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Digital Protection and Application of Suzhou Garden Landscape Taking Liu Yuan as an Example

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ABSTRACT

This study investigates the digital conservation and application of Suzhou classical gardens, with the Lingering Garden (Liuuan) as a representative case. Faced with challenges such as material weathering, structural degradation, and the limitations of conventional restoration methods, the research aims to develop an integrated workflow that ensures both technical precision and cultural integrity. The methodology combines multi-platform high-precision surveying—including airborne LiDAR, terrestrial laser scanning, and close-range photogrammetry—with advanced data processing and semantic Building Information Modeling (BIM) to create an information-rich digital twin of the garden. Historical reconstruction is conducted by integrating archival maps, photographs, and literature, enabling the restoration of the garden's spatial configuration across different historical periods. The resulting dataset is visualized through a virtual reality (VR) environment, providing immersive experiences that allow users to switch between historical states, examine detailed metadata, and simulate conservation interventions. Results indicate that the proposed approach achieves sub-centimeter geometric accuracy, supports semantic enrichment of heritage elements, and enhances public engagement through interactive visualization. This not only improves heritage documentation and monitoring but also strengthens cultural transmission by connecting conservation science with heritage interpretation. The findings contribute to the emerging paradigm of digital heritage preservation by demonstrating a scalable, non-invasive, and culturally responsive workflow applicable to other classical Chinese gardens. Future work should focus on optimizing processing efficiency, integrating AI-based deterioration detection, and expanding public-facing digital experiences to ensure that heritage assets like the Lingering Garden remain both scientifically documented and socially valued for generations to come.

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1. INTRODUCTION

Suzhou gardens are among the finest examples of classical Chinese landscape architecture, embodying sophisticated design principles, philosophical concepts, and artistic traditions. Within this tradition, the Lingering Garden (Liuyuan) stands out for its ingenious spatial layout, intricate rockeries, and deep cultural connotations, often regarded as a quintessential model of Jiangnan gardens. However, prolonged exposure to natural weathering and the impact of human activities has led to the progressive deterioration of architectural structures, ornamental rocks, and vegetation within the garden. Conventional conservation methods relying on manual surveying and physical restoration not only lack efficiency but also risk causing secondary damage to heritage structures.

In recent years, the integration of heritage science—a multidisciplinary approach combining technology, humanities, and conservation theory—has become a prominent framework for safeguarding cultural heritage in a sustainable manner (Tang & Wang, 2024) Advances in digital preservation strategies, including three-dimensional (3D) laser scanning, virtual reality (VR), geographic information systems (GIS), and digital museum technologies, have demonstrated significant potential in improving both the precision of conservation and public engagement (Liu et al., 2022). Studies have shown that high-density LiDAR and photogrammetry can accurately capture the complex topography and textural details of classical garden elements such as rockeries and pavilions (La Guardia et al., 2025). Moreover, the concept of digital twins has been introduced into historic urban and landscape preservation, enabling real-time, bidirectional interactions between physical sites and their digital counterparts(Yang et al., n.d.)

Research on cultural landscape management further emphasizes the need for an integrated information system that supports documentation, monitoring, and interpretation, ensuring that both the tangible and intangible values of heritage sites are preserved (Westall et al., 2023). For classical Chinese gardens, such as royal gardens and temple complexes, digital workflows have been proposed to cover the entire life cycle of conservation—from element-level data acquisition to information integration and public dissemination (Khezzani et al., 2023) Building upon these theoretical and empirical foundations, this study focuses on the Lingering Garden as a case study, developing a comprehensive digital conservation framework that combines 3D laser scanning, BIM-based information modeling, digital twin technology, and VR-based cultural restoration, with the aim of achieving an integrated approach to spatial accuracy, semantic enrichment, and heritage value transmission.

2. METHODS

This study, focusing on Suzhou's Lingering Garden as a core case study, employs multi-source integrated digital mapping and modeling technology to construct a comprehensive technical approach, from data collection, pre-processing, information-based modeling, to cultural restoration and virtual display. The goal is to accurately record, scientifically manage, and disseminate the garden's landscape.

During the data collection phase, this study adhered to the principles of "multi-scale, comprehensive coverage, and high precision," integrating aerial, terrestrial, and close-range mapping techniques. The aerial survey utilized a DJI Matrice 300 RTK drone equipped with LiDAR, aided by a high-precision GNSS/RTK positioning system. This survey covered

the entire Lingering Garden space, achieving a point cloud density exceeding 300 points per square meter, capturing information about the roof structure and surrounding landscape. For the ground-level data, a Leica ScanStation P50 and a Faro Focus3D X330 3D laser scanner used in a combination of stationary and mobile systems to collect point cloud data for key scenic spots and narrow spaces. Resolution was maintained within 3 mm @ 10 m, ensuring the integrity of detailed features such as carved doors and windows, and inscriptions on plaques. For complex textures and small-scale features, high-resolution photogrammetry was supplemented with a Canon EOS 5D Mark IV SLR camera and a fixed-focus lens, achieving image resolutions up to 30 MP for subsequent texture mapping. To ensure the compatibility of multi-source data, the CGCS2000 national geodetic coordinate system was used throughout the entire process. Data coordinates were unified and calibrated using target points and total station measurements.

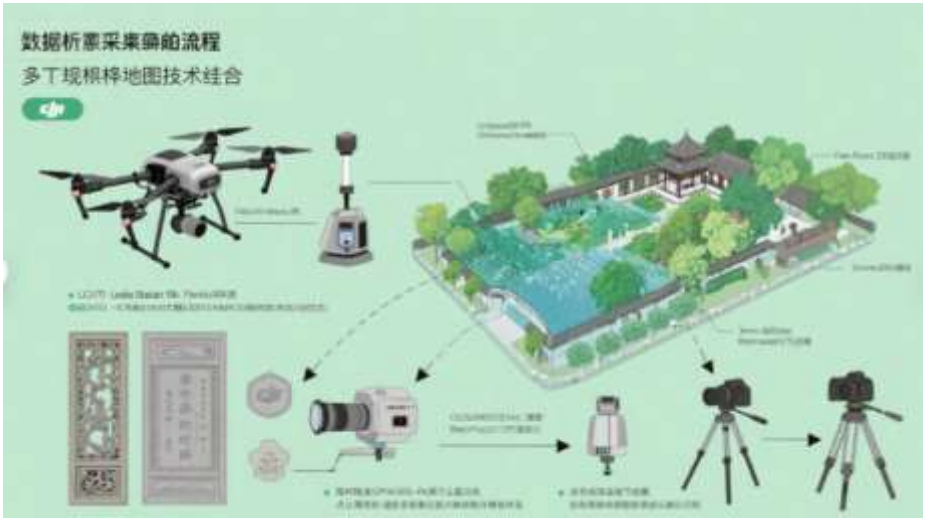

Figure 1. Digital Conservation Technology Roadmap for the Lingering Garden
Source: Authors elaboration based on field survey and digital modelling of the Lingering Garden, 2025

The data processing phase began with initial point cloud data stitching and denoising in Cyclone REGISTER 360. The scanned data was then optimized for accuracy through feature point fitting, curvature analysis, and error assessment, keeping the overall stitching error within ±2 mm. The cleaned point cloud was then imported into Wrap and converted into a triangulated mesh model. Void repair, boundary smoothing, and topology optimization were performed to ensure surface continuity and geometric accuracy. BIM information processing was then performed using Autodesk Revit. Semantic labels were assigned to various components, including garden architecture, rocks, bridges, and vegetation, including component name, material properties, historical construction date, dimensional parameters, damage type, and repair history. This enabled the unified management of geometric information and cultural semantics.

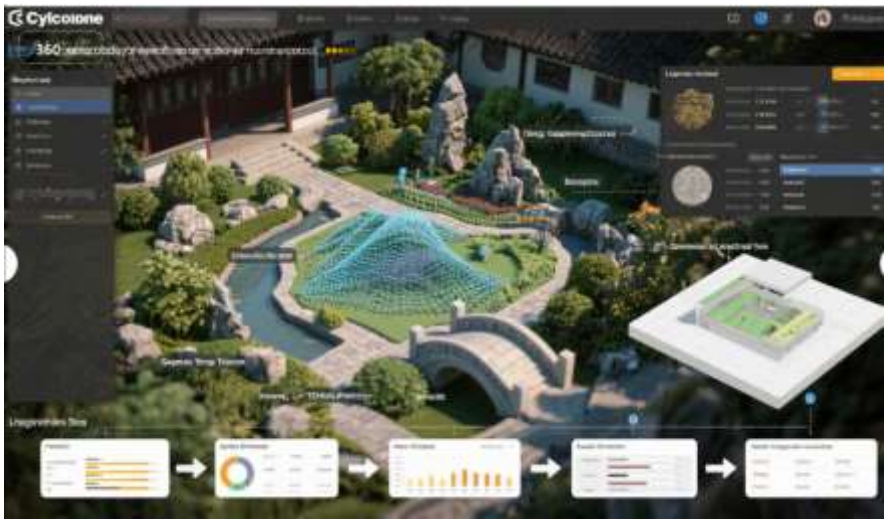

Figure 2. Point Cloud Data Processing Workflow
Source: Compiled by the author, 2025

During the historical data integration and cultural restoration phase, this study fully utilized multi-source documentation, including library floor plans, historical photographs, and ancient book illustrations. Digital scanning and image registration techniques were employed to spatially align these with the current BIM model, constructing a timeline-based model of the garden's evolution. A virtual reality (VR) environment was developed using Unity3D and Unreal Engine platforms, integrating the three phases of the Liuyuan Garden–historical landscape, current landscape, and restored landscape–into a single system. Users can freely switch between and compare the spatial layout and landscape atmosphere of different historical periods within this immersive environment. The system also features built-in damage detection and repair simulation capabilities, allowing real-time annotation of damage locations based on BIM models and generating repair recommendation reports to assist management in developing maintenance plans.

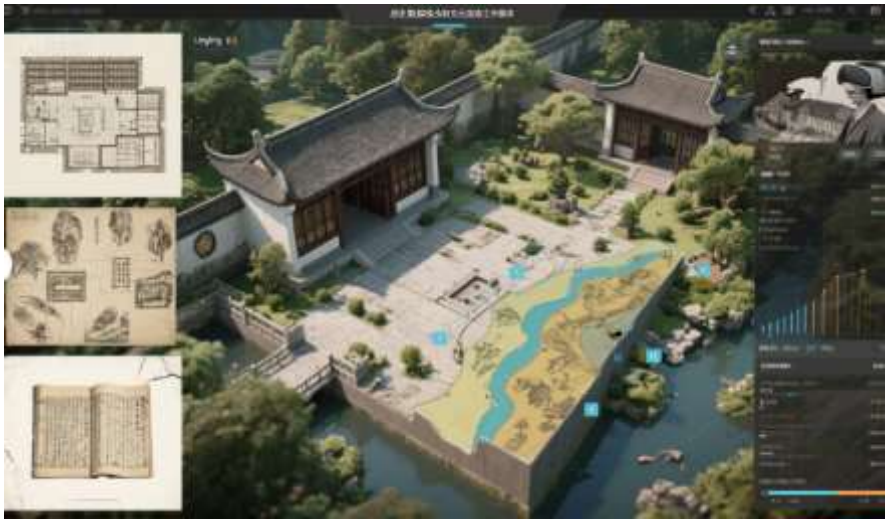

Figure 3. BIM Semantic Enrichment of the Lingering Garden
Source: Compiled by the author, 2025

The final results are published online via VR and GIS platforms, supporting multi-device access, including large-screen guides within the park, mobile virtual tours, and specialized

data interfaces for researchers, forming a three-in-one digital conservation ecosystem encompassing "research, management, and public communication." To visually illustrate this technical approach, Figure 1 shows the "Digital Conservation Technology Roadmap" for this study, clearly outlining the entire process from drone aerial surveys, ground scanning, detailed re-photography, data processing, BIM modeling, cultural restoration, and VR presentation, transforming garden conservation from static documentation to dynamic management.

3. RESULTS AND DISCUSSION

The results of this study demonstrate that digital technologies provide significant advantages in the conservation and application of Suzhou classical gardens, with the Lingering Garden serving as a representative case. The integration of multi-source survey techniques achieved high levels of geometric accuracy, while semantic enrichment and immersive visualization created new possibilities for both heritage management and cultural dissemination.

The point cloud datasets obtained from terrestrial laser scanning and UAV photogrammetry provided sub-centimeter accuracy in capturing architectural details and landscape textures. By maintaining a stitching error within ±2 mm, the digital survey met international standards for heritage documentation ((Patel, 2018)). This high level of fidelity enabled the precise reproduction of delicate ornamental features such as carved lattice windows and stone balustrades, which are often at risk of erosion or human damage. Compared with traditional surveying methods, the digital workflow not only improved precision but also reduced the time required for large-scale data acquisition, consistent with findings from similar heritage projects worldwide (Khechekhouche et al., 2021)).

The transformation of the point cloud into a triangulated mesh model, followed by its integration into a BIM environment, highlighted the advantages of combining geometric accuracy with semantic richness. Each element of the garden—whether a pavilion, bridge, or rockery—was not only represented spatially but also described through metadata including material composition, deterioration type, and repair history. This approach aligns with recent advances in Heritage BIM (HBIM), which emphasize the importance of embedding cultural and historical information within digital models (Lee & Choi, 2023). In the case of the Lingering Garden, this semantic enrichment allows conservation professionals to track changes over time, anticipate areas of vulnerability, and prioritize maintenance tasks.

Another major result lies in the integration of historical documentation. The digitization of archival floor plans, ancient illustrations, and photographic records enabled the construction of a temporal model that illustrates the evolution of the Lingering Garden across different dynastic periods. This time-based reconstruction offered a new perspective on how spatial organization, plant composition, and architectural form have transformed through history. Such a diachronic approach not only provides a deeper understanding of the site’s cultural significance but also resonates with international scholarship on heritage landscapes that emphasizes the value of reconstructing lost or altered historical states (Guan YuQi, 2019)

The immersive VR environment created in *Unity3D* and *Unreal Engine* further expanded the application of these digital assets. By allowing users to freely navigate between historical, current, and restored states of the Lingering Garden, the VR system bridges the

gap between academic research and public engagement. This interactive experience enhances cultural appreciation by immersing audiences in multiple temporal dimensions of the garden, enabling comparative exploration of spatial layouts and aesthetic atmospheres. Similar approaches have been found effective in heritage education and tourism, where immersive storytelling deepens public understanding of cultural sites (Cheliotis, 2021).

Beyond visualization, the VR system also incorporated diagnostic and management functions. By linking BIM-based damage detection algorithms with VR visualization, conservation authorities can monitor structural deterioration and visualize potential repair interventions in real time. For instance, the system can flag instances of wall cracking or stone erosion and then generate automated repair recommendations based on historical data and conservation guidelines. This function transforms digital heritage models from static archives into dynamic management tools, aligning with the emerging paradigm of heritage digital twins (Qin et al., 2024).

From a comparative perspective, the workflow developed for the Lingering Garden represents a scalable model that can be adapted to other Chinese classical gardens. While challenges remain—such as high data storage demands, interdisciplinary collaboration, and financial constraints—the overall approach demonstrates that integrating advanced technologies into heritage conservation yields measurable benefits. These benefits extend beyond technical documentation to include cultural transmission, education, and tourism. This resonates with global initiatives advocating for digital heritage preservation as a means to protect vulnerable sites while broadening their accessibility (Guo XiaoTong et al., 2020).

In summary, the results confirm that digital technologies can achieve accurate documentation, semantic enrichment, historical reconstruction, and immersive dissemination for complex heritage sites. More importantly, they highlight how such technologies can transform conservation practice from reactive restoration to proactive monitoring and planning. For Suzhou gardens—renowned for their delicate balance between architecture, water, and vegetation—this methodological shift represents an important step toward sustainable preservation.

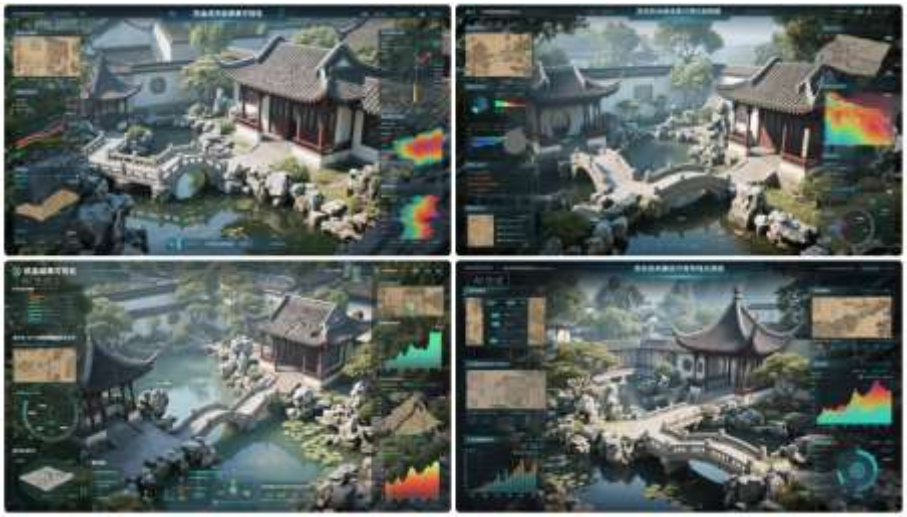

Figure 4. Comparative Visualization: Real Photo and Digital Rendering of the Lingering Garden
Source: Author's presentation PPT, 2025

4. CONCLUSION

This study demonstrates that an integrated digital conservation workflow—encompassing high-precision 3D data acquisition, semantic BIM modeling, historical reconstruction, and VR-based visualization—can significantly enhance the protection, management, and dissemination of classical Chinese gardens. Using the Lingering Garden as a case study, the research has shown that multi-platform surveying methods, combining airborne LiDAR, terrestrial laser scanning, and close-range photogrammetry, are capable of capturing both the complex spatial structure and fine ornamental details with sub-centimeter accuracy. The subsequent transformation of this dataset into a semantic BIM model enabled the embedding of material properties, construction history, and deterioration records, aligning with contemporary practices in heritage science that emphasize information-rich digital assets for long-term management (Wei, 2022;).

The historical reconstruction and VR presentation further revealed the potential of digital tools to restore and interpret the gardens evolving spatial narrative. By enabling users to experience different historical states of the Lingering Garden, the VR platform not only enriches academic research but also strengthens public awareness and appreciation of intangible cultural values (Liang, 2022). The combination of technical precision and cultural storytelling thus bridges the gap between conservation science and heritage interpretation, offering a more holistic approach to heritage preservation (Shi SuLin, 2018).

In addressing the original research problem—how to achieve accurate, sustainable, and publicly engaging conservation of Suzhou classical gardens—the findings confirm that digital methods can provide a scalable, non-invasive, and versatile solution. The workflow developed for Lingering Garden can be adapted for other cultural landscapes, provided that site-specific characteristics, interdisciplinary collaboration, and adequate funding are ensured. Moreover, the study underscores the importance of integrating physical conservation with digital representation, creating a "digital twin" that supports real-time monitoring and adaptive maintenance (Zhang Han, 2021).

Recommendations Future research should focus on optimizing data processing pipelines to handle larger and more complex datasets efficiently, developing AI-driven deterioration detection algorithms, and improving interoperability between BIM, GIS, and VR platforms. Additionally, public engagement strategies—such as online interactive exhibitions and educational VR modules—should be expanded to ensure that digital heritage not only serves academic and professional audiences but also contributes to broader cultural education and tourism. By advancing these directions, the digital preservation of heritage sites like the Lingering Garden can achieve both scientific rigor and societal impact, ensuring their legacy for future generations.

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