

SYSTEMATIC METHOD FOR MONITORING AND EARLY-WARNING OF GARDEN HERITAGE ONTOLOGY USED IN THE SUZHOU CLASSICAL GARDEN HERITAGE

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Highlights

- ▶ This article refines monitoring indicators and evaluation standards for garden heritage ontologies.
- ▶ Quantifies monitoring data of garden heritage ontologies.
- ▶ Specifies early-warning gradation which can exhibit further damage level for garden heritage.
- ▶ Constructs garden heritage monitoring and early-warning grading model based on fuzzy cluster analysis.
- ▶ Obtains early-warning gradation results for architecture, ancient tree, rock, water and furnishing heritage.
- ▶ Spatial distribution map of early-warning grade was obtained.

Abstract. Taking garden heritage ontologies as the object, this paper explores monitoring and early-warning methods of heritage based on fuzzy cluster analysis. A monitoring and early-warning system for garden heritage ontologies is designed and consists of monitoring indexes, a monitoring program, monitoring data collection, application of an early-warning grading evaluation model and conclusion of early-warning grading. Taking the Suzhou classical garden heritage as an example, it can be concluded that the systematic method can integrate various qualitative and quantitative index values and collectively reflect the overall state of garden heritage ontologies as well as match a heritage monitoring ontology with an early warning grade by calculating the data similarity matrix, membership matrix, fuzzy similarity matrix, fuzzy equivalent matrix and cut matrix. Five kinds of heritage ontologies with a total of twenty-seven heritage monitoring indicators are applied in the model and then be matched with MATLAB software to obtain accurate early-warning results. When types of heritage ontology need to be expanded, the heritage is further refined, or the heritage is more comprehensive, this method is applicable.

Keywords: garden heritage, monitoring and early warning, Suzhou classical garden, early-warning gradation, systematic method.

Introduction

Garden heritage refers to the natural and cultural heritage that is strongly related to the construction and aesthetic activities of the landscape, including natural and cultural heritage sites that have been registered in national and world heritage lists, and the tangible heritage protected by law but not yet registered on the heritage lists, such as traditional gardens, cultural landscapes, and scenic spots (Li & Yuan, 2014). From the Athens Charter (Congrès International d'Architecture Moderne [CIAM], 1933) and

the Venice Charter (International Council of Monuments and Sites [ICOMOS], 1964) to the Convention Concerning the Protection of the World Cultural and Natural Heritage (United Nations Educational, Scientific and Cultural Organisation [UNESCO], 1972), the protection of garden heritage has gone through the process of ideological beginning, protection principles and consensus formation. The Charter of the International Council on Monuments and Sites adopted in Moscow (ICOMOS, 1978) explicitly defined valuable historical parks as heritage sites under

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protection for the first time. The Florence Charter (ICOMOS & International Federation of Library Associations [IFLA], 1981) clearly defined the concept of a historical garden.

In 1992, the concept of cultural garden heritage was proposed (UNESCO World Heritage Centre, 1992). The Operational Guidelines for the Implementation of World Heritage Convention (UNESCO World Heritage Centre, 1992) identified park landscapes as landscapes intentionally designed and built by humans and stated that they are often (but not always) related to religion or other monuments or groups of buildings. As one theme of cultural garden heritage, garden heritage is an important part of cultural garden heritage. At present, there are 27 world heritage sites with a garden theme (Wu et al., 2016). China has 5 of these sites. They are the Chengde Mountain Resort (1994), Suzhou Classical Gardens (1997, 2000), Summer Palace (1998), Beijing Royal Altars-Temple of Heaven (1998) and Hangzhou West Lake (2011) (Li & Yuan, 2014; Wu et al., 2016). In addition to world heritage sites, China also has a kind of garden heritage with cultural relics protection. At present, the list consists of 537 garden heritage sites (Wu et al., 2016). The principles for conservation of heritage sites in China states that cultural landscape is a kind of cultural relic and historic site with living characteristics, and it is in a process of constant change. Suzhou Classical Gardens have become weak and vulnerable as time has gone by. Improper use and erosion by natural forces often cause accidental damage to the garden. Therefore, using scientific methods to explore the classical garden heritage monitoring and early-warning system is an important component of current heritage conservation research (Feilden & Jokilehto, 2008).

The UNESCO World Heritage List contains more than 1,000 cultural, natural and mixed heritage sites, many of which are threatened today (Cigna et al., 2018). Levin pointed out that 54 UNESCO World Heritage Sites are in danger, of which 40% are in the Middle East (Levin et al., 2019). To reduce the risk of conflict, preventive protection is an effective method for heritage site protection (Eken et al., 2019). UNESCO has proposed to carry out world heritage monitoring for 20 years, and requires monitoring sites to provide monitoring reports every 6 years (Zhou, 2015). In 2002, the United Kingdom introduced the Draft Indicators for World Heritage Monitoring (Zhang, 2011). In 2009, UNESCO proposed the concept of risk management for cultural heritage monitoring (Song, 2013). A risk assessment system for cultural heritage protection in Italy began (Arborea et al., 2014). Both Canadian and British heritage management agencies have introduced advanced technologies to monitoring (Kiriyama et al., 2010) and evaluated the collected monitoring data (Madole, 2014). Wu combined the cases of the Suzhou Tiger Hill Pagoda, the main hall of Baoguo Temple, and the Winding Brook Chamber of Lingering Garden to find solutions to heritage problems from the perspective of monitoring and maintenance (Wu, 2011).

Zhang pointed out difficulties and significant features in monitoring heritage sites in China (Zhang, 2012). Zhu conducted research into monitoring technologies (Zhu et al., 2010). Jiang focused on dynamic monitoring theory, indicators, and technologies based on RS, GIS and GPS technology (Jiang, 2010).

The early warning of garden heritage protection is to analyze and evaluate the garden heritage and its external space status in a certain period, then forecast, determine the space condition and change trend, speed, etc., forecast the space-time scope and danger degree of abnormal conditions, and put forward warning information and corresponding preventive measures according to the specific situation of abnormal changes (Yang et al., 2015). Early warning is the ultimate goal for monitoring. Early warning in the field of cultural heritage did not officially become a responsibility of the UNESCO World Heritage Centre until 1994. Bahraminejad proposed an early warning system and optimization method that can make up for deficiencies in protection and management of heritage sites (Bahraminejad et al., 2018). Leng studied the protection of historical villages based on the fuzzy analytic network process (F-ANP) (Leng, 2011). Wei studied ancient trees in the Humble Administrator's Garden in Suzhou and proposed early warning levels and protection measures for ancient trees (Wei et al., 2010). Yang proposed the object, content, method and effect of early warnings for garden heritage sites (Yang et al., 2015).

In summary, the international conventions and heritage protection charters indicate the recognition of garden heritage protection and put forward the basis and guidelines for garden heritage protection. Many studies have revealed techniques, monitoring and early-warning methods for garden heritage protection. However, there have been too many qualitative discussions in the past, and quantitative studies are still lacking. Compare to community participation in cultural heritage management (Li et al., 2020) research in this paper concerned government-led monitoring and applied a new method to work with monitoring data in which comprise five heritage ontologies, four criteria and 27 indicators. Not only analyzing species diversity (Cheryl et al., 2018), assessing the heritage value of scenic, natural and cultural (Carolina et al., 2018), it focused on architectural heritage, ancient tree heritage, rock heritage, water heritage and furnishing heritage, pursued improvement of heritage management in accordance with monitoring and early-warning results obtained. The research revealed that active participant (Hotimah et al., 2015), especially monitoring heritage becomes absolutely necessary to preserve garden heritage ontologies. Different from regarding BIM as a resource in heritage management (Godinho et al., 2019), this work applied Matlab software and implement more matrix calculation to achieve a manageable model as a useful decision support tool within the heritage management framework. The method and practice can develop the policy networks (Zhao et al., 2020) of garden heritage protection management.

1. Method

Based on monitoring of the Suzhou Classical Garden heritage ontologies, this paper proposes a monitoring and early-warning indicator system and evaluation criteria for garden heritage ontologies and then carries out early warning grading in the Suzhou Classical Garden using fuzzy cluster analysis (Wen & Ding, 2001).

1.1. Indicators and weights for monitoring and early warning of garden heritage

According to differences in building appearance, building structure, and building decoration, there are 11 monitoring indicators related to buildings, such as vertical settlement, column inclination, deflection of beam, and building displacement. Monitoring indicators of garden rocks focus on safety and affected factors. The indicators include plant influence, water influence, human influence, and security and stability of the rocks. Monitoring indicators for ancient trees include growth situation, site environment, trauma symptoms, and the degree of damage. Water monitoring indicators include changes in water form and quality. Monitoring indicators for furnishings are divided into 5 categories according to furnishings and management. All indicators are shown in Figure 1.

Aided by MATLAB software, the AHP method was used to determine weights for early warning evaluation based on monitoring indicators of garden heritage ontologies and passed the consistency test. According to saaty 1–9 scale method, the measurement scale was divided into nine levels, among which 1, 3, 5, 7, 9 correspond to equally important, slightly important, relatively important, very important and absolutely important, while 2, 4, 6, 8 is between two adjacent states. Combined with hierarchical structure of indicators, along with scores from experts in a meeting, the judgment matrix of relative importance for indicators in five heritage ontologies are obtained, as shown in Tables A1–A5 of Appendix. All weights are shown in Table A6 of Appendix.

1.2. Early-warning evaluation standards for garden heritage ontologies

The evaluation standard is the criterion for evaluating the damage to heritage ontologies. The early-warning grades for garden heritage are divided into normal, first level, second level and third level. The corresponding evaluation score is from 1 to 4 points. The early-warning evaluation standards for garden architecture heritage are shown in Table A7 of Appendix.

1.3. Garden heritage early-warning grading model based on fuzzy cluster analysis

Fuzzy clustering analysis methods (Fuzzy C-Means Algorithm) are suitable for robust analysis of non-precise data, especially subjective data (Ferraro & Giordani, 2017). It was used to investigate the sustainability of renewable energy (Wang & Yang, 2020), integrate cooperative game data envelopment analysis model with application in hospital efficiency (Omrani et al., 2018) as well as online control indoor environment’s safety and health (Cao et al., 2020). Since garden heritage monitoring and early warning evaluation are relate to many subjective indicators, the grading model can derive from this method. Articles in Fuzzy Sets and Systems journal show more detail processing, formula and matrixes (Saha & Das, 2018). Main steps of fuzzy clustering analysis comprise similarity matrix, membership matrix, fuzzy similarity matrix, fuzzy equivalent matrix, λ -cut matrix construction and so on (Wen & Ding, 2001).

The model integrates various qualitative and quantitative monitoring values and collectively reflect the overall state of heritage ontologies. First, through initial quantification of the data, the model puts all qualitative and quantitative indicators of heritage monitoring objects together for data analysis. Second, it matches a heritage monitoring object with an early warning grade through calculation of the data similarity matrix, membership matrix, fuzzy similarity matrix, fuzzy equivalent matrix and cut matrix. It classifies the early warning level of heritage monitoring objects.

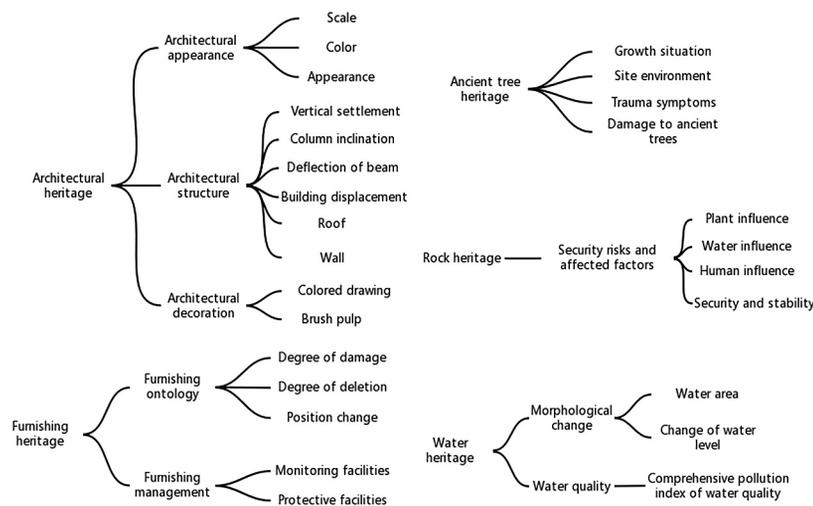


Figure 1. Monitoring indexes of garden heritage

1.4. Monitoring and data collection

Heritage monitoring uses a combination of on-site inspection, visual inspection, and instrument monitoring. The monitoring work is divided into two sub-items: daily monitoring and deformation monitoring (Bai et al., 2013). Daily monitoring relies on patrol and visual inspections. Monitoring content includes the peeling, pollution, and fading of paint on walls, columns, beams, doors, windows and guardrails. Other items include whether the roof, doors and windows are damaged or rotten, whether there are cracks or leaks on the roof, whether the tiles and ridge are intact, whether there are weeds on the roof and so on. Finally, one monitors whether the wall is deformed, inclined, weathered, or soaked and whether the surface of brush slurry has fallen off or is moldy or discolored.

Deformation monitoring includes monitoring the vertical settlement, horizontal displacement, column inclination,



Figure 2. Building Structural Monitoring

and beam deflection. It must be carried out strictly in accordance with the Code for Measurement of Building Deformation. Vertical settlement monitoring uses precise level measurement methods, and settlement monitoring points are placed under the pillars of each building. The adjustment control software Nasew V3.0 (Sunwaysurvey, Beijing, China) of the engineering control network was used to carry out rigorous adjustment calculations, and the elevation values for each settlement monitoring point were obtained. Vertical settlement of monitoring points is the difference between this monitored elevation value and the last monitored elevation value. Horizontal displacement monitoring is performed by the total station polar coordinate method; several monitoring points are arranged on each building, and each monitoring point is arranged on a column. Column tilt monitoring is monitored by using a hanging plumb line, and the amount of architectural tilt can be determined based on its deviation value. Deflection is the bending value of a garden building and its components in a horizontal or vertical direction. Beam deflection monitoring uses a total station to directly measure the elevation of each nail root and takes the difference between average elevations of two ends and elevation at the middle. Figure 2 shows beam deflection, horizontal displacement monitoring, and damage to the wall and leaking windows.

1.5. Systematic method of garden heritage monitoring and early warning

Indicators of heritage ontology at garden heritage sites are monitored. Combined with monitoring data, based on early-warning evaluation standards and index weights, and quantified and standardized monitoring data, the early-warning grading evaluation model was applied and MATLAB software was used for calculations, leading to a systematic method of garden heritage monitoring and early warning, as shown in Figure 3.

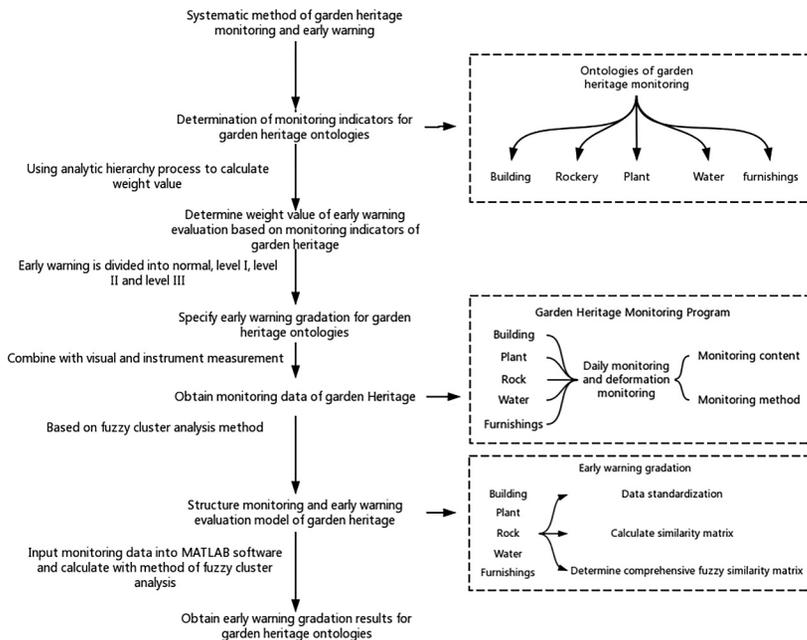


Figure 3. Garden heritage monitoring and early warning system

The garden heritage monitoring and early-warning system involves five kinds of heritage ontology, for a total of twenty-seven heritage monitoring indicators. Considering the large number of monitoring objects at a heritage site and the monitoring results for many years, a large amount of monitoring data is available. These data can be fully combined with the heritage monitoring and early-warning system, undergo scientific analysis, and then be matched with MATLAB software, to obtain accurate early-warning results.

2. Results and discussions

2.1. Garden architecture

2.1.1. Monitoring results

Five representative buildings (the Cloud-crowned Peak, the Hanbi Mountain Villa, the Pellucid Building, the Donglai Cottage, the Sishi Hall) among 20 architectural heritage sites of the Lingering Garden and Garden of Cultivation were taken as examples. Quantitative data, including vertical settlement, horizontal displacement, column tilt and beam deflection, were monitored. The qualitative monitoring data are the latest data from building monitoring. Data in Table 1, Table 2, Table 3 and Table 4 were obtained in August 2018 and reflect the monitoring records of vertical settlement, horizontal displacement, and beam deflection at the Cloud-crowned Peak in the Lingering

Garden. Table A8 (in Appendix) shows the raw data for all monitoring indicators for five buildings.

Table 1. Settlement monitoring record of the Cloud-Capped Building in the Lingering Garden

Column number	Last elevation (mm)	Current elevation (mm)	Settlement amount (mm)	Settlement rate (mm/d)
Column number 1	2398.82	2400.27	1.45	0.0020
...
Column number 7	2422.71	2425.44	2.73	0.0038
...
Column number 13	2423.66	2425.24	1.58	0.0022
Maximum settlement rate: 0.0038 mm/d				

2.1.2. Quantification of qualitative monitoring data

Many indicators in garden heritage monitoring are qualitative. For example, the scale, color, shape, roof, wall, painting of garden architecture and all rockery, plants and furnishings monitoring indicators are qualitative indicators. A qualitative index can be quantified by the early warning evaluation standard. First, one assigns different grades to the early warning of the heritage ontology (as

Table 2. Displacement monitoring record of the Cloud-Capped Building in the Lingering Garden

Monitoring point	Last coordinate value (mm)		Current coordinate value (mm)		Deformation value (mm)		Tools used
	X	Y	X	Y	ΔX	ΔY	
A (column 1)	45 194 045	51 240 052	45 194 048	51 240 055	3	3	Total station TS30, Reflector
B (column 7)	45 198 284	51 251 360	45 198 279	51 251 364	-5	4	
Maximum displacement: 5 mm							

Table 3. Tilt monitoring record of the Cloud-Capped Building in the Lingering Garden

Column number	Last measurement data (mm)				Current measurement data (mm)				Conclusion (mm)
	east	west	south	north	east	west	south	north	
Column number 2		20	8			30	28		10 to west, 20 to south
Column number 6		30	32			35	55		5 to west, 23 to south
...	
Column number 13	12		45		13		50		1 to east, 5 to south
Analysis: Inclination of No. 2, No. 6 and No. 12 columns changes greatly, so attention shall be paid to maintenance. Maximum column inclination: 23 mm									

Table 4. Deflection monitoring record of the Cloud-Capped Building in the Lingering Garden

Number of bearing beam	Length of bearing beam (mm)	Last measurement (mm)	Current measurement (mm)	Change value (mm)
Numbers 4–13	4400	10	-10	-20
Numbers 1–10	4400	3	9	6
Maximum deflection of beam: 20 mm				

Note: “+” is downward, “-” is upward.

shown in Table A7 of the Appendix). Second, one compares monitoring results of the heritage ontology with the early-warning grade evaluation standards and scores them. For example, after initial quantification of monitoring data in Table A8, Table A9 (in Appendix) is obtained.

2.1.3. Early warning results

Based on the monitoring data, the early-warning evaluation method for heritage was applied and analyzed by MATLAB software, and the early-warning grades of five buildings were obtained, as shown in Table 5.

Table 5. Early warning grade for architecture in the Lingering Garden and Garden of Cultivation

Early-warning grade	Name	Location
Normal	The Donglai Cottage; The Sishi Hall	Garden of Cultivation
First level	The Hanbi Mountain Villa	Lingering Garden
Second level	The Cloud-Capped Building	Lingering Garden
Third level	The Pellucid Building	Lingering Garden

Taking all garden architecture in the Lingering Garden and Garden of Cultivation as the object, a spatial distribution map of early-warning grade was obtained, as shown in Figure 4 and Figure 5.

For the evaluation of early warning grade of architectural

heritage, it is necessary to subdivide the monitoring index system and select the most critical indicators, the disease types of the architectural heritage shall be investigated before the assessment, the existing structural problems and natural environmental impact factors shall be diagnosed to avoid over monitoring (Mesquita et al., 2018). The main information collection methods of digital monitoring of architectural heritage include traditional measurement technology, Photogrammetric technology and 3D laser scanning technology (Zhou, 2018). Traditional measurement technology from data acquisition to analysis has to go through manual processing. Photogrammetric technology has a wider range of data collection, and also makes the work efficiency significantly improved. 3D laser scanning technology is mainly used in the monitoring of the surface damage and geometric deformation of architectural heritage (Campiani et al., 2019). A monitoring and management system of architectural heritage based on the data results of digital technology was summarized, but did not make a study on the early warning of architectural heritage (Gao, 2018). A finite element software ANSYS can also be used to proposed the damage early warning mechanism applicable to traditional wood structure (Meng, 2018).

2.2. Rock heritage

Taking all garden rocks in the Lingering Garden, Garden of Cultivation, Humble Administrator’s Garden and Lion Forest Garden as objects, the results of early-warning grade evaluation of rocks were obtained, as shown in Table 6.

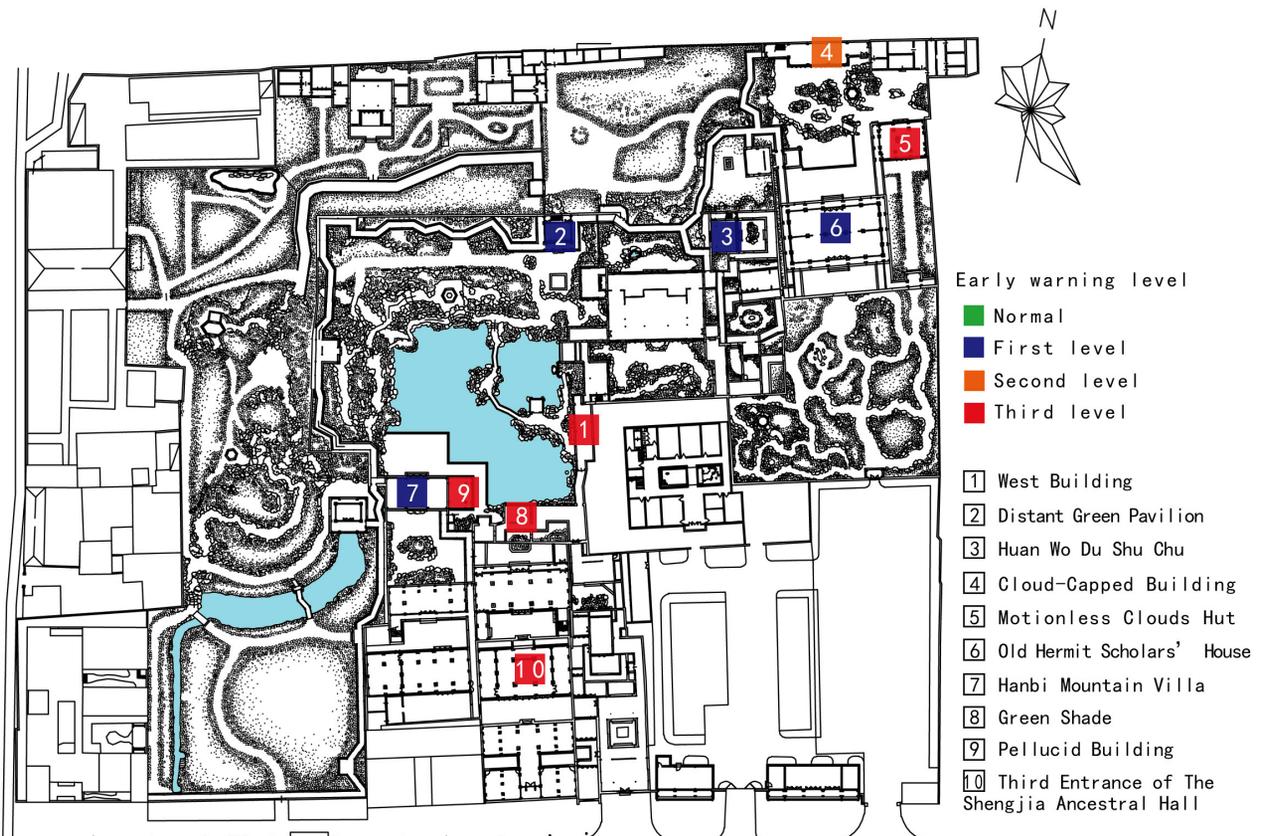


Figure 4. Early warning level of garden architecture heritage in the Lingering Garden

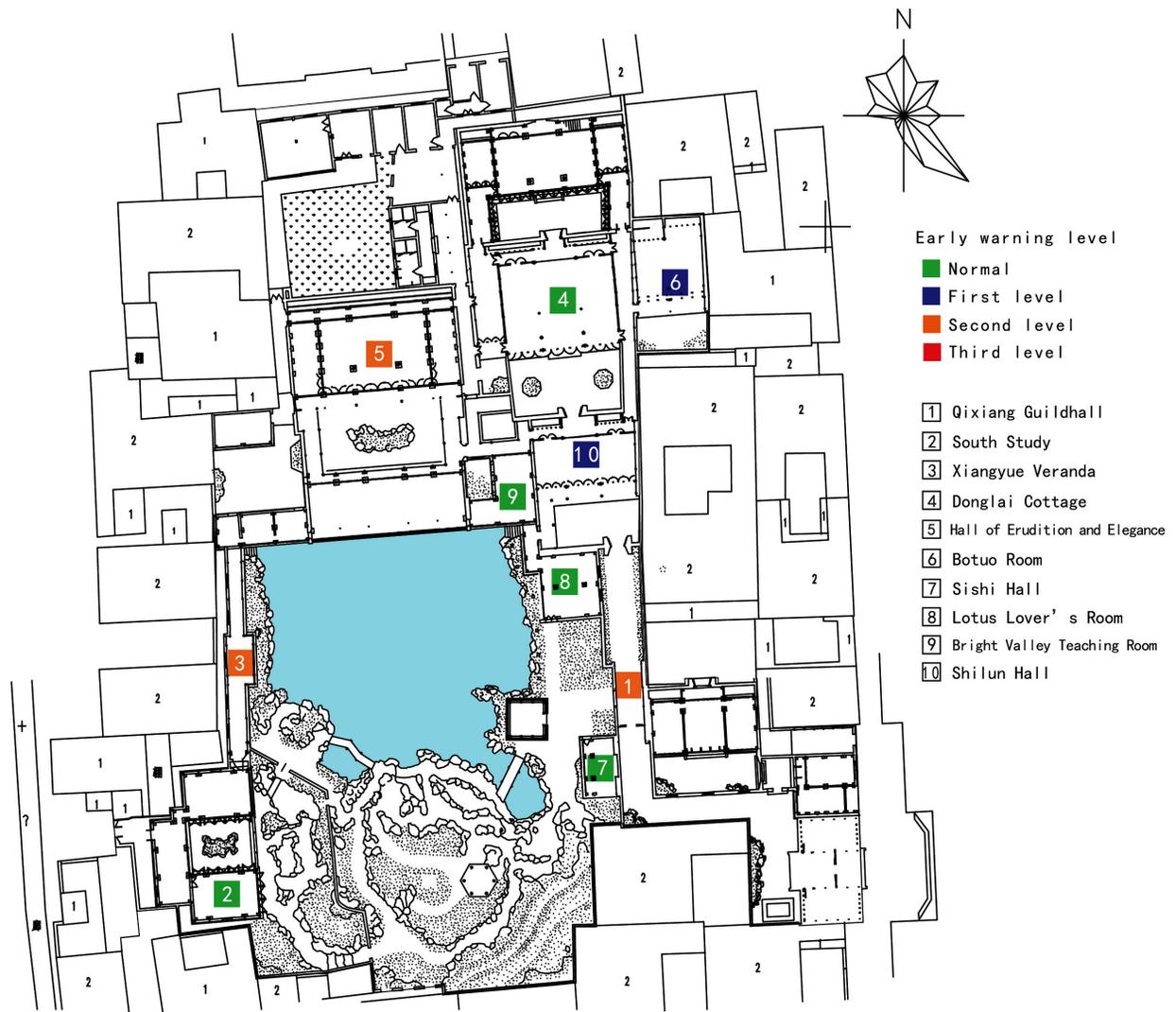


Figure 5. Early warning level of garden architecture heritage in the Garden of Cultivation

Table 6. Early-warning grade for rocks in the Lingering Garden, Garden of Cultivation, Humble Administrator's Garden and Lion Forest Garden

Early warning grade	Name	Location
Normal	Canglin Stone	Lingering Garden
First level	Cloud Capped Peak	Lingering Garden
Second level	Qingyao Island (north)	Garden of Cultivation
Second level	Lion Rolling Hydrangea	Lion Forest Garden
Third level	Water Shore Rock	Humble Administrator's Garden
Third level	Duanxia Peak	Lingering Garden
Third level	Rockery Hills	Lingering Garden

The shape of rock heritage is irregular, so it is difficult to measure it accurately by traditional measurement methods. A photogrammetry with lidar technology was proposed a digital measurement method for rockery heritage

(Zhang et al., 2018). UAV aerial camera and photogrammetry technology were also used to measure the rock heritage and compared the accuracy of the two technologies (Gu et al., 2016). Further, digital photogrammetry, lidar scanning and point cloud visualization technology were applied to collect spatial information of rockery and build a digital 3D model (Yang & Han, 2018). The appliance of new measurement technology makes it possible for the dynamic monitoring of the rock heritage. Comparing the data in different periods, it can be quickly and accurately identified the changes of elements for rockery heritage.

2.3. Ancient tree heritage

The archive of ancient trees in the Lingering Garden and Garden of Cultivation are shown in Table A10 of Appendix. Among them, No. 002# and 003# *Ginkgo biloba* Linn. was obviously tilted (Figure 6), and the growth of *Platycladus orientalis* (Linn.) and *Podocarpus macrophyllus* (Thunb.) Sweet was weak.

Taking all ancient trees in the Lingering Garden and Garden of Cultivation as objects, the results of the



Figure 6. The *Ginkgo biloba* Linn. obliquity is obvious in the middle of the Lingering Garden

early-warning grade evaluation of ancient trees were obtained, as shown in Table 7.

As time has gone by, the adaptability of ancient trees to environmental changes is gradually weakened, and the aging phenomenon is serious. Beside artificial on-site measurement and document recording, non-destructive testing technology, ultrasonic stress wave testing (Du, 2015), GPR testing (Gan, 2016) and micro drill resistance testing (Shi et al., 2017) were mostly used to obtain the data of tree diseases. For example, in Yangzhou Slender West Lake scenic spot, 157 ancient trees were evaluated for health by using non-destructive monitoring technology, 88.59% of them are in good health, and some of them are seriously decayed. On the other hand, mathematical morphology and skeleton extraction algorithm were used to finish the thin line processing of trunk image, so as to calculate the inclination angle of trunk (Jin, 2018). A real-time monitoring micro-environment based on Internet technology was conducted (Yin, 2016) which can help to avoid environmental effect to ancient trees.

Table 7. Early-warning grade of ancient trees in the Lingering Garden and Garden of Cultivation

Early warning level	Name	Location
Normal	No. 019# <i>Magnolia grandiflora</i> Linn.	Lingering Garden
First level	No. 018# <i>Lagerstroemia subcostata</i> Koehne	Lingering Garden
Second level	No. 016# <i>Platycladus orientalis</i> (Linn.) Franco	Lingering Garden
Second level	No. 012# <i>Podocarpus macrophyllus</i> (Thunb.) Sweet	Lingering Garden
Third level	No. 003# <i>Ginkgo biloba</i> Linn.	Lingering Garden
Third level	No. 002# <i>Ginkgo biloba</i> Linn.	Lingering Garden
Third level	No. 003# <i>Hovenia acerba</i> Lindl.	Garden of Cultivation

2.4. Water heritage

Water quality monitoring is mainly to monitor each sub item (BOD5, pH value, ammonia nitrogen, permanganate index, chroma, transparency, total phosphorus and water temperature) of comprehensive water quality pollution index through the monitor (Yuan, 2016). The June 2019 water quality monitoring report of the Suzhou Classic Garden heritage is shown in Table A11 of Appendix. The formula for comprehensive pollution index of water quality is:

$$P = \sum_{i=1}^n W_i \frac{C_i}{S_i}, \quad (1)$$

of which, P is the comprehensive pollution index of water quality, W_i is weight of monitoring project, C_i is over-standard score, and S_i is standard score. The standard score is determined using the Water Environment Quality Standard (GB3838-2002, China). Table A12 (in Appendix) is the initial quantification table for water monitoring data. All monitoring data can be quantified and combined with existing quantitative data for data standardization and then the fuzzy cluster analysis model is applied.

Taking water bodies in the Lingering Garden, Garden of Cultivation, Gentle Waves Pavilion, Master-of-Nets Garden and Lion Forest Garden as the objects, the results for the early-warning grade evaluation for water bodies were obtained, as shown in Table 8.

Table 8. Early-warning grade for water in the Suzhou Classical Garden

Early warning grade	Water bodies and locations
Normal	Central pond in Garden of Cultivation
Normal	Central pool in Lingering Garden
Normal	Internal pool in Gentle Waves Pavilion
First level	Rosy clouds pool in Master-of-Nets Garden
First level	Huanyun billabong, east of Lingering Garden
Second level	Western stream of Lingering Garden
Third level	Mid-lake Pavilion of Lion Forest Garden

Although the measurement is accurate, only discrete sample point data was acquired, and the change rule of large-scale water monitoring data cannot be obtained. This status will be improved by remote sensing technology (Sagan et al., 2020) and large-scale water monitoring data (Chawla et al., 2020; Wang et al., 2020). For the evaluation of water areas with special pollutant types, the single-factor index evaluation method has the problem that the single-factor influence is too large, and the objectivity of the evaluation results cannot be guaranteed (Zhu, 2019). While the method used in the paper produced high accurate and practicable results, which can effectively reduce the impact of single factor on the early-warning results.

2.5. Furnishings heritage

Taking furnishings in the Lingering Garden and Garden of Cultivation as the objects, the results of early-warning grade evaluation of furnishings were obtained, as shown in Table 9.

Table 9. Early-warning grade of furnishings in the Suzhou Classical Garden

Early-warning grade	Category	Location
Normal	Furniture in Enchanted Hall of Five Peaks	Lingering Garden
First level	Calligraphy and painting hanging in Donglai Cottage	Garden of Cultivation
First level	Corridor lantern	Lingering Garden
Second level	Two Kings Stickers Stone	Lingering Garden
Third level	Hall furnishings	Garden of Cultivation
Third level	Miss Building	Garden of Cultivation

A computer technology was used to monitor outdoor furnishings in real time, and collected surface image information (Lin, 2016). Through the parameter evaluation system of K-means clustering algorithm, the monitoring indicators of indoor furnishings can be divided into three levels: excellent, good and substandard (Guo et al., 2019). Furnishings heritage indicators in WGRFM model include 4 secondary indicators, and 4 to 21 tertiary indicators, a total of 61 which was used to predict the displacement and fracture of outdoor furnishings heritage (Zhang, 2016). Work in this paper was applied to monitor and early warn of furnishings heritage indoors and outdoors.

3. Practical applications and future research perspectives

In the 1990s, the demand of “systematic monitoring of world cultural heritage” was put forward. China participated in the preparation of the second round of periodic report in 2010–2011, providing the possibility for follow-up data tracking and analysis (Wei, 2019). In 2015, after two rounds of periodic reports, China began to implement the annual report system of world cultural heritage monitoring, and fulfilled the monitoring obligations at the national level (Zhao, 2018). This policy not only provides a standardized module for the monitoring and early warning of world cultural heritage, but also becomes an important guiding ideology for the systematic monitoring of heritage sites.

Based on the existing monitoring system of heritage sites, this paper constructs a monitoring and early warning model for garden heritage, and applies it to practical projects. Good reference is provided to continuously monitoring of Suzhou Classical Garden and other heritage

sites. At present, heritage monitoring technology is developing from traditional measurement methods to digital technology. More accurate monitoring data can be obtained by using remote sensing technology to avoid the generation of monitoring data errors (Li, 2020). In construction of garden heritage monitoring and early warning, it is necessary to integrate and analyze the data. Big data technology has five advantages such as large quantity, many kinds, high value, fast speed and high precision (Gan, 2017). It can carry out data analysis across departments and regions. It is a new research direction to achieve more scientific and comprehensive management, which has great development space and application prospects (Gao et al., 2019).

According to the subordination of the evaluated objects, fuzzy cluster analysis is carried out from multiple indexes. Combining the qualitative and quantitative factors for the ontologies, the results of early warning and grading of garden heritage proposed in this study are objective. But it is necessary to use AHP method to discuss the evaluation indexes in a more detailed and hierarchical way, so as to avoid the occurrence of super fuzzy phenomenon (Cheng, 2017).

With regard to relationship between environmental factors and diseases of heritage, this paper considers that the monitoring and early warning system of garden heritage is not only limited to the garden heritage itself, but also the influencing factors of the garden heritage. The research needs to establish an environmental monitoring database to provide data for the early warning system of environmental factors (Lombardo et al., 2019), and continue to explore the impact of temperature, humidity, light, environmental pollution, passenger flow on the heritage early warning level.

Results of early warning gradation reflect the damage degree and alarm level of garden heritage, but it can't determine the most dangerous critical alarm value of heritage object. In addition to the corresponding level of early warning, the management measures of heritage protection should also be directly corresponding to the monitoring data, so as to facilitate the adoption of protection measures in case of extreme changes in a single factor and avoid the indirect obstruction of the implementation of heritage protection measures by the level of early warning. How to combine early warning gradation results of heritage with specific management measures of heritage protection and utilization is a problem that needs further discussion.

Conclusions

Early warning is the goal of monitoring. Only through early warning can the monitoring value be truly reflected. Garden heritage monitoring and early warning are an important part of garden heritage protection. After long-term heritage monitoring, combined with the garden heritage early-warning model, the damage to heritage monitoring objects is analyzed by cluster analysis and classified by early warning and management, so that monitoring

can play a practical role. Garden heritage monitoring and early-warning systems can make heritage protection more targeted, more prompt and effective.

The early-warning classification results aimed at five types of heritage ontology. If types of heritage ontology need to be expanded, the heritage is further refined, or the heritage is more comprehensive, the systematic method is also applicable. Garden heritage monitoring and early-warning systems can provide early warnings for heritage ontology itself, heritage single points and even heritage sites. It integrates garden heritage into heritage monitoring indicators (including index weight), index evaluation standard, early-warning grade, and so on, according to heritage site, heritage ontology, and influencing factors, and it realizes the dual goals of garden heritage monitoring and early warning under the support of powerful monitoring technology and monitoring behavior.

Garden heritage protection is a long-term systematic engineering project. With research in garden heritage monitoring and early-warning gradation, the ontologies of heritage are clustered and classified, and a large amount of accurate results from monitoring data operation is obtained. That makes it possible to monitor and early warn the garden heritage in absence of critical thresholds for heritage monitoring and early warning to avoid catastrophe, loss, and destructive events in heritage protection and management. The research can realize scientific long-term dynamic monitoring and protective early warning for garden heritage sites.

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APPENDIX

Table A1. Relative importance judgment matrix for monitoring indicators of architecture heritage

Architectural heritage	Scale	Color	Appearance	Vertical settlement	Column inclination	Deflection of beam	Building displacement	Roof	Wall	Color drawing	Brush pulp
Scale	1	3	2	1/4	1/4	1/5	1/3	2	1/2	1/3	1/3
Color	1/3	1	1/2	1/6	1/6	1/7	1/5	1/2	1/4	1	1
Appearance	1/2	2	1	1/5	1/5	1/6	1/4	1	1/3	2	2
Vertical settlement	3	6	5	1	1	2	1/2	5	3	6	6
Column inclination	4	6	5	1	1	1/2	2	5	3	6	6
Deflection of beam	5	7	6	2	2	1	3	6	4	7	7
Building displacement	3	5	4	1/2	1/2	1/3	1	4	2	5	5
Roof	1/2	1/2	1	1/5	1/5	1/6	1/4	1	1/3	2	2
Wall	2	4	3	1/3	1/3	1/4	1/2	3	1	4	4
Color drawing	1/3	1	1/2	1/6	1/6	1/7	1/5	1/2	1/4	1	1
Brush pulp	1/3	1	1/2	1/6	1/6	1/7	1/5	1/2	1/4	1	1

Table A2. Relative importance judgment matrix for monitoring indicators of rock heritage

Rock Heritage	Plant influence	Water influence	Human influence	Security and stability
Plant influence	1	2	3	1/3
Water influence	1/2	1	3	1/4
Human influence	1/3	1/3	1	1/5
Security and stability	3	4	5	1

Table A3. Relative importance judgment matrix for monitoring indicators of ancient tree heritage

Ancient Tree Heritage	Growth situation	Site environment	Trauma symptoms	Damage to ancient trees
Growth situation	1	1/3	2	1/4
Site environment	3	1	4	1/3
Trauma symptoms	1/2	1/4	1	1/5
Damage to ancient trees	4	3	5	1

Table A4. Relative importance judgment matrix for monitoring indicators of water heritage

Water heritage	Water area	Water level	Comprehensive pollution index of water quality
Water area	1	1/2	1/5
Water level	2	1	1/3
Comprehensive pollution index of water quality	5	3	1

Table A5. Relative importance judgment matrix for monitoring indicators of furnishing heritage

Furnishing heritage	Degree of damage	Degree of deletion	Position change	Monitoring facilities	Protective facilities
Degree of damage	1	1/3	3	1/2	2
Degree of deletion	3	1	5	2	4
Position change	1/3	1/5	1	1/4	1/2
Monitoring facilities	2	1/2	4	1	3
Protective facilities	1/2	1/4	2	1/3	1

Table A6. Weights value of monitoring indicators for garden heritage ontologies

Indicators	Weight value										
	Scale	Color	Appearance	Vertical settlement	Column inclination	Deflection of beam	Building displacement	Roof	Wall	Color drawing	Brush pulp
Architectural heritage	0.06	0.02	0.04	0.16	0.17	0.25	0.14	0.04	0.08	0.02	0.02
Rock Heritage	Plant influence			Water influence		Human influence		Security and stability			
	0.23			0.16		0.08		0.54			
Ancient Tree Heritage	Growth situation			Site environment		Trauma symptoms		Damage to ancient trees			
	0.12			0.27		0.08		0.53			
Water heritage	Water area			Water level		Comprehensive pollution index of water quality					
	0.12			0.23		0.65					
Furnishing heritage	Degree of damage			Degree of deletion		Position change	Monitoring facilities		Protective facilities		
	0.16			0.42		0.06	0.26		0.10		

Table A7. Early warning evaluation standard for garden architecture heritage

Indexes	Early Warning grade				
	normal (1 point)	first level (2 points)	second level (3 points)	third level (4 points)	
Architecture appearance	scale	Scale, volume and elevation have not changed, the relationship between building and garden environment has not changed	Scale, volume and elevation change slightly, basically maintaining the relationship between building and garden environment	Scale, volume and elevation change greatly, which affects the relationship between building and garden environment	Large changes have taken place in scale, volume and elevation, which seriously affect the relationship between building and garden environment

Indexes		Early Warning grade			
		normal (1 point)	first level (2 points)	second level (3 points)	third level (4 points)
	Color	No change in color of roof, wall, column, beam frame, door and window, no effect on architectural style and authenticity	Color of roof, wall, column, beam frame, door and window changes partly, no effect on overall architectural style and authenticity	Color of roof, wall, column, beam frame, door and window changes in large areas, which affects the overall architectural style and authenticity	Color of roof, wall, column, beam frame, door and window changes too much, overall architectural style is damaged, the authenticity is missing
	Appearance	Appearance of roof, corner warping, door and window shape, beam frame, etc. has no change, maintained authenticity	Small changes happen in the shape of roof decoration, corner warping, door and window, beam frame, etc. No effect on overall authenticity	Appearance of roof decoration, corner warping, door and window shape, beam frame, etc. has changed greatly, which affects the authenticity	Large changes to the shape of roof decoration, corner warping, door and window, beam frame, etc. Seriously affecting the authenticity
Architecture structure	Vertical settlement	Settlement rate is between -0.01 mm/d and 0.005 mm/d	Settlement rate is between -0.01 mm/d and -0.08 mm/d or 0.005 mm/d and 0.03 mm/d	Settlement rate is between -0.08 mm/d and -0.15 mm/d or 0.03 mm/d and 0.08 mm/d	Settlement rate is greater than -0.15 mm/d or 0.08 mm/d
	Column inclination	Change value is less than 10 mm	Change value is between 10 and 30 mm	Change value is between 30 and 60 mm	Change value is greater than 60 mm
	Deflection of beam	Change value is less than 5 mm	Change value is between 5 and 10 mm	Change value is between 10 and 20 mm	Change value is greater than 20 mm
	Building displacement	Change value is less than 5 mm	Change value is between 5 and 10 mm	Change value is between 10 and 20 mm	Change value is greater than 20 mm
	Roof	No leakage on roof, tile and ridge are in good condition, no weeds on roof	Roof is covered with grass, ridge and tile are slightly damaged	Small cracks on roof allow some rain leakage, roof ridge and tile are damaged	Roof rain leakage area is large, tile and ridge are seriously broken
	Wall	Wall is intact without inclination	Some walls are deformed and some windows are damaged	Deformation of wall is serious, or wall is weathered and caustic	Wall is weathered and caustic, wall body is tilted seriously, leaking window is damaged
Architecture decoration	Color painting	Color painting is not fading, cracking, warping or falling	Color painting has fading reaction or small cracks	Color painting has obvious fading, cracking, warping and falling off	Color painting is seriously fading, cracking, warping and falling off
	Brush pulp	No peeling damage or change in brush pulp	Smudging, mildew and discoloration happen partly in brush pulp	Brush pulp is peeling, damaged and corroding	A large area of peeling and serious damage to brush pulp

Table A8. Original monitoring data of architectural features in the Lingering Garden and Garden of Cultivation

Name of architectures	Location	Architecture appearance				Architecture structure						Architecture decoration	
		scale	color	appearance	Vertical settlement (mm/d)	Column inclination mm	Deflection of beam mm	Horizontal displacement mm	Roof	Wall	Color drawing	Brush pulp	
The Cloud-Capped Building	Lingering Garden	Scale, volume and elevation have no change between building and garden environment has no change	Paint on doors and windows is seriously discolored	No change in shape, retains authenticity	0.0038	23	20	5	No leakage on roof, tiles and ridge are in good condition, no weeds on roof	Wall is intact without inclination	Color painting is not fading, cracking, warping and falling	No peeling damage	
The Hanbi Mountain Villa	Lingering Garden	Same as the Cloud-Capped Building	No change in color, retains architecture style and authenticity	Same as the Cloud-Capped Building	-0.0008	15	49	0	Same as the Cloud-Capped Building	Same as the Cloud-Capped Building	Same as the Cloud-Capped Building	Same as the Cloud-Capped Building	
The Pellucid Building	Lingering Garden	Same as the Cloud-Capped Building	Paint is spalling	Missing transparent tile	-0.0011	30	3	1	Same as the Cloud-Capped Building	Same as the Cloud-Capped Building	Same as the Cloud-Capped Building	Same as the Cloud-Capped Building	
The Donglai Cottage	Garden of Cultivation	Same as the Cloud-Capped Building	Same as the Hanbi Mountain Villa	Same as the Cloud-Capped Building	-0.002	22	14.5	4.1	Same as the Cloud-Capped Building	Wall deformation	Same as the Cloud-Capped Building	Same as the Cloud-Capped Building	
The Sishi Hall	Garden of Cultivation	Same as the Cloud-Capped Building	Color of cornice board faded seriously, approaching decay	Eaves damaged	0.001	12	10	5.2	Roof leakage	Same as the Cloud-Capped Building	Same as the Cloud-Capped Building	Same as the Cloud-Capped Building	

Table A9. Quantified garden architecture heritage monitoring data

Name of garden architecture	Location	Architecture appearance			Architecture structure						Architecture decoration	
		scale	color	appearance	Vertical settlement (mm/d)	Column inclination mm	Deflection of beam mm	Horizontal displacement mm	Roof	Wall	Color drawing	Brush pulp
The Cloud-Capped Building	Lingering Garden	1	3	1	0.0038	23	20	5	1	1	1	1
The Hanbi Mountain Villa	Lingering Garden	1	1	1	-0.0008	15	49	0	1	1	1	1
The Pellucid Building	Lingering Garden	1	2	4	-0.0011	30	3	1	1	1	1	1
The Donglai Cottage	Garden of Cultivation	1	1	1	-0.002	22	14.5	4.1	1	3	1	1
The Sishi Hall	Garden of Cultivation	1	2	2	0.001	12	10	5.2	2	1	1	1

Table A10. Statistics for ancient trees in the Lingering Garden

Numbers	Name	Position	Height	Bust (cm)	Base girth (cm)	Crown width	Tree age (year)	Growth situation
M-1	No. 002# <i>Ginkgo biloba</i> Linn.	West of central pool	25 m	340	370	17.2×17.9 m	343	Growth potential is strong, there are a few dead branches in the crown, inclination of tree is obvious.
M-2	No. 003# <i>Ginkgo biloba</i> Linn.	West of central the Satisfaction Pavilion	20 m	253	350	14.8×15.1 m	243	Growth potential is strong, but some thick roots are bare, and tree inclines obviously.
M-3	<i>Lagerstroemia subcostata</i> Koehne	Northwest of central rockery	9.5 m	150	220	10×9 m	240	Growth potential is general, the main trunk is slightly inclined to the north, lateral roots are exposed.
M-5	<i>Magnolia grandiflora</i> Linn.	Northeast of gate of Youyi village	17 m	260	290	15×12 m	150	Growth potential is strong.
M-9	<i>Platycladus orientalis</i> (Linn.)	Southwest of central pool	5 m	90	93	4×4 m	320	Growth potential is weak. Leaves are gray and yellowish, dead ends are serious, there are many dead branches, upper crown withers. Trunk inclines to the south.
M-14	<i>Podocarpus macrophyllus</i> (Thunb.) Sweet	Northeast of south yard of Yifeng pavilion	6 m	80	85	4×4 m	113	Growth potential is weak, main trunk cracked into two pieces, south half withered, tree top once cut off, the sprouting branches formed a cluster similar to a crown.

Table A11. Water quality monitoring report of the Suzhou Classic Garden

Sample locations	BOD ₅ mg/L	PH value	Ammonia nitrogen mg/L	Permanganate index mg/L	Dissolved oxygen mg/L	Chro- ma	Transpa- rency	Total phos- phorus mg/L	Tem- pera- ture °	Compre- hensive pollution index of water quality
Central pool of Lingerling Garden	4.4	7.48	0.228	3.3	3.94	2	119	0.06	20.8	0
Huanyun billabong, east of Lingerling Garden	1.5	7.38	0.228	5.3	3.78	2	128	0.40	20.2	40
Western stream of Lingerling Garden	1.3	7.31	0.930	3.8	3.54	2	155	0.80	19.9	80
Central pond in Garden of Cultivation	4.2	8.88	0.392	4.4	4.92	8	65	0.17	20.9	0
Mid-lake Pavilion of Lion Forest Garden	1.8	7.40	0.990	3.7	4.25	2	106	1.32	20.1	190
Internal pool of Gentle Waves Pavilion	1.3	7.44	0.520	4.0	3.49	2	150	0.12	20.0	0
Rosy clouds pool of Master-of-Nets Garden	2.0	8.16	0.203	2.6	3.94	2	158	0.54	20.2	54
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Table A12. Quantified water heritage monitoring data

Sample locations	Change of water form		Water quality
	water area	water level	comprehensive pollution index
Western stream of Lingerling Garden	1	3	80
Central pool of Lingerling Garden	1	1	0
Huanyun billabong in the east of Lingerling Garden	1	1	40
Central pond in Garden of Cultivation	1	1	0
Internal pool of Gentle Waves Pavilion	1	2	0
Rosy clouds pool of Master-of-Nets Garden	1	1	54
Mid-lake Pavilion of Lion Forest Garden	2	3	190