architecture

MDPI

Concept Paper

A Conceptual Framework for Integrating Terrestrial Laser Scanning (TLS) into the Historic American Buildings Survey (HABS)

Junshan Liu [1,*], Danielle Willkens [2] and Russell Gentry [2]

[1] McWhorter School of Building Science, Auburn University, Auburn, AL 36849, USA
[2] School of Architecture, Georgia Institute of Technology, Atlanta, GA 30332, USA; danielle.willkens@design.gatech.edu (D.W.); russell.gentry@design.gatech.edu (R.G.)
* Correspondence: liujuns@auburn.edu

Abstract: The preservation of historic structures is a complex and evolving field that requires a delicate balance between traditional methods and modern technology. This paper presents a conceptual framework for integrating terrestrial laser scanning (TLS) into the Historic American Buildings Survey (HABS), bridging the gap between the past and the future. By examining the historical context of the HABS and the emerging potential of TLS, the paper explores the feasibility, effectiveness, and methodological considerations for incorporating this advanced technology into the standard heritage building documentation practice. The research is structured into four main chapters, each addressing a critical aspect of the integration process, from the proposal of the study to the development of guidelines for TLS data acquisition, processing, and management. The paper also delves into the selection of projects for case studies, the application of the framework, and a critical evaluation of its effectiveness. As a conceptual paper, it lays the foundation for a Ph.D. dissertation, offering a comprehensive roadmap for future research and practical implementation. The insights and guidelines provided in this paper aim to enhance the accuracy, efficiency, and richness of heritage documentation, contributing to the broader field of heritage preservation and underscoring the importance of embracing technological advancements while honoring historical integrity.

Keywords: architectural heritage; conceptual framework; heritage building documentation; Heritage Documentation Program (HDP); LiDAR; preservation

Citation: Liu, J.; Willkens, D.; Gentry, R. A Conceptual Framework for Integrating Terrestrial Laser Scanning (TLS) into the Historic American Buildings Survey (HABS). *Architecture* **2023**, *3*, 505–527. https://doi.org/10.3390/architecture3030028

Academic Editors: Carlos J. Rosa Jiménez and Daniel Navas Carrillo

Received: 14 August 2023
Revised: 1 September 2023
Accepted: 5 September 2023
Published: 7 September 2023

1. Introduction of Heritage Documentation Programs (HDP) and Historic American Buildings Survey (HABS) in the U.S.

1.1. Origin of America's Heritage Documentation Programs

The 1930s were a tumultuous period in American history, marked by the Great Depression. Amidst widespread economic hardships and soaring unemployment rates, the National Park Service's (NPS) Heritage Documentation Programs (HDP) emerged as a beacon of hope. Originally known as the Historic American Buildings Survey (HABS) [1], it was established in 1933 with a dual mission: to meticulously document America's architectural heritage and to provide employment opportunities for architects, draftsmen, and photographers who found themselves jobless due to the economic downturn [2,3].

During its early stages, the HABS was primarily steered by architects and photographers, who embarked on a journey to capture the essence of America's architectural marvels. Some of the earliest projects undertaken by the HABS include documenting iconic structures like the Plum Street Temple in Cincinnati and the early skyscrapers of Chicago. The initiative was lauded by professionals for its precision and attention to detail, and it resonated with the general public for its commitment to preserving the nation's architectural legacy [2].

1.2. Evolution and Expansion of the HDP

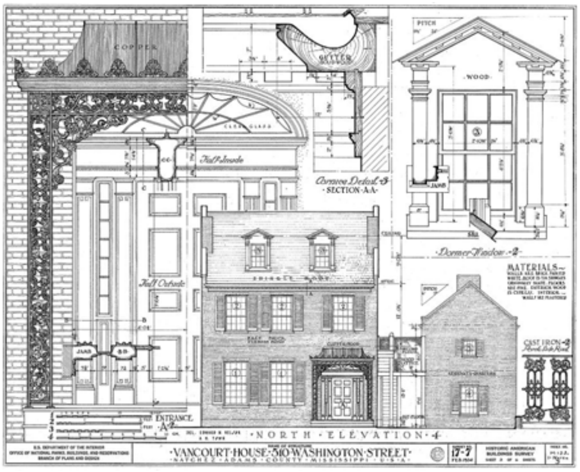
Since its inception, the HDP has grown to include three primary programs: the HABS, the Historic American Engineering Record (HAER), and the Historic American Landscapes Survey (HALS) [4]. These programs have documented significant architectural, engineering, and landscape sites across the U.S., aiming to preserve, provide public access, educate, and set the standard for heritage documentation.

- HABS: As the cornerstone of HDP, established in 1933, the HABS's mission revolves around documenting a diverse range of American structures, from grand architect-designed towers to the more modest vernacular constructions.
- HAER: Started in 1969, with a lens on America's engineering marvels, the HAER captures the essence of bridges, ships, factories, and other feats of engineering.
- HALS: Commissioned in 2000, the HALS delves into the nation's historic landscapes, capturing everything from meticulously designed gardens to expansive urban parks and untouched rural vistas.

1.3. Technological Evolution in HABS's Documentation Methods

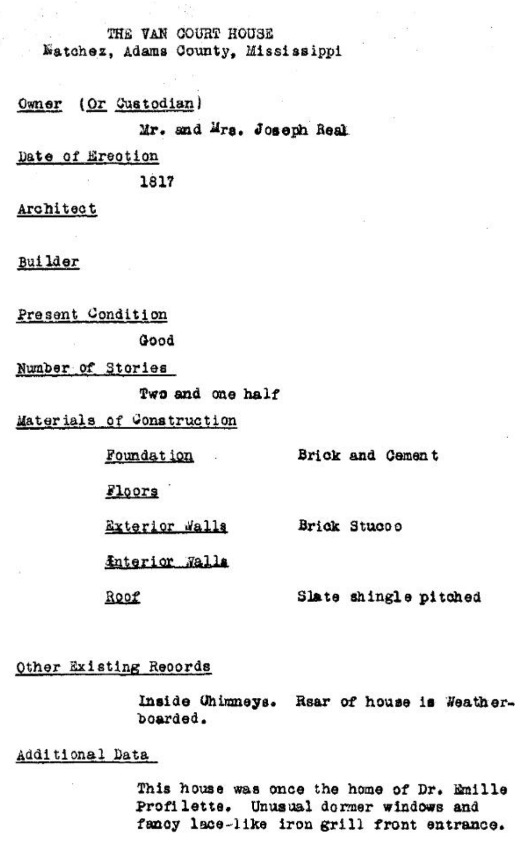
The HABS's commitment to accuracy has driven continuous evolution in its documentation methodologies. Initially reliant on measured drawings, large-format black and white photography, written historical reports, and field notes (as illustrated in Figure 1), the HABS has embraced technological advancements. From architectural photogrammetry in the 1950s to laser scanning technologies in the 2000s, the HABS has adapted to capture the essence of America's heritage with increasing precision. The HABS was initially reliant on the following methods:

- **Measured Drawings:** The primary objective of measured drawings is to offer a detailed and accurate representation of a site's architectural features. Produced after meticulous on-site measurements, these drawings capture the structure's proportions, dimensions, and intricate details. The data recorded include scale-specific representations, detailed floor plans, elevations, cross-sectional views, and close-ups of specific architectural or engineering features.
- **Large-Format Black and White Photography:** This technique aims to visually document the site or structure in its current state, capturing its fine details, contrasts, and textures. Black and white photography is favored for its timeless quality and ability to provide a detailed visual archive. The photographs taken encompass exterior and interior views, close-up shots of specific architectural elements, and broader contextual images that place the structure within its environment.
- **Written Historical Reports:** These reports narrate the comprehensive history and significance of the site or structure. They encompass details about the site's history, architectural style, construction methods, and any alterations it might have undergone. The data within these reports include a detailed historical background, architectural analysis, insights into the site's cultural and social significance, and a bibliography of consulted sources.
- **Field Notes:** Field notes are a crucial supplement to other documentation techniques. They involve the recorder's firsthand observations, sketches, and annotations made during on-site visits. The primary objective of field notes is to capture immediate insights, preliminary measurements, and contextual details that might not be evident in formal drawings or photographs. These notes often provide a richer understanding of the site, capturing nuances like material finishes, decay patterns, or anecdotal histories shared by locals. Over time, field notes have evolved from handwritten notes to digital annotations, but their essence remains the same: to provide a raw, unfiltered perspective of the site during the documentation process.



(**a**)

(**b**)



THE VAN COURT HOUSE
Natchez, Adams County, Mississippi

Owner (Or Custodian)
Mr. and Mrs. Joseph Real

Date of Erection
1817

Architect

Builder

Present Condition
Good

Number of Stories
Two and one half

Materials of Construction

Foundation — Brick and Cement

Floors

Exterior Walls — Brick Stucco

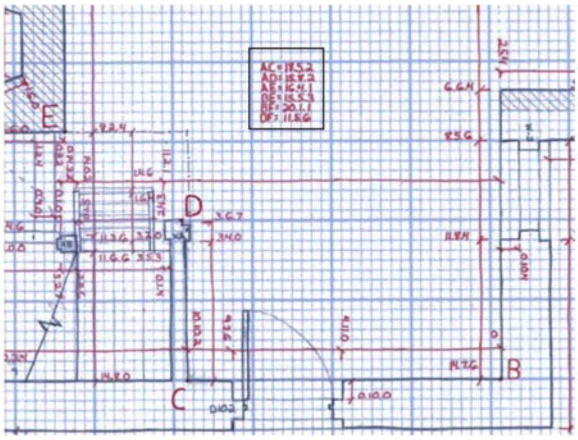
Interior Walls

Roof — Slate shingle pitched

Other Existing Records
Inside Chimneys. Rear of house is Weather-boarded.

Additional Data
This house was once the home of Dr. Emille Profilette. Unusual dormer windows and fancy lace-like iron grill front entrance.

(**c**)



(**d**)

Figure 1. A sample of HABS documentation, including (**a**) measured drawings; (**b**) photography; (**c**) historical reports; and (**d**) field notes [5,6].

Over the decades, the HABS has evolved its surveying methodologies and techniques from analog surveys to digital technologies [7]. In the 1950s, it incorporated architectural photogrammetry to capture the Plum Street Temple in Cincinnati and the early skyscrapers in Chicago [8]. The 1970s saw the use of aerial photogrammetry to record historical sites such as Native American villages in Arizona and New Mexico [9]. The 1980s witnessed the introduction of computer-aided design and drafting (CADD) for creating measured drawings for projects such as the Washburn A. Mill project in Minneapolis, Minnesota [3]. The 1990s brought laser technologies to the HABS's projects, and in the 2000s, the HABS began experimenting with laser scanning technologies in various projects, including the

Statue of Liberty in New York City [7]. Figure 2 shows the HABS's evolution timeline with technologies.

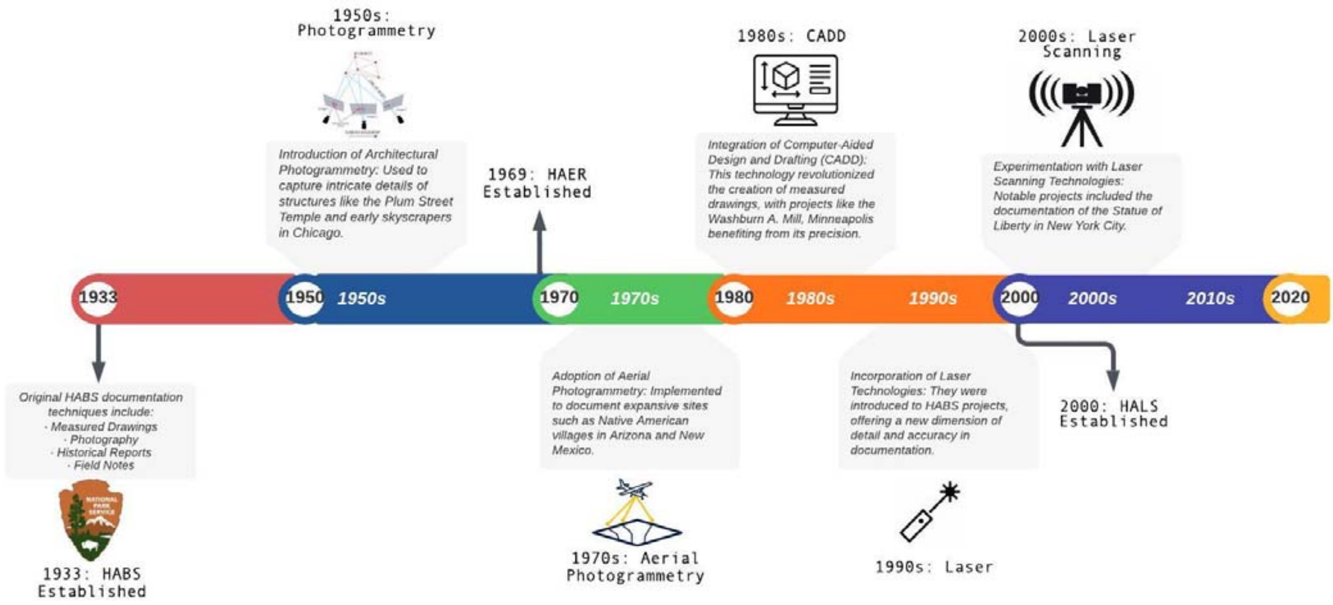


Figure 2. Timeline of HABS's technological evolution.

1.4. Challenges Faced by HABS

The HABS has profoundly influenced the preservation of America's cultural heritage. Its detailed records serve as an essential touchstone for scholars, educators, historians, and the wider public. Through its endeavors, the HABS has documented historical structures and heightened public consciousness about the imperativeness of safeguarding America's heritage for future generations.

Various challenges have also marked the journey of the HABS. As it integrated new technologies, the program grappled with the complexities of promoting public engagement, training its personnel, and ensuring consistent documentation quality. The vast datasets generated posed their own set of management issues. Financial constraints, especially during economic downturns, often put the program in a position where it had to achieve its goals with limited resources. Furthermore, despite the critical nature of the HABS's work, raising public awareness and maintaining engagement demanded continuous outreach and educational efforts.

1.5. Objective and Significance of the Study

The primary objective of this study is to critically examine the integration of a contemporary reality capture (RC) technology, terrestrial laser scanning (TLS), within the framework of HABS documentation. This examination seeks to understand how technological advancements can enhance the preservation, documentation, and accessibility of America's cultural heritage. The significance of this research lies in its potential to inform and recalibrate the HABS's methodologies, ensuring alignment with the evolving technological paradigm. By exploring innovative approaches and tools, this study aims to contribute valuable insights to the field of heritage documentation and preservation.

1.6. Nature of the Paper

It is essential to emphasize that this paper is conceptual in nature. It does not present empirical data or specific findings but rather explores theoretical frameworks, methodologies, and technological advancements relevant to the HABS. The paper synthesizes the existing literature, historical context, and technological trends to analyze the subject matter comprehensively.

This paper also serves as the groundwork for the lead author's Ph.D. dissertation. By laying a solid foundation in understanding the historical evolution, technological advancements, and challenges faced by the HABS, it establishes a platform for further in-depth research and exploration. The insights and perspectives presented in this paper will be instrumental in shaping the direction and focus of the author's doctoral research, contributing to the broader academic discourse on heritage documentation.

1.7. Abbreviations

This paper uses abbreviations to refer to various terms and concepts. To avoid confusion and ensure clarity, below is a list of these abbreviations and their corresponding meanings:

- AR: Augmented Reality
- BIM: Building Information Modeling
- CADD: Computer-Aided Design and Drafting
- CRGIS: Cultural Resources Geographic Information Systems
- GIS: Geographic Information Systems
- HABS: Historic American Buildings Survey
- HAER: Historic American Engineering Record
- HALS: Historic American Landscapes Survey
- HBIM: Heritage Building Information Modeling
- HDP: Heritage Documentation Program of the National Park Service
- LiDAR: Light Detection and Ranging
- MEP: Mechanical, Electrical, and Plumbing
- NPS: National Park Service of the U.S.
- PC: Point Cloud
- QAQC: Quality Assurance and Quality Control
- RC: Reality Capture
- TLS: Terrestrial Laser Scanning
- UAV: Unmanned Aerial Vehicle
- VR: Virtual Reality

2. A Comparative Analysis of Laser Scanning Technology in Building Construction and Historic Documentation

2.1. Introduction to Laser Scanning Technology

Laser scanning, also known as Light Detection and Ranging (LiDAR), recognized by its primary technique of terrestrial laser scanning (TLS), has revolutionized the documentation and analysis of the built environment in the geometrical aspects. This section provides an overview of the fundamental principles of laser scanning, emphasizing its significance in capturing the intricate details of structures, from modern buildings to historic edifices.

The fundamental principle behind laser scanning is the emission of a laser beam directed at a structure. The time this beam takes to reflect back after making contact with the object's surface is meticulously measured. This time-of-flight measurement is subsequently translated into distance data. Amalgamating with the laser beam's horizontal and vertical angles facilitates the precise spatial positioning of each measured point in the local coordinate system. With millions of such measurements taken in a single scan, the outcome is a dense "point cloud (PC)". This cloud, comprising myriad data points, assembles to form an intricately detailed and highly accurate three-dimensional portrayal of the structure in question. Such precision allows for the capture of even the most nuanced architectural elements and potential structural anomalies like deformations or cracks [10–12].

The most significant advantages of laser scanning technology for documenting the built environment over other techniques include its high accuracy [13,14], fast speed for the amount of data captured over the time spent [15], and thoroughness of non-invasive object capture [16,17] that does not require a returned field survey [18]. As Al-Bayari and Shatnawi mentioned in their study [19], 25–30% of the time needed for field surveys could be reduced using TLS to capture and document heritage.

On the other hand, TLS has several drawbacks. It is expensive. A laser scanner can easily cost tens of thousands of dollars [18]. It requires specialty software, substantial hardware, and highly trained professionals to process and handle the scan data [13,20]. A laser scan survey can also be time-consuming [21], especially when it is used to capture large and complex sites and is sensitive to the environment such as lighting conditions, dust, fog, rain, etc. [18]. Factors such as data acquisition time, environmental conditions, and data processing time can all contribute to the overall time required for the survey.

The versatility of laser scanning is evident in its applicability across a structure's life cycle, encompassing stages from site planning, design, construction monitoring, operation and maintenance (O&M), heritage documentation, and asset management, to eventual demolition.

2.2. Comparative Analysis: Laser Scanning in Building Construction vs. Heritage Documentation

Laser scanning has emerged as a pivotal tool in both building construction and heritage documentation. Its transformative potential is evident in its diverse applications across these domains. This section carries out a comparative analysis of how laser scanning is employed in these two distinct fields, highlighting the methodologies, objectives, and potential for synergy.

2.2.1. Laser Scanning for Building Construction

In the field of building construction, laser scanning is mainly used for acquiring measurements and as-built conditions for construction management due to its levels of accuracy and time saving which are difficult to achieve using traditional techniques [22]. The technology is used in various practical applications, such as as-built documentation (Figure 3), quality assurance and quality control (QAQC), generating project record drawings, tracking work progress, and clash detection during construction projects [23–27].

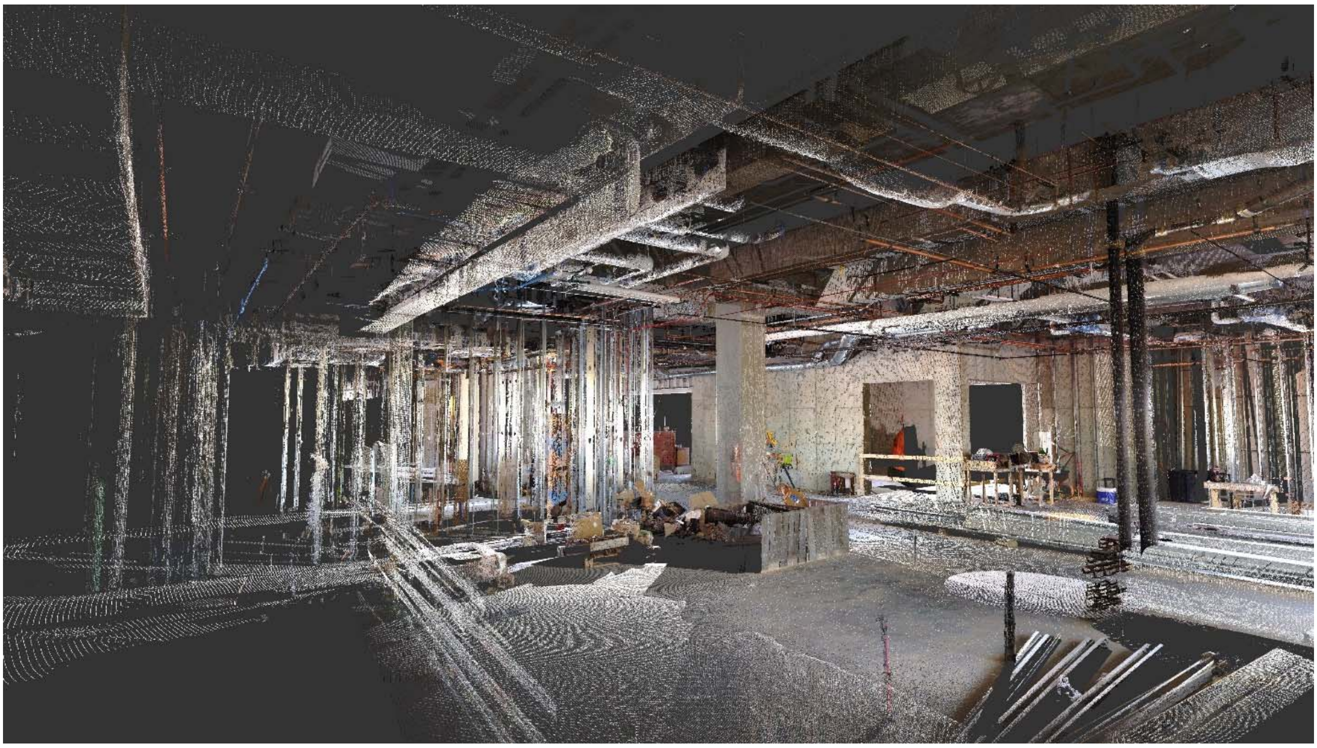


Figure 3. A TLS PC of a commercial construction project was captured to document the project's as-built conditions.

Scanning Methodology

The primary objectives of scanning an ongoing construction project are to document the project's progress and record the building elements that might be enclosed or obscured in the later stages of construction [28]. To achieve these objectives, the methodology for using laser scanning in this context is more fluid and dynamic than in heritage documentation [24]. The scanning process is typically carried out periodically throughout the project. This approach allows for capturing the evolving state of the construction site at various phases, providing a detailed record of the project's progress. This can be invaluable for project management purposes, as it allows for the tracking of work completed, identifying deviations from the plan, and early detection of potential issues. Given the need for frequent scanning, the scans' resolution may be lower than those used for heritage documentation [27]. This practical compromise allows for quicker scans, reducing the impact on the construction schedule and easing the demand for scan data storage. Also, lower resolution scans are typically sufficient for capturing the standardized structural and MEP (mechanical, electrical, and plumbing) elements of the modern building, which are the primary focus at this stage. Furthermore, the scanning process in building construction often focuses on specific portions of the building that are relevant at each stage of the project. For example, as different parts of the building are constructed, they may be scanned before they are enclosed or obscured by subsequent work. This selective scanning approach allows for the efficient use of resources, focusing on the areas of most interest at each stage of the project.

Intended Outputs

The use of laser scanning in building construction yields several key outputs. One of the primary products is a series of PCs. These PCs, representing various stages of the project and specific building elements, provide a detailed and accurate 3D representation of the building at different points in time, effectively capturing the evolution of the project. Additionally, laser scans can be used to create as-built 2D drawings or building information modeling (BIM) models, which serve as supplemental materials to the as-built records. Furthermore, captured scans can be used to compare with the original design and construction documents to generate QAQC reports. These reports offer insights into the accuracy and quality of the construction process, helping to identify deviations from the plan and ensuring that the building is constructed according to its design [22,29].

2.2.2. Laser Scanning for Historic Documentation

Transitioning from modern constructions, laser scanning finds a unique and invaluable place in the domain of historic documentation. In historic building documentation, laser scanning is used to capture the existing conditions of the heritage (as shown in Figure 4) and subsequently use the captured data to conduct a structural assessment and develop materials (e.g., 2D drawings or heritage building information models) to help manage and interpret the heritage asset. Laser scanning's specific applications in heritage documentation include heritage building information modeling (HBIM) development [11,30–35], structural analysis [16,36], damage detection [12,37], and integrating with virtual reality (VR) and augmented reality (AR) technology to create virtual museums/tours [32] for public education and research. Importantly, laser scanning also proves to be invaluable in documenting historic buildings that are in poor condition. As demonstrated in cases like the Kunerad Mansion in Slovakia [18], TLS can rapidly acquire data in challenging environments, such as areas with poor lighting and structural instability. This non-destructive technique allows for comprehensive and accurate documentation, which is crucial for any subsequent restoration or conservation efforts [38,39].

Figure 4. A TLS PC of a heritage building, the Old Depot Museum, in Selma, Alabama, USA.

Scanning Methodology

Scanning a heritage structure is like taking a 'snap-shot' of the building, capturing a comprehensive and accurate record of the heritage site or structure in its current state, and documenting the unique architectural characteristics of the historic building. To achieve this objective, the laser scanning approach in heritage documentation is more static and thorough compared to the fluid and selective approach used in building construction. The process typically involves a single, comprehensive survey of the site or structure. This survey aims to capture the entire structure in as much detail as possible. This approach is necessary because historical buildings often have unique architectural features that are important to document accurately for preservation and study purposes. Furthermore, given the historical nature of these sites, there may be limited opportunities to perform additional scans in the future, making it crucial to capture sufficient data in the initial survey. Given the need for comprehensive coverage and high detail, the resolution of the scans in heritage documentation is typically medium to high. Super-high resolution scans may sometimes be performed to record specific architectural details. While this approach may require more time and resources than lower-resolution scans, capturing the fine details of historical architecture is necessary.

Intended Outputs

Laser scanning technology produces several significant outputs for heritage documentation. One of the primary products is HBIM models (as shown in Figure 5), created using scan data. These provide a detailed and accurate representation of the heritage site, which can be used for preservation planning, damage assessment, and restoration work. Another key output is the creation of 3D interactive environments that integrate VR or AR with the scan data. These environments offer an immersive way for the public to explore and learn about heritage sites, serving as a powerful tool for interpretation and public education [40–42]. The PC data can also be used to develop 2D drawings (as shown in Figure 6) as a means of documentation of the historic structures [30,43].

Figure 5. An HBIM model of the Old Depot Museum was developed using the TLS PC.

Figure 6. A front elevation of the Old Depot Museum was created using the TLS PC.

2.2.3. Comparison and Contrast of Laser Scanning Use in Both Disciplines

Drawing parallels and distinctions between the two domains provides insights into the adaptability and versatility of laser scanning technology. The similarities and differences between the use of laser scanning in building construction and heritage documentation are summarized in Table 1.

Table 1. Comparison and contrast of laser scanning use in building construction vs. heritage documentation.

Aspect	Building Construction	Heritage Documentation
	Similarities	
Planning	Both require thorough planning for field survey.	
Technology	Both may deploy other remote sensing technologies to enhance data capture, such as photogrammetry and Unmanned Aerial Vehicle (UAV).	
Outputs	Both generate 3D PCs. Both may subsequently create 2D drawings and BIM models using the PC data.	
	Differences	
Objectives	Document the project's progress and record the building elements that might be enclosed or obscured in the later stages of construction.	Capture a comprehensive and accurate record of the heritage site or structure in its current state, and document the unique architectural details.
Scanning Process	Scanning process is fluid and carried out periodically.	Scanning process is more static and typically involves a one-time comprehensive survey.
Resolution	Lower resolution used due to the need for frequent scans and selective scan coverage.	Medium to high resolution used to capture fine details characteristic of historical architecture.
Personnel	Scans are carried out by field engineers, virtual design and construction (VDC) engineers, or professional surveyors.	Scans are carried out by researchers, preservationists, or professional surveyors.
Outputs	A series of PCs, as-built 2D drawings or BIM models, and QAQC reports.	HBIM models and 3D interactive environments integrating VR or AR with the scan data for public education and research.

2.2.4. Combination of Methods from Both Disciplines and Contradictions

Bridging the methodologies from both fields can lead to innovative applications and solutions. Laser scanning methodologies from building construction and heritage documentation can be used in combination in several ways.

One valuable application that combines the techniques from both fields is monitoring changes in a historic structure over time [37,44]. By taking scans periodically, it is possible to document the evolution of the structure, track the effects of conservation or restoration efforts, and identify any potential issues or areas of concern. This approach combines the thoroughness and detail of heritage documentation scans with the periodic monitoring typically used in building construction.

Another application that may benefit from combining both methodologies is during conservation or restoration [19,45]. In such projects, the comprehensive and detailed scanning approach used in heritage documentation can be used to capture the existing conditions of the historic site before any interventions. This provides a detailed record of the site's original state, which can be invaluable for documentation purposes and can guide the conservation and restoration efforts. Once the interventions begin, the more fluid and dynamic scanning approach used in building construction can be adopted. This allows for monitoring the progress of the conservation, restoration, or adaptive reuse work and can help identify any deviations from the plan or potential issues early on.

The different objectives of the two methods can also lead to contradictions. For instance, the practical focus of building construction can conflict with the emphasis on capturing unique architectural details and historical features in heritage documentation. Furthermore, the resource requirements for the two methods can be contradictory. The comprehensive and high-resolution scans used in heritage documentation can be resource-intensive, requiring significant time and computational resources. In contrast, the more fluid and dynamic scans used in building construction are designed to be quicker and less demanding on resources. Balancing these different requirements can be challenging, particularly in projects with limited resources or tight schedules.

2.3. Gaps and Opportunities for Future Research

The implementation of laser scanning technology in the built environment faces several gaps, including time-intensive data acquisition, complex data processing, lack of integration with other technologies, and the absence of standardized processes and best practices [11,46], all of which pose challenges to its effective and efficient use.

In data processing and interpretation, the complexity of raw scan data presents a significant challenge. The data can be intricate and challenging to process, archive, share, and interpret, necessitating specialized hardware, software, and expertise. This complexity can become a barrier to the effective utilization of the technology. However, this gap also presents an opportunity. Developing more user-friendly software, practical scanning and data management processes, and training programs could significantly enhance users' ability to practice laser scanning surveys effectively. This could also involve creating techniques that automate data processing tasks.

Despite their differences, building construction and heritage documentation fields can learn much from each other in addressing these gaps. Building construction often involves working with complex datasets and using software tools for design and project management tasks. Insights from this field could inform the development of user-friendly software, processes, and training programs for laser scanning. On the other hand, heritage documentation emphasizes interpreting historical features and records. The methodologies used in this field could provide valuable insights into using scan data to help interpret and visualize construction projects. By learning from each other, these two fields can collectively enhance the use of laser scanning technology, making it a more effective tool for building construction and heritage documentation. Figure 7 illustrates a roadmap suggesting future research directions and opportunities to bridge the identified gaps.

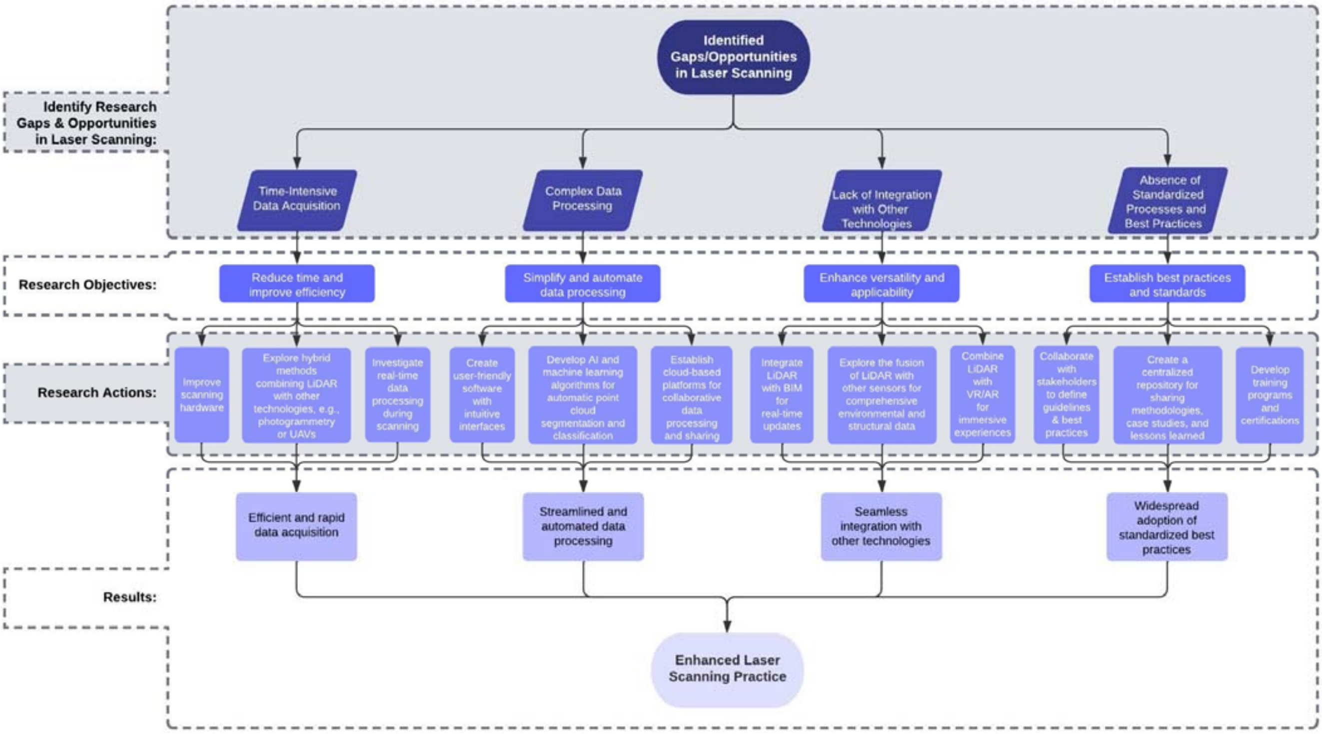


Figure 7. A roadmap for future research in the field of laser scanning for the built environment.

This chapter has delved into the applications of laser scanning technology in building construction and historic documentation, offering a comparative analysis that highlights both similarities and differences. The adaptability of laser scanning across these fields is evident, with unique methodologies and objectives tailored to each domain. The advantages of laser scanning, such as accuracy and speed, are balanced by challenges like cost and complexity. Innovative combinations of methods from both disciplines present exciting opportunities for future research and practical applications.

3. Laser Scanning in HABS Documentation

The HABS has long been a cornerstone in the preservation and documentation of America's architectural heritage. As technology has evolved, so have the methods employed by the HABS to capture the intricate details of historic structures. In the 2000s, the HABS began experimenting with laser scanning technology for data acquisition in various projects, such as the Gesu Catholic Church in Miami, Florida [47], the Treviño-Uribe Rancho complex in San Ygnacio, Texas [48], and the Castle Pinckney, Charleston, South Carolina [49]. However, the HABS or HDP never officially acknowledged the implementation of laser scanning technology in their documentation until the late 2010s.

3.1. HDP's "Brief" and Its Critiques on Laser Scanning for Heritage Documentation

In 2016, the HDP published a brief (the Brief) titled "Producing HABS/HAER/HALS Measured Drawings from Laser Scans," which discusses using laser scanning technology to document America's architectural, engineering, and landscape heritage [50]. This document acknowledges the benefits of laser scanning, such as extreme accuracy and potential time saving in the field, especially for large or inaccessible structures.

However, the Brief also highlights several critiques of using laser scanning. The main critiques revolve around the stability and permanence of 'digital born' records and the experiential aspect of documentation. The Brief raises concerns about the long-term permanence of digital files, pointing out that the Library of Congress still requires documentation in hard copy due to concerns about the durability and longevity of digital files. It also argues that "*while laser scans can provide a wealth of data, they do not engage the recorder in the same way that hand-measuring does*". This lack of engagement, it argues, can "*undermine the hands-on experience advocated by HABS/HAER/HALS*" [50].

The existing literature points out that laser scanning has emerged as a pivotal technique in heritage asset research and has become an indispensable tool for heritage documentation [51]. Contrarily, the Brief seems to view laser scanning exclusively as a tool for capturing the existing conditions of heritage sites, with the collected data then being used to create 2D drawings, an essential component accepted by the HDP's collections. However, the landscape of heritage documentation technology, particularly laser scanning, has evolved significantly over the past decade.

The researcher challenges the HDP's stance on using laser scanning for heritage documentation, presenting his quantitative and qualitative counterarguments in the following sections. The authors also propose that the HDP should consider updating its heritage documentation standards to embrace laser scanning fully. This integration could not only fulfill the objectives of HDP documentation but also significantly enhance the quality, permanence, and public accessibility of their documentation records.

3.2. Quantitative Analysis

Quantitatively, the published literature has verified that laser scanning in heritage documentation offers superior accuracy, significant time saving, more comprehensive coverage, easy manageability and accessibility of captured data, cost-effective data storage solutions, and improved permanence of digital records compared to traditional hand-measuring techniques.

- **Accuracy of Captured Data:** Laser scanning technology has revolutionized the heritage documentation field by providing unprecedented accuracy levels. Unlike traditional hand-measuring techniques, which are prone to human error and can be limited by physical constraints, laser scanners can capture highly detailed and precise measurements of structures, often down to the millimeter [13,51–53]. This high level of accuracy enhances the documentation's quality and provides valuable data for conservation and restoration efforts.

- **Time Saving**: Other than its superior accuracy, laser scanning can offer significant time savings, especially when documenting large or complex structures. As Al-Bayari and Shatnawi's study [19] mentioned, 25–30% of the time needed for field surveys could be reduced using TLS to capture and document heritage. While the initial investment in laser scanning equipment can be substantial, the efficiency gains can lead to considerable cost savings over time.
- **Complete Coverage of Captured Structure**: One of the key advantages of laser scanning is its ability to capture data from all the visible surfaces of a structure, including areas that may be difficult or impossible to reach with hand measuring. This ensures a more comprehensive documentation of the structure [15–17].
- **Manageability of Digital Files**: Digital files offer significant advantages in terms of manageability compared to traditional hard copy records (e.g., drawings, field notes). They can be easily organized, searched, and shared, making them highly accessible to a wide range of users [18].
- **Economics and Accessibility of Cloud Storage**: The trend in the field of heritage documentation is shifting towards the use of cloud storage for point cloud data generated from laser scanning [54]. With the advent of cloud storage, preserving large amounts of digital data has become increasingly affordable and accessible. Unlike physical storage for hard copy records, which can be costly and space-consuming, cloud storage offers a cost-effective and scalable solution for preserving digital records [55].
- **Improved Permanence of Digital Records**: While concerns have been raised about the permanence of digital records, advancements in digital storage technology have greatly improved their longevity. Data stored in the cloud are typically replicated across multiple servers and locations, providing high redundancy and protection against data loss [56]. Furthermore, cloud service providers routinely perform data integrity checks and offer robust data recovery options [57], which highlight the improved permanence of digital records compared to traditional hard copy records.

3.3. Qualitative Analysis

The counterargument to the HPD's Brief also hinges on the qualitative benefits of laser scanning in heritage documentation. These include its non-invasive data collection capability, the enhanced public accessibility and visibility it offers through interactive 3D PCs, and the immersive interpretation of heritage sites it enables with VR technologies. Furthermore, when laser scanning is integrated with other reality capture techniques such as photogrammetry, 360-degree photography, and UAVs, it ensures more comprehensive and effective documentation of heritage sites.

- **Non-Invasive Contact Scanning Techniques**: Laser scanning is a non-contact data collection method, which has a significant advantage when dealing with fragile or delicate heritage structures. This non-invasive technique ensures that the structure is not damaged or altered during documentation [16,17].
- **Accessibility and High Visibility of PCs**: Laser scanning produces high-density 3D PCs that can be easily visualized and manipulated on a computer, providing a highly interactive and engaging way for the public to explore heritage sites versus traditional 2D drawings or photographs. This can enhance public understanding and appreciation of these sites [58,59].
- **Interpretation of Heritage with VR Technologies**: The PCs produced by laser scanning can be integrated with VR technologies to create immersive experiences that bring heritage sites to life. This can provide a deeper level of engagement and understanding for the public, especially for sites that are not physically accessible [43,60].

- **Use of Multiple Reality Capture Techniques**: In most documentation projects, a combination of reality capture techniques is used, such as laser scanning, photogrammetry, 360-degree photography, and UAVs [20,61–63]. For instance, Markiewicz and Robak [64] generated high-resolution orthoimages based on TLS data and close-range images in their study. This multimodal approach ensures comprehensive coverage of the site and allows for the strengths of each technique to be leveraged.

While the Brief argues that laser scanning does not engage the recorder in the same way as hand measuring, it is important to consider that engagement is not solely defined by the physical act of measuring. Engagement can also be fostered through the intellectual and analytical processes involved in processing, interpreting, and understanding the data collected.

- **Enhanced Engagement through Technology**: Laser scanning can actually enhance the recorder's engagement with the heritage site. The planning process of setting up the scan locations and routes, selecting the appropriate settings for the scanners, registering and processing the captured scans, and interpreting the resulting PC data all require a deep understanding of the heritage and its characteristics [11,65]. This can foster a different but equally valuable form of engagement compared to traditional hand-measuring techniques.
- **In-Depth Understanding of Heritage**: Laser scanning provides a wealth of data that can reveal subtle details and patterns that may not be noticeable through hand measuring, for instance, the deflections of beams which are not visible during manual measurement but can be identified during modeling using PC data. This can lead to a more in-depth understanding of the structure, construction, and condition [62]. The process of analyzing these data can engage the recorder in a deep intellectual exploration of the site.
- **Safety and Accessibility**: The researchers argue that laser scanning can also allow recorders to engage with sites that would be inaccessible or unsafe for hand measuring. This can expand the range of sites that can be documented and provide opportunities for engagement with a wider variety of structures [66].
- **Integration with Hand-Measuring Techniques**: It is also worth noting that laser scanning does not have to replace hand measuring entirely. The two techniques can be used in conjunction, with laser scanning providing a broad overview of the site and hand measuring being used to document specific details or features [67]. This integrated approach can provide the best of both worlds, combining the efficiency and accuracy of laser scanning with the hands-on engagement of hand measuring (e.g., flowers or leaves in the arch details).

3.4. Discussion

The researchers believe that incorporating laser scanning into the HABS practice can significantly enhance the quality, accessibility, and educational value of documentation. Laser scanning offers a non-invasive, highly accurate, and comprehensive method for capturing heritage sites, and when combined with other RC techniques, it provides a robust and effective solution for heritage documentation. Furthermore, the resulting 3D PCs and their integration with VR technologies can offer immersive and engaging experiences for the public, thereby fostering a deeper understanding and appreciation of the heritage.

To integrate laser scanning in heritage documentation, the HABS needs to develop comprehensive guidelines for laser scanning data acquisition and management, update its standards to accept diverse digital outputs such as PCs and 3D (HBIM) models, and enhance its digital materials management systems to effectively store, preserve, and share these diverse digital files with the public.

- **Development of Laser Scanning Guidelines for Data Acquisition and Management:** The HABS should develop comprehensive guidelines that outline best practices for using laser scanning in heritage documentation. These guidelines would ensure that laser scanning is used effectively and consistently, maximizing its benefits while minimizing potential errors or issues. These guidelines should encompass all facets of data acquisition, including scanner selection, scan setup, data capture, and quality control [67]. They should also provide guidance on data management, including data processing, data format compatibility, and storage. However, while crafting these guidelines, the HABS must ensure they are not overly specific to allow for technological advancements and must consider the resource availability of the recorders [11].

- **Acceptance of Diverse File Types for Heritage Documentation:** The current HABS standards primarily accept 2D drawings for heritage documentation. However, laser scanning and other advanced technologies can produce various digital outputs, including PCs and 3D models [7]. To accommodate these advancements, they should update their standards to accept diverse file types. Specifically, for PCs, universal or popular formats like LAS, LAZ, and E57 should be considered. For 3D models, IFC formats are recommended for cases where textures are not essential, while native formats can be used for more descriptive information and textures. These diverse file types offer a more comprehensive and interactive documentation of heritage sites.
- **Update of Digital Materials Management Systems and Platforms:** To accommodate these diverse file types, the HABS will need to update its digital materials management systems and platforms. These systems should be capable of accepting, archiving, and sharing a wide range of digital files, including large and complex files like point clouds and HBIM models. They should also ensure the long-term preservation of these files, with robust data backup and recovery protocols. Furthermore, these platforms should be designed to facilitate public access to the digital files, allowing the public to explore and interact with the heritage sites in new and engaging ways [7].

To conclude, the incorporation of laser scanning into HABS documentation represents a significant opportunity to enhance the quality, accessibility, and educational value of heritage documentation. It reflects a broader trend towards embracing technological innovation in preserving cultural heritage. By recognizing and harnessing the potential of laser scanning, the HABS can position itself at the forefront of this exciting frontier, ensuring that the documentation of architectural heritage remains accurate, engaging, and resilient in the face of future challenges.

4. Framework of a Study for Incorporation of TLS into the HABS Documentation

To fully investigate the incorporation of TLS into the HABS's heritage documentation, as his Ph.D. dissertation, the lead author has developed a proposal to study the HABS's integration of the technology. This chapter presents a comprehensive outline of the proposed dissertation (as illustrated in Figure 8) along with a brief discussion of each chapter. Given the nascent stage of the dissertation, the focus here is not on the actual data or findings but on the structure and validation of the proposed methodology.

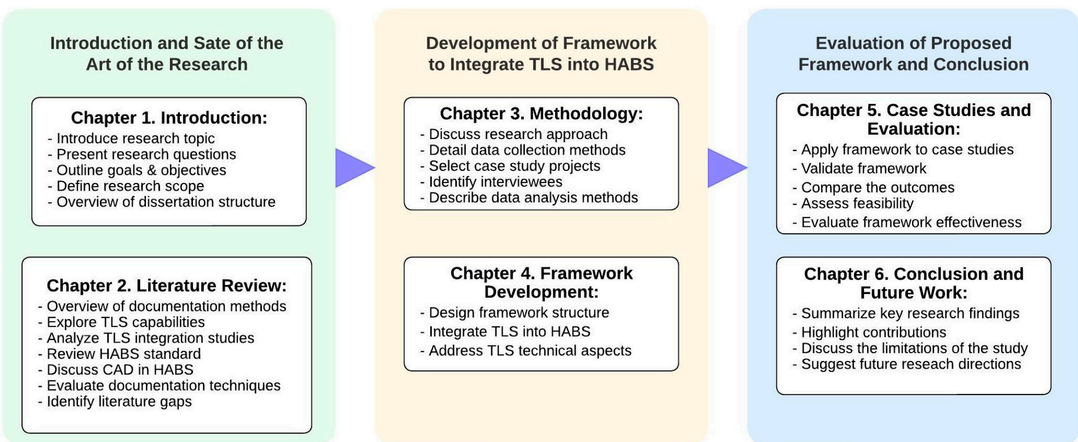


Figure 8. Proposed dissertation structure.

4.1. Dissertation Outline

The following is a structured outline of the proposed dissertation, providing a roadmap for the research journey and the main objectives of each chapter:

- **Chapter 1: Introduction.** This chapter sets the stage by introducing the research topic, and highlighting the problem statement, research questions, goals, objectives, and the overall structure of the dissertation. It will:
    - Highlight the significance of heritage building documentation and the challenges faced.
    - Present the research questions that guide the study.
    - Enumerate the research goals and objectives that the study aims to achieve.
    - Define the scope of the research and provide an overview of the dissertation's structure.
    - Conclude by emphasizing the importance of the study in the context of heritage building documentation.
- **Chapter 2: Literature Review.** This chapter delves deep into the existing literature to provide a comprehensive understanding of the current state of heritage building documentation, the HABS, and TLS technology. It will:
    - Begin with an overview of historic building documentation methods and their inherent challenges.
    - Explore the capabilities and applications of terrestrial laser scanning (TLS) in this domain.
    - Analyze previous studies that have attempted to integrate TLS data into historic building documentation.
    - Provide a detailed review of the HABS standard, its implementation techniques, and the essential data elements it records.
    - Discuss the integration of computer-aided design and drafting (CADD) into the HABS.
    - Review techniques used to evaluate the effectiveness of historic building documentation.
    - Identify gaps in the current literature that this study aims to address.
- **Chapter 3: Methodology.** This chapter outlines the research methodology employed in the study. It will:
    - Discuss the overall research approach and design.
    - Detail the methods and sources used for data collection, including the selection of historic buildings for case studies, interviews, and consultations.
    - Describe the methods used for data analysis, including the identification of essential data elements and the development of the proposed framework.
- **Chapter 4: Development of the Proposed Framework.** This chapter focuses on the design and development of the proposed framework. It will:
    - Discuss the design and structure of the framework.
    - Explore how TLS techniques can be integrated into existing HABS documentation workflows for data acquisition.
    - Consider the various aspects of TLS used for historic building documentation, including best practices, data processing, file formats and management, metadata standards, and interoperability.
- **Chapter 5: Case Studies and Evaluation.** This chapter applies the proposed framework to real-world scenarios. It will:
    - Detail the application of the framework to selected historic buildings.
    - Evaluate the framework's effectiveness in capturing and enhancing essential data elements.
    - Compare the outcomes with traditional HABS documentation methods in terms of quality, accuracy, and completeness.

  - Assess the framework's ability to enhance HABS documentation with TLS data.
  - Discuss the feasibility of implementing the framework in real-world HABS documentation practices.
- **Chapter 6: Conclusion and Future Work**. This concluding chapter will:
  - Recap the research objectives and summarize the key findings.
  - Discuss the contributions of the study to the field of historic building documentation and HABS standards.
  - Highlight the limitations of the study and suggest potential directions for future research.
  - Offer recommendations for subsequent studies in this domain.

4.2. Study of HABS's Adoption of CADD

The HABS has historically exhibited a cautious approach when it comes to the adoption of new technologies. This measured pace was evident in its integration of CADD into its documentation guidelines in the late 1990s. While the integration of such technologies can offer enhanced precision and efficiency in the documentation processes, the transition often involves addressing various challenges, both technical and operational.

The dissertation delves into the HABS's journey of incorporating CADD into its practices. This exploration is not merely a historical recounting but serves as a lens to understand the organization's decision-making processes, its weighing of pros and cons, and the challenges it faced during the integration. By studying this past adaptation, the researchers can glean insights into the HABS's potential trajectory with emerging technologies, such as TLS.

4.3. Framework Development

The proposed framework for integrating TLS into the HABS documentation will detail the guidelines for TLS data acquisition, processing, and management, as shown in Figure 9. The following is a detailed breakdown:

- **Guidelines for TLS Data Acquisition:**
  - Equipment Selection: A discussion on the types of TLS equipment suitable for heritage documentation, considering factors like resolution, range, and accuracy.
  - Site Preparation: The steps to prepare a heritage site for scanning, including considerations for safety, obstructions, and optimal scanning positions.
  - Scanning Protocols: The detailed procedures for conducting the scans, including scanner settings, number of scan positions, and overlap considerations.
  - Quality Assurance: The methods to ensure the acquired data meet the required standards, such as using control points or reference markers.
- **Guidelines for TLS Data Processing:**
  - Data Registration: The techniques to align and merge multiple scans into a cohesive point cloud.
  - Noise Reduction: The procedures to remove unwanted data or noise from the scans, ensuring clarity.
  - Data Simplification: The techniques, like decimation, to reduce the size of the dataset without significant loss of detail.
  - Data Conversion: Converting PC data into formats suitable for HABS documentation, such as 2D drawings or 3D models.
- **Guidelines for TLS Data Management:**
  - Data Storage: Recommendations for storing large TLS datasets, considering factors like data integrity, redundancy, and accessibility.

  - ○ Metadata Standards: Establishing standards for metadata accompanying TLS datasets, ensuring future users understand the context, equipment used, and any processing applied.
  - ○ Data Interoperability: Ensuring the data can be easily integrated with other datasets or platforms commonly used in the HABS documentation.
  - ○ Data Archival: The long-term preservation strategies for the data, considering evolving data formats and storage technologies.

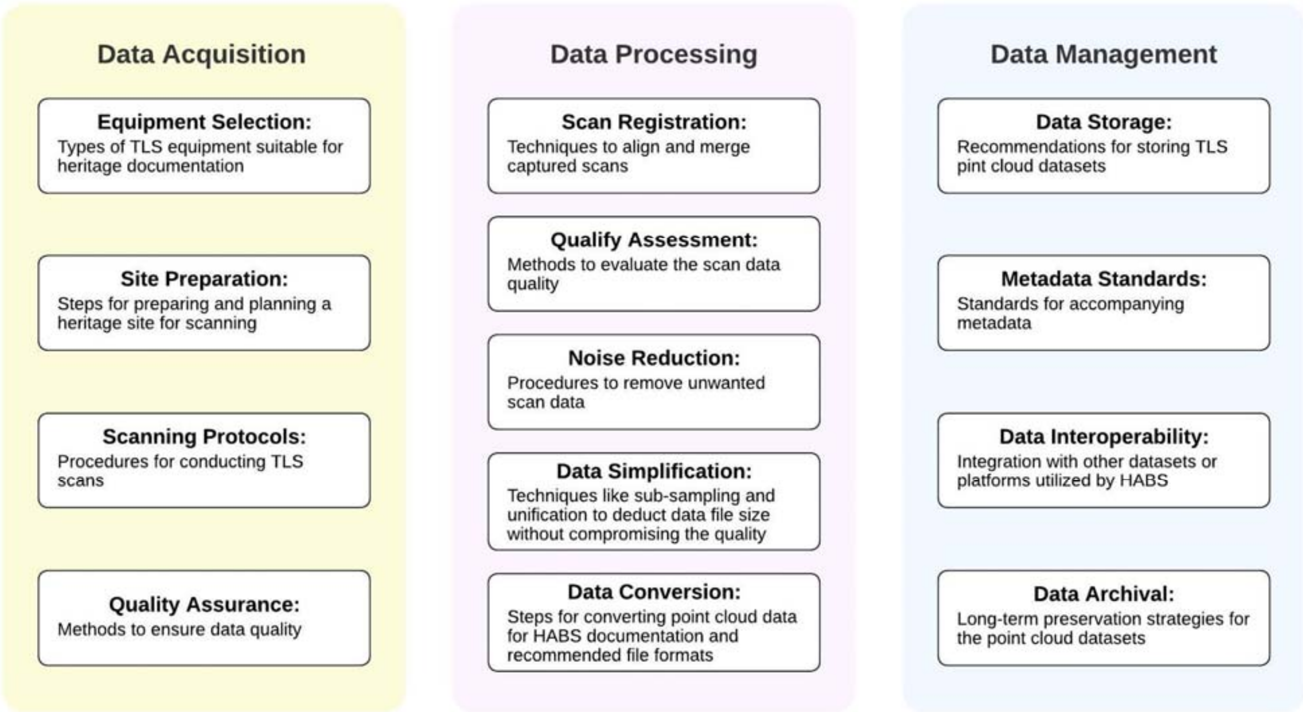


Figure 9. Elements of proposed guidelines for TLS integration into HABS documentation.

4.4. Selecting Projects for Case Studies

The selection of projects for case studies in this research is a critical step, as these projects serve as representative samples to validate the proposed framework. Given the context of the research on the integration of TLS into the HABS documentation, the following are proposed scenarios for selecting case study projects:

- Historical Significance:
  - ○ Rationale: Projects that have a high historical or architectural significance would be ideal, as they represent the core mission of the HABS.
  - ○ Example: A church where significant Civil Rights Movement events took place and that has been a local landmark.
- Complexity of Structure:
  - ○ Rationale: Buildings with intricate designs or unique architectural features can test the precision and capabilities of TLS.
  - ○ Example: A historic courthouse with its complex vaults.
- Previous Documentation:
  - ○ Rationale: Buildings that have been previously documented using traditional HABS methods can provide a basis for comparison.
  - ○ Example: A historic courthouse that has detailed blueprints and photographs from decades ago.

- Restoration or Renovation Projects:
  - Rationale: These projects often require detailed documentation before, during, and after the restoration, making them suitable for evaluating the continuous utility of TLS.
  - Example: A historic church undergoing restoration to its original grandeur.
- Varied Size and Scale:
  - Rationale: To test the scalability of TLS, projects ranging from small historic homes to large public buildings should be considered.
  - Example: A small 19th-century slave cabin versus a sprawling university building from the early 20th century.
- Projects Under Threat:
  - Rationale: Buildings that are under threat from urban development, natural disasters, or decay can be prioritized, as timely and detailed documentation can be crucial.
  - Example: An historic chapel that is infested by termites.

4.5. Framework Implementation

In the implementation phase of the proposed framework, a systematic approach will be adopted to ensure the effective use of TLS in the documentation of the selected case study buildings. This approach will include the following steps, as illustrated in Figure 10.

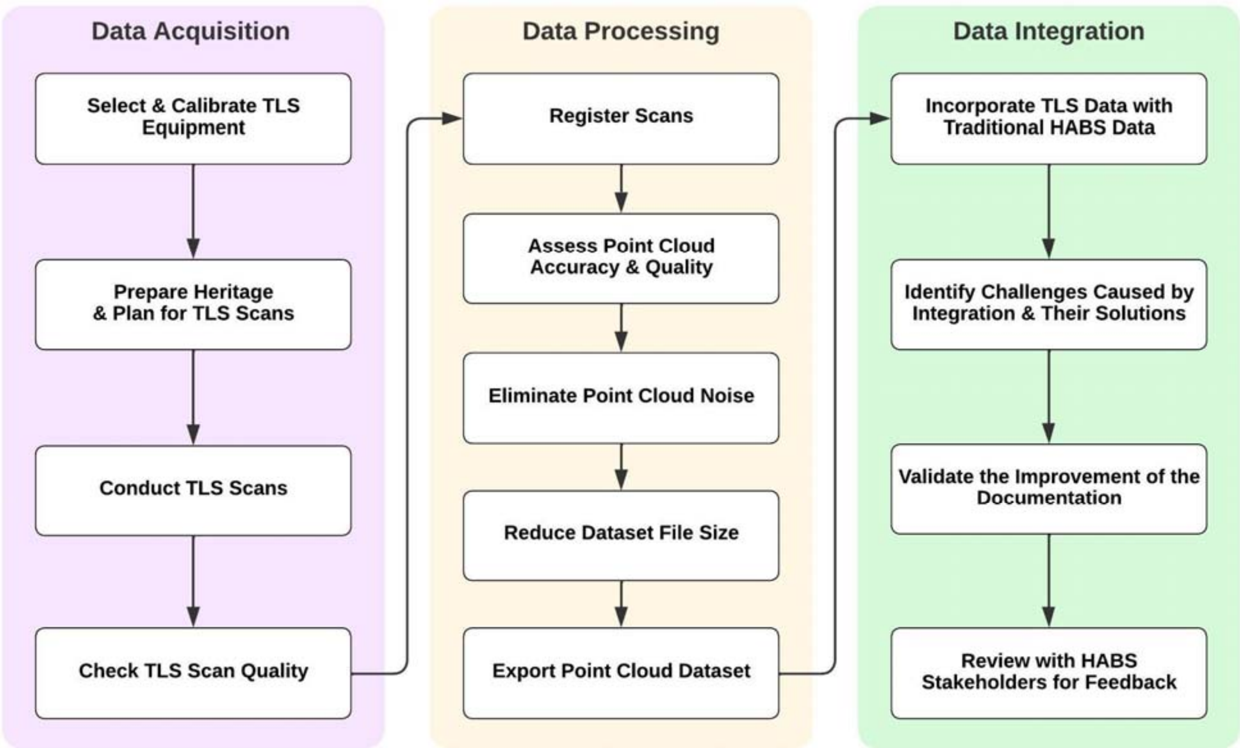


Figure 10. The workflow for implementing the proposed framework in case study projects.

- **Data Acquisition:** The initial step involves the meticulous acquisition of data from each selected historic building. This process will be guided by the comprehensive guidelines delineated in Chapter 4. The aim is to ensure that the data captured are both comprehensive and of high quality, setting a solid foundation for the subsequent stages of the framework.
- **Data Processing:** Once the raw data are acquired, they undergo a rigorous processing phase. The raw scans, which are often vast and intricate, are methodically converted

into formats that are more suitable for HABS documentation. This transformation will make the data more manageable and optimize them for integration into the HABS system.

- **Data Integration:** The processed TLS data will then be integrated into the HABS documentation. This stage is crucial as it combines traditional documentation methods with the advanced capabilities of TLS. However, integration is not without its challenges. Some modifications to the initial framework may be necessary to ensure that the TLS data fit within the established HABS documentation standards. This step may also involve the key stakeholders of HABS documentation, such as heritage professionals, HABS documentation experts, or HABS staff. The researcher might consult them for feedback on the integrated documentation, ensuring it meets industry standards and expectations.

4.6. Evaluation of the Framework's Effectiveness

The effectiveness of the proposed framework will be critically evaluated on multiple fronts, including the following:

- **Data Enhancement:** An enhancement in the essential data elements may be observed when the framework is applied. By comparing the documentation before and after the implementation of the framework, the added depth, detail, and dimensionality brought about by the TLS data may become evident.
- **Comparison with Traditional Methods:** When the outcomes produced by the framework are compared with traditional HABS documentation methods, distinctions will be noted. In terms of quality, the documentation derived from the framework may exhibit greater richness and detail. The accuracy of the documentation may also be enhanced with precise measurements and accurate spatial relationships.

4.7. Assessment of the Framework's Enhancement

The assessment phase delves deeper into the enhancements brought about by the framework.

- **TLS Data Integration:** The integration of TLS data into HABS documentation may add significant value. This will likely be evident in the improved visual representations, the creation of detailed 3D models, and the ability to capture intricate measurements that might be overlooked in traditional methods.
- **Stakeholder Feedback:** Feedback will be sought from diverse stakeholders, including heritage professionals, HABS documentation experts, HABS/NPS staff, and other relevant parties. Their insights provide a holistic view of the resulting documentation, highlighting its strengths and areas for improvement.
- **Feasibility of Framework Implementation:** The practicality of implementing the proposed framework in real-world scenarios is also scrutinized. During case studies, potential challenges may occur. They may range from the limitations of the equipment used for TLS, to restrictions in accessing certain parts of the heritage sites, to complexities in data processing. Each challenge will provide valuable lessons for refining the framework.

5. Conclusions

The research presented in this conceptual paper has explored the integration of terrestrial laser scanning (TLS) into the Historic American Buildings Survey (HABS) documentation. This study has laid the groundwork for a Ph.D. dissertation and paved the way for future research in this vital area of heritage documentation. The study set the stage for a comprehensive overview of TLS's feasibility and effectiveness in HABS integration. A thorough review of the existing literature revealed the current state of heritage building documentation and identified gaps that this research aimed to fill. The methodology was thoroughly outlined, providing a robust framework for the investigation, and leading to the development of a comprehensive proposal to study the HABS's integration of TLS.

The significance of this research is manifold. It represents a convergence of traditional practices with modern technology, with potential benefits including enhanced precision, efficiency, and innovation in heritage documentation. By addressing the identified gaps in the literature and providing fresh insights, this study contributes to ongoing innovation in the field.

As a conceptual paper, this study serves as a precursor to a more extensive Ph.D. dissertation. It has established a theoretical foundation, delineated a research path, and proposed a methodical approach to the subject matter. The insights gained and the framework developed offer a valuable starting point for a doctoral candidate to delve deeper into the complexities of integrating TLS into the HABS.

The journey embarked upon in this paper represents a thoughtful exploration of a complex and relevant research topic. By weaving traditional practices together with cutting-edge technology, it has opened new horizons in heritage building documentation. The challenges and opportunities presented by the integration of TLS into the HABS are vast and multifaceted. This study has taken an essential step in unraveling them, setting the stage for future research that can build upon this foundation.

Author Contributions: Conceptualization, J.L., D.W. and R.G.; methodology, J.L.; validation, J.L.; formal analysis, J.L.; investigation, J.L.; data curation, J.L.; writing—original draft preparation, J.L.; writing—review and editing, D.W.; visualization, J.L. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data that support the findings of this study are available upon request from the corresponding author.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Balachowski, J.D. *HABS/HAER Guidelines: Recording Structures and Sites with HABS Measured Drawings*; U.S. Department of the Interior, National Park Service, Cultural Resources: Washington, DC, USA, 2001.
2. Corkern, W.C. Architects, Preservationists, and the New Deal: The Historic American Buildings Survey, 1933–1942. Ph.D. Thesis, The George Washington University, Washington, DC, USA, 1984.
3. Massey, J.C.; Schwartz, N.B.; Maxwell, S. *Historic American Buildings Survey/Historic American Engineering Record: An Annotated Bibliography*; Historic American Buildings Survey/Historic American Engineering Board; U.S. Department of the Interior, National Park Service: Washington, DC, USA, 1992.
4. U.S. Department of the Interior, National Park Service. *Secretary of the Interior's Standards and Guidelines for Architectural and Engineering Documentation—HABS/HAER Standards*; U.S. Department of the Interior, National Park Service: Washington, DC, USA, 1990.
5. Barland, W.; Van Court, E.; Profilet, L.; Britton, A.; Baker, A.; Waterman, T.; Butters, J.; Granberry, T.; Nelson, E.; Martin, B.; et al. *Historic American Buildings Survey*; Library of Congress: Natchez, MS, USA, 1933.
6. Akboy, S. The HABS Culture of Documentation with an Analysis of Drawing and Technology. Ph.D. Thesis, Texas A&M University, College Station, TX, USA, 2012.
7. Borchers, P.E. Photogrammetry of the Indian Pueblos of New Mexico and Arizona. *Photogrammetria* **1975**, *30*, 189–196. [CrossRef]
8. Burns, J.A. *Recording Historic Structures*; John Wiley & Sons: Hoboken, NJ, USA, 2003.
9. Lemmens, M. Terrestrial Laser Scanning. In *Geo-Information: Technologies, Applications and the Environment*; Lemmens, M., Ed.; Geotechnologies and the Environment; Springer: Dordrecht, The Netherlands, 2011; pp. 101–121, ISBN 978-94-007-1667-4.
10. Liu, J.; Azhar, S.; Willkens, D.; Li, B. Static Terrestrial Laser Scanning (TLS) for Heritage Building Information Modeling (HBIM): A Systematic Review. *Virtual Worlds* **2023**, *2*, 90–114. [CrossRef]
11. Olsen, M.J.; Kuester, F.; Chang, B.J.; Hutchinson, T.C. Terrestrial Laser Scanning-Based Structural Damage Assessment. *J. Comput. Civ. Eng.* **2010**, *24*, 264–272. [CrossRef]
12. Martín-Lerones, P.; Olmedo, D.; López-Vidal, A.; Gómez-García-bermejo, J.; Zalama, E. BIM Supported Surveying and Imaging Combination for Heritage Conservation. *Remote Sens.* **2021**, *13*, 1584. [CrossRef]
13. Moyano, J.; Gil-Arizón, I.; Nieto-Julián, J.E.; Marín-García, D. Analysis and Management of Structural Deformations through Parametric Models and HBIM Workflow in Architectural Heritage. *J. Build. Eng.* **2022**, *45*, 103274. [CrossRef]

14. Rocha, G.; Mateus, L. A Survey of Scan-to-BIM Practices in the AEC Industry—A Quantitative Analysis. *ISPRS Int. J. Geo-Inf.* **2021**, *10*, 564. [CrossRef]
15. Abbate, E.; Invernizzi, S.; Spano, A. HBIM Parametric Modelling from Clouds to Perform Structural Analyses Based on Finite Elements: A Case Study on a Parabolic Concrete Vault. *Appl. Geomat.* **2022**, *14*, 79–96. [CrossRef]
16. Franco, P.A.C.; de la Plata, A.R.; Franco, J.C. From the Point Cloud to BIM Methodology for the Ideal Reconstruction of a Lost Bastion of the Caceres Wall. *Appl. Sci.* **2020**, *10*, 6609. [CrossRef]
17. Palcak, M.; Kudela, P.; Fandakova, M.; Kordek, J. Utilization of 3D Digital Technologies in the Documentation of Cultural Heritage: A Case Study of the Kunerad Mansion (Slovakia). *Appl. Sci.* **2022**, *12*, 4376. [CrossRef]
18. Al-Bayari, O.; Shatnawi, N. Geomatics Techniques and Building Information Model for Historical Buildings Conservation and Restoration. *Egypt. J. Remote Sens. Space Sci.* **2022**, *25*, 563–568. [CrossRef]
19. Alshawabkeh, Y.; Baik, A.; Fallatah, A. As-Textured As-Built BIM Using Sensor Fusion, Zee Ain Historical Village as a Case Study. *Remote Sens.* **2021**, *13*, 5135. [CrossRef]
20. Mammoli, R.; Mariotti, C.; Quattrini, R. Modeling the Fourth Dimension of Architectural Heritage: Enabling Processes for a Sustainable Conservation. *Sustainability* **2021**, *13*, 5173. [CrossRef]
21. Fobiri, G.; Musonda, I.; Muleya, F. Reality Capture in Construction Project Management: A Review of Opportunities and Challenges. *Buildings* **2022**, *12*, 1381. [CrossRef]
22. El-Omari, S.; Moselhi, O. Integrating 3D Laser Scanning and Photogrammetry for Progress Measurement of Construction Work. *Autom. Constr.* **2008**, *18*, 1–9. [CrossRef]
23. Gikas, V. Three-Dimensional Laser Scanning for Geometry Documentation and Construction Management of Highway Tunnels during Excavation. *Sensors* **2012**, *12*, 11249–11270. [CrossRef]
24. Guan, S.; Zhu, Z.; Wang, G. A Review on UAV-Based Remote Sensing Technologies for Construction and Civil Applications. *Drones* **2022**, *6*, 117. [CrossRef]
25. Liu, J.; Bugg, R.A.; Fisher, C.W. Advancing Erosion Control Analysis: A Comparative Study of Terrestrial Laser Scanning (TLS) and Robotic Total Station Techniques for Sediment Barrier Retention Measurement. *Geomatics* **2023**, *3*, 345–363. [CrossRef]
26. Blair, S. Contractors Adopt Laser Scanners to Verify As-Builts. *ENR Eng. News-Rec.* **2015**, *274*, 31.
27. Aryan, A.; Bosché, F.; Tang, P. Planning for Terrestrial Laser Scanning in Construction: A Review. *Autom. Constr.* **2021**, *125*, 103551. [CrossRef]
28. Wetzel, E.; Liu, J.; Leathem, T.; Sattineni, A. The Use of Boston Dynamics SPOT in Support of LiDAR Scanning on Active Construction Sites. In Proceedings of the 39th International Symposium on Automation and Robotics in Construction (ISARC 2022), Bogota, Colombia, 12–15 July 2022.
29. Liu, J.; Willkens, D. *Reexamining the Old Depot Museum in Selma, Alabama, USA*; WIT Press: Santiago de Compostela, Spain, 2021; Volume 205, pp. 171–186.
30. Adami, A.; Bruno, N.; Rosignoli, O.; Scala, B. HBIM for Planned Conservation: A New Approach to Information Management. In Proceedings of the CHNT23, Vienna, Austria, 12–15 November 2018; p. 41.
31. Banfi, F. HBIM, 3D Drawing and Virtual Reality for Archaeological Sites and Ancient Ruins. *Virtual Archaeol. Rev.* **2020**, *11*, 16–33. [CrossRef]
32. Antonopoulou, S.; Bryan, P. *BIM for Heritage: Developing a Historic Building Information Model*; Liverpool University Press: Livepool, UK, 2017; ISBN 978-1-84802-487-8.
33. Barontini, A.; Alarcon, C.; Sousa, H.S.; Oliveira, D.V.; Masciotta, M.G.; Azenha, M. Development and Demonstration of an HBIM Framework for the Preventive Conservation of Cultural Heritage. *Int. J. Archit. Herit.* **2022**, *16*, 1451–1473. [CrossRef]
34. Liu, J.; Willkens, D.S.; Foreman, G. An introduction to technological tools and process of Heritage Building Information Modeling (HBIM). In Proceedings of the EGE Revista de Expresión Gráfica en la Edificación, Valencia, Spain, 30 June 2022; pp. 50–65.
35. Anton, D.; Pineda, P.; Medjdoub, B.; Iranzo, A. As-Built 3D Heritage City Modelling to Support Numerical Structural Analysis: Application to the Assessment of an Archaeological Remain. *Remote Sens.* **2019**, *11*, 1276. [CrossRef]
36. Pathak, R.; Saini, A.; Wadhwa, A.; Sharma, H.; Sangwan, D. An Object Detection Approach for Detecting Damages in Heritage Sites Using 3-D Point Clouds and 2-D Visual Data. *J. Cult. Herit.* **2021**, *48*, 74–82. [CrossRef]
37. Muradov, M.; Kot, P.; Markiewicz, J.; Łapiński, S.; Tobiasz, A.; Onisk, K.; Shaw, A.; Hashim, K.; Zawieska, D.; Mohi-Ud-Din, G. Non-Destructive System for in-Wall Moisture Assessment of Cultural Heritage Buildings. *Measurement* **2022**, *203*, 111930. [CrossRef]
38. Tejedor, B.; Lucchi, E.; Bienvenido-Huertas, D.; Nardi, I. Non-Destructive Techniques (NDT) for the Diagnosis of Heritage Buildings: Traditional Procedures and Futures Perspectives. *Energy Build.* **2022**, *263*, 112029. [CrossRef]
39. Murphy, M.; McGovern, E.; Pavia, S. Historic Building Information Modelling (HBIM). *Struct. Surv.* **2009**, *27*, 311–327. [CrossRef]
40. Banfi, F.; Previtali, M.; Stanga, C.; Brumana, R. A Layered-Web Interface Based on HBIM and 360° Panoramas for Historical, Material and Geometric Analysis. *ISPRS-Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci.* **2019**, *XLII-2/W9*, 73–80. [CrossRef]
41. Banfi, F. The Evolution of Interactivity, Immersion and Interoperability in HBIM: Digital Model Uses, VR and AR for Built Cultural Heritage. *ISPRS Int. J. Geo-Inf.* **2021**, *10*, 685. [CrossRef]
42. Santos, C.G.R.; Araújo, T.D.O.; Chagas, P.R., Jr.; Neto, N.C.S.; Meiguins, B.S. Recognizing and Exploring Azulejos on Historic Buildings' Facades by Combining Computer Vision and Geolocation in Mobile Augmented Reality Applications. *J. Mob. Multimed.* **2017**, *13*, 57–74.

43. Rashidi, M.; Mohammadi, M.; Sadeghlou Kivi, S.; Abdolvand, M.M.; Truong-Hong, L.; Samali, B. A Decade of Modern Bridge Monitoring Using Terrestrial Laser Scanning: Review and Future Directions. *Remote Sens.* **2020**, *12*, 3796. [CrossRef]
44. Li, J.; Jawadwala, H.; Pan, A.; Jeon, J.; Lin, Y.-C.; Hasheminasab, M.; Yin, H.; Habib, A.; Cai, H.; Qu, M. Digital Reconstruction and Restoration of Architectural Heritage: Samara House. *Technol. Archit. Des.* **2022**, *6*, 232–245. [CrossRef]
45. Baik, A.H. *Heritage Building Information Modelling for Implementing UNESCO Procedures: Challenges, Potentialities, and Issues*; Routledge: London, UK, 2020; ISBN 978-1-00-007960-9.
46. Lopez, R.; Mader, C.; Sarafraz, A.; Yin, L. HABS-Historic American Buildings Survey and the Integration of New Technology. *Rev. Cient. Arquit. Urban.* **2017**, *38*, 91–103.
47. Glowacki, K.T.; Billingsley, A.J.; Baaske, B.; Briscoe, F.; Warden, R.; Champagne, L. Investigating Vernacular Design at the Treviño-Uribe Rancho Complex in San Ygnacio, Texas. In Proceedings of the 2020 Virtual Conference of the Vernacular Architecture Forum, Virtual, 9 May 2020.
48. Wilson, A.R.; Schara, M. Castle Pinckney. *WIT Trans. Built Environ.* **2012**, *123*, 43–54.
49. Lavoie, C.C.; Lockett, D. *Producing HABS/HAER/HALS Measured Drawings from Laser Scans: The Pros and Cons of Using Laser Scanning for Heritage Documentation*; U.S. Department of the Interior, National Park Service: Washington, DC, USA, 2016.
50. Moyano, J.; Nieto-Julián, J.E.; Lenin, L.M.; Bruno, S. Operability of Point Cloud Data in an Architectural Heritage Information Model. *Int. J. Archit. Herit.* **2022**, *16*, 1588–1607. [CrossRef]
51. Gonzalez-Jorge, H.; Solla, M.; Armesto, J.; Arias, P. Novel Method to Determine Laser Scanner Accuracy for Applications in Civil Engineering. *IET Sci. Meas. Technol.* **2012**, *6*, 6–12.
52. Leon, I.; Pérez, J.J.; Senderos, M. Advanced Techniques for Fast and Accurate Heritage Digitisation in Multiple Case Studies. *Sustainability* **2020**, *12*, 6068. [CrossRef]
53. Vo, A.-V.; Konda, N.; Chauhan, N.; Aljumaily, H.; Laefer, D.F. Lessons Learned with Laser Scanning Point Cloud Management in Hadoop HBase. In *Advanced Computing Strategies for Engineering*; Smith, I.F.C., Domer, B., Eds.; Springer International Publishing: Cham, Switzerland, 2018; pp. 231–253.
54. Krumm, N.; Hoffman, N. Practical Estimation of Cloud Storage Costs for Clinical Genomic Data. *Pract. Lab. Med.* **2020**, *21*, e00168. [CrossRef] [PubMed]
55. Lunt, B.M.; Linford, M.R.; Davis, R.C.; Jamieson, S.; Pearson, A.; Wang, H. Toward Permanence in Digital Data Storage. In *Archiving Conference*; Society of Imaging Science and Technology: Springfield, VA, USA, 2013; Volume 2013, pp. 132–136.
56. LaBarca, J.E. Image Storage and Permanence Considerations in the Long-Term Preservation of Photographic Images—Update 2010. *J. Phys. Conf. Ser.* **2010**, *231*, 012008. [CrossRef]
57. Sanchez, J.; Franco, P.; de la Plata, A. Achieving Universal Accessibility through Remote Virtualization and Digitization of Complex Archaeological Features: A Graphic and Constructive Study of the Columbarios of Merida. *Remote Sens.* **2022**, *14*, 3319. [CrossRef]
58. Rocha, J.; Tomé, A. Multidisciplinarity and Accessibility in Heritage Representation in HBIM Casa de Santa Maria (Cascais)—A Case Study. *Digit. Appl. Archaeol. Cult. Herit.* **2021**, *23*, e00203. [CrossRef]
59. Banfi, F.; Brumana, R.; Stanga, C. Extended Reality and Informative Models for the Architectural Heritage: From Scan-to-BIM Process to Virtual and Augmented Reality. *Virtual Archaeol. Rev.* **2019**, *10*, 14–30. [CrossRef]
60. Fryskowska, A.; Stachelek, J. A No-Reference Method of Geometric Content Quality Analysis of 3D Models Generated from Laser Scanning Point Clouds for HBIM. *J. Cult. Herit.* **2018**, *34*, 95–108. [CrossRef]
61. Rocha, G.; Mateus, L.; Fernandez, J.; Ferreira, V. A Scan-to-BIM Methodology Applied to Heritage Buildings. *Heritage* **2020**, *3*, 47–65. [CrossRef]
62. Kot, P.; Markiewicz, J.; Muradov, M.; Lapinski, S.; Shaw, A.; Zawieska, D.; Tobiasz, A.; Al-Shamma'a, A. Combination of the Photogrammetric and Microwave Remote Sensing for Cultural Heritage Documentation and Preservation—Preliminary Results. *Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci.* **2020**, *XLIII-B2-2020*, 1409–1413. [CrossRef]
63. Markiewicz, J.; Robak, A. The Generation of High-Resolution Orthoimages Based on TLS Data and Close-Range Images—The Case Study. *J. Mod. Technol. Cult. Herit. Preserv.* **2022**, *1*, 1–13. [CrossRef]
64. Banfi, F.; Roascio, S.; Paolillo, F.; Previtali, M.; Roncoroni, F.; Stanga, C. Diachronic and Synchronic Analysis for Knowledge Creation: Architectural Representation Geared to XR Building Archaeology (Claudius-Anio Novus Aqueduct in Tor Fiscale, the Appia Antica Archaeological Park). *Energies* **2022**, *15*, 4598. [CrossRef]
65. Banfi, F.; Brumana, R.; Landi, A.G.; Previtali, M.; Roncoroni, F.; Stanga, C. Building Archaeology Informative Modelling Turned into 3D Volume Stratigraphy and Extended Reality Time-Lapse Communication. *Virtual Archaeol. Rev.* **2022**, *13*, 1–21. [CrossRef]
66. Foreman, G.; Liu, J. Reality Capture for Historic BIM (HBIM) Development of the Old Polk County Courthouse in Bartow, Florida, USA. *IOP Conf. Ser. Earth Environ. Sci.* **2022**, *1101*, 082024. [CrossRef]
67. Warchoł, A. The Concept of Lidar Data Quality Assessment in the Context of Bim Modeling. *Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci.* **2019**, *XLII-1-W2*, 61–66. [CrossRef]