Application of Photogrammetry as a Tool used for Conservation of Heritage Structure

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***Abstract*— The conservation of heritage buildings is essential for preserving cultural identity and historical significance. As urbanization and climate change threaten these structures, innovative methodologies are crucial for their protection. This research explores the application of photogrammetry as a vital tool for the conservation of heritage buildings. As Remondino & El-Hakim, 2006 mentions "*Photogrammetry, a technique that utilizes photography to measure and analyze physical objects, provides high-resolution, accurate three-dimensional models of structures, enabling detailed documentation and monitoring.*" This study emphasizes the importance of heritage conservation in maintaining the architectural integrity and cultural narrative of communities. Heritage buildings serve as tangible links to the past, offering insight into historical architectural practices and societal values. The deterioration of these structures not only affects aesthetic appreciation but also threatens the historical and cultural context they embody. By leveraging photogrammetry, conservationists can create precise digital records of buildings, facilitating restoration efforts and ongoing maintenance. This technique allows for non-invasive assessments, reducing the risk of damage during inspections and enabling the monitoring of structural health over time, as noted by Fassi and Cuca (2014). Furthermore, the digital models generated through photogrammetry can be utilized for virtual tourism, educational purposes, and public engagement, fostering a greater appreciation for heritage preservation. The research highlights case studies where photogrammetry has been successfully implemented in the conservation of various heritage sites, illustrating its versatility and effectiveness. The findings underscore the potential of this technology to revolutionize conservation practices, providing a framework for integrating modern techniques into traditional preservation efforts. In conclusion, the application of photogrammetry offers a comprehensive solution for the documentation, analysis, and conservation of heritage buildings. As threats to cultural heritage continue to grow, adopting such innovative technologies is imperative for safeguarding our architectural heritage for future generations.**

Keywords*— Heritage, conservation, photogrammetry, preservation technology, 3D modelling, cultural.

I. Introduction

The conservation of heritage buildings is crucial for preserving cultural identity and maintaining a link to historical and architectural traditions. As urbanization and climate change increasingly threaten these structures, innovative methodologies are needed to protect them from deterioration. Photogrammetry, a science that collects physical data from 2D images, offers a promising solution for the conservation of heritage buildings. By using overlapping aerial or terrestrial photos, photogrammetry software generates highly accurate .3D representations of structures. This technique, more precise than other 3D surveying methods, allows for detailed documentation of heritage sites. The two primary types of photogrammetry—terrestrial and aerial—offer flexibility in capturing data, with terrestrial photogrammetry providing close-range accuracy for distances up to 200 meters. Photogrammetry's outputs, such as digital elevation models (DEMs) and ortho-rectified images, are valuable tools for creating accurate, scalable visual records of historical sites. These digital models not only enable non-invasive structural assessments but also serve as critical resources for future restoration efforts, ensuring that even if the physical structure is damaged or lost, its design can be preserved. Despite its advantages, photogrammetry remains underutilized in heritage conservation. This research aims to highlight the potential of photogrammetry as a comprehensive tool for preserving heritage structures, offering case studies that demonstrate its effectiveness in maintaining architectural integrity and cultural significance. The study fills a gap in the field by illustrating how photogrammetry can revolutionize heritage conservation practices.

II. Literature Review

Heritage conservation is the practice of preserving, protecting, and restoring historical structures, monuments, and sites of cultural importance. These buildings often represent unique architectural styles, social histories, and artistic achievements of past societies. Conservation efforts focus on maintaining the physical integrity and authenticity of these structures, while simultaneously ensuring that future generations have access to these historical landmarks (Feilden, 2003). However, the challenges posed by urbanization, environmental degradation, and natural disasters have intensified the need for advanced conservation techniques. This context has led to the growing interest in technological solutions like photogrammetry for heritage conservation (Alshawabkeh, 2017).

A. *The Role of Photogrammetry in Conservation*

Photogrammetry is the process of using 2D photographs to measure and analyze objects, creating high-resolution 3D models. Traditionally employed in the fields of topography and cartography, it has evolved into a critical tool for heritage conservation, offering detailed digital representations of buildings and monuments (Remondino & El-Hakim, 2006). Photogrammetry allows conservators to capture precise spatial data from heritage structures, enabling them to create accurate models for documentation, monitoring, and restoration. With its non-invasive nature, this technology is particularly valuable for fragile and vulnerable historical structures. According to Remondino (2011), photogrammetry offers several advantages over other 3D surveying techniques such as laser scanning. It is more cost-effective and offers a higher level of detail due to its ability to use more individual points in the 3D modeling process. Fassi and Cuca (2014) emphasize that photogrammetry's versatility, combined with its ability to capture data from aerial and terrestrial platforms, makes it an indispensable tool for heritage conservation.

B. *Types of Photogrammetry and Their Applications in Heritage*

Conservation Photogrammetry can be categorized into two types: aerial and terrestrial. Aerial photogrammetry uses images captured from drones or aircraft, which are particularly useful for mapping large areas such as archaeological sites or large monuments. Terrestrial photogrammetry involves handheld or tripod-mounted cameras and is often referred to as close-range photogrammetry, suitable for smaller-scale heritage structures and detailed work on facades and interiors.

Aerial photogrammetry has been widely used in archaeological research, where large and complex sites such as ancient cities and ruins need to be mapped in their entirety. Researchers such as Chiabrando et al. (2016) have utilized drone-based photogrammetry to create 3D models of archaeological sites, which not only help in the restoration of the sites but also facilitate virtual tourism and educational projects. Similarly, terrestrial photogrammetry has proven effective in capturing intricate details of heritage structures, enabling conservators to create detailed documentation for future restoration efforts (Santagati, 2013). This method is especially useful for buildings with highly ornate architectural features that require careful conservation to maintain their cultural and historical value.

C. *Case Studies in the Application of Photogrammetry for Heritage Conservation*

Numerous case studies demonstrate the efficacy of photogrammetry in heritage conservation. One notable example is the use of photogrammetry in the restoration of the UNESCO World Heritage Site of Alhambra in Spain. Remondino and Rizzi (2010) describe how photogrammetry was employed to create a comprehensive digital model of the site, which provided conservators with precise measurements and detailed images of the intricate Moorish architecture. This model allowed conservators to document the existing condition of the site accurately and monitor changes over time, leading to better-informed decisions during restoration efforts. Another case study from Italy illustrates how photogrammetry was used to restore the historic San Pietro di Castello church in Venice. Researchers used terrestrial photogrammetry to create a detailed 3D model of the church's deteriorating stone facade, enabling them to accurately document the damage and plan the necessary conservation measures (Fassi et al., 2015). The data collected was instrumental in ensuring the authenticity of the restoration, as it allowed conservators to match new materials with the original architecture. Photogrammetry has also been applied in the preservation of ancient sculptures and artifacts. In a study on the Acropolis Museum in Athens, researchers used photogrammetry to create detailed digital models of ancient Greek statues. These models were used not only for documentation but also to assist in restoration work, allowing conservators to visualize how missing parts of the statues could be reconstructed accurately (Mavromati & Georgopoulos, 2014).

D. *Challenges in Implementing Photogrammetry in Heritage Conservation*

Despite its advantages, photogrammetry presents several challenges when applied to heritage conservation. One major issue is the level of expertise required to operate photogrammetry software effectively. As stated by Lerma et al. (2014), not all conservationists possess the technical skills to conduct photogrammetric surveys or analyse the resulting data. Furthermore, the initial setup for photogrammetry, particularly for large-scale projects, can be time-consuming and requires high-quality imaging equipment. These barriers can deter smaller heritage organizations or those with limited funding from utilizing photogrammetry to its full potential. Another challenge is the processing time required for large datasets. For example, the 3D modelling of large sites or highly detailed structures often requires extensive computing power and long processing times. Fassi et al. (2017) discuss how the data obtained from a single photogrammetric survey can sometimes exceed terabytes, making it necessary to invest in powerful computing resources and storage solutions. Moreover, the issue of data storage and long-term accessibility is crucial, as heritage institutions must ensure that digital records remain accessible and usable for future generations. Environmental conditions can also affect the quality of photogrammetry results. Lighting, shadows, and atmospheric conditions such as dust or fog can interfere with the accuracy of the images collected, especially in outdoor settings (Farella et al., 2019). Furthermore, photogrammetry may struggle to capture certain complex geometries or surfaces, such as reflective or transparent materials, which could limit its application in some conservation contexts.

E. The Future of Photogrammetry in Heritage Conservation

As technology continues to evolve, the application of photogrammetry in heritage conservation is likely to expand. The integration of artificial intelligence (AI) and machine learning into photogrammetric processes promises to streamline data processing and enhance the accuracy of 3D models. AI can be used to identify patterns in the degradation of heritage structures, enabling predictive maintenance and more effective restoration planning (Santagati et al., 2017). Virtual reality (VR) and augmented reality (AR) are also being integrated with photogrammetry to create immersive experiences of heritage sites. These technologies allow users to explore digital reconstructions of historical landmarks, offering new opportunities for education, public engagement, and tourism. By combining photogrammetry with VR/AR, researchers can make heritage conservation more accessible to a broader audience, fostering a deeper appreciation for cultural preservation. Photogrammetry has proven to be a powerful tool in the conservation of heritage structures. Its ability to create highly accurate, non-invasive digital models has revolutionized the way conservators document and restore historical buildings. Despite the challenges of cost, expertise, and data management, photogrammetry's potential continues to grow as technological advancements make the process more efficient and accessible. As the field of heritage conservation evolves, photogrammetry is likely to play an increasingly central role in preserving cultural heritage for future generations. This literature review highlights the significant contributions photogrammetry has made to heritage conservation, while also pointing to the need for ongoing innovation and research in this area.

III. Research Methodology

The methodology employed for applying photogrammetry to conserve a heritage structure in Bangalore. The research aimed to create a detailed 3D model of the building using a combination of photography and Agisoft Metashape software. This process involved capturing high-resolution images of the structure, followed by image processing to generate a photorealistic 3D model. The methodology used is based on simulation, where real-world data (photographs) are used to create a digital model, replicating the physical structure for documentation and conservation.

A. Site Selection and Preperation

The site chosen for this study is a heritage building in Bangalore, known for its historical and architectural significance. The site was surveyed to determine the best approach for image capture, with attention to lighting conditions and access to different areas of the building. Key features of the structure, such as intricate carvings, windows, and facades, were identified for detailed documentation.

B. Tools and Eqipment Used

1) Photography: A high-resolution digital camera was used for capturing images. The camera settings, such as ISO, aperture, and shutter speed, were kept constant to ensure uniformity across all photographs. Overlapping images were taken from different angles and distances to facilitate accurate 3D reconstruction.

2) Agisoft Metashape Software: The software was used to process the images and create a 3D model of the building. Metashape is a powerful tool for photogrammetry, capable of aligning photos, creating dense clouds, and generating textured 3D models with high accuracy.

C. Image Capture Process

The primary step involved capturing high-resolution images of the building from various angles and levels to ensure comprehensive coverage of the structure. The following steps were followed during the image capture process:

1) Distance and Levels: Photographs were taken from a distance of approximately 5 feet at three different levels:

a) Bottom level (ground level)

b) Middle level (around halfway up the structure)

c) Top level (near the roofline)

2) Camera Settings: A fixed set of camera settings was used throughout the process to maintain consistent exposure and image quality. These settings included a fixed ISO, aperture, and shutter speed, ensuring that the lighting conditions did not vary across images.

3) Image Overlap: Photos were taken with an overlap of 60% between consecutive images. This overlap was necessary to ensure that the software could identify common features between images, enabling proper alignment in the later stages.

D. Photogrammetry Software Processing (Simulation)

Once the photographs were captured, they were imported into Agisoft Metashape for further processing. The following steps were undertaken in the software to generate the 3D model, simulating the real-world structure through a digital representation:

1) Photo Alignment: The first step in Metashape was to align the photos. The software detected and matched common points (known as "tie points") across multiple images, building a sparse point cloud that represented the rough geometry of the building. This process established the spatial relationships between the images and laid the foundation for further modelling.(Fig.1 and Fig.2)

2) Dense Cloud Creation: After the initial alignment, a dense cloud was generated. This step involved analysing the aligned photos and creating a much more detailed point cloud, representing the building's surface in high resolution. Each point in the dense cloud corresponded to a specific point on the building, and this formed the backbone of the 3D model.(Fig.3)

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3) Mesh Generation: From the dense cloud, a mesh was created. This mesh is a digital surface model made up of thousands of interconnected triangles. These triangles form the 3D structure's outer surface, enabling the representation of the building's intricate architectural features. The mesh provided the detailed geometric shape needed to simulate the physical structure digitally. (Fig.3)

4) Texture Creation: To give the model a photorealistic appearance, textures were applied to the mesh. The software used the original photos to map textures onto the 3D surface, ensuring that the final model closely resembled the actual building in terms of colour, material, and texture. This step enhanced the model's visual accuracy, making it valuable for documentation and conservation analysis.(Fig.4)

Fig.3.

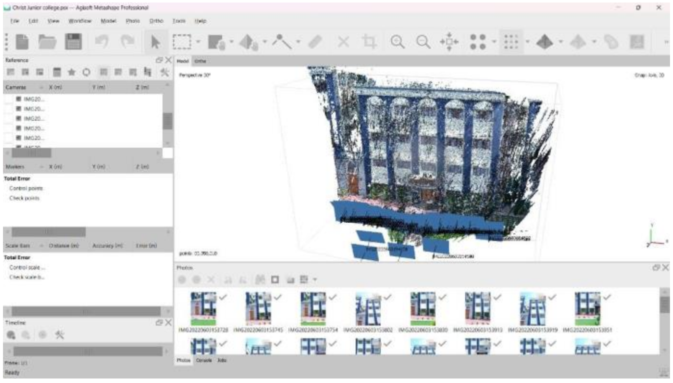

Fig. 1.

Fig.4.

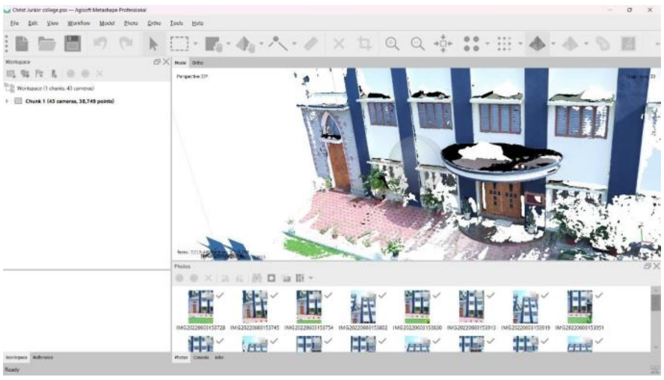

Fig.2.

Fig.5.

E. Model Review and Refinement:

After generating the 3D model, it was thoroughly reviewed for accuracy and completeness. Areas with missing data were corrected by re-aligning certain images or capturing additional photographs if necessary. Any noise or extraneous points in the model were removed, and the mesh was optimized to ensure smooth rendering without losing detail. (Fig.5)

F. Simulation in Conservation Efforts:

The 3D model produced through photogrammetry simulation serves as an invaluable tool for conservation efforts. With this digital simulation of the heritage structure, conservationists can:

1) Document Current Condition: The model provides a highly accurate representation of the building's current state, capturing even the smallest architectural details. This documentation can be archived for future reference, ensuring that the building's appearance is preserved even if physical deterioration occurs over time.

2) Non-invasive Monitoring: The digital simulation enables conservationists to monitor changes in the building's structure without physically interacting with it. The model can be updated periodically to detect any signs of structural decay or damage.

3) Restoration Planning: If parts of the building become damaged or decayed, the model can be used as a reference for restoration, ensuring that the repairs are historically accurate and that the architectural integrity of the building is preserved.

4) Public Engagement: The 3D model can be used for virtual tours and educational purposes, allowing the public to interact with the building's digital replica. This helps in raising awareness about the importance of heritage conservation.

G. Challenges and Considerations

1) Lighting Conditions: During the image capture process, lighting conditions can significantly affect the quality of the images. Overexposed or underexposed images can reduce the accuracy of the photogrammetry process. To address this, photos were captured at optimal times of the day with even lighting.

2) Complex Structures: Photogrammetry struggles with capturing reflective surfaces or areas with complex geometries. Additional images were taken at various angles to overcome this limitation and ensure full coverage of intricate architectural details.

IV. Unit of Analysis, Independent and Dependent Variables:

1) Unit of Analysis: Heritage structures.

2) Independent Variables: Photogrammetry techniques (camera settings, processing methods)

3) Dependent Variables: 3D model, conservation outcomes, and structural documentation.

V. Conclusion

This research demonstrates the immense potential of photogrammetry as an effective tool for the conservation of heritage structures. Through the successful application of photogrammetry to a heritage building in Bangalore, the study illustrates how precise 3D models can be generated from simple photographic data, offering a non-invasive method to document, monitor, and conserve architectural heritage. By using Metashape software and systematic photography, a highly detailed and accurate digital model was created, which can be utilized for future restoration efforts and long-term conservation planning. The ability of photogrammetry to capture intricate details, ensure historical accuracy, and monitor structural health makes it an invaluable resource in the preservation of cultural heritage. As heritage structures face growing threats from urbanization and environmental changes, embracing innovative technologies like photogrammetry is vital for ensuring their survival. The simulation-based methodology applied in this study contributes to the broader field of heritage conservation, offering a practical framework for integrating modern tools into preservation practices. Future research could explore ways to overcome the limitations of photogrammetry, such as lighting challenges and processing times, further expanding its applicability.

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