

Rescue Documentation and Digital Preservation of Alambagh Palace: A Comparative TLS-Based Heritage Survey in Uttar Pradesh

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Abstract: The rapid deterioration of historical monuments in India necessitates the adoption of advanced digital documentation methods for heritage preservation. This study presents a detailed Terrestrial Laser Scanning (TLS) survey of the Alambagh Palace in Lucknow, a Nawabi-era structure built by Wajid Ali Shah and currently in a state of neglect. Using the Leica ScanStation P40 and Differential GPS for global referencing, high-density point clouds were generated to achieve millimetric precision in documenting architectural features, including missing turrets, eroded floral motifs, and structural cracks. Photorealistic 3D models were developed to support conservation planning, immersive visualization, and virtual heritage tourism. Comparative analysis with other TLS-based surveys in Uttar Pradesh—such as Gulistan-e-Iram, Farhat Baksh Kothi, Chhatar Manzil, Kardameshwara Mahadev Temple, and Shri Kashi Vishwanath Temple—highlights both methodological consistency and site-specific challenges. Unlike policy-driven projects such as Kashi Vishwanath, the Alambagh survey exemplifies preventive digital preservation, emphasizing the urgent need for a state-level digital heritage repository. The findings demonstrate the scalability of TLS technology across secular and sacred contexts, offering new opportunities for conservation science, heritage policy, and digital tourism in India.

Keywords: Terrestrial Laser Scanning (TLS); LiDAR heritage documentation; Point cloud modeling; 3D reconstruction; Digital heritage repository; Structural condition assessment.

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I. INTRODUCTION

The preservation of cultural heritage has become an essential focus in the twenty-first century as historical monuments and archaeological sites are increasingly threatened by urbanization, pollution, climate change, and neglect. India, with its rich civilizational history spanning millennia, is home to an extensive array of heritage structures, including Buddhist stupas, Mughal palaces, medieval temples, and structures of Nawabi architecture. However, the rapid pace of physical deterioration has outpaced traditional conservation methods, prompting the need for digital technologies for heritage documentation and preservation.

Light Detection and Ranging (LiDAR) has significantly advanced the methods used for recording and visualizing monuments. Unlike manual surveying, which is both labor-intensive and prone to human error, LiDAR produces highly precise 3D point clouds that capture every structural detail with millimetric precision (Figure 1). This digital archive is

invaluable for restoration planning, virtual tourism, education, and enhancing disaster resilience in the region. Internationally, LiDAR has played a crucial role in revealing hidden archaeological landscapes, such as Angkor Wat in Cambodia (Evans et al., 2013), protecting monumental architecture, such as Gothic cathedrals in Europe (Grussenmeyer et al., 2008), and developing immersive models for cultural outreach (Remondino, 2011; Evans et al., 2013; Fieber et al., 2015).

In Uttar Pradesh (U.P.), a state renowned for its Indo-Islamic palatial complexes and Hindu temple architecture, the Remote Sensing Applications Centre (RSAC-UP) has been at the forefront of employing Terrestrial Laser Scanning (TLS) for heritage preservation (Tapete et al., 2015). Recent TLS surveys have been conducted at sites such as Gulistan-e-Iram (RSAC-UP, 2023), Farhat Baksh Kothi and Chhatar Manzil in Lucknow, and the Shri Kashi Vishwanath Temple and Kardameshwara Mahadev Temple in Varanasi (RSAC-UP,

2024), establishing a methodological framework for the scientific documentation of monuments.

➤ *LiDAR in Heritage Documentation: Global Perspectives*

The utilization of LiDAR technology in the preservation of cultural heritage (Tapete et al., 2015) has advanced significantly over the past two decades. Guidelines from the International Society for Photogrammetry and Remote Sensing (ISPRS) and UNESCO underscore the importance of 3D digital documentation as a protective measure against irreversible loss (UNESCO, 2017). In Angkor Wat, Cambodia, Evans et al. (2013) employed airborne LiDAR to uncover extensive hidden landscapes, thereby demonstrating the utility of LiDAR not only in architectural documentation but also in landscape archaeology. In Petra, Jordan, Fieber et

al. (2015) utilized TLS for high-resolution 3D recording of façades, which is essential for monitoring structural degradation. In the context of European cathedrals, Grussenmeyer et al. (2008) compared TLS with photogrammetry and tacheometry for Gothic structures, highlighting the superiority of TLS in terms of completeness and accuracy. At Pompeii, Italy, Remondino (2011) illustrated the integration of LiDAR and photogrammetry workflows to reconstruct ancient urban spaces with a high degree of scientific precision. These studies collectively demonstrate how LiDAR has become the benchmark for monument documentation, providing rapid, detailed, and georeferenced datasets that are adaptable to various applications, including conservation, education, and tourism.

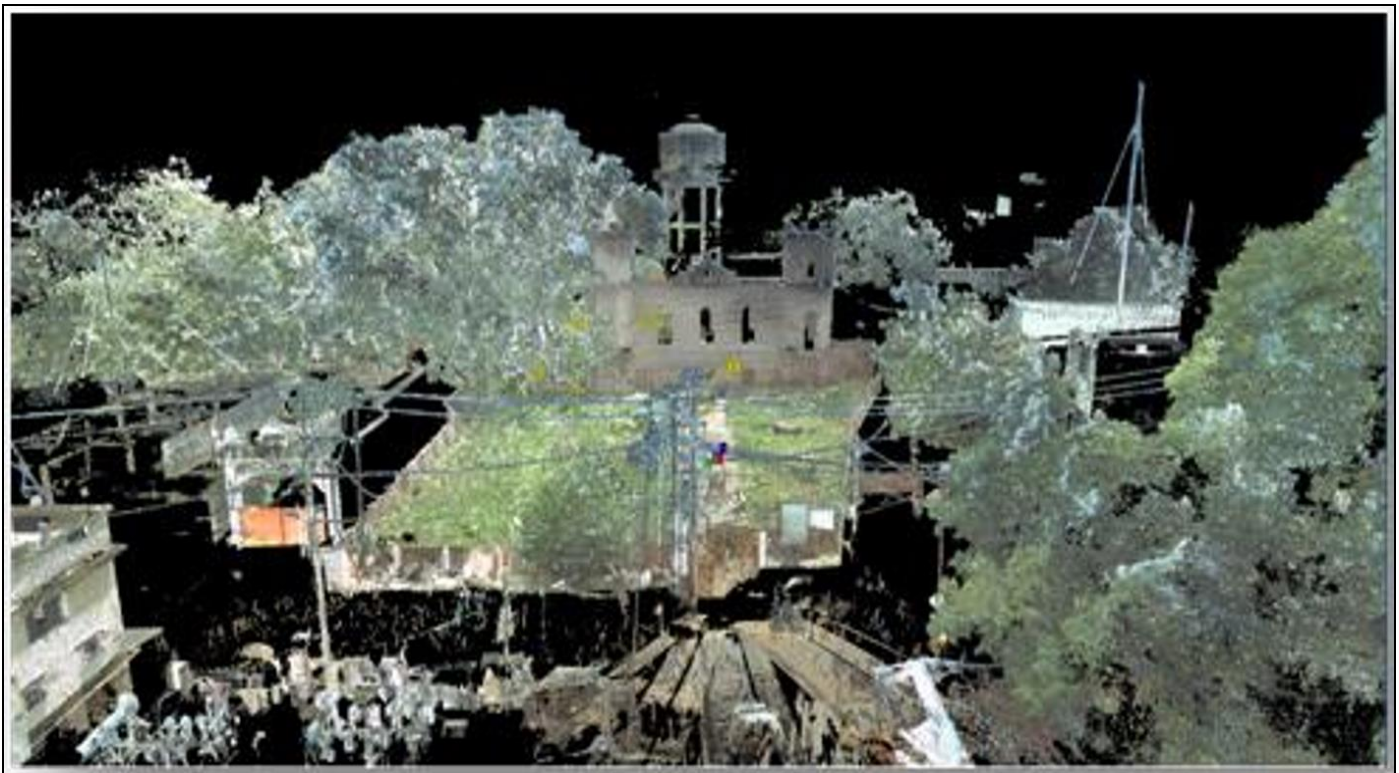


Fig 1 Showing RGB View of Alambagh Place Area with no Noise Filtering

➤ *LiDAR Applications in India*

India has predominantly adopted LiDAR technology in urban planning, forestry, and disaster management, while its application in heritage conservation is still in its nascent stages. Noteworthy instances include the Ajanta–Ellora Caves, where Terrestrial Laser Scanning (TLS) was employed to meticulously document Buddhist and Hindu cave structures with high precision (Patra & Mukhopadhyay, 2019). At the Konark Sun Temple, a TLS survey facilitated detailed façade mapping and provided foundational data for the Archaeological Survey of India (ASI) conservation initiatives (Kumar et al., 2020). In Delhi, pilot projects at the Red Fort have utilized TLS to digitize Mughal architecture, thereby enabling integration with virtual tourism platforms (Joshi et al., 2017). In each of these cases, LiDAR offered a scientifically robust alternative to photogrammetry, supporting both as-built documentation and reconstruction planning.

➤ *Heritage Documentation in Uttar Pradesh: RSAC-UP's Initiative*

Uttar Pradesh, renowned for its diverse heritage sites, ranging from the Nawabi palaces in Lucknow to the Shaivite temples in Varanasi, has emerged as a central focus for LiDAR heritage surveys. The Remote Sensing Applications Centre of Uttar Pradesh (RSAC-UP) has systematically employed Terrestrial Laser Scanning (TLS) for several case studies.

For instance, at Farhat Baksh (Rao, 2025) Kothi and Chhatar Manzil in Lucknow, the use of the Leica P40 TLS combined with a Leica digital camera facilitated the capture of façade and structural features. This approach resulted in the production of RGB-fused point clouds and a virtual fly through animation, thereby enhancing the visualization for conservation planning (Figure 9).

At Gulistan-e-Iram (RSAC-UP, 2023) in Lucknow, the survey emphasized integrated methodologies that combined TLS with close-range photogrammetry. This integration generates detailed 3D architectural blueprints that are instrumental in ongoing restoration efforts.

The Kardameshwara (RSAC-UP, 2018) Mahadev Temple in Varanasi, a religious heritage site characterized by intricate carvings and symbolic geometry, was surveyed using a TLS. This survey produced high-density point clouds that captured sculptural niches and architectural phases, which are critical for understanding the decline of temple architecture in Northern India .

Similarly, the Shri Kashi Vishwanath (RSAC-UP, 2022) Temple in Varanasi was surveyed as part of the redevelopment of the Kashi Vishwanath (RSAC-UP, 2022) corridor. The point cloud datasets documented temple elevations, gold-plated spires, and corridor expansions, directly contributing to the urban planning.

These case studies collectively illustrate a statewide methodological coherence, as all employed the Leica P40 TLS, Differential Global Positioning System (DGPS) for georeferencing, and Leica Cyclone software for processing. Nevertheless, each site presents unique conservation challenges, ranging from the decay of Nawabi palaces in Lucknow to the pressures of ritual continuity and redevelopment in Varanasi.

➤ *Alambagh Palace in Context*

The survey of the Alambagh Palace must be contextualized within this historical framework. Constructed by Nawab Wajid Ali Shah (1847–1856), the palace initially functioned as a military post and subsequently as a refugee camp during the 1857 Sepoy Mutiny. Built with Lakhuri bricks, surrounded by gardens, and embellished with floral motifs, the palace once epitomized Nawabi elegance, but currently exists in a dilapidated state. Unlike Gulistan-e-iram or Kothi Farhat Baksh (Rao, 2025), the Alambagh Palace is not currently subject to structured conservation efforts. Consequently, its TLS survey serves as both an urgent documentation effort and an opportunity to incorporate it into the broader heritage policy framework of Uttar Pradesh.

➤ *Literature Gap and Research Contribution*

Previous RSAC-UP surveys, including those by Farhat Baksh (Rao, 2025), Kothi, Gulistan-e-Iram (RSAC-UP, 2023), and Kardameshwar Mahadev and Kashi Vishwanath (RSAC-UP, 2024) temples, have been documented in technical reports. However, there is a notable lack of comparative academic analyses of multiple TLS heritage projects within a single country. This study addresses this deficiency by offering a comprehensive TLS survey of the Alambagh Palace, performing a comparative analysis with other monuments in Uttar Pradesh, and exploring the broader implications for policy, tourism, and conservation. Through this approach, this study documents the Alambagh Palace and contributes to the development of a statewide strategy for digital heritage preservation in India (Tapete et al., 2015).



Fig 2 Photo Realistic Visualization of Front view of Alambagh Palace in RGB

II. STUDY AREA AND METHODOLOGY

➤ *Study Area: Alambagh Palace*

The Alambagh Palace, positioned near the Lucknow–Kanpur highway in Uttar Pradesh (Figure 3), is a notable example of Nawabi-era architecture, reflecting both aesthetic refinement and historical significance. Erected between 1847

and 1856 under the patronage of Nawab Wajid Ali Shah, the last sovereign of Awadh, the palace was initially conceived as a leisure retreat, enveloped by lush gardens and orchards (Figure 4). However, following the Sepoy Mutiny of 1857, the palace was repurposed into a fortified military post and later a refugee camp, marking the shift of Lucknow from Nawabi opulence to colonialism.

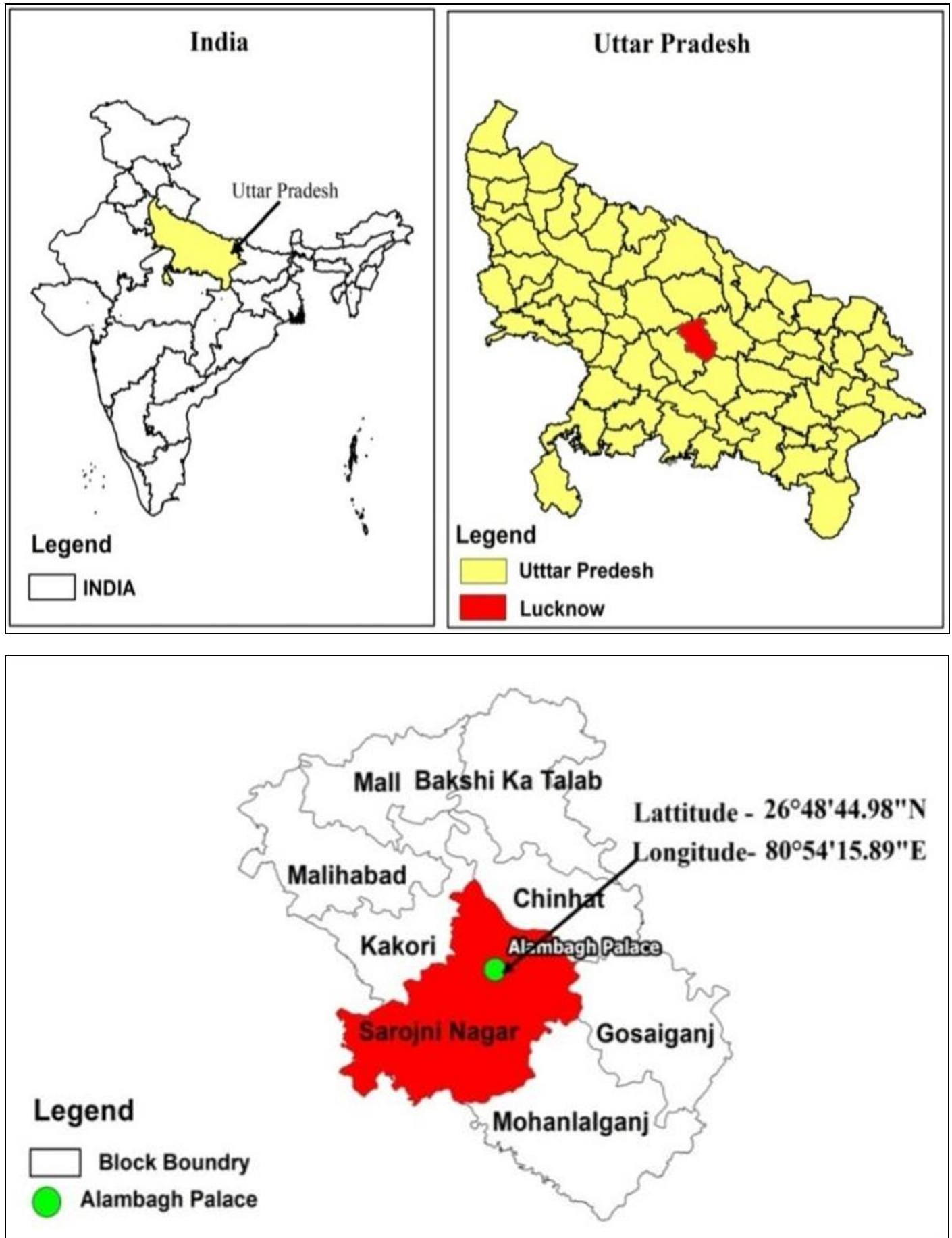


Fig 3 Location Map of the Study Area-Alambagh Palace

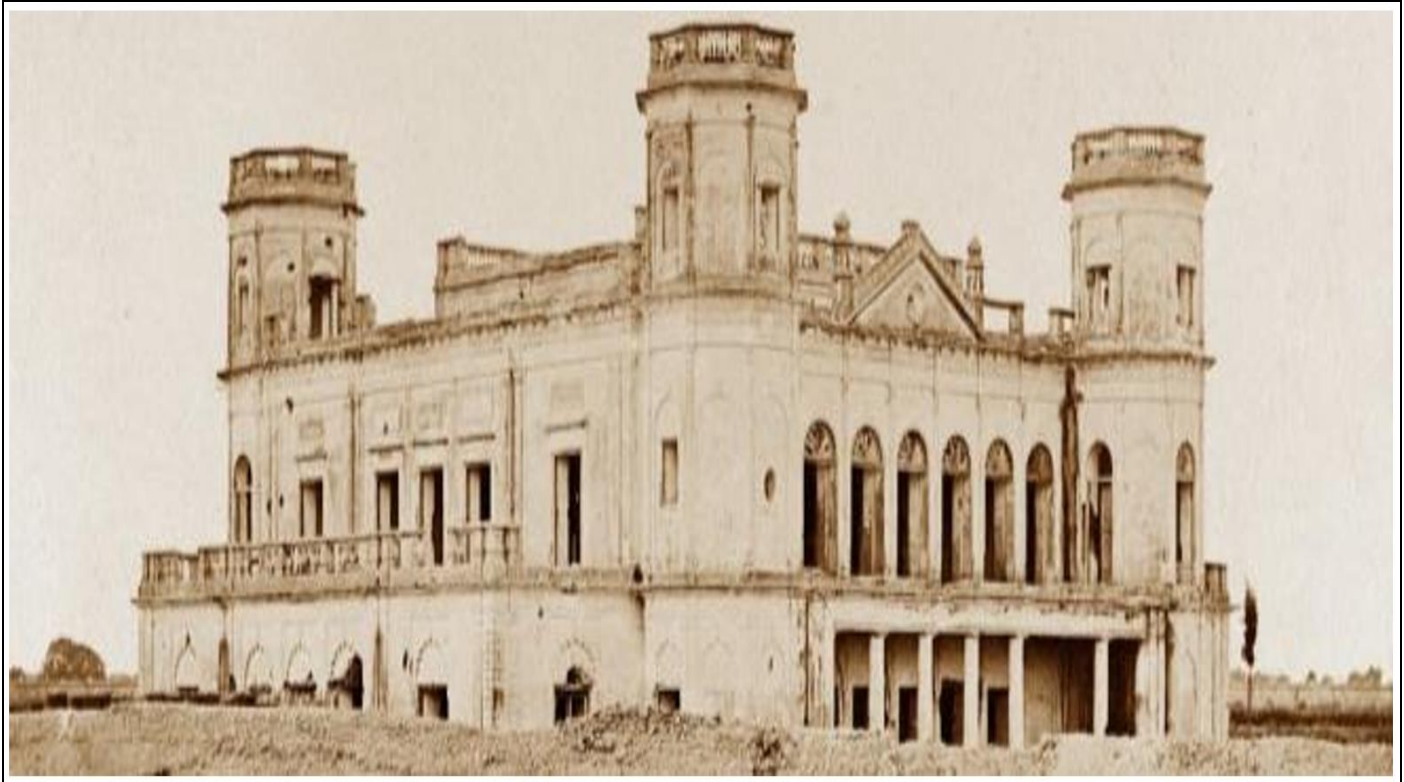


Fig 4 Black & White Photo of Alambagh Palace, Lucknow by Felice Beato

The palace is a two-story edifice constructed from Lakhaury bricks, a hallmark of Nawabi architecture, recognized for their compact size and resilience. Originally, the structure boasted expansive halls, lofty rooms, intricate floral motifs, and ornamental turrets (minarets). The central block was flanked by gardens and open courtyards, creating a space that served both residential and ceremonial purposes. Over time, the palace has suffered deterioration: the floral motifs and wall engravings have faded due to exposure to the elements; two turrets at the rear have disappeared, likely due to neglect; and several walls, doors, and windows have exhibited cracks or partial collapse. Presently, the site offers both a challenge and an opportunity: despite the damage to its historical character, precise digital documentation through TLS facilitates the accurate reconstruction of lost features.

➤ Objectives of the Survey

The TLS-based documentation of the Alambagh Palace was directed by three principal objectives: Digital Documentation and Preservation, Restoration and Reconstruction Support, and Tourism and Education. The first objective was to create a millimeter-accurate 3D dataset of the palace to preserve its memory against further degradation. The second objective involved the use of TLS point clouds to facilitate the scientific reconstruction of damaged or missing features, particularly turrets (Figure 11

B). The third objective was to generate a photorealistic 3D model suitable for virtual walkthroughs, museum exhibitions, and heritage education.

➤ Equipment and Data Acquisition

• Instruments Employed:

The Leica ScanStation P40 TLS offers a medium-range capability of up to 270 m, with an accuracy of 1.2 mm, allowing for precise millimetric feature capture (Figure 5). It operates on the principle of a pulse-based green laser. The Leica DGPS Setup, comprising both Base and Rover units (Figure 6), was used to establish ground control points (GCPs) essential for global georeferencing. Tripods and range poles were used to ensure the stability and precise positioning of the scanner during the survey (Figure 6). Targets play a critical role in the registration of multiple point clouds, facilitating seamless integration.

• Software Utilized:

Leica Infinity 2.3.0 was employed for data management and pre-processing. Cyclone 9.3.2 was used for point cloud registration, filtering, and RGB integration (Figure 1). 3D Reshaper 18.1.7 was used for advanced feature extraction and model generation.



Fig 5 The Leica Scan Station P40 TLS



Fig 6 Tripod, Base Rover & Controller

The equations are an exception to the prescribed

➤ Survey Methodology

The TLS survey was conducted following a detailed multi-step process, consistent with the methodologies of other RSAC-UP heritage projects (Figure 7): Planning and Control Setup A base station was established using DGPS to ensure global stabilization. Survey control points or targets were strategically placed across the palace walls and gardens to achieve optimal coverage. TLS Data Collection The Leica P40 scanner emitted millions of laser pulses, each measuring the distance to the surface points. Multiple scans were performed at various strategic locations to comprehensively cover the façades, turrets, gardens, and interiors. The Cyclone software was used to merge the scans into a single, unified point cloud, aligning the data through targets and GCPs. Noise Filtering and Cleaning Erroneous reflections from vegetation, glass, and metallic objects were removed. The resulting point cloud captured the geometry with sub-centimeter precision (Figure 12). Photorealistic Visualization RGB values were integrated from the camera inputs to create true-color 3D models. The final output enabled interactive visualization from multiple angles. Feature Extraction Structural dimensions of walls, turrets, motifs, and doors were measured. Missing turrets were digitally reconstructed using a symmetry-based extrapolation of existing structures (Figure 11B).

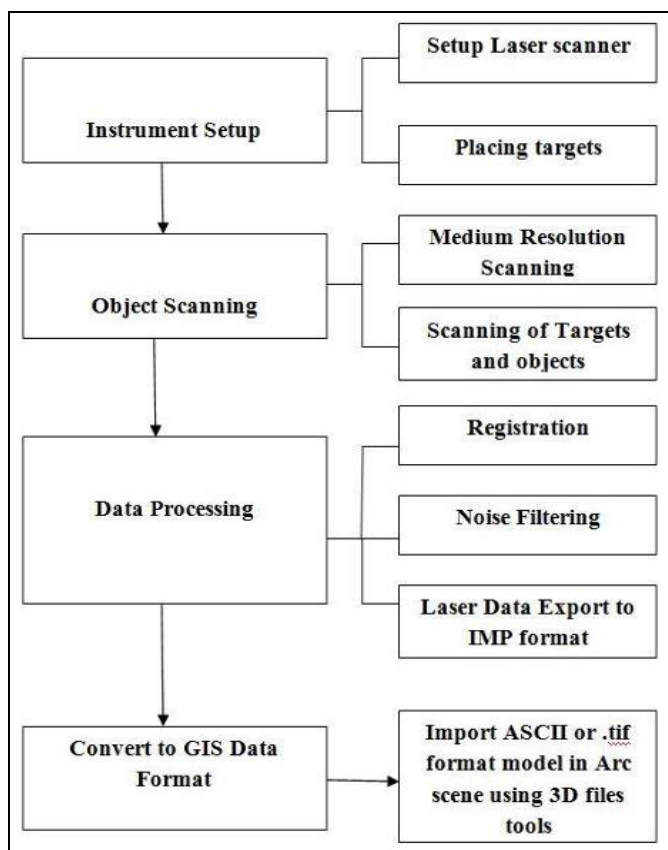


Fig 7 TLS Survey Methodology

➤ Methodological Consistency Across UP Heritage Surveys

A notable achievement of the RSAC-UP heritage program is the establishment of standardized TLS workflows

across a range of monuments. The Farhat Baksh (Rao, 2025) Kothi and Chhatar Manzil in Lucknow employed the Leica P40 system along with Cyclone to achieve photorealistic colorization. This initiative also produced fly through animations, thereby broadening the scope of the visualization. The Gulistan-e-Iram (RSAC-UP, 2023) project in Lucknow focused on integrating TLS with close-range photogrammetry, which is particularly advantageous for capturing interior and decorative details. At the Kardameshwara (RSAC-UP, 2018) Mahadev Temple in Varanasi, TLS was used to document the garbhagriha, mandapa, and sculptural niches. The primary challenge was the documentation of intricate carvings and the temple's elevation, where Cyclone proved effective in achieving millimetric precision in the data. The survey of the Shri Kashi Vishwanath (RSAC-UP, 2024) Temple in Varanasi, conducted during the corridor redevelopment project, yielded 3D datasets of gold-plated spires, temple elevations, and adjacent shrines, providing essential data for the planners. Across all sites, including the Alambagh Palace, the Leica P40 + Cyclone workflow ensured consistent data quality, enabling cross-site comparisons and the potential development of a statewide digital heritage repository.

➤ Significance of the Methodology

The TLS methodology applied at Alambagh Palace is distinguished by several critical features: precision, achieving millimeter-level detail vital for restoration efforts; efficiency, as it surpasses manual surveys in speed and comprehensiveness; scalability, with its applicability extending to both palatial complexes in Lucknow and religious temples in Varanasi; and Policy Utility, as it establishes foundational datasets for the Archaeology Department and Smart Cities heritage projects. By aligning with methodologies utilized at Gulistan-e-Iram (RSAC-UP, 2023), Farhat Baksh (Rao, 2025), Kardameshwara (RSAC-UP, 2018), and Kashi Vishwanath, the survey conducted at Alambagh Palace sets a precedent for the emerging geospatial standards in heritage documentation across Uttar Pradesh.

III. RESULTS

➤ Point Cloud Capture

The TLS survey at Alambagh Palace resulted in a detailed point-cloud dataset, capturing the exterior architectural elements with millimetric accuracy. Each scan position contributed millions of 3D points, which were subsequently integrated into a cohesive cloud. Initially, the raw scans exhibited noise artifacts owing to factors such as vegetation, reflective surfaces, and urban interference (Figure 8). Through rigorous filtering, a refined dataset was achieved that accurately preserved the geometry of walls, doors, windows, and decorative motifs (Figure 9). The georeferencing process, employing DGPS, ensured that the point cloud was not only internally consistent but also globally referenced, enabling its compatibility with broader geospatial frameworks and potential integration into Smart City heritage layers.

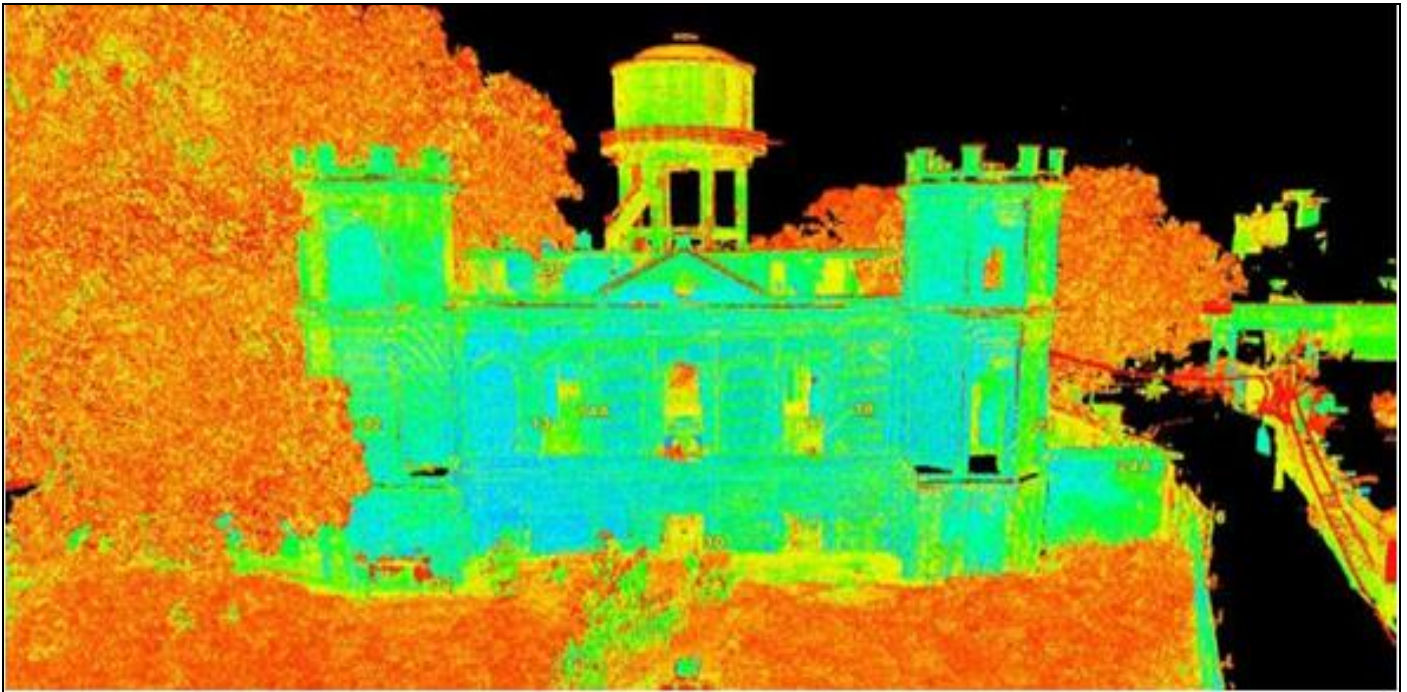


Fig 8 Point Cloud Data View of Alambagh Palace without Filtering

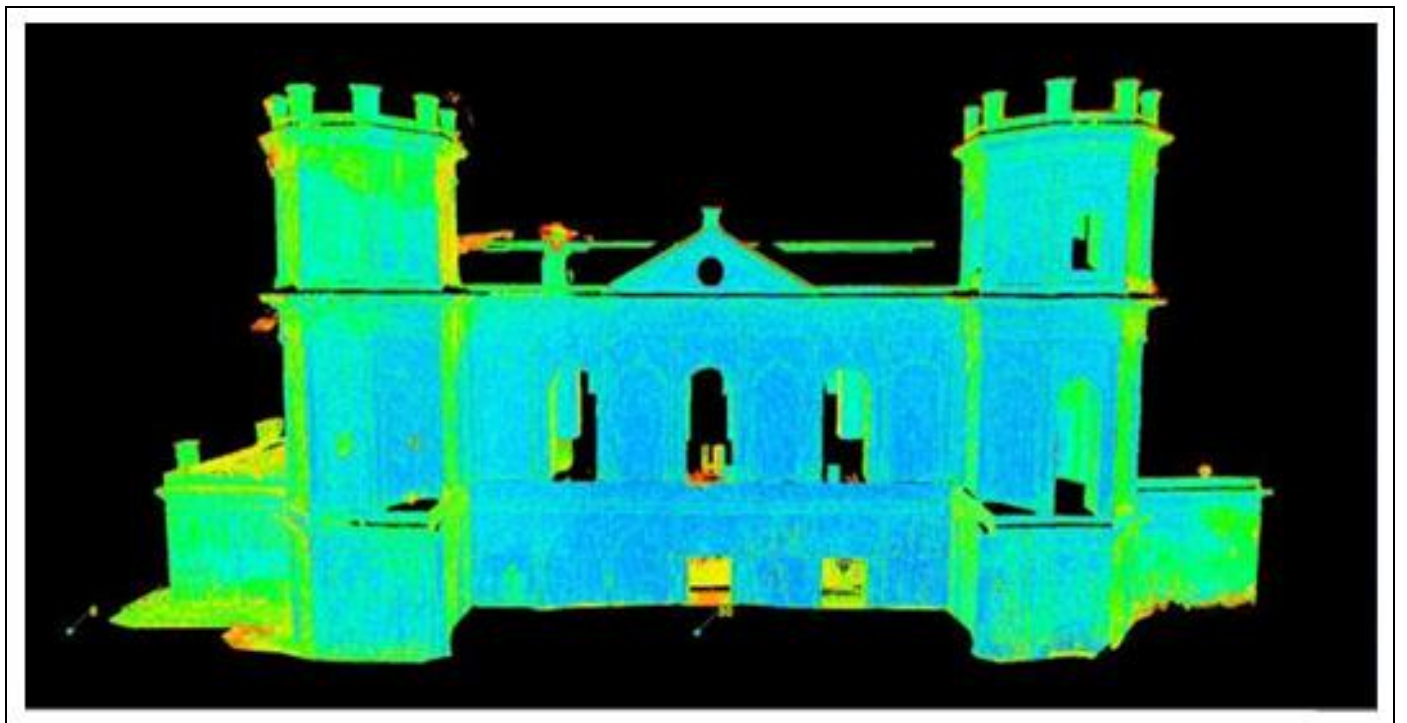


Fig 9 Point Cloud Data View of Alambagh Palace after Filtering

➤ Dimensional Accuracy and Measurements

Terrestrial Laser Scanning (TLS) offers significant advantages, particularly in generating precise as-built measurements. The survey conducted on Alambagh Palace provided the following detailed data: the dimensions of the palace, including the length, width, and height of each structural block, were recorded with remarkable accuracy of ± 1.2 mm (Figure 10 A, B, C, D & E). The thickness and vertical alignment of the walls were meticulously measured to evaluate the structural stability. The documentation of door and window openings was comprehensive, capturing even

ornamental arch designs. Additionally, shallow engravings on bricks and plaster, such as floral motifs and carvings, were digitally preserved. Detailed scans of the existing turrets (minars) were conducted, with their dimensions serving as a reference for reconstructing the two missing turrets at the rear of the palace (Figure 11). This high level of detail empowers heritage engineers to conduct comparative analyses between the original dimensions and reconstructed models, ensuring that future restoration efforts remain true to the original architecture of the structure.

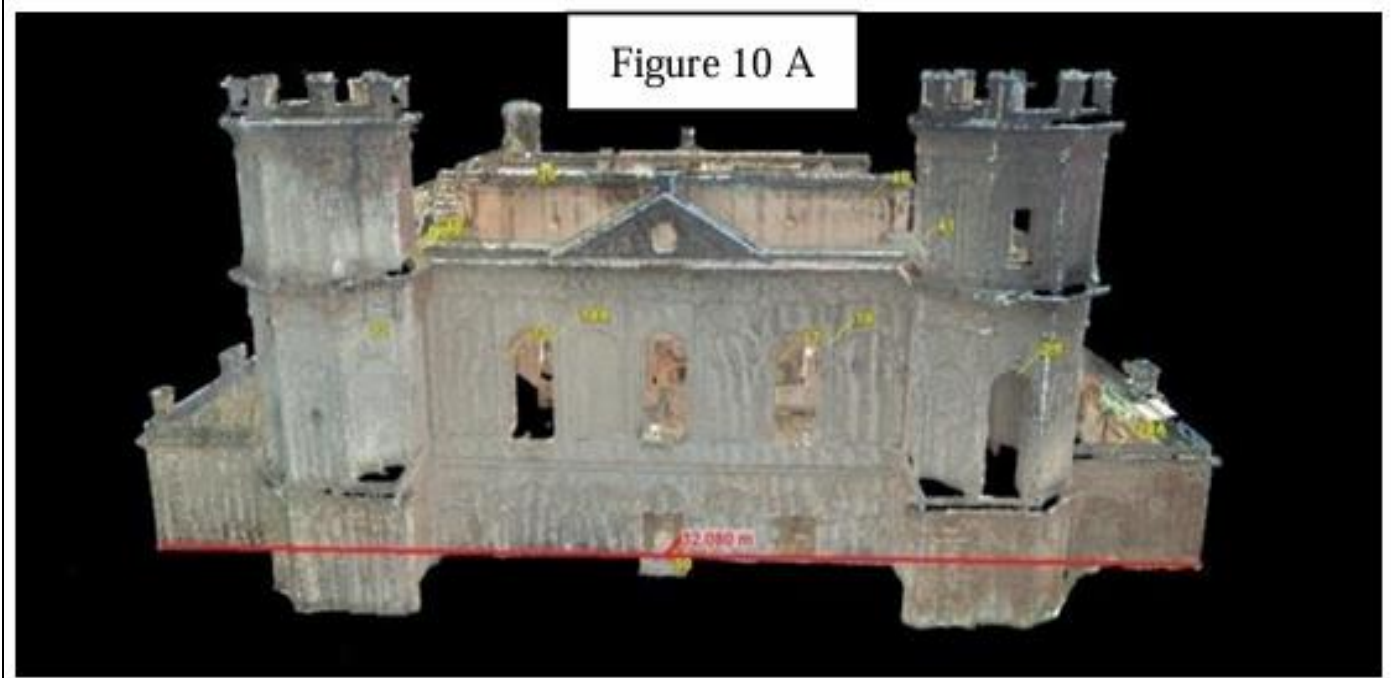


Fig 10 A & B: Measurements on Photo Realistic Data



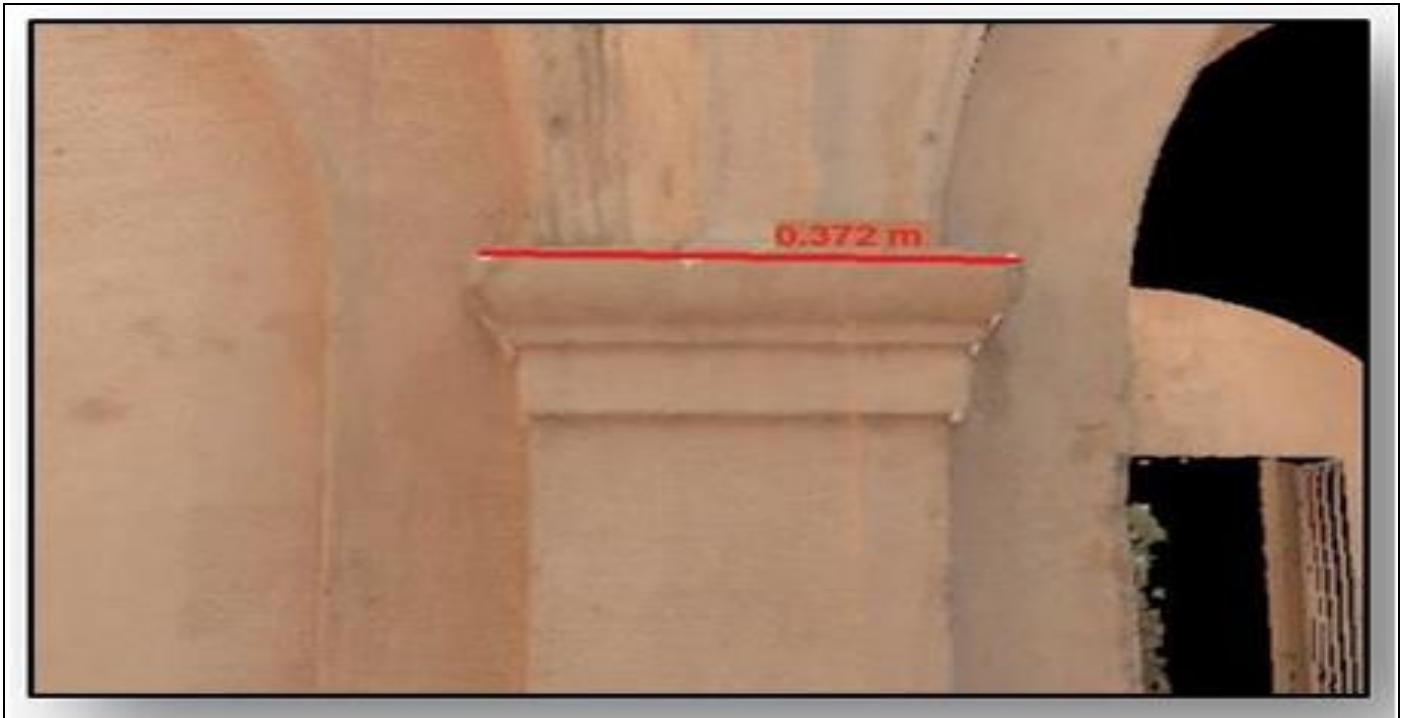


Fig 10 C, D & E: Measurements of Structures

➤ *Photorealistic Visualization*

The RGB-integrated point cloud facilitated the creation of photorealistic 3D models of the palace, enabling stakeholders to visualize the site within a virtual environment. (Figure 2, 11 A & B) Front View Models: The façade was meticulously captured, illustrating the intricate interplay of arches, turrets, and brickwork. Aerial Oblique Views: These perspectives provide valuable insights into the spatial relationship between the palace and its gardens, emphasizing

the harmonious integration of architectural and natural elements characteristic of the Nawabi design. Interior Hall Models: The scans revealed details such as ceiling heights, spatial configurations, and the condition of ornamental features. This photorealistic visualization is crucial not only for conservation planning but also for tourism, as it supports the development of immersive walk-throughs for public engagement.



Fig 11 A Photorealistic view and Measurement



Fig 11 B Photorealistic view and Measurement
(Turret Missing)

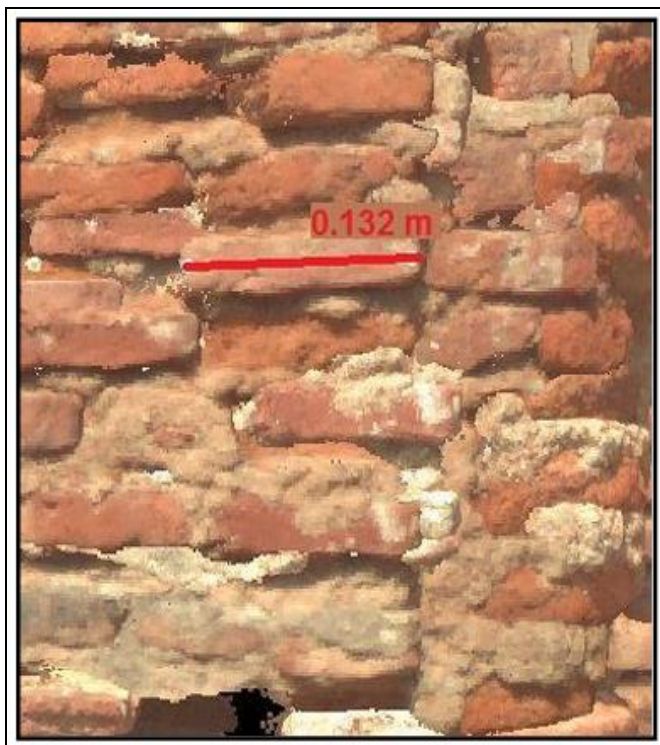


Fig 12 Photorealistic View Measurement of Bricks and
Missing Plaster

➤ Condition Assessment

The TLS analysis verified the notable degradation of the palace structure. The plaster layers have deteriorated, exposing the underlying brickwork of the walls (Figure 12). The floral motifs have weathered to the brink of disappearance. Although two turrets were absent, they could be digitally reconstructed using data from the remaining turrets. The doors and windows suffered partial collapse, with some frames showing signs of warping. Vegetation encroachment is apparent in the courtyards and within wall fissures. By digitally capturing these details, the survey offers a time-stamped record of the current state that can serve as a reference point for future assessments.

➤ Comparative Insights with Other UP TLS Surveys

The Alambagh Palace project, when juxtaposed with other RSAC-UP TLS initiatives, exhibits a unique set of characteristics. The Farhat Baksh (Rao, 2025) and Chhatar Manzil (Lucknow) projects primarily focus on the aesthetic grandeur of façades. In contrast, the Alambagh project focused on addressing structural deterioration and restoring missing components. The Gulistan-e-Iram (RSAC-UP, 2023) project in Lucknow integrated TLS with photogrammetry, particularly for interior documentation, whereas the Alambagh survey predominantly utilized TLS, with RGB integration to enhance visual realism. The Kardameshwara (RSAC-UP, 2024) Mahadev Temple in Varanasi employs TLS to meticulously document carvings and religious iconography. Conversely, the Alambagh project showcased TLS's effectiveness of TLS in capturing the intricacies of palatial Indo-Islamic architecture, underscoring its broader applicability. The Kashi Vishwanath (RSAC-UP, 2024) Temple in Varanasi aligned its TLS efforts with a redevelopment initiative and produced detailed models of the spires and corridors. In contrast, the Alambagh project stands as an independent heritage preservation effort, prioritizing conservation over redevelopment. Thus, the Alambagh project contributes significantly to the diversity of TLS applications in Uttar Pradesh, demonstrating its adaptability to both secular and religious architectural contexts.

➤ Comparative Insights with Other UP

A key finding of the TLS survey is the potential for digital reconstruction (Table 1). By employing the existing dimensions of the turrets, the two absent turrets can be digitally modeled and virtually integrated into the palace structure and transformed into blueprints for physical reconstruction by conservation authorities. Additionally, missing floral motifs and doorways can be accurately replicated through symmetric extrapolations from existing sections. This method provides a scientifically validated framework for an authentic restoration. specifications of this template. You will need to determine whether or not your equation should be typed using.

Table 1 Technical Specifications of the Leica Scan Station P40 TLS System.

Parameter	Specification
Range	Up to 270 m (long-range mode)
Accuracy (position)	3 mm at 50 m
Accuracy (angle)	8 arc-seconds
Scan rate	1 million points per second
Field of View (FoV)	360° (horizontal), 270° (vertical)
Wavelength	1550 nm
Output format	Point clouds (LAS, PTS, E57, etc.)

➤ *Broader Implications*

Conservation Authorities: The Archaeology Department and INTACH can employ TLS data as a foundational benchmark for any physical intervention. Tourism Development: The creation of photorealistic 3D models can be incorporated into virtual heritage platforms, thereby enhancing public engagement with the Nawabi history of Alambagh. Education: Universities and cultural institutions are encouraged to utilize point-cloud datasets for educational purposes in heritage science and digital archaeology . Policy: This highlights the imperative for comprehensive TLS documentation of all significant monuments in Uttar Pradesh and their integration into a statewide Digital Heritage Repository.

➤ *Broader Implications*

The TLS survey of Alambagh Palace was conducted with notable success (Table 2), achieving several key outcomes: capturing structural features with millimetric precision, producing photorealistic 3D models for enhanced visualization, and identifying damaged and missing elements, thereby facilitating scientific reconstruction. Furthermore, the survey positioned Alambagh within a comparative framework of Uttar Pradesh's LiDAR heritage projects, elucidating both the shared characteristics and unique challenges.

Table 2 Survey Metadata for the Alambagh Palace TLS Survey.

Attribute	Value
Year of survey	2019
Location	Alambagh Palace, Lucknow, Uttar Pradesh
Scanner used	Leica ScanStation P40
DGPS checkpoints	6
Scan positions	20+
Total points captured	~150 million
Processing software	Leica Cyclone, 3D Reshaper
Output	Registered point clouds, 3D models

IV. BROADER IMPLICATIONS

➤ *Introduction to Comparative Framework*

While the TLS survey of Alambagh Palace offers significant insights into the Nawabi architectural heritage, its true value becomes apparent when compared with other LiDAR-based heritage surveys conducted in Uttar Pradesh. Since 2017, RSAC-UP has undertaken multiple projects employing a consistent methodological framework (Leica

P40 TLS + DGPS + Cyclone processing) across a diverse range of heritage typologies, including palatial Nawabi residences, Indo-Islamic gardens, medieval Shaivite temples, and sacred Hindu complexes. This comparative perspective underscores both the shared advantages (such as accuracy, visualization, and reconstruction potential) and site-specific challenges (including architectural complexity, religious significance, and policy context).

Table 3 Comparative TLS Survey Results Across Selected Monuments in Uttar Pradesh.

Monument	Year	No. of Scans	DGPS Control	Key Findings
Alambagh Palace, Lucknow	2019	20+	6	Missing turrets, floral motifs eroded, 3D reconstruction feasible
Gulistan-e-Iram, Lucknow	2020	20+	5	Structural cracks, façade displacement documented
Kardameshwara Mahadev Temple, Varanasi	2018	15+	4	Detailed shikhara captured, encroachment observed
Shri Kashi Vishwanath Temple, Varanasi	2022	60+	7	Complete 3D model of temple complex, crowd-management application
Farhat Baksh Kothi & Chhatar Manzil, Lucknow	2023	30+	6	Riverfront façade documented, integration with digital archives

➤ *Lucknow Monuments: Palatial Heritage*

Alambagh Palace (1847–1856) was constructed by Nawab Wajid Ali Shah, serving both residential and military purposes. A survey highlighted structural decay, missing turrets, and floral motifs. It is unique as a site from the mutiny era, linking architecture to the history of colonial resistance. Farhat Baksh (Rao, 2025) Kothi and Chhatar Manzil are early 19th-century Nawabi palaces, later adapted to colonial rule. A TLS survey produced RGB point clouds and fly through animations to showcase the grandeur of the façade (Figure 11). The focus was on the preservation of Indo-European hybrid architecture rather than its reconstruction. Gulistan-e-Iram (RSAC-UP, 2023) is a lesser-known Nawabi residence surveyed using TLS integrated with photogrammetry. This approach was particularly useful for interiors, decorative niches, and faded ornamental plaster, demonstrating the advantages of hybrid workflows for heritage with fragile surface textures. Comparative Insight: Alambagh Palace differs from Farhat Baksh (Rao, 2025) and Gulistan in terms of its condition and conservation status. While Farhat Baksh (Rao, 2025) and Chhatar Manzil remain iconic yet partly maintained, Alambagh is in a dilapidated state, with TLS serving as an urgent rescue-documentation tool. Gulistan highlighted the value of hybrid techniques, whereas Alambagh relied primarily on TLS because of structural instability, which limited interior photogrammetry.

➤ *Varanasi Temples: Religious Heritage*

The Kardameshwara (RSAC-UP, 2024) Mahadev Temple, situated in Khandava, Varanasi, is an integral part of the Panchakosi pilgrimage circuit. The TLS survey meticulously documented the garbhagriha (sanctum), mandapa, and intricate niches, providing high-precision data. This data is instrumental for both archaeological research on late northern Indian temple architecture and the conservation of the sculptural elements.

The Shri Kashi Vishwanath (RSAC-UP, 2024) Temple, recognized as one of the most sacred Jyotirlingas, was surveyed during the Kashi Vishwanath (RSAC-UP, 2024) corridor redevelopment. The TLS survey generated comprehensive datasets of golden spires, façades, and temple elevations, which were integrated with urban planning initiatives. Notably, this TLS survey was uniquely associated with a policy-driven redevelopment project, in contrast to Alambagh, which remains outside the scope of structured conservation efforts.

Comparative Insight: The Alambagh Palace exemplifies secular Nawabi heritage, whereas temples in Varanasi represent sacred religious heritage. The policy context is markedly different: the Kashi Vishwanath TLS informed redevelopment and tourism infrastructure, the Kardameshwara (RSAC-UP, 2024) TLS guided archaeological preservation, and the Alambagh TLS serves as a prompt for future conservation planning.

➤ *Cross-Site Methodological Commonalities*

At all locations, certain methodological practices were consistently applied: The Leica ScanStation P40 TLS was utilized as the primary instrument, ensuring uniform accuracy

across sites. Georeferencing was achieved using DGPS-based ground control points. The software suite includes Cyclone for tasks such as registration and cleaning, with the occasional use of 3D Reshaper or photogrammetry, particularly noted in Gulistan. The resulting outputs were characterized by dense point clouds, photorealistic 3D models, and measurements with millimeter precision (Figure 11). This methodological uniformity allows for the seamless integration of datasets from the palaces in Lucknow and temples in Varanasi into a comprehensive digital repository dedicated to the heritage of Uttar Pradesh.

➤ *Architectural and Conservation Challenges*

The architectural heritage of Lucknow, represented by palaces such as Alambagh, Farhat Baksh (Rao, 2025), and Gulistan, showcases a unique blend of Indo-Islamic and European styles. These historical structures are currently facing issues such as structural deterioration, the absence of certain components, and the degradation of decorative plasterwork. Terrestrial Laser Scanning (TLS) is instrumental in addressing these challenges by facilitating the reconstruction of lost architectural features, including the turrets of Alambagh. Conversely, the temples of Varanasi, such as Kardameshwara (RSAC-UP, 2024) and Kashi Vishwanath, are significant Shaivite religious sites, noted for their symbolic geometric designs. These temples face challenges stemming from high pilgrimage traffic, the need to maintain ritual practices, and the pressures of urban development. TLS is pivotal in these contexts for structural assessment and ensuring the harmonious integration of urban areas. Therefore, TLS exhibits versatility in adapting to the distinct conservation needs of Lucknow's military history and Varanasi's religious heritage.

➤ *Policy and Tourism Implications*

The comparative analysis identified distinct policy contexts (Table 3)). The Kashi Vishwanath (RSAC-UP, 2024) TLS is directly shaped by redevelopment efforts that merge heritage documentation with significant urban transformation. Conversely, the Kardameshwara (RSAC-UP, 2024) TLS focuses on supporting archaeological and religious preservation without engaging in extensive urban interventions. Farhat Baksh (Rao, 2025) and Gulistan TLS are primarily dedicated to academic and conservation objectives, with particular emphasis on Nawabi architecture. Alambagh TLS currently functions as documentation awaiting policy application, underscoring the importance of its integration into Lucknow's heritage management strategies. From a tourism perspective, TLS datasets offer the potential for conversion into virtual reality walk-throughs, digital exhibitions, and augmented reality overlays. In Lucknow, Nawabi palaces, including Alambagh, can be developed into a digital heritage circuit that complements the physical heritage trail. In Varanasi, the TLS enhances the pilgrimage experience by providing virtual access to global devotees.

➤ *Synthesis*

The comparative review highlights that although the Alambagh Palace TLS shares methodological elements with other surveys, its pressing conservation needs render it

unique. Unlike the Kashi Vishwanath project (RSAC-UP, 2024), where TLS was integral to a significant redevelopment, or Gulistan, where it aided restoration, Alambagh serves as a case study of preventive digital preservation for a site that has been overlooked. Collectively, these surveys demonstrate the adaptability of TLS technology across various heritage settings in Uttar Pradesh, paving the way for a comprehensive digital heritage repository that includes secular and sacred, palatial and religious, as well as urban and rural monuments.

V. DISCUSSION AND CONCLUSION

A. Discussion

The TLS survey of Alambagh Palace, when evaluated in conjunction with other LiDAR-based heritage surveys in Uttar Pradesh, underscores the transformative potential of geospatial technology for cultural preservation. Beyond the immediate technical outputs, such as dense point clouds, photorealistic 3D models, and precise measurements, TLS introduces a novel paradigm for documenting, monitoring, and reimagining heritage.

➤ From Rescue Documentation to Active Policy

In Uttar Pradesh, Terrestrial Laser Scanning (TLS) surveys can be categorized into two primary types: policy-driven initiatives, exemplified by the Kashi Vishwanath (RSAC-UP, 2024) Temple survey, which directly informed corridor redevelopment, and conservation-focused projects, such as the Gulistan-e-Iram (RSAC-UP, 2023) and Kardameshwara (RSAC-UP, 2024) Mahadev Temples, which established foundational datasets for preservation efforts. The Alambagh Palace survey represents the third category, namely, the rescue documentation of neglected heritage sites. Unlike the Kashi Vishwanath (RSAC-UP, 2024) project, it lacks institutional follow-up; however, it functions as a crucial digital safeguard against potential losses. This underscores the pressing need for a state-level heritage digital policy to ensure the integration of all TLS datasets into the planning framework.

➤ Integration with Other Technologies

Terrestrial Laser Scanning (TLS) is a robust technology; however, it falls short when employed in isolation. Research, such as that by Gulistan-e-Iram (RSAC-UP, 2023), emphasizes the advantages of integrating TLS with close-range photogrammetry to improve texture detail. On a global scale, workflows that integrate TLS, Unmanned Aerial Vehicle (UAV) LiDAR, and Structure-from-Motion photogrammetry have shown superior effectiveness (Remondino, 2011). For the Alambagh site, future investigations could benefit from incorporating drone-based imagery to create a hybrid model that accurately captures both the architectural features and the surrounding environment.

➤ Heritage Tourism and Virtual Accessibility

The photorealistic models created at Alambagh Palace, Farhat Baksh (Rao, 2025), and Kashi Vishwanath (RSAC-UP, 2024) underscore the significance of Terrestrial Laser Scanning (TLS) in advancing virtual heritage tourism. With

platforms like Google Arts & Culture already incorporating 3D models, the TLS datasets from Uttar Pradesh have the potential to be transformed into immersive virtual reality tours. This transformation would not only enhance global accessibility but also alleviate the physical impact on vulnerable monuments and sites. In the context of Lucknow, this innovation could lead to the establishment of a "Digital Nawabi Circuit," facilitating connections between Alambagh, Gulistan, and Chhatar Manzil through online and augmented-reality experiences.

➤ Conservation Science and Authentic Restoration

Terrestrial Laser Scanning (TLS) offers precision at the millimetric level, which is crucial for the accurate restoration of architectural elements that have been lost. For instance, at Alambagh, the dimensions of the existing turrets can be used to reconstruct those that are missing. Similarly, at Kardameshwara (RSAC-UP, 2024), carvings and niches can be digitally preserved for future replication. This scientific precision ensures that restoration efforts are based on verifiable data, thereby reducing reliance on conjecture.

➤ Towards a Digital Heritage Repository for Uttar Pradesh

The standardized nature of the RSAC-UP TLS workflows, which include the Leica P40, DGPS, and Cyclone, offers a promising avenue for the integration of data at the state level. By consolidating datasets from Alambagh, Farhat Baksh (Rao, 2025), Gulistan, Kardameshwara (RSAC-UP, 2024), and Kashi Vishwanath, Uttar Pradesh has the potential to create one of India's inaugural Digital Heritage Repositories. This repository would serve multiple purposes: as a research archive for scholars and archaeologists, as a conservation reference for the Archaeological Survey of India (ASI) and the Indian National Trust for Art and Cultural Heritage (INTACH), as a tourism resource for Smart Cities initiatives, and as a policy framework that integrates heritage preservation with digital governance.

B. Conclusion

The TLS survey conducted at the Alambagh Palace underscores both the potential and the pressing necessity for digital heritage documentation in Uttar Pradesh. The study achieved several key objectives: it meticulously captured the architectural features of the palace with millimetric precision (Figure 12), developed photorealistic 3D models that facilitate immersive visualization, identified damaged and missing elements to aid in authentic reconstruction, and situated Alambagh within a comparative framework of other TLS projects in U.P., highlighting shared methodologies and distinct conservation contexts. Comparative analysis reveals that while the Kashi Vishwanath TLS was part of a prominent redevelopment initiative and the Kardameshwara (RSAC-UP, 2024) TLS focused on archaeological preservation, the Alambagh TLS serves as preventive documentation for a neglected site. This distinction highlights the uneven policy landscape for heritage in the U.P., where some monuments receive institutional attention while others depend solely on digital surveys for preservation. Looking forward, three priorities are evident: the integration of TLS with UAV photogrammetry to create hybrid models, the institutionalization of TLS within the U.P. heritage

management framework, and the transformation of TLS datasets into public-facing VR/AR heritage platforms. By positioning Alambagh Palace within the broader spectrum of U.P.'s TLS heritage projects, this paper illustrates the scalability of LiDAR technology across secular and sacred, urban and rural, and iconic and neglected monuments. Ultimately, TLS is not merely a technical tool but a cultural safeguard that ensures that monuments endure in digital memory even when their physical forms are at risk.

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