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Comparative Review: Laser Scanning and Drone Technology for Heritage Architectural 3D Documentation

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3D Laser scanning,
Drones,
Heritage documentation,
Photogrammetry.

Abstract: Innovation documentation procedures are very necessary for the protection of cultural heritage sites in general. This study investigates the capabilities of 3D laser scanning and drone photogrammetry in saving accurate documenting and preserving the delicate features of architectural history. The objective of the study is to establish a definitive plan for choosing the optimal technology, either 3D laser scanning or drone photogrammetry, based on the specific needs and status of a restoration project. That's by analysing the benefits and limitations of both technologies and investigating the potential for integrating them together. This research aims to determine the most suitable applications for each approach by evaluating their performance in terms of accuracy, resolution, data acquisition speed, and adaptation to varied environmental conditions. The results demonstrate that 3D laser scanning is highly effective in collecting intricate features, whereas drone photogrammetry provides quick coverage of large areas. The study's findings indicate that employing a combined strategy can greatly increase the quality and efficiency of architectural documentation. This, accordingly, leads to enhanced preservation efforts and deeper comprehension of cultural assets.

1. Introduction

All through history, humanity has built structures that stand as confirmation to our artistic, creative, and architectural genius. These social and cultural heritage sites are not just brick and mortar; they are windows to the past, offering invaluable experiences into bygone periods of years. However, safeguarding these fundamental and irreplaceable treasures presents a constant challenge. Traditional strategies methods of documentation, while

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significant, often battle to capture the complex points, details, and sheer scale of these architectural and structural elements. This is where digital revolution steps in, providing a robust solution through advanced technologies such as 3D laser scanning and drone photogrammetry.

This is by analysing the potential for changing and total transformation offered by advanced tools in accurately recording cultural heritage sites using 3D laser scanning. Adding to this innovative technology that accurately captures complex features, creating incredibly precise digital copies of heritage structures. These mentioned 3D models enable comprehensive examination and observation of a building's state, revealing concealed attributes and construction strategies that could sometimes remain undetected. Drones' technology offers exceptional access to distinct locations which are difficult-to-reach. Such skill of exploring or navigating inconvenient situations enables accurate data collection, ensuring that no information missed, ignored, overlooked or unrecorded.

The combined strengths of 3D laser scanning and drone photogrammetry can be harnessed to create a rich tapestry of information. Researchers, conservators, and the public are empowered to document with precision, capturing intricate details and hidden features that offer a deeper understanding of the history, materials, and construction techniques of the structure. They also strengthen the ability to monitor any changes, tracking subtle changes over time to enable early detection of deterioration and inform preventative conservation efforts. Additionally, they can create high-resolution digital archives that safeguard cultural heritage against potential damage or destruction.

This new and unique approach of architectural documentation shows great potential for the long-term future of safeguarding cultural assets. This paper seeks to fill these gaps by performing a comparative analysis of 3D laser scanning and drone photogrammetry for the purpose of documenting architectural history. The by understanding the power of 3D laser scanning and drones to achieve this goal. Aiming to create a decision-making framework that will assist practitioners in choosing the most appropriate technology for individual restoration projects, by analysing the strengths and limitations of each technique. In addition, the project will explore the potential advantages of integrating these technologies to generate more comprehensive and precise digital records.

2. Literature Review

As documentation function as a very essential type of collection required for scientific works and research, bridging the gap between the past and the present. It includes applying scientific concepts to historical events, considering their complexity, and promoting comprehension. Thus, utilize innovative and modern technological advancements to highlight the historical eras and how they have evolved over time. The Athens Charter (1931) and the Venice Charter (1964) have recognized documentation for building heritage as a key component of conservation and preservation. The Athens Charter (1931) requires "exact documentation" for preservation, restoration, or uncovering, which included analytical reports, drawings, and photographs as an important start and ongoing process in both preservation and conservation. [2]. In the field of build heritage documentation, geometric documentation plays a significant role. This study examines the definition, importance and standers related to geometric documentation. Considering the goal of documenting and built heritage is comprehensiveness. Includes numerical, pictorial, visual, narrative, and social aspects. Thus, geometric documentation forms a crucial component of this comprehensive approach. [3]. Highlighting the geometric documentation definition by UNESCO in 1972 [4], as encompasses various methods and techniques for architectural heritage recording. This can broadly categorize these methods into traditional, architectural, and digital documentation (Fig. 1).

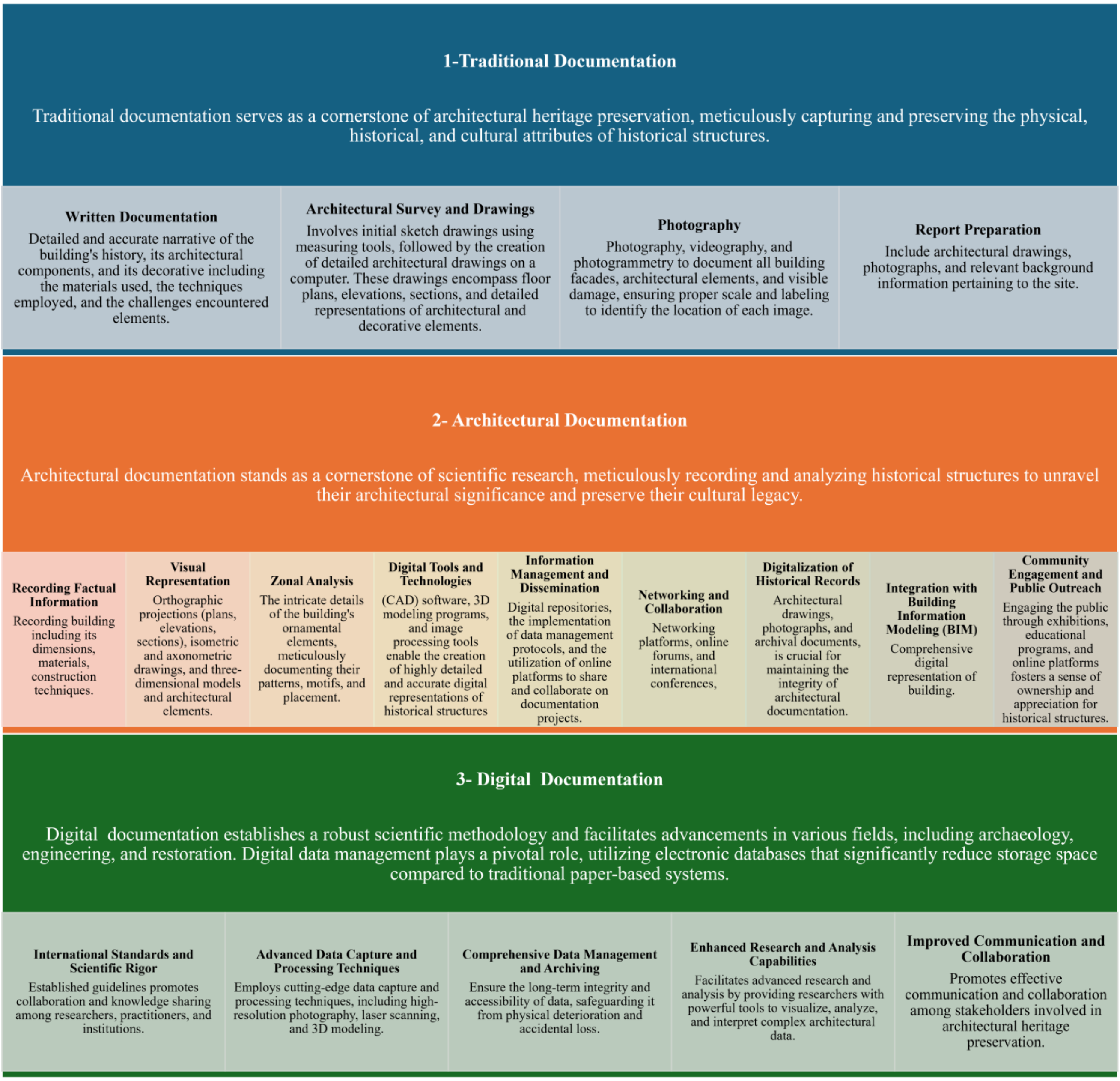

Fig.1: Traditional, Architectural, and Digital Documentation. Source: Authors

By discussing the moder technology advent for revolutionized documentation, by providing researchers with new powerful tools and software that expanded the scope and depth of historical inquiry by using digital archives, advanced imaging techniques, and sophisticated data analysis, providing access to previously inaccessible aspects of the past.
Adding to these technological advancements, documentation has transcended its traditional role as a simple archive. As, it has become a dynamic and transformative force in historical research. Allowing researchers now to reconstruct complex historical narratives together, by identifying different connections, and exposing hidden patterns that illuminate the underlying dynamics of historical change.

3. Methodology

This research presents a comparative analysis of laser scanning and drone photogrammetry for 3D documentation of heritage architecture. The research methodology involves a comprehensive literature review to identify the strengths, limitations, and benefits of each technique. Based on these findings, conduct a comparative analysis to determine the most suitable method for diverse heritage preservation projects, Fig., 2.

Fig.2: Research Methodology. Source: Authors

- Step One: Conducting a comprehensive literature review on heritage documentation, starting with traditional documentation and ending with the different types of digital documentation.
- Step Two: Examining in detail the two digital heritage documentation techniques', which are 3D laser scanning and drone photogrammetry.
- Step Three: Analysing each technique by analysing the benefits, limitations, and strengths of each one.
- Step Four: Comparative Analysis and Findings through the Integration of the Workflow for 3D Model Generation, and the Potential Benefits of Integrating Both Technologies
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4. Digital Heritage Documentation techniques

Digital surveying techniques offer a powerful tool for building heritage documentation, but their effectiveness varies depending on scale, accuracy, and environmental conditions. [5] The diversity of hardware and principles behind these techniques leads to difference in their application, flexibility, and lead to more achievable accuracy. Built heritage consider a unique challenge. Conder it as a 3D combination of various components, complex geometries, and a range of scales and detail levels. A high quality of digital record should be capturing not only the overall geometric space but also for the subtle details with precision and comprehensiveness. [6]

Achieving High quality digital data for built heritage documentation often presents a dilemma for practitioners. Ideal conditions include skilled professionals, ample time, and a controlled environment factors not always readily available. Additionally, powerful hardware and software are crucial for data processing. These limitations can force practitioners to compromise on the desired level of detail in the digital record, potentially leading to outputs that fall short of expectations. This compromises the ability of the documentation to effectively represent the values and condition of the built heritage for its intended audiences, such as conservators, researchers, and the public. Combining terrestrial laser scanning (TLS) and close-range photogrammetry (CRP) offers a promising solution. Each technology has inherent strengths that can address the weaknesses of others. Studies have demonstrated the effectiveness of combining these techniques, as well as their growing popularity among documentation practitioners.

However, existing research on TLS and CRP integration for built heritage documentation is limited. Existing methods tend to be case-specific and lack broader applicability. There's a lack of clarity on key factors like the suitability of each technology, data fusion methods, and documentation quality requirements for various projects. Documentation practitioners need a systematic method with practical implications to fully harness the potential of TLS and CRP integration for high-quality built heritage documentation. Fig. 3 illustrates some tools and techniques for architectural heritage documentation.

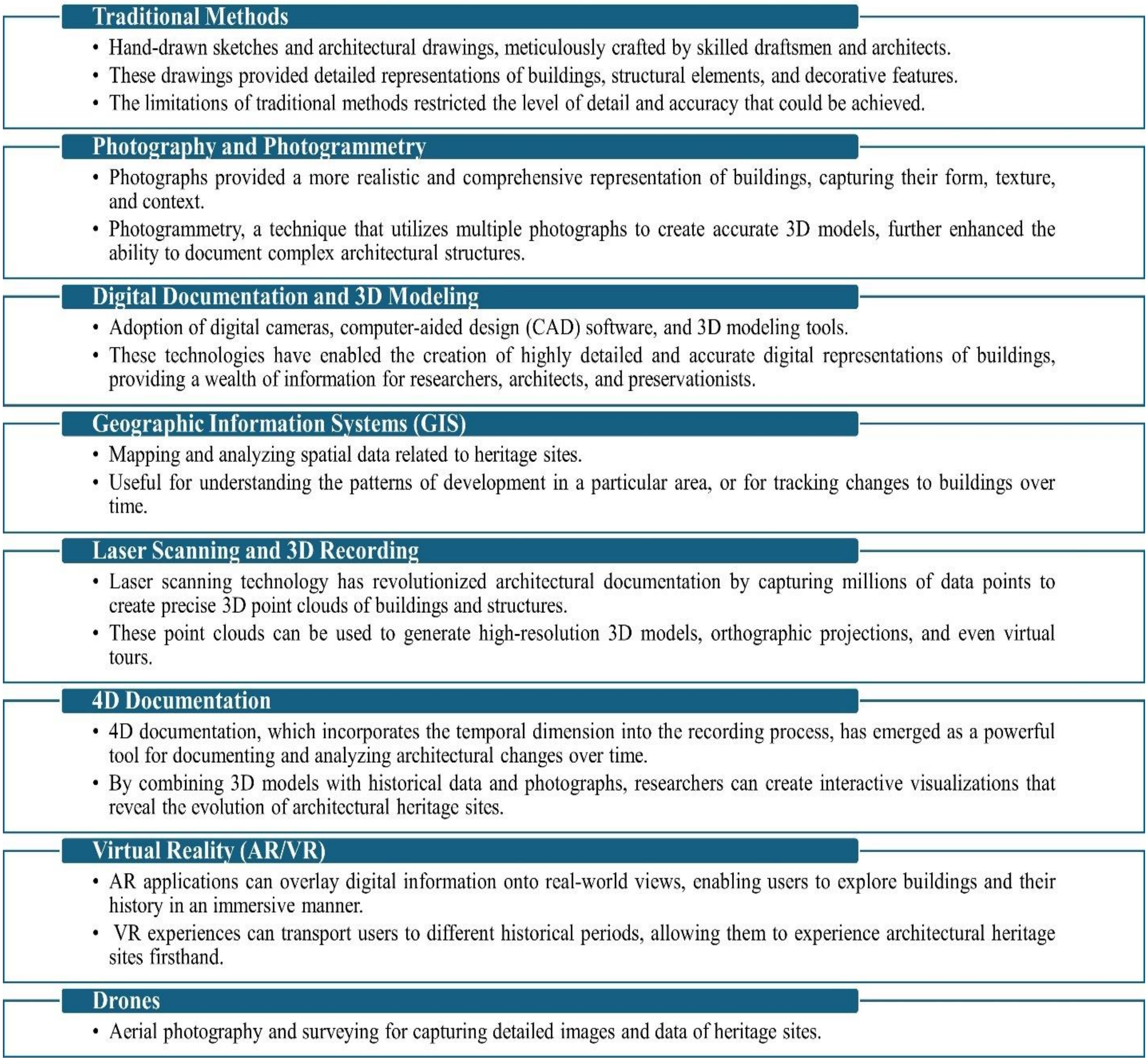

Fig. 3: Tools and Techniques for Architectural Heritage Documentation. Source: Author

4 .1 Built Heritage Documentation using Digital Captures

Built heritage documentation aims to bridge the past, present, and future, fostering communication among various stakeholders involved in conservation efforts (London Charter, 2009). To be effective, this documentation needs to be sustainable, accessible, and adaptable. [9] There are established guidelines for producing these 2D drawings, specifying appropriate scales and their corresponding accuracy levels. These scales range from capturing broad site plans to intricate ornamentation details [8].The required measurement accuracy for these drawings varies depending on the scale. Drawings, for instance, can achieve a suitable level of detail for research and preservation purposes with a measured accuracy of 3–9 mm. Higher accuracy might be necessary for environmental context, while recording highly intricate details may require even greater precision (up to 0.25 mm).

4.1.1 Close-Range Photogrammetry: Capturing Details

Photogrammetry is the science of extracting information from photographs. Digital photogrammetry has emerged as a powerful tool for architectural documentation, allowing the creation of 3D models from sequences of 2D images. [9] This method, commonly known as "Structure from Motion" (SfM), is highly automatable. Close-Range Photogrammetry (CRP) deals with photographs taken at close range (less than 300 meters) and can achieve millimeter- or even micrometer-level accuracy. CRP can utilize a variety of cameras and platforms, such as tripods and unmanned aerial vehicles (UAVs).

4.1.2 3D Laser Scanning: A Powerful Tool

Laser scanning, also known as LiDAR [10], is a non-contact surveying technique that rapidly captures a physical object's surface using laser light. This creates a highly accurate 3D representation in the form of a digital point cloud. Technology has seen significant advancements in recent decades, making it faster, more accurate, and more accessible. There are two main types of 3D laser scanners: triangulation-based scanners for small objects and time-of-flight scanners for larger, more complex structures like buildings.

4.1.3 The Importance of High-Resolution Data

3D laser scanning has become a vital tool for documenting cultural heritage for long-term conservation. [11] High-resolution 3D records enable detailed monitoring, research, dissemination, and understanding of cultural history. This necessitates the creation of vast archives with secure storage for these large datasets. Preserving raw data formats is crucial, as advancements in technology will allow for future reprocessing and analysis. Some cases even allow for the creation of physical replicas using 3D data, sparking discussions about authenticity and the role of high-resolution facsimiles in heritage preservation. There are various 3D laser scanning methods, each with its own strengths and limitations. The choice of method depends on the specific application. 3D data can capture large-scale landscapes or focus on the intricate details of sculptures. It can reveal subtle marks that are invisible to the naked eye and serve as a permanent record of an object's exact size and shape. [12]

3D scanners capture information about the object and its surrounding environment. You can then edit, analyse, or 3D print this digital replica. Typically, in the field, it takes multiple scans from different angles to capture the entire object. Then align and merge these individual scans to create a complete 3D model. The most common 3D laser scanning technologies include [13, 14].

- Time of Flight
- Triangulation
- Phase Shift
- Stereo

4.2 Highlighting the Advantages of 3D Laser Scanning for Heritage Preservation

Traditional 3D measurement methods often presented challenges for heritage preservation. 3D laser scanning technology, however, has revolutionized this field by offering several key advantages: [15, 16, and 17]

- **Non-contact data collection:** Unlike traditional methods that require physical contact, 3D laser scanning captures data without touching the fragile surfaces of historical structures. This eliminates the risk of damage during the documentation process.
- **High data sampling rate and resolution:** The technology captures a vast amount of data points at a very high resolution, resulting in incredibly detailed 3D models. This level of detail allows for the accurate representation of even the most intricate features of a structure.
- **High precision:** 3D laser scanning produces highly precise measurements, ensuring the accuracy of the captured data. This is crucial for creating reliable documentation that can be used for restoration and conservation efforts.
- **Omnidirectional data collection:** The technology can capture data from all angles, making it possible to document even complex or hard-to-reach areas of a structure. This comprehensive data allows for a complete picture of the building's condition.

These combined features enable 3D laser scanning to effectively capture detailed 3D information about a structure, including its geometry, intricate details, and surface materials. This data can then be used for a variety of applications in heritage preservation, such as:

- **Data acquisition and storage:** Creating a permanent digital record of a historical structure that can be used for future reference and study.
- **Data analysis and condition monitoring:** Analysing the captured data to identify potential problems or areas of deterioration, allowing for preventive conservation measures.
- **Digital display and visualization:** Creating realistic 3D models that can be used for educational purposes, public outreach, and virtual tours.

Sometimes, it can combine 3D laser scanning with other technologies, such as tilted aerial photography from drones, to collect preliminary data. Furthermore, by integrating this data with Building Information Modelling (BIM), by creating a comprehensive digital model that serves various purposes throughout the preservation process.

In conclusion, 3D laser scanning offers a powerful and versatile tool for architectural heritage preservation. Its non-invasive nature, high accuracy, and comprehensive data capture capabilities make it invaluable for documenting and safeguarding our historical structures for future generations. 3D laser scanning offers several advantages for architectural heritage preservation. It allows for:

- Non-contact data collection
- High data sampling rate
- High resolution
- High precision
- Omnidirectional data collection

These features enable the technology to effectively capture detailed 3D information about a structure, including its geometry, intricate.

4.3 Drones Tools for Architectural Heritage Documentation

Drones, also known as unmanned aerial vehicles (UAVs), are revolutionising the field of architectural heritage documentation. Their ability to capture high-resolution data from delicate environments makes them invaluable throughout the entire preservation process, from initial data collection to final reconstruction. [18,19]

- **Regulations and Safety:** Safe and legal drone operation is crucial. Resources, along with airspace maps, are readily available online.
- **Flight Planning for Optimal Data Capture:** Effective drone use requires careful planning. Flight planning software allows users to define study areas, set flight paths, and automate image acquisition. Key considerations during flight planning include:
    - **Area Delineation:** Defining the specific area to be documented ensures efficient data collection.
    - **Photo Overlap:** Sufficient overlap between images (most software offers default settings) is critical for generating high-quality 3D models.
    - **Altitude:** Balancing image resolution with area coverage. Lower altitudes provide greater detail but cover smaller areas. Flight time is another factor, as current drones typically have limited battery life.

4.3.1 Capturing Details with High-Resolution Technologies

Drones equipped with various high-resolution sensors can capture intricate details of architectural heritage sites: [20,21]

- **Aerial Photography and Videography:** High-resolution images and videos from various angles provide a comprehensive overview for:
    - **3D Modelling:** Creating highly accurate 3D models for visualization, structural analysis, and restoration planning.
    - **Documenting Restoration Progress:** Monitoring restoration progress by capturing regular aerial images to identify potential issues and create a detailed record.
    - **Preservation Efforts:** Identifying areas requiring urgent attention and planning necessary interventions.
- **LiDAR (Light Detection and Ranging):** LiDAR drones emit light pulses that bounce off objects, creating highly detailed 3D point clouds for:[22]
    - **Analysing Archaeological Sites:** Uncovering hidden structures and revealing details about past construction methods.
    - **Recording Intricate Details:** Capturing intricate details of historical buildings with exceptional accuracy.
    - **Measuring Structures for Restoration:** Providing precise measurements for restoration purposes, ensuring structural integrity and maintaining historical fidelity.

- **Multispectral Imaging:** These drones capture data beyond the visible spectrum, revealing features invisible to the naked eye, useful for:
  - **Archaeological Discoveries:** Uncovering hidden structures or past modifications to historical sites.
  - **Damage Detection:** Identifying damage invisible in regular photographs, facilitating timely repairs and preventing further deterioration.

4.3.2 Data Processing and Deliverables

The following steps are required and necessary for acquiring processing drone captured till images, Fig.4:

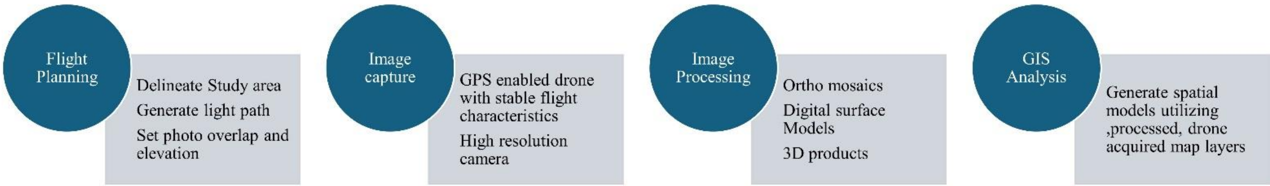

Fig. 4: Workflow for acquiring and processing drone captured still images. Source: Lorah, Paul, Alice Ready, and Emma Rinn. "Using drones to generate new data for conservation insights." International Journal of Geospatial and Environmental Research 5, no. 2 (2018): 2.

Drone-captured images are typically geotagged JPEG files. Software programs can process these overlapping images to generate various deliverables:

- **2D Mapping Products:**
  - Digital Terrain Models (DTMs) represent bare-earth elevation.
  - Digital Surface Models (DSMs) capture the entire surface including vegetation.
  - Ortho mosaics: geometrically corrected aerial photographs.
- **3D Products:**
  - Colorized point clouds.
  - Textured meshes for realistic visualizations.
  - 3D PDFs for sharing and analysis.

4.3.3 Advantages of Drone Applications in Architectural Preservation

Drones offer significant advantages over traditional methods for architectural documentation [23,24]:

- **Precision Measurements:** Drone-based laser scanning provides accurate measurements of angles, distances, and surface details.
- **Efficient Data Collection:** Drones can rapidly collect data, eliminating time-consuming and error-prone manual techniques.
- **Improved Visualization:** 3D models derived from drone data offer a clear virtual representation of the architecture.

- **Speed and Efficiency:** Drones can quickly scan complex structures, reducing manual labor and saving time and resources.
- **Cost-Effectiveness:** While there is an initial investment, drone technology can be cost-effective in the long run due to its speed and efficiency.
- **Enhanced Safety:** Drones can access areas that are dangerous or inaccessible to humans, minimizing risk.
- **Regular Inspections:** Drones facilitate frequent and easy inspections of construction sites, providing valuable data for progress monitoring.
- **Efficient Surveying and Mapping:** LiDAR technology on drones allows for precise 3D modeling and measurement of buildings, eliminating the need for time-consuming manual methods, Fig. 5.

Fig 5: Advantages of Drone Applications in Architectural Preservation. Source: https://www.linkedin.com/pulse/transforming-building-documentation-future-drone-scanning-ydlkc/

By leveraging these advantages, drones are playing a critical role in the preservation of our architectural heritage. They help us document valuable sites with exceptional detail, understand them more fully, and ultimately ensure their legacy continues for future generations.

5. Results

Comparative Analysis and Findings for Historical Architectural Documentation Techniques and comparing two prominent technologies used in architectural documentation: 3D laser scanning and drone photogrammetry, Table 1. Both methods capture real-world objects and create 3D digital representations. However, they differ in their underlying principles, data acquisition techniques, and suitability for specific applications. Focusing on the two prominent technologies used in architectural documentation; 3D laser scanning and drone photogrammetry, both methods capture real-world objects and create 3D digital representations, but they differ in their underlying principles, data acquisition techniques, and suitability for specific applications, Table 2; 3.

Table 1: Comparative Analysis and Findings: Architectural Documentation Techniques. Source: Authors

Feature	3D Laser Scanning	Drone Photogrammetry
Technology	Uses lasers to measure distances and create 3D models.	Captures multiple photographs from a drone to create 3D models using software.
Variations	• Close-range (intricate details) • Medium-range • Long-range • Pulse-based (long-range) • Phase-shift (medium & long-range)	* N/A
Recording Distance	• Close-range: 8-10 cm • Medium-range: 0.6 m - 30 m • Long-range: Up to 330 m	Close-range and long-range possible
Resolution	High (100 microns)	Varies depending on several factors (camera quality, software processing)
Applications	• Historical sites (indoor & outdoor) • Intricate details (statues, carvings) • Flat surfaces (walls, paintings) • High & low reliefs	• Building facades & exteriors • Large-scale architectural features • Difficult/dangerous to access areas
Environmental Conditions	• Works best with Cloudy days with even light (no rain)	• Soft light (no harsh shadows), minimal wind

Table 2: Benefits of each Techniques. Source: Authors

Feature	3D Laser Scanning	Drone Photogrammetry
Works on Challenging Surfaces	Yes	Less effective
Less Sensitive to Lighting Changes	Yes	Requires specific lighting conditions
High-Resolution & Accurate Data Capture	Yes	Lower accuracy than laser scanning
Eye-Safe Scanning	Yes	N/A
Portable & User-Friendly Scanners Available	Yes	Lightweight and mobile
Contactless Scanning	Yes	Yes
Captures Vast Areas Quickly	No	Yes
Captures Movement	No (limited)	Yes (useful for studying specific features)

Table 3: Limitations of using each Techniques. Source: Authors

Feature	3D Laser Scanning	Drone Photogrammetry
Limited Texture & Surface Capture	Yes	Provides richer texture data
Resolution Varies with Range	Yes	Consistent within a single flight
Slower Scanning Speeds	Yes	Faster data capture compared to scanning
Challenges with Reflective Surfaces	Yes	Can be mitigated with proper scanning techniques
Bulky Traditional Scanners (Some Models)	Yes	Lightweight equipment
Lower Accuracy than Laser Scanning	No	Yes
Requires Reference Points for Scale	No	Yes
Longer Processing Times for Complex Models	Yes	Faster than processing large scan datasets
Subject to Weather Conditions & Airspace Regulations	No	Yes

This analysis highlights the complementary strengths of 3D laser scanning and drone photogrammetry for historical architectural documentation, Table 4.

Table 4: Strengths of each Techniques. Source: Authors

3D Laser Scanning Strengths	Drone Photogrammetry Strengths
• High-resolution data capture for intricate details and accurate measurements. • Versatile technology with various scanner types for diverse applications. • Well-suited for capturing historical sites, building elements, and flat surfaces. • Offers contactless scanning for various objects and environments.	• Rapid capture of objects, ideal for fast-paced documentation. • Lightweight and portable equipment facilitates easy deployment in challenging areas. • Effective for capturing building exteriors and large-scale architectural features. • Captures movement, making it suitable for dynamic objects.

6. Integrated 3D Modelling Approach

This follows a groundbreaking workflow for capturing and modelling intricate architectural details. Achieving a comprehensive 3D representation of a structure by combining 3D laser scanning and UAV photogrammetry, Fig.,6.

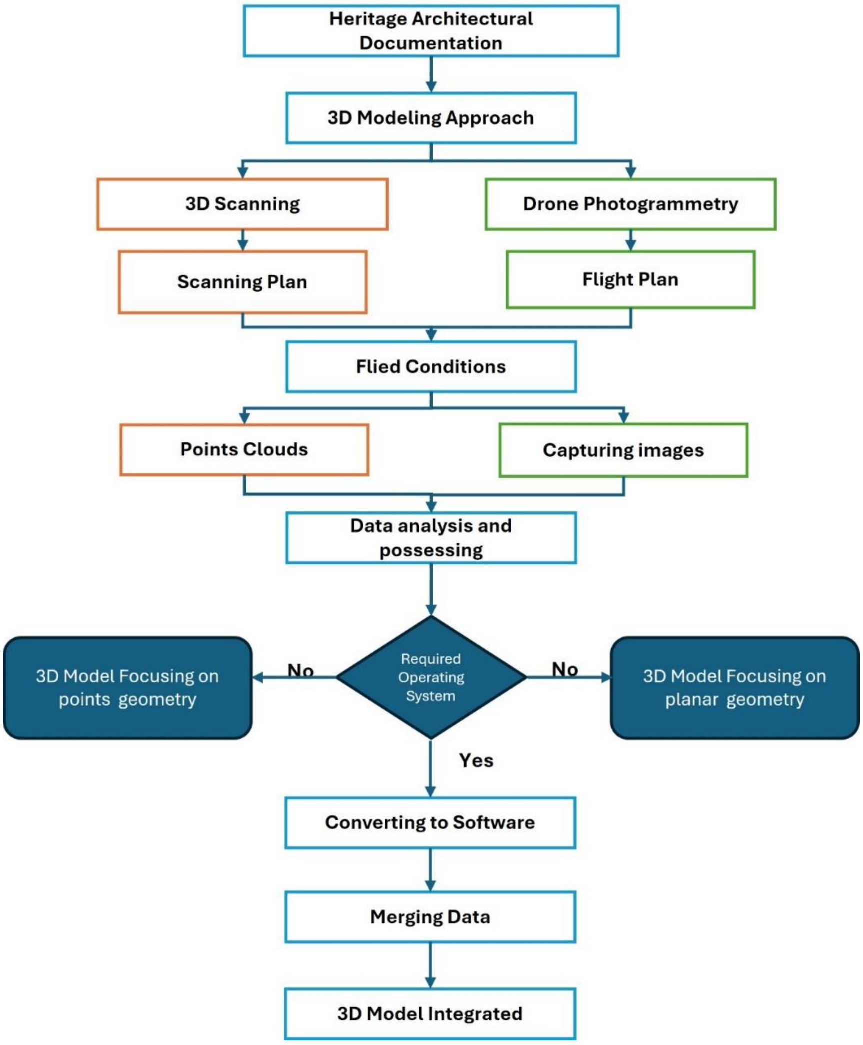

Fig. 6: Integrated Workflow for 3D Model Generation

7. Conclusions

Our built environment's enduring legacy is based on meticulous documentation. Which explores two transformative technologies—3D laser scanning and drone photogrammetry—empowering architects and preservationists to safeguard these historical treasures.

Selecting the Right Tool as the optimal technology hinges on the specific project requirements of each approach's strengths perspective:

- **3D Laser Scanning:**
  - **Unparalleled Detail:** Ideal for capturing intricate features and surfaces with high-resolution data. Perfect for historical sites, carvings, and demanding precise measurements.
  - **Adaptable Expertise:** Offers diverse scanner types for various applications. Handles flat surfaces, building elements, and various environments with contactless ease.

- **Drone Photogrammetry:**
  - **Rapid Capture:** Excels in speedy data acquisition, making it ideal for fast-paced projects.
  - **Unmatched Mobility:** Lightweight and portable equipment allows for effortless deployment in challenging locations, capturing building exteriors and large-scale features.
  - **Capturing Movement:** Uniquely captures movement, valuable for documenting dynamic objects.

In essence, 3D laser scanning reigns supreme for high-resolution, detailed capture of intricate features and challenging surfaces. Drone photogrammetry becomes the preferred choice when capturing large areas, building facades, or difficult-to-access areas quickly.

By understanding these strengths and limitations, professionals can make informed decisions:

- **High-Resolution Precision:** For intricate details, precise measurements, and high-resolution data, 3D laser scanning is the undisputed champion.
- **Rapid Documentation & Accessibility:** For fast capture of building exteriors, large-scale features, or areas with difficult access, drone photogrammetry is the ideal tool.

The Future: A Symphony of Technologies

The collaborative power of these technologies is the most exciting prospect. Merging their strengths unlocks a comprehensive and efficient approach to architectural documentation. This convergence empowers professionals to:

- Capture detailed building exteriors with drones.
- For intricate details and interiors, use laser scanning.
- Create a unified 3D model, offering a complete picture of the structure.

This integrated approach will revolutionise architectural documentation, fostering a deeper understanding and appreciation of our built heritage for generations to come.

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