

Article

Methods of Conserving and Managing Cultural Heritage in Classical Chinese Royal Gardens Based on 3D Digitalization

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Abstract: In this study, we aimed to implement information obtained and refined from garden elements in heritage conservation, monitoring, and management to precisely construct an information model of classical Chinese gardens, including information on the garden entity, garden space, and garden attributes, etc., and to improve the management efficiency of classical Chinese royal gardens. Three-dimensional laser scanning technology and point cloud information were used to accurately collect and process digital information from classical Chinese royal gardens. After classifying and processing the point cloud data, correlations therein could be further assessed and used to greatly improve the accuracy and management efficiency of spatial information. To provide a more convenient solution for the subsequent conservation and management of landscape heritage, a method for establishing a three-dimensional digital information database and a full life-cycle application management platform for classical Chinese royal gardens is proposed in this research. This method has broad applications for the digital conservation and management of cultural heritage.



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1. Introduction

The digitalization of information is an important scientific means for conserving, restoring, and passing on cultural heritage. The digital reconstruction of cultural heritage sites involves the complete collection, integration, and modeling of their geometric shapes, colors, postures, history, etc., constituting the basis of digital archiving for cultural heritage [1,2]. Terrestrial laser scanning mainly consist of a scanning mirror and a servo motor, allowing them to be flexible and portable for the quick, thorough, and precise collection of 3D geometric information about the surface features of heritage sites. This technology is widely used in engineering construction, construction supervision, urban 3D model reconstruction, earthwork measurements, landslide monitoring, cultural heritage conservation, industrial facility measurements, crime scene investigations, accident scene reconstruction, and other fields [3]. As far as cultural heritage is concerned, TLS have been widely applied in the measurement, monitoring, and conservation of historical sites, cave temples, ancient buildings, etc. [4–8].

Traditional Chinese gardens are an important part of the nation's cultural heritage, among which the imperial gardens from the Qing Dynasty at the Summer Palace are considered a world cultural heritage site. As an important extension of 3D digitalization, point cloud directly supports the digital sampling, virtual restoration, 3D reconstruction and archiving, etc. of cultural heritage sites [9–12]. The digital collection and archiving of Chinese traditional gardens has evolved; however, many important elements make up the artificial and natural features of Chinese royal gardens, including various

forms and complex classification objects such as water bodies, rocks, plants, buildings, topography, historical information, etc. As a consequence, the diverse settings, complex morphological structures, target occlusion and overlapping, large spatial density differences, etc. are common problems in the classification of 3D point clouds for this type of cultural heritage site [13–19].

Traditionally, a garden heritage analysis is carried out using manual methods, especially in the survey phase. Combining triangulation and digital photogrammetry, the geometric and the texture/material properties of a garden element can be obtained; this information can then be digitized on a 2D platform, and a 3D model can be produced. At the same time, a historical analysis can be performed, examining past sources, documentation, and all other existing information [20].

The current trend, however, is to combine digital photogrammetry with laser scanning, as described in many articles [21–30]. Digital photogrammetry is based on the triangulation principle [25,30], as the images produced are taken from different viewpoints [30]. Combining this with laser scanning allows for the capture of high-resolution photographs of the materials' textures [31,32] and, as a consequence, information on any material degradation. The photographs need to be postprocessed, which is normally possible with software. However, combining laser scanning and digital photogrammetry can be difficult, as both devices must be properly calibrated; therefore, error propagation is likely to occur [31]. This method consists of taking photographs while moving the camera continuously, trying to detect convergent images, and then digitally reconstructing the geometry [32]. Some terrestrial laser scanners (TLS) are based on the triangulation principle as well [25,31,33]. They produce a point cloud of the scanned object [28], which needs to be postprocessed and then transformed into a 3D model [28,34]. Point cloud postprocessing is still a time-consuming task [34–36], even if some attempts have been made to speed it up [29,35]. TLS can be integrated with a geographic information system (GIS) to geo-locate the scanned object using Cartesian coordinates, and to analyze the geospatial data. The latest techniques use unmanned aerial vehicles (UAV, commonly known as drones) combined with GIS to scan the surroundings. These techniques are particularly useful when the landscape is connected to the building being studied, as previously used for the Borobudur Temple [35].

TLS outputs are point clouds and need to be processed before building the BIM model [37]. No specific heritage-related issues have been found in this practice; however, building a BIM model is a propaedeutic task. The most common operations are the following:

- Noise elimination [8,25,38], which consists of detecting and eliminating scanned items that are not part of the case study;
- Point cloud registration [18,28,34,35], which consists of merging different point clouds of the same object, derived from different scanning sessions; and
- Meshing, which consists of creating triangulated surfaces to be turned into 3D models afterwards, performed using specific software [34].

This task is long and elaborate, but some attempts have been made to automate it [24,25,29,34,39]. Research on automation has been intense, as this would allow for quicker and cheaper surveys to be performed when applied to the heritage sector. Moreover, an architect/restorer charged with digitizing and conserving a heritage building would struggle to manually postprocess points cloud by themselves. These tasks are not particularly straightforward, and very often, specific photogrammetry knowledge is required. For instance, Garagnani developed a new plug-in, called Green Spider, which helps in the automation of importing point clouds [24,27,28]. Green Spider imports select points of a point cloud and transforms them into snaps (i.e., reference points), allowing the bonds to be retraced and converted into 3D smart objects. Practically, Green Spider allows the user to select which points of the cloud are needed and converts them into masses (i.e., 3D undefined objects). These masses can then be imported in any 3D modelling platform—after being embedded with semantic information, such as materials, dimensions, etc.—and then inserted into the BIM model as “families”, i.e., categories of similar objects.

Other attempts at automating postprocessing have also been made. In 2014, Oreni et al. [30–36,39] developed a methodology using Non-Uniform Rational Basis Splines (NURBS). NURBS allows for modelling based on vector extraction from point clouds using mathematical functions. Another example is the Cloud-to-BIM-to-FEM method, which is not exactly an automation process, but rather, a procedure that converts point clouds into BIM and then simulates the structural behavior using the Finite Element Method (FEM).

Until now, few attempts have been made to assess the conditions of heritage sites (which could be defined as an assessment of the state of conservation of an object in view of its desired uses) using BIM. Hypothetical reconstructions of ruins/damaged buildings [28,40] and stratigraphic depictions [32,41] have been made, but evidently, assessing their condition is a difficult task, as the interpretational skills of professionals play an important role in such tasks [33,38]. In practice, the outcome of condition assessments strongly depends on the experience and rigorousness of the professionals involved.

The abovementioned experiments are elective, even if they do not completely solve the BIM integration problem, as conversions from volumetric objects (i.e., simple digital masses) to “smart” (i.e., parametric) ones are complicated for people without a strong IT background. However, they represent an important achievement and a potential starting point for further research [6].

Below, we review the research issues that have emerged in relation to heritage science.

- Survey techniques: different methods have been used, from traditional approaches to advanced automated methods, such as TLS integrated with GIS, digital photogrammetry, and UAVs. Using these methods, a point cloud digitally representing a real building is obtained. However, a common problem is optimizing the conversion from point clouds to 3D models. The exportation step is still difficult and time-consuming, even if some attempts have been made to automate this process.
- Point clouds: the latest survey techniques used to build a heritage model present the data in a point cloud format, which has the capacity to capture very fine details; however, this conversion to a 3D model is also intricate and time-consuming. Further research is needed to identify which LoD is required to facilitate different tasks (analysis, monitoring, and recording the conditions).
- Parametric smart object libraries are an attempt to square the circle: to create generalizable objects that can represent the individual features of historic buildings. Their advantage is that they contain virtual representations of existing constructive elements that only need to be modelled once. Their parametric nature provides a great advantage, as they can be modified and updated as needed, e.g., with maintenance, changes, new discoveries, etc. Parametric libraries can also contain different kinds of objects: constructive elements, architecture-language components, constructive techniques, etc. Two main libraries have been constructed so far: HBIM and JHBIM, which is a specific HBIM extension for Old Jeddah. These libraries were created following the procedural modelling rules and were coded with GDL scripts to automatically create elements that are based on shape grammars. Nevertheless, using parametric smart object libraries can be slightly restrictive; if a specific architectural style is not present in parametric libraries, they need to be manually modified. As new libraries for historical styles are developed, new research will be needed to identify the limitations of this approach.
- Unified visualization between 3D model and metadata: the most advantageous feature of BIM for heritage science is perhaps its ability to link 3D models to metadata. Interesting experiences have been reported in the use of video game engines to perform virtual tours of 3D models populated with related metadata. However, research is urgently needed in the development of a heritage-specific technology that can sustain and display heritage science information, including historical data, the conditions of the site, environmental parameters, risks to the materials, and forecasts.

From the findings and remarks on previous research, we conclude that further research is needed. Specifically, future work should focus on how to (visually) unify 3D smart models and metadata; how to automate importing processes (from point clouds to 3D

smart models); and how to include the conditions, risks, environmental parameters, and forecasts in the model.

Life-cycle management will continue to be important in the landscape heritage of a site until the site eventually degrades over time due to research activities, such as surveying and mapping, recording, protection, and monitoring; therefore, we propose a digital platform for gathering complete information on heritage sites for integrated information management [38,42–45], as consolidating this information helps in the protection, research, and utilization of heritage sites. This life-cycle management method can help establish a professional collaborative platform for landscape heritage conservation and more accurately integrate its history, current situation, intervention, and management information with future development and applications. It greatly promotes the optimization, reorganization, and social sharing of landscape heritage information [41,46,47]. In this paper, the Jianxin Courtyard, a typical classical Chinese royal garden, was taken as an example. A TLS was used to digitally collect information about this site, and a ground laser point cloud was used to classify and extract the garden elements. Then, our life-cycle management method was used for follow-up monitoring and management [2,16]. With improvements in digital technologies, the simultaneous improvement of the methods and concepts used in the conservation and management of landscape heritage is urgently needed.

2. Materials and Methods

2.1. Methodological Approach

As our aims were (i) to implement the information obtained and refined from garden elements, (ii) to improve heritage protection, monitoring, and management, (iii) to accurately construct an information model of classical Chinese gardens, including information on the garden entity, garden space, and garden attributes, and (iv) to improve the life-cycle management efficiency of classical Chinese royal gardens, we constructed an information model based on methods applied in and data obtained from surveying and mapping Beijing royal gardens. Additionally, classifying garden elements such as garden buildings, ancient trees, water revetments, paving sketches, and mountains and stones can provide support for the management of classical Chinese gardens [17]. Reclassifying the elements of classical Chinese gardens based on the information model is also in accordance with traditional landscape architecture theory, surveying and mapping practice theory, and the relevant requirements of historical garden conservation. Additionally, putting forward a universal classification system is helpful in further systematizing the study of classical Chinese gardens and in facilitating the application and management of information.

A metric and documentary analysis of the garden of a particular historical, architectural, or archaeological site of interest can be divided into the following phases:

- Historical analysis; surveying and 3D metric data processing; identification of the characteristic elements and their modelling;
- Digitization of semantic, documentary, and graphic information; point cloud data processing based on the garden element characteristics of a Chinese royal garden; and informatization, conservation, and management of garden elements;
- Construction of a cultural heritage protection platform and application of the 3D information system. Figure 1. showed the flowchart for building a database of classical Chinese royal gardens.

2.2. Materials and Equipment

- The ground 3D laser scanning equipment used in this study was a Focus 3D X 330, a phase 3D laser scanner based on pulse ranging from the FARO Company. The equipment used was a type of high-speed 3D scanner with an ultralong measuring distance that can scan objects 330 m away under direct sunlight, with a measuring speed of 976,000 points per second, an actual error ± 2 mm, and a scanning range of 360° horizontally and 300° vertically.

- A digital camera allowed us to employ oblique photogrammetry and to provide color in the point cloud generated by the scanner. We used a SONY A7R4 and a tripod to maintain the same camera location and angle. The scanning site is shown in Figure 2.

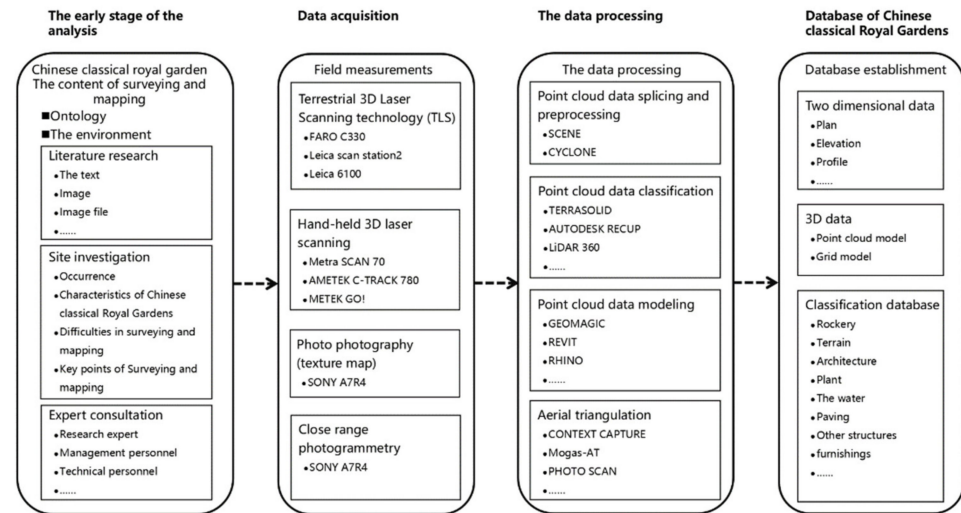


Figure 1. Flowchart for building a database of classical Chinese royal gardens.



Figure 2. Scanning operation.

2.3. Data Collection and Site Survey

2.3.1. Historical Analysis and Site Location

Before conducting the study, drawings of and relevant information about the study site were collected. The collection and analysis of existing drawings and files are helpful in fully understanding the historical changes, garden layout, landscape relationship, and level of surveying and mapping conducted for such gardens within the last century. Additionally, a number of previous maps of the site were scanned and collected, as shown in Figure 3 (a. Jianxin Courtyard in the “Map of Jingyi Garden” by QING Gui and SHEN Huan et al., in the 1780s; b. Jianxin Courtyard in the “Yangshilei” Xiangshan Site Map from 1800; c. plan of Jianxin Courtyard in the “History of Chinese Classical Gardens” by ZHOU Wei quan in 1999; d. general plan of the Jianxin Courtyard renovation from Beijing Construction Engineering Architecture Design Institute in 2006; e. 3D point cloud scans from different locations). Furthermore, in combination with the site survey, the actual situations in the gardens were observed and compared with existing information.



Figure 3. Jianxin Courtyard historical maps collection and scanning mapping display in different periods.

2.3.2. Optimization of the Site Layout Method

According to the Venice Charter (1964), Florence Charter (1982), Nara Declaration on Authenticity (1994), Xi'an Declaration (2005) and other documents, conservation efforts for historical sites are gradually being expanded, and these methods of conservation are no longer restricted to only the historical sites themselves, but rather, focus on the overall relationship between the heritage sites and their surrounding environments. In areas with complex topographies and abundant garden elements, many measurements from multiple angles at different points are necessary due to mutual occlusions of the measured objects. Then, images must be superimposed to obtain a complete result. After obtaining multisite data, complete spatial information is obtained by combining computer and manual identification of the feature points. Figure 4 shows a scan of the distribution of points in the Jianxin Courtyard. Figure 5 presents a Space Partition Point Cloud Map of the Jianxin Courtyard.

2.3.3. Garden-Wide Data Acquisition for the Jianxin Courtyard

The surveying and mapping conducted for this study not only include the digital surveying and mapping of various garden elements in the Jianxin Courtyard, but also consider the surrounding environment. A total of 102 sites were surveyed using noncontact 3D laser scanning, including the outside environment, garden buildings, vegetation information, water bodies, and rockery space. The point cloud quality was set to 1/8 and 3x, and the point distance was set to 12.272 mm to improve the scanning efficiency. The point cloud quality was then set to 1/4 and 3x, and the point distance was set to 6.136 mm to obtain the details and complete texture information. The scanner has a built-in 70 megapixel digital camera, which could take digital photos of the whole site after scanning at each site to record RGB information within the scanning range.

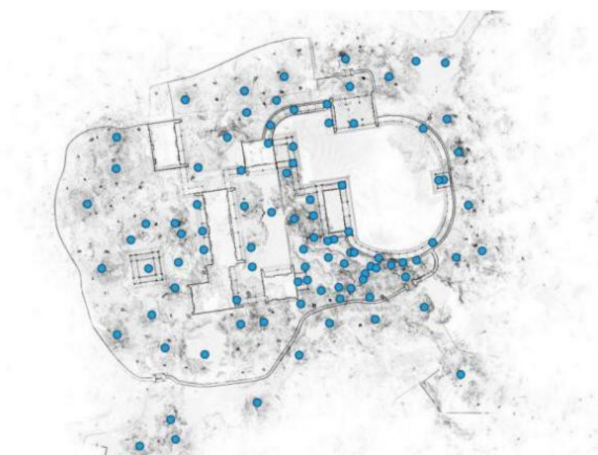


Figure 4. Scan of the distribution of points for Jianxin Courtyard.



Figure 5. Point cloud map of the space partition in Jianxin Courtyard.

The point cloud data of 102 sites in Jianxin Courtyard obtained through the above steps were imported into a classification software for preprocessing and point cloud registration, the processing of which specifically comprised the following steps:

Firstly, data importing and data preprocessing. The above site files were preprocessed, and the color photos taken by scanners in the field were matched with the point cloud data from the site, thereby providing RGB values for each scanning site.

Secondly, point cloud registration: automatic registration processing was performed, and the software automatically extracted feature points according to the coincidence rate of each site. The ICP (Iterative Closest Point) algorithm was used to accurately splice adjacent sites and minimize the error function value. The maximum error of this point cloud splicing was 11.1 mm, and the midpoint error was 9.7 mm, where the registration results allowed a midpoint error ≤ 15 mm, which can be used as the baseline for subsequent studies.

The 3D real scenic point cloud model of Jianxin Courtyard Garden obtained from the above steps can be further explored in supporting software, such as viewing, box selection, and deletion. To facilitate docking with subsequent processing, the garden-wide 3D point cloud model of the Jianxin Courtyard was transformed into the XYZ text format of an ordered point cloud, that is, each line of the exported file contained a scanning point, and the file of each scanning point was determined based on its three direct coordinates and their functional relationship. The model can fully represent the characteristics of various elements in the Jianxin Courtyard and the overall spatial layout of the garden. A garden-wide point cloud model of the Jianxin Courtyard is shown in Figure 6. We can also carry out basic measurements and other operations on the point cloud model of the

Jianxin Courtyard Garden and obtain information on the relevant attributes of the garden space and elements; for example, the Jianxin Courtyard covers an area of 5257 m², with the greatest lengths being 62.05 m from north to south and 84.72 m from east to west, and with a water body area of 655 m². Details of the rockery volume, plant number, building area, etc. of each part are shown below.



Figure 6. Garden-wide orthogonal maps from the point cloud model of the Jianxin Courtyard.

After obtaining a garden-wide 3D point cloud model of the Jianxin Courtyard, current high-resolution point cloud orthogonal maps, high-resolution TIF overview maps, etc. that truly and objectively reflect the internal and external conditions and can be used for the overall spatial pattern analysis of gardens, garden monitoring, and other purposes can be further automatically generated, thereby greatly facilitating subsequent zoning, classification, conservation, and management.

2.4. Basic Processing of Various Garden Elements of the Jianxin Courtyard

To complete the transformation of the point cloud model into a surface model, the reverse engineering software Geomagic was used to process the above data and provide solutions for any model acquisition problems in the landscape elements, such as incomplete rockery drawings, the pursuit of natural modeling, irregular structures, and almost impossible traditional forward modeling. The main processing steps included performing dot coloring, selecting disconnected items, removing isolated points in vitro, unifying sampling, packaging, filling a single hole, deleting nails, examining the elements using a grid doctor, and exporting the models.

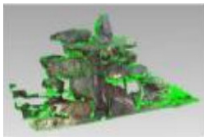
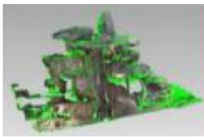
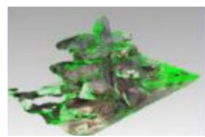
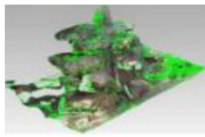
For noise caused by rough surfaces, low surface reflectivity, or long scanning distances, it was necessary to adjust the distance or increase the characteristic points or target points of certain measured objects. For any errors generated by the scanner itself, insufficient accuracies, or slight vibrations during scanning, the parameters could be adjusted. Additionally, we manually deleted unwanted data caused by accidental noise from people, trash cans, birds, etc.

2.5. Sampling and Processing Method for Garden Element Characteristics

Since different garden elements have their own characteristics, adopting processing methods and parameter settings according to such characteristics is necessary. If the shape of the building is regular and the surface is smooth, only curvature sampling parameters that are too high are needed, e.g., a curvature sampling rate of 65%. In contrast, if the shape of rockery is irregular, e.g., there are many potholes on the surface, the details need to be preserved as much as possible, or more suitable sampling parameters are needed, i.e., a

curvature sampling rate of 95%. However, due to the sparse point clouds in branchlets and leaves, plants may lose multiple feature points when connections are removed. (Table 1)

Table 1. Table of experimental values of the rockery cloud sampling rate of the Jianxin Courtyard.

| Sampling Rate of Rockery Points | | | | |
|---------------------------------|---|---|--|---|
| Curvature Sampling Rate | Curvature Sampling Rate of 35% | Curvature Sampling Rate of 65% | Curvature Sampling Rate of 85% | Curvature Sampling Rate of 95% |
| Number of points | 1,917,808 | 3,561,643 | 4,657,533 | 5,205,478 |
| Number of triangles | 3,705,153 | 6,820,175 | 8,411,795 | 9,906,289 |
| Number of holes | 3711 | 9024 | 13,031 | 14,278 |
| Encapsulation result |  |  |  |  |

The 3D real-life model of the Jianxin Courtyard encapsulated in the above steps was created based on information from various garden elements, and was finally exported in the STL format, which is common for conventional 3D models, using the Geomagic software platform. Additionally, this file can be used as the basic spatial data file in the study of classical garden information models, and can be added to multiple platforms for subsequent use elsewhere. The encapsulation process for rockery points is shown in Figure 7.

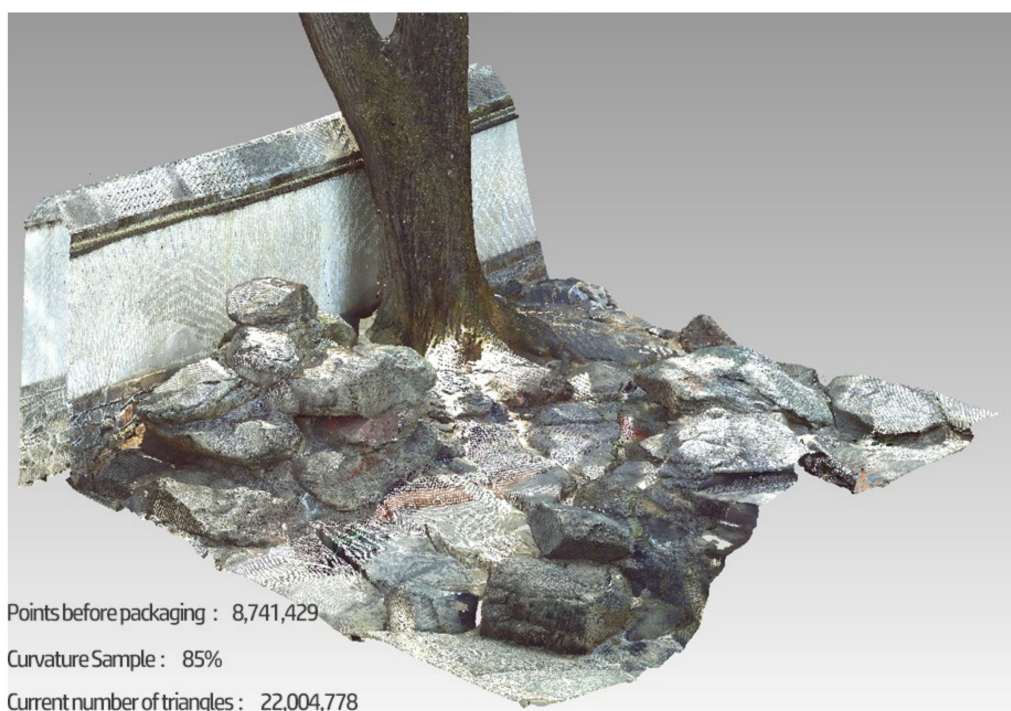


Figure 7. Encapsulation process for rockery points.

By rationalizing the classification of garden information, semantic information about the surface features can be extracted more accurately. Separated elements are convenient for subsequent management and application, and can be processed specifically for the purpose of a study, which is convenient for the standardization of database records and management methods.

In the march towards the conservation of classical Chinese garden heritages and 3D digital systematization, the methods applied in and data obtained from surveying and mapping Beijing royal gardens can serve as the basis for the construction of an information model. Additionally, classifying garden elements such as buildings, ancient and famous trees, water revetments, paving sketches, and mountains and stones can provide support in the management of classical Chinese gardens.

3. Results and Discussion

3.1. Results of the Element Classification

3.1.1. Element Classification

Considering that the results of surveying and mapping should accurately reflect the characteristics of a building, the spatial information obtained for ancient Chinese royal gardens is classified on the basis of the basic garden elements. The main contents include the following categories: water body, plant, environment, rockery, architecture, transportation, and others, as shown in Table 2 below. The classification results of the garden-wide point cloud elements are shown in Figure 8. The resultant two-dimensional plan diagram is shown in Figure 9.

Table 2. Classification of basic garden elements in royal gardens.

| Information Category | Specific Contents |
|----------------------|---|
| Water body | Water body, revetment, slope protection, facilities, etc. |
| Plant | Trees, shrubs, vines, bamboos, herbs, etc. |
| Environment | Outside terrain, outside transportation, other outside elements, etc. |
| Rockery | Rockeries, stacked stones, etc. |
| Architecture | Building monomers, structures, decorations, interior pavements, etc. |
| Transportation | Garden roads, sites, etc. |
| Others | Interior furnishings, sketches, etc. |

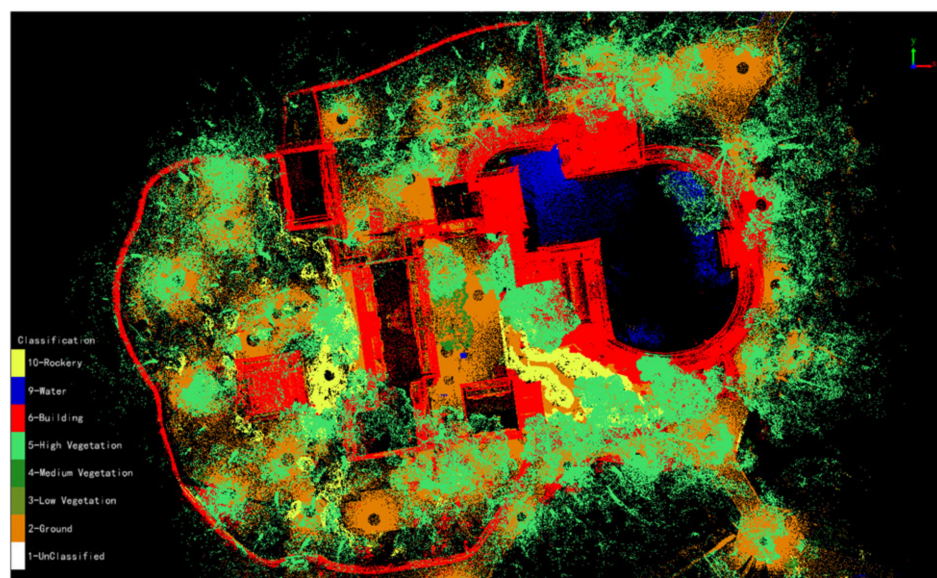


Figure 8. Classification results of garden-wide point cloud elements.



Figure 9. The resulting two-dimensional plan.

3.1.2. Classification Collection and Processing Results

- Filter extraction and manual refinement of ground points Ground point filtering is a primary step in 3D laser point cloud processing; it is also a prerequisite for the reasonable classification of other surface features. In this classification, an improved progressive encryption triangulation filtering algorithm was adopted, in which the computer constructs a triangulation network with the maximum building size as the parameter for the initial ground points, and iterative encryption is continuously carried out. In the experiment, we found that, because of the complex terrain conditions, the many buildings and the high plant coverage rate of the Jianxin Courtyard, the automatic filtering results of ground points based on building size parameters could not meet the experimental requirements, so quadratic surface filtering was applied instead. In this method, the point cloud is meshed, the lowest point of the mesh in a certain size range is selected to build a quadric surface, and the distance between the point cloud and the fitting surface in the calculation range are compared with the set distance threshold; this method is more suitable for an environment with topographic relief such as in the Jianxin Courtyard Garden, and can obtain more complete information about the ground points. When dealing with a high-precision point cloud model, manual checking and editing are carried out at the same time. Polygon and profile editing are used to select and refine the point cloud with TIN filtering, and the point clouds mistakenly divided into ground points are classified according to their attributes. The process of manual refinement of a ground point cloud is shown in Figure 10.
- Rockery Point Cloud Processing Information Considering the particularities of rockery elements, the exclusion method can be adopted for the fine classification of rockery spaces, and the remaining parts can be obtained after extracting other elements [45]. The irregularities of the rockery structure and the complexity of the topographic

relief in the Jianxin Courtyard caused overlap in the rockery foundation and ground, which led to the rockery point cloud being mistakenly divided into ground points and to the root system of large trees caused by the combination of rockery elements and plant elements being misjudged as rockery points. On the basis of automatic classification, it was necessary to artificially refine the selection and to convert it into rockery points according to the classification of attributes. According to the data processing, the corresponding rockery information was obtained, as shown in Figure 11 and Table 3 below.

- Fine differentiation of vegetation monomer information from the Jianxin Courtyard The method of plant segmentation mainly follows the top-down segmentation of an airborne Lidar point cloud and the down-top segmentation of a ground laser Lidar point cloud. Through ground laser scanning, we could clearly identify trunks in the gardens, so the attributes except DBH for a single tree could be measured. Before single tree segmentation, the filtering and normalization of ground points in the Jianxin Courtyard were necessary to prevent elevations such as undulating terrain from influencing single plant segmentation. In addition to big trees such as *Sophora japonica* and *Pinus tabulae*, there were also many shrubs with a smaller DBH and crown breadths, which were easy to ignore. Therefore, during actual operations, it was necessary to reduce the minimum threshold for elevation in the DBH point cloud (the default minimum in the software is 1.2m) and to adjust the maximum threshold (the default minimum in the software is 1.4m) accordingly, so that the data covered all possible DBH dimensions of plants, which was beneficial to automatic identification by the software and for avoiding subsequent manual fitting due to size mismatches. After dividing single trees based on point cloud data, unique color correspondences and ID information were assigned to each tree and a seed point file CSV was generated simultaneously, which could be superimposed onto the point cloud and present information on the attributes of each plant in the garden more intuitively. Figure 12 showed the point classification and single tree division of garden-wide plants in the Jianxin Courtyard. Table 4. showed the statistical table of plant information from Zone A in the Jianxin Courtyard. In our study, a total of 116 trees in the Jianxin Courtyard were obtained. The plant with the largest DBH was 0.962 m; the plant with the smallest DBH was 0.051 m; the plant with the largest crown breadth was 23.854 m; the plant with the smallest crown breadth was 0.546 m; the plant with the largest height was 11.912 m; and the plant with the smallest height was 1.299m.
- Garden-wide building monomer separation Relative to the terrain, rockery, and vegetation elements, the garden architecture is more regular regarding its overall composition, and its classification was relatively simple. For convenience in classification, the ground points, rockery points, and plant points could be close to reduce occlusion, and the remaining point clouds could be observed by rotation and then classified from unclassified points to building points, using a profile tool or a polygon selection tool. A garden-wide architectural point cloud classification and orthogonal map of the Jianxin Courtyard is shown in Figure 13.

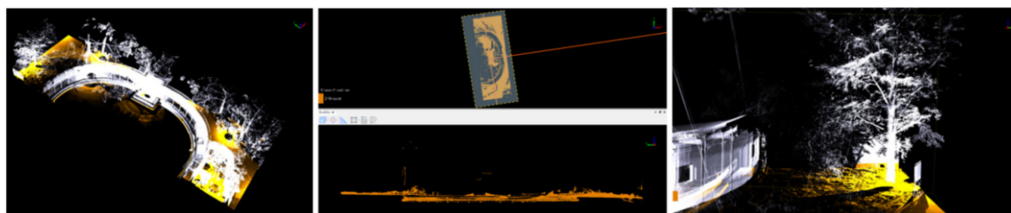


Figure 10. Polygon and profile editing are used to select and refine the point cloud with TIN filtering and manual refinement of a ground point cloud.

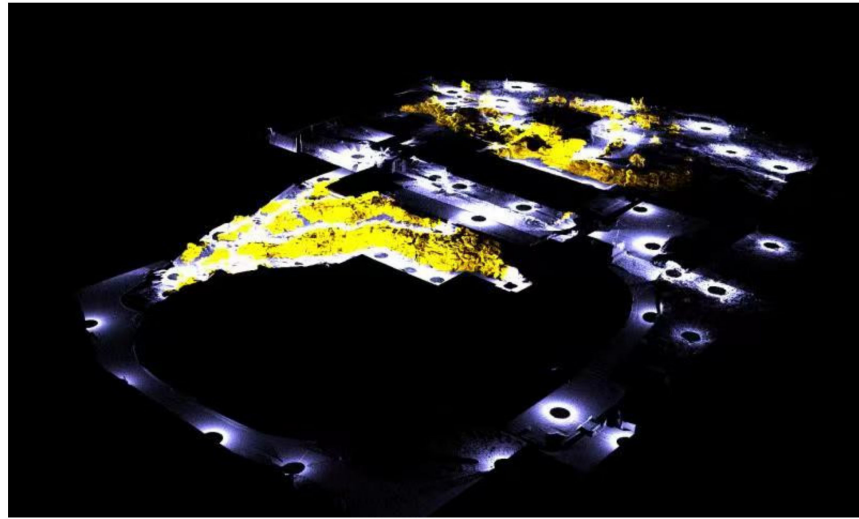


Figure 11. Rockery point cloud information model after automatic selection, attribute classification and manual refinement selection.



Figure 12. Point classification and single tree division of garden-wide plants in the Jianxin Courtyard.



Figure 13. Classification results of the garden-wide architectural point cloud of the Jianxin Courtyard.

Table 3. Processing information for the rockery point cloud.

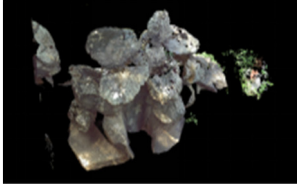
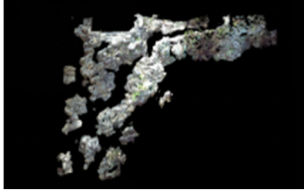
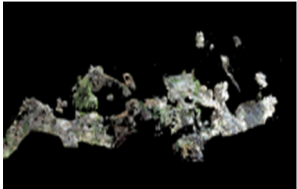


| Mountain Preview | Projected Area /m ² | Surface Area /m ² | Rockery Volume /m ³ |
|---|-----------------------------------|---------------------------------|-----------------------------------|
|  | 5.9941 | 14.3998 | 7.7295 |
|  | 321.3985 | 825.1359 | 1194.1027 |
|  | 350.7361 | 932.2432 | 1187.3004 |
|  | 21.6262 | 58.2563 | 52.265 |
|  | 482.0896 | 1072.2976 | 248.29 |

Table 4. Statistical table of plant information from Zone A in the Jianxin Courtyard.

| Statistics for the Plant Information from Zone A of the Jianxin Courtyard | | | | | | | |
|---|----------|---------|-------------|-------|----------------|------------|--------------|
| Tree ID | X | Y | Tree Height | DBH | Crown Diameter | Crown Area | Crown Volume |
| 1 | 1877.96 | 254.988 | 9.38 | 0.666 | 9.366 | 68.896 | 300.514 |
| 2 | 1881.71 | 253.501 | 6.182 | 0.058 | 5.873 | 27.087 | 92.033 |
| 3 | 1885.647 | 248.68 | 10.5 | 0.962 | 13.413 | 141.299 | 721.399 |
| 4 | 1885.714 | 251.668 | 2.723 | 0.216 | 2.737 | 5.883 | 10.4 |
| 5 | 1884.294 | 253.254 | 2.302 | 0.082 | 1.929 | 2.923 | 4.008 |
| 6 | 1893.42 | 215.085 | 2.378 | 0.247 | 3.047 | 7.293 | 11.777 |
| 7 | 1894.236 | 220.025 | 9.594 | 0.452 | 7.174 | 40.421 | 207.195 |
| 8 | 1886.011 | 249.834 | 3.261 | 0.096 | 1.343 | 1.417 | 0.73 |
| 9 | 1891.506 | 214.464 | 2.174 | 0.12 | 0.642 | 0.324 | 0.389 |
| 10 | 1877.48 | 252.606 | 6.739 | 0.065 | 7.526 | 44.486 | 185.014 |

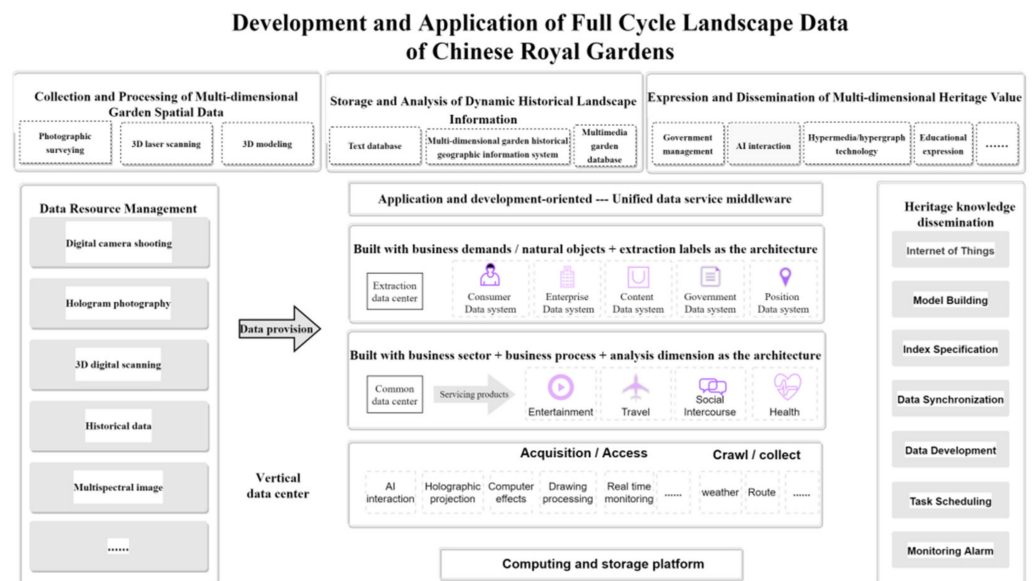


Figure 14. The whole landscape data development process for Chinese royal gardens.

3.2. Garden Elements in 3D Data Information Management

Currently, the most advanced and effective information management technologies in the field of cultural heritage information management are geographic information systems (GIS) and building information models (BIM) [3,7,46], between which the BIM has clear advantages in the management of information about objects such as building monomers and components, which can be split into the internal and external structures of a building, and can provide information on its materials and dimensions [41,47]. However, for the spatial geographical environment outside the building and the interrelations among other elements, the GIS platform is also needed for information management. This study combined BIM and GIS for information management of the Jianxin Courtyard, using the GIS for system management and BIM for model construction and information management of the architecture and its construction.

The creation of an information model includes garden entity information, spatial information, and attribute information. In this paper, the Arc GIS software was used to construct an information model of the Jianxin Courtyard. From the perspective of attribute information, it was necessary to first encode the spatial information of the Jianxin Courtyard; to clarify the names, categories, related sources and accurate information of elements; and to form several Excel files including basic information, historical changes in the garden, elemental information, etc. Relevant basic information can then be retrieved and used at any time through information model hyperlinks, allowing interaction between people and information models. As for spatial information, realizing the management of all garden elements in the Jianxin Courtyard Garden relies on a 3D real-life model thereof. According to the above classification operations, the process includes the following categories:

- Garden architecture objects: graphic data were drawn and stored based on the surface data type. After opening attribute information from the surface data, it was linked to all of the basic information contained in the element code and the 3D real-life model.
- Garden water objects: graphic data were drawn and stored based on the surface data type to realize a visual representation of the water information. Because the ground 3D laser scanner could not collect echoes when scanning and mapping the water body, it was necessary to manually establish the shape and depth of the water body when establishing a real-life model for subsequent management.
- Plant objects: graphic data were drawn and stored based on the point data type. Ancient trees are a very important part for combing through the history of gardens. In the above classification operations, the plant elements in the Jianxin Courtyard were

segmented. In this study, the positions of ancient trees were located point by point in the 3D real-life model of the Jianxin Courtyard, and such information included the basic attribute information about ancient trees such as position, DBH, crown breadth, and tree height.

- Rockery objects: graphic data were drawn and stored based on the surface data type. The types of rockeries in the Jianxin Courtyard could be classified into single peaks, pavilion hills, terrace hills, pool hills, etc., which were combined with other garden elements in a variety of ways.

The establishment of a 3D information model of the garden will serve many purposes. The system can allow information queries, information editing, measurements and analyses, exhibitions, and other functions. In addition to accurate information about the landscape of a heritage site, this system will also incorporate nonmaterial information such as climate information, social elements, historical memories, cultural activities, animal activities, etc. into the construction of the heritage landscape information model. The basic value of the site and the nonmaterial information that can be excavated with a deeper impact on cultural significance were determined by means of historical literature crawling and a public survey questionnaire. Then, the corresponding technical methods could be adopted to multiply the amount of information acquired and to give it historical and humanistic emotional value. In the context of the current era, the study of information technology in classical gardens is particularly important for their conservation. In addition to using information management technologies such as BIM and GIS in the conservation and management phases, based on the characteristics of classical gardens, which encompasses many scopes and time spans, the 3D visualization of classical gardens should be studied separately to propose methods that can better integrate this information.

The construction of a digital heritage information platform for cultural heritage involves integrating cultural heritage information, status data, and various databases so that cultural heritage stakeholders can easily access heritage information and share the data and values they have obtained. Using the new platform to integrate heritage information resources and to integrate historical and current data can improve the ability of multiple parties to understand cultural heritage comprehensively and plan holistically.

The platform mainly covers information service tools such as: dynamic data from heritage, historical, and cultural information; application steps; information dissemination tools; and information collection tools. It not only supports the display and dissemination of existing information on cultural and historical landscapes, but also captures and records information on historical landscapes held by different stakeholders. It includes diverse data applications, such as dynamic monitoring data of cultural heritage based on the Internet of Things, which provides comprehensive dynamic monitoring and sharing of information on the current state of the cultural heritage environment.

Based on a variety of information service tools, the principle of disaggregated information supply is used to provide customized data content and usage for different stakeholders. This mainly includes the application of cultural heritage data services based on GIS, the application of urban history visualization based on hypertext preprocessing technology, multimedia GIS-based public data collection applications, etc.

The main advantages of using this management system are as follows.

The shift from one-way heritage information release to multidimensional information interactions and strengthened interactions based on human perspective. The interaction among multidimensional information becomes a digital cultural heritage information service [40,48–51].

Development from standardized information integration to customized information modules to promote landscape value recognition. Digital heritage information services for cultural and historical landscapes fully recognize the diversity of heritage stakeholders and the importance of multiple values for the conservation and development of cultural and historical landscapes [52].

Emphasis on the cultivation of digital heritage information and the promotion of public participation in heritage conservation decisions. In addition to an emphasis on the construction of digital heritage information services, the ability of the general public to apply digital technology to participate in practice has been increased at all levels.

Transformation from an “information service” to a “knowledge service”, which helps build consensus on cultural heritage development. Digital models of cultural and historical landscapes are gradually transforming from “heritage information services” to “heritage knowledge services” [37,53].

3.3. Application of 3D Information System

Based on digitized heritage archives, the cultural heritage application management platform was built to go beyond the traditional concept of a “heritage database”; as such, it is no longer limited to the integration and one-way distribution of heritage information. It also allows for the exploration of a more active and creative digital cultural heritage information service model. Digital heritage information services are jointly constructed by both the host and the client. Local governments, as the driving force of information services, not only provide comprehensive and scientific heritage information, but also continuously explore innovative ways and tools for information dissemination, and thus, also play the role of a coordinator. Additionally, landscape heritage stakeholders, as the objects of information services, are no longer just passive recipients of heritage information, but are increasingly involved in the landscape heritage information and knowledge creation processes. The holistic, dynamic, relevant, local, and value-driven concepts advocated by the cultural heritage multidimensional management platform can be fully reflected in this management model. Additionally, the inclusiveness, flexibility, and systemic nature of digital technology are necessary to achieve innovation in cultural heritage information services.

Large-scale digitalization and informatization, which are being improved day by day, have gradually developed from a “digital city” to a “smart city”, which brings about important opportunities for the digital preservation of cultural heritage. On the one hand, the focus of research and practice on heritage information services needs to expand from the construction of heritage data platforms to a more inclusive and comprehensive heritage knowledge service system to better coordinate the relationship between heritage conservation and urban development. On the other hand, heritage information services need to dialectically look at the issue of standardization and individualization, paying attention to the construction of relevant standards and norms for digital heritage information, while fully considering the individualization, localization, and technological innovation of heritage information service platforms and exploring heritage information service models and data structures. In addition, the heritage information service platform needs to (i) highlight the main stakeholders; (ii) to strengthen participation and contributions to the collection, organization, and dissemination of information on heritage sites; and (iii) to promote the continuation and development of the heritage value of urban historical landscape. Figure 14 shows the development and application route of full-cycle landscape data from Chinese royal gardens. Figure 15 shows the real-time cloud interaction between mobile and computer information for users with different needs.

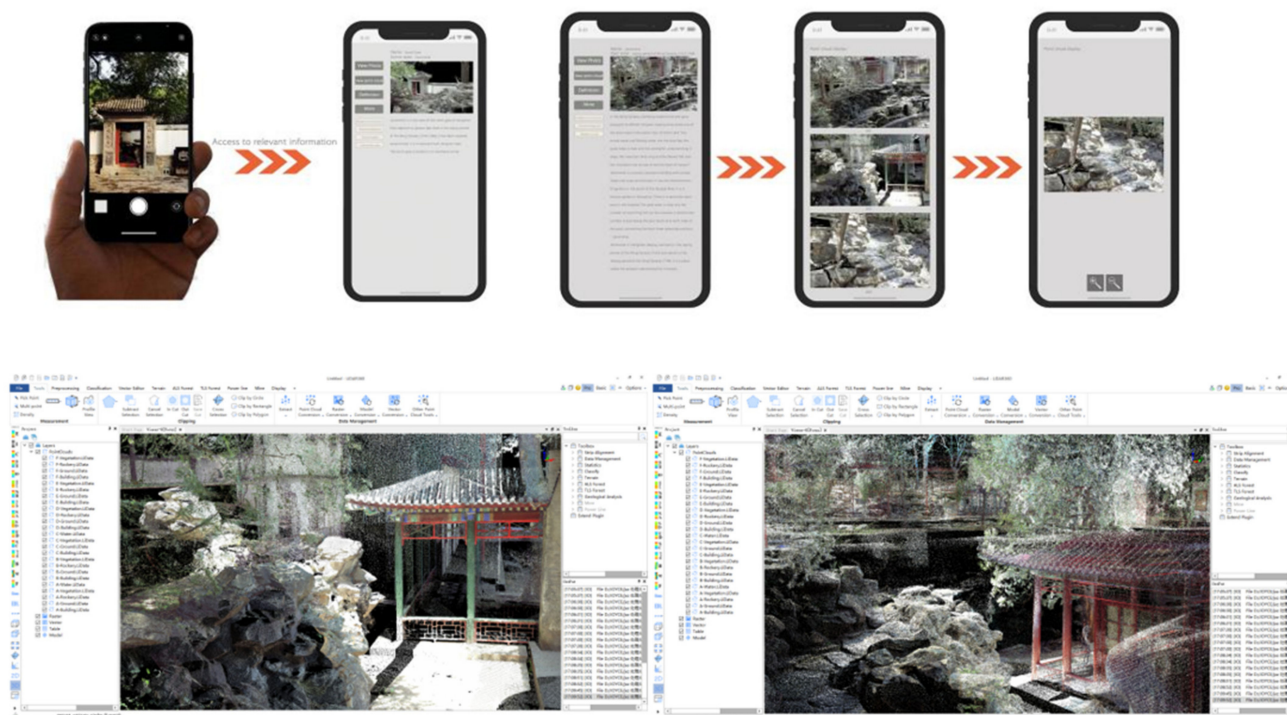


Figure 15. Real-time cloud interaction between mobile and computer information.

4. Conclusions

This study explained how to collect and classify 3D digital information from classical Chinese royal gardens, how to construct an information model of these gardens, and how to use these results and methods for the conservation, management, and subsequent application of cultural heritage. By integrating existing theories and methods, and based on the characteristics and research needs of classical Chinese royal gardens, we suggested a digital method that can be used for the management and application of cultural heritage in such sites. Methods for the digital identification and collection of information used for the construction of an information model of classical Chinese royal gardens, the fine splitting and integration of garden data, the information protection and management of garden elements, and the subsequent development and application space are proposed. These methods are not only useful for the conservation of classical Chinese royal gardens, but also for overcoming the limitations of traditional classical Chinese garden surveys and studies; they are also applicable to other, similar cultural heritage studies or projects. By establishing a collaborative digital platform for landscape heritage conservation, the history, status, intervention, and management of gardens can be organically integrated, transforming landscape heritage from a passive to an active and systematic form of conservation. It can also provide a reference for subsequent cultural heritage conservation and digital development efforts.

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