	Integrates both (laser/structured light + images)
Geometric Accuracy	Very High (mm to cm level)	Medium (cm to sub-cm level, setup-dependent)	Very High
Color/Texture	Low/None (requires external photography)	High (direct from images)	Very High (photogrammetry textures on LiDAR geometry)
Speed of Capture	Fast (especially for large areas, high point density)	Moderate to Slow (depends on image count, site size)	Moderate to Fast (workflow-dependent)
Cost (Equipment)	High (tens of thousands to hundreds of thousands USD)	Lower (hundreds to thousands USD for cameras/drones)	Higher (combines costs of both primary methods)
Environmental Impact	Less affected by light; some vegetation penetration	Highly dependent on uniform lighting, clear line of sight; no vegetation penetration	Less affected by light, good vegetation handling (LiDAR); high texture quality (photogrammetry)
Data Volume	Very High	High	Very High
Skill Required	High (specialized training for operation & processing)	Moderate to High (for accurate results, post-processing)	High (for integration and optimization)
Key Output	Dense point clouds	Textured 3D mesh, point clouds	High-accuracy, textured 3D models (point clouds, meshes)
Typical Use	Structural analysis, precise mapping, deformation detection, inaccessible areas	Visual documentation, small object modeling, surface deterioration, virtual tours, large site aerials	Comprehensive digital twins, high-fidelity virtual reconstructions, detailed analysis requiring both precision and realism

Table 1- Comparison of Initial Data acquisition methods for HBIM & DT (Source - Author)

3. Comparative Analysis of Initial Data Acquisition Methods

Key methods include LiDAR (Light Detection and Ranging), 3D scanning, photogrammetry, and combined approaches. Each has distinct advantages and limitations in terms of accuracy, speed, cost, and suitability for various heritage contexts. Summarized in table 1.

3.1 LiDAR and 3D Scanning

Figure 4 - LiDAR & Terrestrial Laser Scanning Artistic Expression (Source - Author)

LiDAR (Light Detection and Ranging) and terrestrial 3D laser scanners are active sensing technologies that emit laser pulses to measure distances, creating highly accurate, dense point clouds. Their advantages include High Accuracy and Precision, capable of millimeter-level accuracy for detailed architectural documentation, deformation monitoring, and structural analysis (Ahmad et al., 2021). LiDAR offers significant advantages: rapid data capture, acquiring vast geometric data quickly; it's non-invasive and safe for fragile structures (Ahmad et al., 2021); it's less light-dependent than photogrammetry, excelling in low-light conditions; and advanced systems provide vegetation penetration, revealing obscured features.

LiDAR, however, has notable disadvantages. High cost is a significant barrier, encompassing expensive equipment and specialized software. LiDAR generates large data volumes, demanding powerful computing and expertise. It faces line-of-sight limitations, necessitating multiple scans to overcome occlusions in complex geometries. Finally, challenges exist with reflective/transparent surfaces, as laser beams scatter or pass through materials like glass, leading to incomplete data.

3.2 Photogrammetry

Photogrammetry is a passive, image-based technique that reconstructs 3D models from multiple overlapping 2D photographs, commonly using Structure-from-Motion (SfM) algorithms for automated processing.

Its advantages include Cost-Effectiveness, as it can be performed with relatively inexpensive equipment, from smartphones to UAVs. It captures Rich Color and Texture inherently, creating photorealistic 3D models ideal for visual documentation and surface analysis. Photogrammetry offers Versatility and Flexibility, applicable to scales from small artifacts to large buildings, and is Non-contact and Safe for fragile assets.
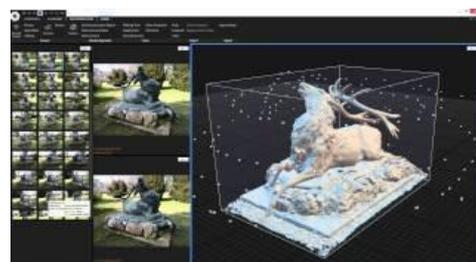

Figure 5 - Photogrammetry 3D Model Creation Using Overlapping Photographs (Source - RealityScan)

Photogrammetry has several disadvantages: it's light-dependent, needing consistent lighting and not suitable in dark, shadowed environments; it struggles with featureless/reflective surfaces; it offers lower geometric accuracy compared to TLS, especially for complex or distant objects; it requires intensive processing power and time; and it cannot penetrate vegetation or other obstructions.

3.3   Combined Methods (Hybrid Approaches)

Increasingly, the most effective approach for comprehensive heritage documentation combines LiDAR/3D scanning with photogrammetry, leveraging the strengths of each technology while mitigating individual weaknesses.

Advantages: This hybrid method produces High-Fidelity Models, where LiDAR provides precise geometric accuracy and a robust metric backbone, and photogrammetry enriches the model with photorealistic color and texture. This results in highly accurate, detailed, and visually realistic 3D models for diverse applications, from engineering analysis to virtual tourism. It ensures Comprehensive Data Capture, documenting all aspects of a heritage asset, including intricate geometries, material properties, and surrounding context. The combined approach effectively Overcomes Individual Limitations; for instance, LiDAR can capture obscured features, while photogrammetry provides color for reflective surfaces where LiDAR might struggle.

Disadvantages: This methodology comes with Increased Complexity, requiring advanced planning, specialized data fusion software, and higher levels of technical expertise for both acquisition nd post-processing. There are Higher Costs due to investment in both types of equipment and potentially more expensive software licenses. Finally, it generates Larger Data Volumes, demanding greater storage and processing capabilities.

4.   Methodology

4.1   Research Approach

This research employed a multi-methodological approach, centered on the development and application of an Analytic Hierarchy Process (AHP) model. This framework served as a systematic and transparent means for evaluating and selecting from a range of technology alternatives based on a predefined set of criteria.

Developing the AHP framework involved a series of structured steps. The process began with Defining the Goal: "Selecting Best Primary Data Acquisition Method for 3D Mapping." Following this, a set of Criteria was identified through expert consultation, deliberately excluding factors that were not generalizable or had a low impact. The Alternative Types were also determined through expert consultation, recognizing the most widely used technologies in the field. A crucial step was conducting Pairwise Comparisons, where the relative importance of criteria and the performance of alternatives were quantified based on expert opinion and a review of existing literature. This data was then processed through a Synthesis and Ranking step to produce a prioritized list of technology options. The model's operational utility was demonstrated through its Validation via a real-world case study of a specific heritage site. The framework's adaptability was further showcased by creating hypothetical technology proposals for four other culturally significant sites, proving its ability to respond to unique project requirements and site characteristics.

4.2   The Analytic Hierarchy Process (AHP) Model Development

The AHP model was developed in a hierarchical structure, beginning with the overarching goal and progressively disaggregating the problem into its constituent criteria and alternatives. (See figure 4)
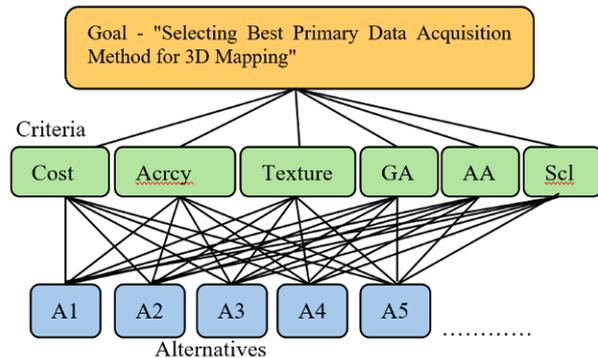

Figure 6 - AHP process applied (Source-Author)

4.2.1. Defining the Goal
The foundational element of the AHP model was the clearly defined objective: "Selecting Best Primary Data Acquisition Method for 3D Mapping". This goal provided the central focus for all subsequent evaluations and comparisons within the framework.

4.2.2. Identifying Criteria
To ensure the framework's practical applicability, six key criteria were shortlisted based on expert consultation. Factors were deliberately excluded if they were not generalizable or had a low impact on most projects. These criteria represent the most critical factors influencing the quality and feasibility of a data acquisition project:

- **Cost (C1):** The total financial expenditure for the technology, covering equipment, personnel, and operational costs.
- **Geometric Accuracy (C2):** The precision of the captured geometric data, which is essential for creating faithful representations and performing dimensional analysis.
- **Texture Quality (C3):** The fidelity of the captured visual data, crucial for detailed material analysis and photorealistic rendering.
- **Ground Accessibility (C4):** The ease and effectiveness of deploying a technology from the ground, a vital factor for sites with restricted aerial access.
- **Aerial Accessibility (C5):** The capability to capture data from the air, providing a significant advantage for large, tall, or complex high-level structures.
- **Scale (C6):** The technology's suitability for capturing a wide range of sizes, from small, intricate details to vast, expansive structures.

4.2.3. Identifying Alternatives
Eight distinct technology alternatives, representing a comprehensive range of available 3D documentation methods, were selected for evaluation. These alternatives include both standalone technologies and hybrid approaches that combine the strengths of different methods to mitigate their individual weaknesses :

Terrestrial Lidar (TLr)
Drone Lidar (DLr)
Drone Photogrammetry (DP)
Terrestrial Photogrammetry (TP)
Terrestrial Laser Scanning (TLS)
Terrestrial Laser Scanning + Terrestrial Photogrammetry (TLS+TP)
Terrestrial Lidar + Terrestrial Photogrammetry (TLr+TP)
Drone Lidar + Drone Photogrammetry (DL+DP)

4.3 The AHP Application Process

4.3.1. Pairwise Comparisons
With the criteria and alternatives defined, a series of pairwise comparisons were conducted. This process involves comparing each element at a given level of the hierarchy against every other element in that same level with respect to the element above it. For example, each criterion was compared against every other criterion with respect to the overarching goal. Similarly, each alternative was compared against every other alternative with respect to each of the six criteria. These comparisons were based on expert judgment, using a nine-point scale to express the relative importance of one element over another. This structured, step-by-step comparison process is what provides the raw data for the AHP calculation, allowing a comprehensive set of preferences to be captured and quantified.

4.3.2. Synthesis and Ranking
The final step of the AHP methodology is the synthesis of the pairwise comparison data to produce a final, ranked list of the alternatives. The judgments from the comparison matrices are mathematically processed to derive a set of normalized weights. For each matrix, the principal eigenvector is calculated to determine the relative priority of each element. These priorities are then aggregated in a hierarchical manner to compute a final, overall score for each technology alternative. This final score represents the alternative's weighted performance across all criteria, providing a single numerical value that enables a clear and objective ranking. The output of this process is a data-driven recommendation that is transparent and directly traceable to the specific judgments made during the pairwise comparison stage.

4.4 Validation of the Application

The developed AHP framework was validated through a detailed application. The framework's core utility was demonstrated by applying it to the Lankathilake Pilimage case study, a real-world scenario that allowed for a direct evaluation of the model's output. Following this, the framework was further applied to generate technology proposals for four other sites, each with unique characteristics and challenges. This two-pronged approach not only confirmed the framework's effectiveness in a specific instance but also showcased its adaptability and generalizability for the broader context of Sri Lankan heritage preservation.

5. Technology Selection Framework

The technology selection framework consists of a pairwise comparison table for the project's criteria with respect to the project goal. This needs to be filled using any AHP tool.
Importance should be given according to the project goal.
Within the AHP framework, the relative importance of each technology alternative was determined through a process of pairwise comparisons. This systematic evaluation involved assessing each alternative against every other alternative, using a nine-point scale to quantify their relative priority. This structured approach, based on expert judgment, provides the data for the AHP calculations. These tables are the main finding of this research through literature review and expert input.
We can use these tales to decide best alternatives for any site using an AHP tool.
These pairwise comparisons for alternatives with respect to each criterion shown in below tables.

	TL	DLr	DP	TP	TLS	TLS+TP	TLr+TP	DL+DP
TL	1	5	1/3	1/7	1/3	5	7	9
DLr	1/5	1	1/5	1/7	1/5	1/2	1	2
DP	3	5	1	1/5	3	5	7	9
TP	7	7	5	1	5	7	9	9
TLS	3	5	1/3	1/5	1	3	5	7
TLS+TP	1/5	2	1/5	1/7	1/3	1	2	9
TLr+TP	1/7	1	1/7	1/9	1/5	1/2	1	5
DL+DP	1/9	1/2	1/9	1/9	1/7	1/9	1/5	1

Table 2 - Pairwise Comparisons For Criteria With Respect To Cost

	TL	DLr	DP	TP	TLS	TLS+TP	TLr+TP	DL+DP
TL	1	7	7	5	3	1/3	1/5	1/7
DLr	1/7	1	7	5	1/5	1/5	1/7	1/2
DP	1/7	1/7	1	1/3	1/5	1/7	1/9	1/3
TP	1/5	1/5	3	1	1/5	1/7	1/9	1/5
TLS	1/3	5	5	5	1	1/2	1/5	5
TLS+TP	3	5	7	7	2	1	1/5	5
TLr+TP	5	7	9	9	5	5	1	7
DL+DP	7	2	3	5	1/5	1/5	1/7	1

Table 3 - Pairwise Comparisons For Criteria With Respect To Geometric Accuracy

	TL	DLr	DP	TP	TLS	TLS+TP	TLr+TP	DL+DP
TL	1	1/5	1/7	1/9	1/3	1/8	1/9	1/7
DLr	5	1	1/5	1/4	3	1/8	1/9	1/7
DP	7	5	1	1/2	5	1/3	1/4	1/2
TP	9	4	2	1	9	1	1/2	2
TLS	3	1/3	1/5	1/9	1	1/8	1/9	1/7
TLS+TP	8	8	3	1	8	1	1/2	2
TLr+TP	9	9	4	2	9	2	1	2
DL+DP	7	7	2	1/2	7	1/2	1/2	1

Table 4 - Pairwise Comparisons For Criteria With Respect To Texture Quality

	TL	DLr	DP	TP	TLS	TLS+TP	TLr+TP	DL+DP
TL	1	9	5	2	3	3	1	5
DLr	1/9	1	1/2	1/9	1/9	1/7	1/9	1/2
DP	1/5	2	1	1/7	1/9	1/7	1/9	1
TP	1/2	9	7	1	1	2	1	9
TLS	1/3	9	9	1	1	1	1	7
TLS+TP	1/3	7	7	1/2	1	1	1/2	7
TLr+TP	1	9	9	1	1	2	1	9
DL+DP	1/5	2	1	1/9	1/7	1/7	1/9	1

Table 5 - Pairwise Comparisons For Criteria With Respect To Ground Accessibility

	TL	DLr	DP	TP	TLS	TLS+TP	TLr+TP	DL+DP
TL	1	1/7	1/9	1	1	1	1	1/9
DLr	7	1	1/2	5	5	5	5	1/2
DP	9	2	1	9	9	9	9	1
TP	1	1/5	1/9	1	1	1	1	1/9
TLS	1	1/5	1/9	1	1	1	1	1/9
TLS+TP	1	1/5	1/9	1	1	1	1	1/9
TLr+TP	1	1/5	1/9	1	1	1	1	1/9
DL+DP	9	2	1	9	9	9	9	1

Table 6 - Pairwise Comparisons For Criteria With Respect To Arial Accessibility

	TL	DLr	DP	TP	TLS	TLS+TP	TLr+TP	DL+DP
TL	1	1/7	1/9	1	1	1	1	1/9
DLr	7	1	1/2	5	5	5	5	1/2
DP	9	2	1	9	9	9	9	1
TP	1	1/5	1/9	1	1	1	1	1/9
TLS	1	1/5	1/9	1	1	1	1	1/9
TLS+TP	1	1/5	1/9	1	1	1	1	1/9
TLr+TP	1	1/5	1/9	1	1	1	1	1/9
DL+DP	9	2	1	9	9	9	9	1

Table 7 - Pairwise Comparisons For Criteria With Respect To Scale

Using these Data tables and the pairwise comparisons of the criteria with respect to project goal, best alternative rankings can be calculated.

6. Application of The Framework

6.1 Case Study: Lankathilake Pilimage

The developed AHP framework was applied to a detailed case study of Lankathilake Pilimage, a historically significant heritage site. The site is a 50-foot-high brick structure renowned for its vaulted roof and a majestic standing Buddha statue within. The unique characteristics of the site—its considerable height and the need to capture the detailed texture of both the exterior brickwork and the intricate interior carvings—presented a complex decision-making problem for technology selection. The pairwise comparisons for this specific case study were carefully calibrated using expert judgement to reflect these project needs, with a high emphasis placed on Aerial Accessibility and Texture Quality to effectively document the vaulted roof and the statue.

This process systematically compared each identified criterion against every other, assigning a score representing its relative importance. See Table 8.

	C1	C2	C3	C4	C5	C6
C1	1	1/5	1/5	1/5	1/9	1/5
C2	5	1	1/2	5	1/3	1/3
C3	5	2	1	7	1	1
C4	5	1/5	1/7	1	1	1/3
C5	9	3	1	1	1	1
C6	5	3	1	3	1	1

Table 8 - Pairwise Comparisons For Criteria With Respect To Project Goal

These judgments culminated in a set of derived weights that accurately reflected the project's strategic requirements. Texture Quality emerged as the highest priority, with a weight of 0.256, directly reflecting the imperative to capture the nuanced details of the brickwork and the Buddha statue. Closely following were Aerial Accessibility (0.237) and Scale (0.234), both weighted highly due to the monument's considerable height, inaccessible roof, and expansive nature. Metric Accuracy (0.143) held moderate importance for precise measurements. Ground Accessibility (0.099) was given a lower priority, as the dominant documentation challenge lay in its verticality, not ground access. Finally, Cost (0.033) was the least prioritized, underscoring the project's commitment to comprehensive, high-quality data over immediate budgetary constraints for a site of such national heritage importance.

Criterion	Weight
Texture Quality	0.256 (Highest Priority)
Aerial Accessibility	0.237 (Second Highest Priority)
Scale	0.234 (Third Highest Priority)
Metric Accuracy	0.143 (Moderate Priority)
Ground Accessibility	0.099 (Lower Priority)
Cost	0.033 (Lowest Priority – Since we got a Collaboration

Table 9 – Calculated weightages of criteria

Then Using AHP calculation tool & pairwise comparisons, Final Scores for each alternative were calculated. The results are presented in the table below (Table 10), with the alternatives ordered by their final scores.

Rank	Alternative	Final Score
1	Drone Photogrammetry	0.189
2	Drone Lidar + Drone Photogrammetry	0.111
3	Terrestrial Laser Scanning + Terrestrial Photogrammetry	0.106
4	Terrestrial Photogrammetry	0.103
5	Terrestrial Lidar + Terrestrial Photogammetry	0.071
6	Terrestrial Lidar	0.071
7	Terrestrial Laser Scanning	0.059

Table 10 - Ranking of Alternatives for Lankathilake Pilimage

The results of the analysis clearly identified Drone Photogrammetry as the most suitable technology for the site. This outcome is highly logical given the site's characteristics. The ability of a drone to capture high-resolution imagery from a vantage point not accessible from the ground is perfectly suited for documenting the 50-foot-high structure and its vaulted roof. Furthermore, photogrammetry's inherent strength lies in its ability to capture rich texture and color data, which is essential for documenting the brickwork and the highly detailed statue. Technology's high score directly reflects its superior performance across the most heavily weighted criteria for this specific project.

The second-ranked option, Drone Lidar + Drone Photogrammetry, also aligns with the site's needs, offering a hybrid approach that would combine the geometric accuracy of Lidar with the texture quality of photogrammetry. Its slightly lower ranking compared to pure Drone Photogrammetry reflects the increased complexity and cost of the combined system, which was a secondary but still present consideration in the model. Purely terrestrial methods, such as Terrestrial Laser Scanning and Terrestrial Photogrammetry, ranked significantly lower, a direct consequence of the difficulty and incompleteness

of data capture from the ground for a structure of this height. The AHP framework effectively translated the site's physical constraints and the project's priorities into a transparent, data-driven recommendation, validating its utility as a decision-making tool.

For the 3D survey, the top-ranked technologies from the AHP model were used. First, Drone Photogrammetry, utilizing a DJI Mavic 3 drone and processed with DJI Terra software, was employed. This method proved highly effective, producing a final 3D model with both exceptional texture quality and high
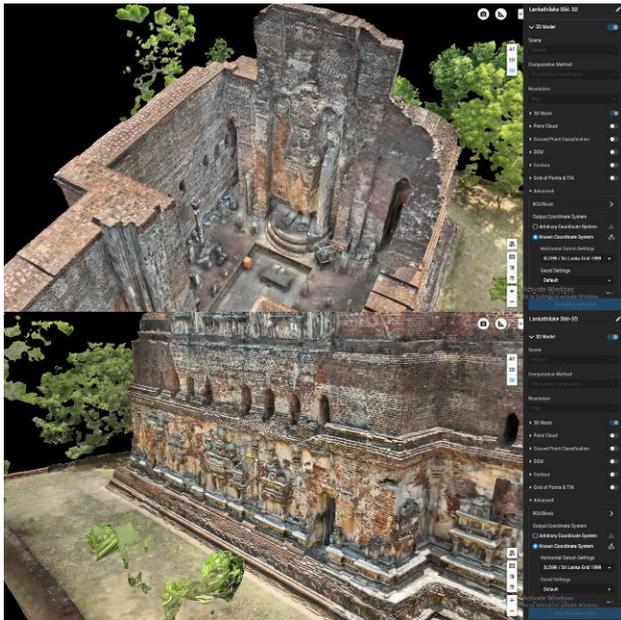
Figure 7 – Drone Photogrammetric Model in DJI Terra (Source - Author)
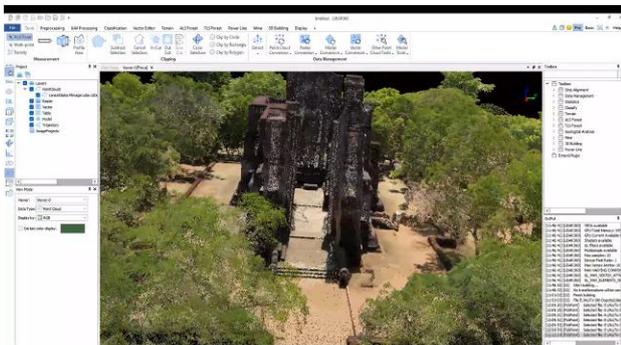
Figure 8 - Captured Drone Lidar point cloud (Source - Author)

geometric accuracy. Subsequently, a Drone Lidar survey was conducted, which generated a highly dense and dimensionally accurate point cloud. However, it was noted that while Lidar provides superior geometric precision, the resulting model lacked high-quality texture, a limitation that could only be overcome by integrating it with photogrammetric data. The application of these two technologies demonstrated a practical understanding of their complementary strengths and weaknesses, validating the AHP model's recommendations for a project requiring both high geometric and textural fidelity.

6.2 Application in Different Heritage Sites

The true strength of the AHP framework lies in its adaptability. While the Lankathilake Pilimage case study provided a clear, specific recommendation, the framework's power is in its ability to generate different optimal solutions for different contexts. The following proposals for four other representative heritage sites demonstrate how the framework's output changes when the project-specific criteria and their prioritization are adjusted. In each case, a re-evaluation of the pairwise comparisons would lead to a different technological recommendation, proving that the framework does not provide a one-size-fits-all solution but rather a context-specific one.

For the Galle Fort (Fortress), a massive walled city, the framework prioritizes Scale and Aerial Accessibility. Given the sheer size of the area, a purely terrestrial survey would be impractical. The resulting recommendation is a hybrid of Drone Photogrammetry and Drone LiDAR. The aerial perspective efficiently covers the extensive fortifications and walls, with Photogrammetry capturing rich visual details and LiDAR ensuring the high geometric accuracy needed for structural analysis of the massive structure.

A contrasting challenge is posed by the Dambulla Cave Temple (Cave Temple), which features fragile frescoes in confined, sensitive spaces. Here, the AHP heavily prioritizes Texture Quality and Ground Accessibility, as aerial mapping is either impossible or secondary to protecting the ceiling art. Consequently, the framework recommends Terrestrial Photogrammetry or Terrestrial Laser Scanning (TLS), as these ground-based methods are optimal for close-quarters capture of high-fidelity data and minimizing risk to the delicate art.

The Ruwanwelisaya, Anuradhapura (Ancient Stupa), demands a solution that balances Scale and Geometric Accuracy due to its vast, curved shape. To rapidly yet accurately map the large surface area, the AHP recommends a hybrid of Drone LiDAR and Terrestrial Laser Scanning (TLS). Drone LiDAR efficiently captures the massive stupa exterior, while TLS is dedicated to the high-accuracy capture of the detailed base and surrounding structures, ensuring dimensional precision for the final m
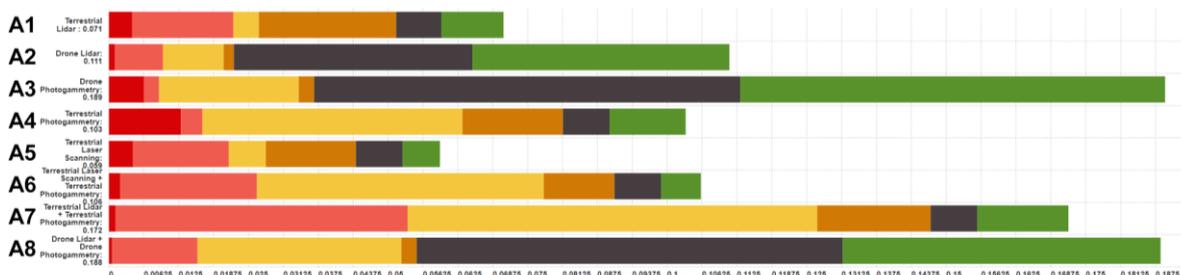

Figure 9 - Scored Alternatives & Contributions to each criterion (Source - Author)

6.3 Summarized Results with Specified Sub alternatives

Even though the framework calculated best possible alternative through the APH method, there are many sub alternatives within these types, with different characteristics. The following table summarizes different sub-alternative methods with a low-cost option and a recommended option for each project scenario.

Project Scenario / Use Case	Key Considerations (Characteristics, Accessibility, Accuracy)	Low-Cost Option (Equipment / Software)	Recommended Option (Equipment / Software)
1. Small Artifacts & Movable Heritage Documentation	Detailed 3D capture of small, portable items for virtual collections, research, and display; direct, all-angle access needed; moderate-high visual and geometric detail.	Smartphone Photogrammetry (e.g., RealityScan,KIRI Engine, Polycam), Entry-level structured light scanner.	High-resolution Digital Camera Photogrammetry with turntable, or professional structured light scanner (e.g., Artec Micro II).
2. Surface Condition & Material Analysis (Paintings, Carvings)	High-resolution capture of surface textures, color, and subtle deterioration patterns on 2D/3D surfaces; close-range access; very high visual fidelity.	High-resolution DSLR Photogrammetry (macro lens), handheld photogrammetry with consistent lighting.	Professional Photogrammetry (e.g., Phase One cameras), structured light scanner (e.g., Artec Space Spider), or multi-spectral imaging.
3. Confined or Dark Structures (e.g., Caves, Tombs)	Acquiring 3D data in challenging environments with limited light and access, often uneven surfaces; portable solutions, specialized lighting. Robust geometry, visual texture.	Portable DSLR Photogrammetry with strong external lighting, or smartphone LiDAR with external lighting.	Handheld Laser Scanner (e.g., Artec Leo, Faro Freestyle) combined with DSLR photogrammetry, or dedicated cave scanning systems.
4. Architectural & Structural Documentation of Buildings	Comprehensive 3D models of large/complex structures (exteriors/interiors) for architectural study; varied access (ground, elevated, confined); good visual and geometric accuracy.	UAV Photogrammetry (prosumer drone like DJI Mavic) for exterior + DSLR Photogrammetry for accessible interiors.	Terrestrial Laser Scanning (TLS) for interiors/complex facades + Professional UAV Photogrammetry (e.g., DJI Matrice with high-res camera) for exteriors (Combined Approach).
5. Large-Scale Archaeological Site & Landscape Mapping	Expansive outdoor areas, including terrain modeling, features, and sometimes revealing hidden structures; requires aerial coverage, potential ground penetration.	UAV Photogrammetry (prosumer drone like DJI Phantom) for basic site mapping and orthophotos.	UAV-mounted LiDAR for terrain and obscured features + Professional UAV Photogrammetry for visual texture and detailed surface models (Combined Approach).
6. Engineering-Grade Precision for Structural Assessment	Very high accuracy for engineering analysis, deformation detection, precise intervention planning; direct access for precise scanning; sub-millimeter geometric accuracy.	Entry-level Terrestrial Laser Scanner (e.g., Leica BLK360) combined with detailed terrestrial photogrammetry.	High-precision Terrestrial Laser Scanner (e.g., FARO Focus S-series, Leica RTC360), potentially combined with photogrammetry for texture, and integrated with structural analysis software.
7. Long-Term Monitoring & Dynamic Digital Twin	Continuous or periodic data capture for real-time analysis of environmental/structural changes; high temporal comparison, real-time data fidelity; ongoing investment.	Periodic photogrammetric scans (DSLR/UAV) for visual change detection, combined with low-cost environmental IoT sensors.	Regular/Automated Terrestrial Laser Scanning for precise deformation monitoring + Integrated IoT Sensor Network (environmental, structural) feeding into a robust Digital Twin platform.
8. Virtual Reconstruction & Historical Interpretation	Recreating lost or significantly altered heritage elements/sites from historical evidence; variable detail based on evidence.	Photogrammetry (from historical photos/new captures) for visual cues, combined with basic 3D modeling software (e.g., SketchUp, Blender).	Combined approach (high-accuracy laser scans + detailed photogrammetry for existing parts), integrated with historical research, CAD/BIM software (e.g., Autodesk Revit, ArchiCAD) for complex modeling.

Table 11 - Summarized results with sub alternatives (Source - Author)

7. Discussion

6.1. Key Findings

The central finding of this research is the demonstration that the AHP framework provides a transparent and data-driven approach to technology selection for HBIM and Digital Twin creation. It effectively addresses the inherent complexity of choosing from a variety of technologies, each with its own set of trade-offs. The framework moves the decision-making process from a subjective, intuitive judgment to an objective, traceable calculation. This transparency is a significant advantage, as it allows project stakeholders to clearly understand the rationale behind the final choice and to ensure that the selection aligns with the project's core objectives. The study also conclusively shows that the final technology choice is not universal; it is highly dependent on the user's input and their unique prioritization of criteria. The AHP model is not a prescriptive tool that provides a single "best" answer for all sites but rather a robust method for arriving at a context-specific, optimal solution.

6.2. Future Narratives

Looking forward, a significant area for development is the creation of a user-friendly software tool based on the AHP framework. Such a tool would abstract the mathematical complexity of the AHP, allowing heritage professionals to easily input their own site-specific criteria and priorities. This would make the framework accessible and scalable for wider application across Sri Lanka's heritage sector and beyond, democratizing the process of informed technology selection.

6.3. Limitations

The AHP framework, while powerful, has key limitations. Primarily, the subjectivity of pairwise comparisons relies on expert judgment; different experts can yield different rankings. This human reliance can be mitigated by involving multiple experts or conducting sensitivity analyses.

Secondly, this AHP framework deliberately considers alternative technologies generally, without specifying particular models or brands. This choice ensures broad, enduring applicability despite rapid hardware advancements. However, it means a subsequent, detailed evaluation is essential to select exact hardware, considering practical, model-specific limitations like cost, availability, or specific model capabilities.
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Conclusion

This research successfully developed and applied a structured technology selection framework based on the Analytic Hierarchy Process for the initial data acquisition phase of HBIM and Digital Twin creation in Sri Lankan heritage sites. The framework provides a systematic and transparent methodology for navigating the complex decision-making landscape of 3D documentation technologies. Through a detailed case study of Lankathilake Pilimage and a series of proposals for other significant sites, the study demonstrated the framework's ability to provide data-driven, context-specific recommendations.

The AHP framework's key contribution is its capacity to transform subjective judgments into a quantifiable, defensible rationale for technology selection. It moves the conversation beyond a simple qualitative comparison of technologies to a rigorous, documented process that aligns technology choice directly with project objectives and site characteristics. The framework is an asset for heritage conservation professionals and researchers, offering a clear and robust method for making informed decisions for the digital preservation of cultural heritage, thereby ensuring the longevity and accessibility of these irreplaceable artifacts for future generations.

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