Digital Footprint of the Xishu Garden: A Case Study of the San Su Shrine Digital Preservation

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Abstract

The Chinese Classical Garden is an important World Cultural Heritage site. The incorporation of digital recording methods in its preservation is an efficacious approach to safeguarding its cultural heritage value. Using the San Su Shrine as a case study, the theoretical framework of landscape informatics is employed in this study to demonstrate the application of 3D laser scanning and unmanned aerial vehicle (UAV) photography technologies in digital conservation research. The objective of this study is to acquire data and construct a three-dimensional (3D) point cloud model. This study employs two-dimensional mapping and 3D real-scene modelling to conduct feature extraction and quantitative analysis in three key areas: garden layout, commemorative items, and narrative spatial units. A research strategy is developed that focuses on the preservation of legacy gardens using digital means. The technical aspects and benefits associated with the recording, analysis, preservation, and restoration of the Xishu Garden are discussed.

1. Introduction

The Chinese Classical Garden is a significant designated World Cultural Heritage site, possessing a deep history and showcasing innovative horticultural methodologies [1]. Furthermore, it is important and valuable in terms of preservation and safeguarding [2, 3]. The Xishu Garden is a prominent branch of the Chinese Classical Garden. Since the historical figure Wen Weng arrived in the region of Shu, which is now known as Sichuan, his successors have constructed ancestral halls and gardens as a means of honouring esteemed individuals. This resulted in the formation of a collection of memorial gardens known as the Xishu Memorial Garden. The San Su Shrine, which is renowned as the cradle of Dongpo Culture and a prominent representative feature of Xishu Garden, was recognized by the United Nations Educational, Scientific and Cultural Organization (UNESCO) with the 'Honorary Certificate of Cultural Heritage Protection' in 2018 [6]. In 2022, Chinese President Xi Jinping paid a visit to the San Su Shrine, where he expressed the sentiment that the San Su Shrine serves as a testament to the depth and richness of Chinese culture [7]. Unfortunately, the San Su Shrine closed for two years due to the 4.20 Lushan earthquake that occurred in 2013 [8]. The restoration of historical sites following earthquakes has emerged as a significant challenge within the field of landscape engineering. The extensive and accurate internal information of the landscape elements and the complicated spatial qualities cannot be faithfully replicated by traditional photography, painting by hand, or other technologies [9]. Hence, there is a pressing need to conduct studies on the preservation of digital information as part of the safeguarding of the San Su Shrine.

Over the past few years, there has been significant advancement in cultural heritage research due to the rapid development of digital technology [10–12]. Digital Dunhuang, Cloud Garden, Classical Garden Preservation, and Architectural Preservation used digital information technology to address the limitations of conventional research methods and expand the scope of digital preservation and analysis of cultural assets. Numerous discoveries were made in relation to the research topic. For instance, two academic studies were conducted on the gardening art of the Jiuzhou Scenic Spot in Yuanmingyuan,
focusing on digitization [13]. Another study explored the spatial characteristics of Shanghai Yuyuan Grand Rockery through the utilization of three-dimensional point cloud technology, emphasizing the concept of a digital heritage landscape [14]. The utilization of digital technology has been used to digitally examine the many components of classical gardens, as well as investigate the three-dimensional digital information pertaining to Suzhou Huanxiu Villa [15].

The full protection of Suzhou Garden, specifically, the Huanxiu Villa, was investigated through the implementation of garden informatics, such as digital mapping, digital analysis, and data platform construction. Several researchers have examined various aspects of digital technology in the field of Building, including in the building itself [16], the characteristics of garden spaces [3, 17–19], the restoration of heritage sites [20, 21], information modelling [22], and the application of technology [23–25]. The development of three-dimensional digital technology for Garden Heritage sites has evolved over time, starting with the combination of terrestrial laser scanning (TLS) and terrestrial digital measurement technology (TDP) [26]. This initial approach has since been enhanced through the integration of various laser scanners, drone photography, and the utilization of sensors or a combination of virtual reality (VR), augmented reality (AR), and mixed reality (MR) technologies [26–28]. As a result, a comprehensive method for three-dimensional digital technology in the context of Garden Heritage sites has been established.

The current body of study pertaining to the San Su Shrine predominantly focuses on its historical culture, gardening art, and landscape components. However, there is a noticeable dearth of studies that employ technological methodologies and digital analysis to examine this subject matter. The utilization of digital technology for the purpose of acquiring comprehensive attributes of various aspects of the San Su Shrine, as well as the establishment of quantitative analysis, has emerged as a novel approach to preserving the shrine. Hence, this paper focuses on the investigation of San Su Shrine, which serves as a prototypical exemplar of Xishu Garden. We conduct a digital investigation of the collection, analysis, and extraction of digital information pertaining to the San Su Shrine following earthquake-induced damage, drawing upon the principles of garden informatics [15]. The results indicate that the utilization of digital information technology is a viable approach for the preservation of the San Su Shrine. Data collection, processing, and analysis of features of the San Su Shrine were conducted using three-dimensional laser scanning and unmanned aerial vehicle (UAV) photography technology. The aim was to achieve the digital preservation and quantitative study of the memorial spaces and garden features of the San Su Shrine. The digital preservation of the San Su Shrine can be used as a reference for studies pertaining to the digital preservation of Xishu Garden and the Chinese Classical Garden.

2. Research location

The San Su Shrine, situated on Shahuhang Street, Dongpo District, in the city of Meishan, holds historical significance as the ancestral home of the renowned literary academics Su Xun, Su Shi, and Su Zhe. These three individuals, belonging to the esteemed Su Family, made notable contributions to the literary landscape during the Northern Song Dynasty. According to a 2018 assessment conducted by UNESCO,
the San Su Shrine holds significant cultural importance for it “has made a great contribution to the spread of Chinese culture worldwide” [29]. The shrine possesses the inherent allure of a Chinese Classical Garden, effectively portraying the father and sons (Su Xun, Su Shi, and Su Zhe) in the living environment and way of life. It exudes an aura of sanctity and reverence, serving as a powerful symbol [5]. The San Su Shrine represents memorial and narrative landscape within the context of the Xishu Garden [6]. The historical progression of this entity can be delineated into four distinct stages of development: the courtyard, the shrine, the Sansu Garden, and the garden-style museum. Following the Song, Yuan, Ming, and Qing Dynasties, the aforementioned region of Xishu (Sichuan area) adopted a notable approach in designing memorial gardens for esteemed individuals, as depicted in Fig. 1 and Fig. 2.

Following the “4.20” Lushan earthquake in 2013, numerous historic edifices inside the San Su Shrine experienced structural impairment. This included the development of cracks in certain walls, damage to roof ridges, and displacement of columns. The duration of the post-disaster reconstruction spanned two years. The restoration efforts primarily encompassed the preservation and upkeep of 16 key structures, restoration of the surrounding gardens, and establishment of a well-defined aquatic habitat (Fig. 3).

The digital research conducted on the San Su Shrine encompasses the eastern memorial ancestral hall area as well as the western garden area. The boundaries of the study area extend from the South Gate to the south to the Half Autumn Water Pond to the north and from the West Gate to the west to the Stele Pavilion to the east. The primary area of focus inside the garden is the memorial ancestral hall region. Consequently, the three-dimensional laser scanner primarily targets the eastern ancestral hall area (see Fig. 4).

3. Materials and methods

3.1. Information collection equipment and methods

The digital information gathering on the San Su Shrine encompasses three distinct components, namely, data collection, data analysis, and digital results presentation. Figure 5 illustrates the technical methods. The objective of the digital study is to conduct a quantitative assessment of the memorial space, garden features, and landscape characteristics of the San Su Shrine by acquiring three-dimensional spatial data.

The utilization of three-dimensional laser scanning offers distinct benefits in terms of enhanced measurement precision and expanded measurement techniques. Typically, short-range and static acquisition methods are employed to collect point cloud data on the surfaces of garden elements [26]. This approach facilitates the creation of a three-dimensional model with enhanced precision and accuracy [30, 31], enabling a comprehensive representation of the multidimensional information pertaining to the measured object [32]. Nevertheless, the installation and operation of a 3D laser scanner in a vast garden area might be challenging due to obstruction by trees, resulting in mutual occlusion and increased complexity. The utilization of flexible drone photography has emerged as a viable supplementary option. In this study, we employ a combination of three-dimensional laser scanning and
unmanned aerial vehicle (UAV) photography technology to conduct a comprehensive assessment and mapping of the San Su Shrine. The 3D laser scanner employed in this study utilizes the FARO Laser Scanner Focus S350 (manufacturer's name: FARO; hardware: FARO Focus Premium; software: FARO SCENE software; quantity:1;), which incorporates a spherical digital camera lens inside its design. The UAV photography utilizes the Pegasus D2000 UAV aerial survey system (D2000GLS20130094) (manufacturer's name: Pegasus; quantity:1;). This system is equipped with a SONY A6000 camera, which boasts an effective pixel count of approximately 24.3 million pixels. The camera sensor size measures 23.5 x 15.6 mm (aps-c) and is configured with a fixed focus of 25 mm.

The surveying and mapping domain includes a comprehensive overview of the garden and its horticultural components. The various landscape components are categorized as garden buildings, garden water features, garden plants, and rockery stones, as shown in Table 1.

<table>
<thead>
<tr>
<th>Information category</th>
<th>Surveying and mapping components</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall layout</td>
<td>San Su Shrine TLS plane layout, aerial photography, etc.</td>
</tr>
<tr>
<td>Building</td>
<td>Building layout, building single plane, building single facade, building single section, structure and size, etc.</td>
</tr>
<tr>
<td>Water landscape</td>
<td>Water landscape plane layout, scale and shape, etc.</td>
</tr>
<tr>
<td>Planting landscape</td>
<td>Plant TLS overall layout, green area, plant monomer TLS point cloud, façade and location, etc.</td>
</tr>
<tr>
<td>Rockery stone</td>
<td>The overall layout of the rock, rock monomer TLS point cloud model, plane, façade and size, etc.</td>
</tr>
</tbody>
</table>

3.2. Data collection

The data collection process encompasses several activities, including on-site surveys, the establishment of control networks and target layouts, building scanning, and the acquisition of textural data [33, 34]. The acquisition of a comprehensive point cloud model and aerial image of the garden is achieved using three-dimensional laser scanning in conjunction with unmanned aerial vehicle (UAV) photography. The diagram depicted in Fig. 6 illustrates the arrangement of the 115 scanning stations for 3D laser scanning. To obtain comprehensive data on the San Su Shrine, employing a spherical digital camera lens capable of capturing 8 photographs at each site is recommended. These photographs should have a resolution of 1920×1920 pixels and be able to capture RGB colour, texture, and other pertinent information. Simultaneously, the utilization of UAV tilt photography technology facilitates the execution of dense matching by leveraging the coordinates of the surface points in a multi-view image. This expedites the acquisition of three-dimensional data pertaining to the surface, as well as high-resolution aerial images [35]. One unmanned aerial vehicle (UAV) is deployed to conduct an aerial survey. The average ground
resolution is established at 5 centim, while the shooting height is approximately 180 m. A total of 395 photographs are acquired, with each individual photograph encompassing an approximate area of 2.22 hectares. Fourteen flight routes are constructed, consisting of five routes that run in an east–west direction and nine routes that run in a north–south direction. These routes are shown in Fig. 7.

3.3. Data processing

The entire point cloud model of the San Su Shrine is originally formed by splicing, removing redundancy, de-noising, and correcting various source data, including scanned data and aerial pictures [23]. This process is carried out using Maptek software (manufacturer: Maptek). Additionally, the aerial image data acquired by the UAV are arranged and condensed. Subsequently, the positional data (POS) and the original source images should be sequentially imported into the Pix4D Mapper software (manufacturer: Pix4D China Technology Co., Ltd) for initial stitching. Ultimately, this process culminates in the creation of a comprehensive aerial photograph depicting the entirety of the San Su Shrine.

4. Results

Digital findings serve as the foundation for quantitative analysis, encompassing two-dimensional photographs, three-dimensional real-scene models, and 3Ds MAX models. Within this context, the two-dimensional imagery encompasses line drawings and measured drawings, whereas the three-dimensional representation of real scenes relies on the utilization of high-precision point cloud data. A point cloud real-scene model, which accurately represents measured items on a 1:1 scale, is obtained by using colour and texture mapping techniques, as depicted in Fig. 8. The initial acquisition of the 3D point cloud real-scene model file of the target item is achieved through the processing and exportation of the max format file, which is generated from the 3Ds MAX model of point cloud data using Clone software (manufacturer: Leica). Next, the 3Ds MAX modelling software (manufacturer: Autodesk) is imported to facilitate both automatic and manual modelling processes [36]. Ultimately, the desired outcome is the acquisition of the 3Ds MAX model corresponding to the specified object.

5. Discussion

5.1. Garden layout

The San Su Shrine adeptly integrates the memorial ancestral halls and the historic garden, resulting in a distinctive layout characterized by a harmonious arrangement of eastern and western elements, as well as a fusion of structured and organic design styles. The eastern ancestral hall region mostly comprises a regular pattern, with a total area of approximately 21,600 . It follows a three-courtyard plan design. The western region is enhanced by the presence of natural gardens, spanning approximately 33,220 . These gardens effectively depict vibrant living scenes of San su.
The characteristics of the garden layout can be summarized by analysing two-dimensional mapping and three-dimensional point cloud real-scene models. The diagram in Fig. 9 illustrates the presence of three courtyards, three axes, one island, and one garden. The initial courtyard comprises the Lobby, East Chamber, West Chamber, and Worship Hall. The second courtyard includes Mo Pavilion, Kuaiyu Pavilion, Sage Hall, and West Chamber. Last, the third courtyard consists of Sage Hall, Laifeng Pavilion, and the left and right hallways. The amalgamation of the aforementioned three configurations yields an architectural arrangement of ancestral halls featuring three courtyards, characterized by a balanced and symmetrical design on both the left and right sides, with carefully proportioned dimensions. The garden pattern consists of the central line and subcentral line, which are formed by three axes: an axis extending from the South Gate to Laifeng Pavilion, an axis extending from Ruilian Pavilion to Dongpo Sculpture, and an axis extending from Oasis Pavilion to Yunyu Tower. The island is positioned in an east–west orientation, offset by approximately 30 m, and features three courtyards. These courtyards create a memorable ancestral hall design that is reminiscent of an island surrounded by sea. The garden exhibits a naturalistic design within the western region, characterized by meandering and meticulously-arranged pathways and interconnected water features that form a circular pattern.

5.2 Memorial Space Unit

The eastern portion of the San Su Shrine encompasses a memorial hall with a notable commemorative axial landscape. This landscape is characterized by the presence of four separate memorial space components, which are encircled by various architectural structures, including the South Gate, Lobby, Worship Hall, Sage Hall, and Laifeng Pavilion. These spatial units have a strong correlation with the primary visual corridor and the tour route. A commemorative spatial sequence of multiple stages (starting, reinforcement, transitional, and the conclusion stages) is constructed through different plant heights, building heights, and distances (Fig. 10).

5.2.1 Starting stage: South Gate - Lobby

Four renowned and antiquated arboreal specimens, namely, *Ginkgo biloba* and *Phoebe zhennan*, are meticulously cultivated in the area spanning the South Gate to the Lobby. Based on empirical measurements, the horizontal visual distance between the South Gate and the ginkgo tree is estimated to be approximately 10.2 m. Furthermore, the ratio of the height of the ginkgo tree to the horizontal visual distance is estimated to be approximately 0.4. The ginkgo tree has a greater vertical stature in comparison to the adjacent buildings, with a height ratio of approximately 2.75:1 in relation to the lobby. Additionally, the ratio of the DBH (diameter at breast height) to its height (D/H) exceeds 2, indicating a cohesive spatial arrangement that does not result in a sensation of dispersion [37]. This characteristic ensures the presence of adequate areas for both gathering and
dispersing. Simultaneously, the presence of towering and age-old ginkgo tree within the lobby serves the important purpose of obstructing the view, strategically setting the stage for the subsequent landscape and serving as the initial focal point of the commemorative landscape sequence.

5.2.2 Reinforcement stage: Lobby-Worship Hall

Four different individuals of *Podocarpus macrophyllus* are systematically planted in a symmetrical arrangement at the four corners of the front entrance located on the southern side of the Worship Hall. The height ratio between the trees and the Worship Hall is approximately 0.21:1, contributing to an expansive and panoramic view that enhances the solemn atmosphere of the hall. Based on the provided measurements, the distance between the Lobby and the Worship Hall is precisely 13.3 m. The height of the hall is 12.18 m, while the vertical angle of view is 36°. Additionally, the ratio of the distance to the height (D/H) falls within the range of 1 to 2. Furthermore, there is a steady decline in elevation between the building and the surrounding vegetation. The arrangement of space in this context creates a sombre and reverential ambiance, although it does not feel spatially confining [37]. It serves as a pivotal element within the overall landscape sequence.

5.2.3 Transitional stage: Worship Hall – Sage Hall

*Osmanthus fragrans*, a traditional garden species, is strategically positioned in front of the entrance on the southern front of Sage Hall. The tree height is proportionally higher than that at Sage Hall, with a ratio of approximately 1.25:1. The height of *Osmanthus fragrans* is comparable to that of the Sage Hall roof, effectively keeping the mood light. Additionally, its stature serves to shield against adverse weather conditions, thus augmenting the overall impression of solemnity and reverence around the main edifice. Based on the recorded measurements, the distance between the Worship Hall and the Sage Hall is precisely 6.4 m. Additionally, the height of the structure is 9.77 m, while the vertical viewing angle is 50°. Furthermore, it should be noted that the ratio of the building height to its distance from the ground (D/H) is less than 1. Additionally, the vertical dimensions of both the building and its surrounding plants are comparable, contributing to a compact spatial arrangement that feels confining [37]. Simultaneously, cultural artefacts and renowned old trees with commemorative significance, such as the Su Residence Old Well and the osmanthus trees, respectively, are strategically positioned in the area to augment the commemorative ambiance and achieve the pivotal juncture of the axial sequence.

5.2.4 Conclusion stage: Sage Hall - Laifeng Pavilion

The Laifeng Pavilion served as the place of study for the two brothers, Su Shi and Su Zhe. *Phyllostachys aurea* and *Cycas revoluta* are strategically planted within the tree pool located near the entrance on the southern side. The height ratio between the tree and Laifeng Pavilion is approximately 0.5:1, resulting in the creation of a serene spatial ambiance. Based on empirical measurements, the distance between Sage Hall and Laifeng Pavilion is precisely 15.8 m. Additionally, the height of Laifeng Pavilion is 7.30 m. The vertical angle of view, observed from a specific vantage point, is 17°. Furthermore, the ratio of the distance to the height (D/H) exceeds 2. Notably, the spatial arrangement between these structures exhibits a gradual opening, hence evoking a perceptible sensation of expansiveness [37].
5.3 Memorial elements

The garden surrounding of San Su Shrine consists of both constructed and natural environments. The commemorative elements encompass many components, such as buildings, plants, water bodys, and rockery stones. Their locations are shown in Fig. 11.

5.3.1 Building

The architectural design of the San Su Shrine originated from the Su Residence, predominantly incorporating elements of Western Sichuan residential homes, as depicted in Fig. 12. Following the renovation and expansion efforts undertaken by previous dynasties, the architectural composition of the park has evolved into a configuration that is primarily characterized by memorial ancestral halls, which occupy approximately 9.4% of the overall area. The predominant architectural arrangement has a north-facing orientation, with seating arranged in a south-facing orientation. The architectural arrangement principles governing the eastern memorial ancestral hall area adhere to a symmetrical structure, wherein the shrine, hall, and pavilion are predominantly situated along a central axis. The grandeur of the memorial surpasses that of the building on all sides, effectively conveying a sense of solemnity and reverence. The Central Axis Building is encompassed by a series of smaller structures, including pavilions, on either side, resulting in the formation of island residences. The structures situated on each side of the central axis exhibit proximity and integration with the encompassing natural environment. The architectural arrangement of the western garden area exhibits greater freedom and flexibility as one moves from east to west, with a gradual reduction in the variety of buildings.

Figure 12 Building facade of the Sage Hall in the San Su Shrine

(Refers to the drawing of the 'Ancient Temple Freshman')

5.3.2 Plant landscape

The San Su Shrine boasts a diverse array of plant species and a substantial expanse of greenery, encompassing approximately 28,458.6 , which corresponds to 53.6% of the entire garden area. A collection of approximately 49 ancient trees can be found at the shrine, including species such as Ginkgo biloba, Lagerstroemia indica, and Osmanthus fragrans. The San Su Shrine boasts a diverse array of garden flora. Table 2 showcases the presence of trees, shrubs, herbs, hydrophytes, and bamboos within the context of commemorative themes. These botanical elements are strategically mixed with structures, rockery stone, and water scene to create a harmonious planting layout. Su Shi, a renowned poet and scholar, expressed his preference for consuming bamboo over meat by stating, "Better eat without meat than live without bamboo". The exclusion of meat from one's diet only affects one's weight, while the lack of exposure to refined cultural influences such as bamboo can change a person more profoundly. Furthermore, the presence of the ancient Ginkgo trees within the designated ancestral hall area serves as a representation of the Sansu period, emphasizing the commemorative and historical attributes of the Xishu Memorial Garden (see Fig. 13).
<table>
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<td></td>
<td>34</td>
<td><em>Rhapis excelsa</em></td>
<td><em>Rhapis</em></td>
<td>Poaceae</td>
</tr>
<tr>
<td></td>
<td>35</td>
<td><em>Phyllostachys heteroclada</em></td>
<td><em>Phyllostachys</em></td>
<td>Poaceae</td>
</tr>
</tbody>
</table>

**5.3.3 Water Landscape**

The San Su Shrine boasts a substantial expanse of water features, constituting approximately 23.17% of the overall garden area. The garden features a diverse array of water landscapes, including the central water landscape spanning 1,900 m, the eastern water landscape covering 1,950 m, and the western water landscape spanning 4,010 m. These water landscapes constitute the primary components of the garden, while a meandering stream traverses the entire garden, forming an interconnected water network. The primary water landscapes near the memorial ancestral hall of the eastern region of the San Su Shrine are the middle water landscape and the west water landscape, both of which are expansive. The northern and southern dimensions measure 83 m and 84 m, respectively, while the eastern and western dimensions measure 19 m and 22 m, respectively. The area ratio is nearly 1:1, with a high degree of symmetry observed between the left and right sides. The memorial ancient ancestral hall is effectively encircled by the surrounding landscape, creating an island-like setting with three water sections interlaced with two bamboo sections (Table 3, Fig. 14).

Table 3

<table>
<thead>
<tr>
<th>Name</th>
<th>Main water</th>
<th>Scattered water</th>
<th>Water body of the whole garden</th>
</tr>
</thead>
<tbody>
<tr>
<td>Region</td>
<td>S1, S7, S14, S15</td>
<td>S2, S3, S4, S5, S6, S8, S9, S10, S11, S12, S13, S16</td>
<td>—</td>
</tr>
<tr>
<td>Area</td>
<td>7,899</td>
<td>4,514</td>
<td>1,2413</td>
</tr>
<tr>
<td>Ratio</td>
<td>63.6%</td>
<td>36.4%</td>
<td>100%</td>
</tr>
</tbody>
</table>

Scattered water area: Main water area ≈ 1:1.7
5.3.4 Rockery stone

The Rockery stone at the San Su Shrine primarily consists of soil stone and stone piles, encompassing approximately 4.4% of the overall garden area. Rockery stone mostly utilizes indigenous red sandstone, blue stone, pebble, and other locally sourced stone materials, hence exhibiting a diverse range of stylistic features. The arrangement of rockery stones is closely interconnected with the order of the tour and the range of visibility, particularly exemplified by Bafeng rockery stone, Lian'ao rockery stone, and Wenfeng rockery stone, as depicted in Table 4. In further examining the Lian'ao rockery stone, it can be observed that this geological formation is situated on the western side of the Pifeng Waterside Pavilion. The Lian'ao rockery stone exhibits a topographical elevation of 5.85 m and spans a width of 8.12 m. When visitors pause to observe the scenery along the garden path, they can discern the intricate features of the Lian'ao rockery stone. The Lian'ao rockery stone is situated at a horizontal distance of approximately 12.4 m from the overlook point. The ratio of the horizontal distance to the height (D/H) is greater than 1, indicating a generally broad spatial overview. The horizontal field of view measures 106°, while the vertical field of view measures 19°. These measurements fall within the optimal range for human perception, allowing individuals to effectively observe scenery. This approach effectively directs the attention of the visitors towards the three prominent figures of the Lian'ao rockery stone, creating an atmosphere that resonates with the historical and cultural significance of the San Su Shrine. With respect to observing the Lian'ao rockery stone in the Dockyard, the horizontal distance between the viewpoint and the stone is 17 m. The horizontal viewing angle is 88°, while the vertical viewing angle is 19°. From this perspective, one can obtain a comprehensive view of the Lian'ao rockery stone topography, enabling a deeper appreciation of the aesthetic essence conveyed through the interplay of towering peaks, rugged stones, and lush forests.

Table 4 Rockery Stone in the San Su Shrine
6 Conclusions

This study focuses on the San Su Shrine, which is considered the representative element of the Xishu Garden. In this study, digital technology is employed for digital information gathering, analysis, and preservation [16]. The findings indicate that these research methods and technical approaches to digitally preserving the features of Xishu Garden are rational. These methods involve the acquisition of quantitative data for a digital representation, the extraction of distinctive elements, and the subsequent synthesis of landscape characteristics. Consequently, a comprehensive framework for the digital preservation of Xishu Garden is established. Upon objective examination, it is evident that the garden's main layout consists of three courtyards, three axes, one island, and one garden. This spatial arrangement showcases a fusion of regular and natural styles. The commemorative central axis consists of four distinct commemorative space units, including the South Gate, Lobby, Worship Hall, Sage Hall, and the Laifeng Pavilion. These components are arranged in a certain sequence that creates a commemorative spatial progression characterized by multiple stages: The starting, reinforcement, transitional, and conclusion stages. The analysis focused on building, vegetation, aquatic landscapes, and rockery stones, with a particular emphasis on understanding the characteristics of the landscape. This research serves as a valuable resource for the digital preservation and research of Classical Gardens.

<table>
<thead>
<tr>
<th>Name</th>
<th>Bafeng Rockery Stone</th>
<th>Lian 'ao Rockery Stone</th>
<th>Wenfeng Rockery Stone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plane graph</td>
<td><img src="image1.png" alt="Bafeng Rockery Stone" /></td>
<td><img src="image2.png" alt="Lian 'ao Rockery Stone" /></td>
<td><img src="image3.png" alt="Wenfeng Rockery Stone" /></td>
</tr>
<tr>
<td>TLS elevation</td>
<td><img src="image4.png" alt="Bafeng Rockery Stone" /></td>
<td><img src="image5.png" alt="Lian 'ao Rockery Stone" /></td>
<td><img src="image6.png" alt="Wenfeng Rockery Stone" /></td>
</tr>
<tr>
<td>Characteristic</td>
<td>Bafeng Rockery Stone is 5.85 m high, 23.75 m wide, 58.36 m long on the north side and 23.2 m long on the south side. The material of the Rockery Stone is mainly natural soil stone in western Sichuan.</td>
<td>Lian 'ao Rockery Stone is 5.85 m high, 8.12 m wide and 33.25 m long. The material of the Rockery Stone is mainly natural red sandstone in western Sichuan.</td>
<td>Wenfeng Rockery Stone is 6.39 m high, 7.74 m wide and 10.34 m long. The main material of the Rockery Stone is cement mortar and wood. After being damaged by the earthquake, it was repaired with natural red sandstone in western Sichuan.</td>
</tr>
</tbody>
</table>
However, there are several aspects of the research that require further improvement. On the one hand, the integration of 3D laser scanning and UAV photography offers several advantages over traditional measurement methods. This fusion technology enables fast, accurate, and comprehensive data collection [20]. Additionally, it allows for the extraction and matching of research-specific datasets, presenting objective data that illustrate the diversity, difference, and variability of the subject. Consequently, this technology provides a scientific foundation for conducting multi-angular analyses of various subjects. Furthermore, it partially addresses the technical limitations of traditional surveying and mapping methods [38]. In contrast, 3D laser scanning technology has the capability to measure certain physical attributes of plants, such as their height, diameter at breast height, and crown diameter, in an intuitive manner. However, this technology is limited in its ability to precisely capture interior characteristics, such as branch shape, branching patterns, and leaf texture. Furthermore, the fluctuating attributes of seasonal and annual variations in plants contribute to the imprecise nature of these data, making them challenging to assess [25]. Anticipating future developments, there is a growing interest in comprehensive research on the three-dimensional spatial characteristics of the Chinese Classical Garden and the Xishu Legacy Garden [17]. Using this technology, it is feasible to comprehensively examine tree species that are at risk of extinction, their patterns of plant growth, and their interconnections with the surrounding ecosystem [39]. Furthermore, it is possible to develop a comprehensive digital platform for surveying, mapping, storing, and managing information. This platform can be expanded by incorporating various data sources, for example, integrating landscape restoration schemes with virtual reality technology [40–42]. Additionally, this platform can facilitate more extensive discussion on the scientific documentation, preservation, research, and interpretation of heritage landscapes [43].

Declarations

Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author upon reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Author contributions

Guo L: 1) Project Leadership and Supervision; 2) Acquisition of Funding and Resources; 3) Research Design; 4) Writing and Revision.
Ma WJ: 1) Research Design; 2) Data Collection and Manipulation; 3) Data Processing and Analysis.


Gong XQ: 1) Literature Review and Synthesis; 2) Full Manuscript Composition and Editing; 3) Data Interpretation and Results Discussion; 4) Guidance for Figures and Charts.

Zhai ZG: 1) Figure and Chart Illustration; 2) Initial Discussion Drafting; 3) Reference Proofreading.

Li MJ: 1) Drawing Technical Workflow; 2) Collaborative Chart Creation; 3) Initial Research Methodology Drafting; 4) Formatting Proofreading.

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Ancient Meizhou city map and Su Residence diagram

(self-painted according to the exhibition data of San Su Shrine)
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Photograph of the San Su Shrine Ancestral Hall Area

(provided by the San Su Shrine Museum)

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Signs of damage at the San Su Shrine

(Provided by the San Su Shrine)
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