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Understanding historic gardens for the sustainable land management of cultural landscapes: Chengde Mountain Resort (CMR) as a case study

Jingsen Lian [a,*], Steffen Nijhuis [a], Nan Bai [a], Gregory Bracken [a], Haoxiang Zhang [a], Xiangyan Wu [b], Dong Chen [b], Jingyu Li [c]

[a] Delft University of Technology (TU Delft), Mekelweg 5, 2628 CD Delft, the Netherlands
[b] Central Academy of Fine Arts, CAFA, China
[c] Department of Landscape Architecture, Tongji University, China

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ABSTRACT

The concept of historic gardens has gradually expanded to encompass a broader range of landscape meanings. UNESCO's cultural landscape categories have significantly influenced land policy improvements in the context of globalization, with historic gardens being classified as Category 1 cultural landscapes. The other categories are organically evolved landscapes (Category 2) and associative cultural landscapes (Category 3). While existing studies have primarily focused on each of these categories individually, it remains unclear how to characterize a cultural landscape when all three categories coexist and influence each other, as seen in complex cases such as the Chengde Mountain Resort (CMR). Furthermore, strategies for improving sustainable land management based on this understanding are still lacking. This study uses landscape mapping to collect data, digitally reconstruct, and characterize cultural landscapes in the CMR based on four environmental factors: topography, accessibility, visibility, and land use changes. Based on this, we illustrate the evolution of the CMR through reconstruction, capturing four phases detailed in 144 scenes. From this, we identify six distinct groups of scenes with six targeted **indicators**, each reflecting specific spatial attributes of Category 1. Additionally, statistical and comparative analyses of land use changes illuminate various landscape dynamics of these scenes that correspond to Categories 2 and 3. The discussion presents a systematic sustainable pathway to characterize the interdependencies among UNESCO's three cultural landscape categories. Based on these findings, this research proposes a three-level management model that connects dynamic authenticity and modern functionality, offering insights for urban policymakers navigating pluralistic cultural landscapes.

1. Introduction

1.1. Literature and context

Recent studies on historic gardens have garnered increasing attention within the field of landscape architecture (Paiva et al., 2021; Lian et al., 2024). Although historic gardens are included in the expanding definition of a "landscape" in the Florence Charter (International Council on Monuments and Sites, 1982), the charter does not emphasize the structural evolution of historic gardens or their interaction with the surrounding land use. Nor does it address the emergence of new heritage characteristics and values in land management, as it remains rooted in a static subject-object perspective and lacks a focus on dynamic authenticity (Jagiełło, 2021; Arikan et al., 2019). Dynamic authenticity emphasizes that cultural landscapes are continuously shaped and negotiated through environmental, social, and cognitive changes (Arikan et al., 2019). To strengthen this argument, we draw on the concept of architectural harmony with nature (Abdulkareem et al., 2024), which emphasizes the reciprocal relationships between built forms, green infrastructure, and surrounding ecological and social systems. This perspective supports the idea that historic gardens should not be treated as isolated artefacts, but as evolving cultural infrastructures embedded in broader spatial and functional landscapes.

This dynamic authenticity concept challenges the traditional view that defines authenticity based solely on material integrity or historical accuracy. Instead, it focuses on the environmental-social needs and

* Corresponding author.
E-mail addresses: J.s.Lian@tudelft.nl (J. Lian), S.Nijhuis@tudelft.nl (S. Nijhuis), n.bai@tudelft.nl (N. Bai), G.Bracken@tudelft.nl (G. Bracken), h.zhang-17@tudelft.nl (H. Zhang), wuxiangyan00@126.com (X. Wu), 15832421504@163.com (D. Chen), jingyu_li@tongji.edu.cn (J. Li).

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sustainable interaction of heritage with contemporary surroundings (Gao and Jones, 2020; Garcia. E & Juan, 2018). As for practices, these are closely linked to sustainable land management and policies (Shen and Chou, 2021; Wang et al., 2023; Yi et al., 2023), as improper urban expansion and tourism-driven land conversion can threaten heritage integrity (Aimar, 2024). Understanding this dynamic integration requires a methodological pathway* that simultaneously and sustainably establishes dynamic structural linkages between historic gardens and landscapes, helping policymakers to capture their unique, interconnected characteristics and values. (Paiva et al., 2021; Funsten et al., 2020; Lian et al., 2024).

To convey the meaning of "historic garden" from an international perspective, we use the relevant conceptual framework for "gardens" outlined in UNESCO's Operational Guidelines (2008) for cultural landscapes. These guidelines classify historic gardens as clearly defined landscapes intentionally designed and created by humans (Category 1), distinguishing them from the other two categories: organically evolved landscapes (Category 2) and associative cultural landscapes (Category 3). UNESCO's cultural landscape categories have significantly influenced policy improvements in the context of globalization (Aimar, 2024). However, there are complex cases such as the Chengde Mountain Resort (CMR) in China (see section 2 for more details), that are distinctive in not fitting solely into Category 1. Instead, CMR significantly exhibits the sophisticated environmental-social characteristics associated with the other two categories (UNESCO, 2008).

Within **Category 1**, historic gardens or parklands have received significant attention as the focus of research (Funsten et al., 2020; Kümmerling and Müller, 2012). Previous studies on Category 1 have primarily focused on identifying the characteristics and attributes of historic gardens using digital technologies and spatial analysis (Lian et al., 2024). The main topics include the documentation and recording of historic gardens (Hess and Ferreyra, 2021), future applications in landscape prototype identification (Goodarzi et al., 2023), digital interpretation and public education, ecological restoration, and sustainable, economy-oriented heritage management strategies (Funsten et al., 2020). The CMR is such a cultural landscape that can be understood as a complex assemblage of historic gardens, reflecting the pinnacle of ancient Chinese spiritual ideals, artistic craftsmanship, and construction techniques.

Category 2 encompasses cultural landscapes shaped by external distinguishable land use changes that have undergone continuous, evolution (Jones, 2003; Scazzosi, 2004). Previous studies on Category 2 have extensively explored macro-level and large-scale research topics such as continuous evolution of cultural landscapes, particularly land transformation, through geostatistical approaches uncovering anthropogenic impact (Giannecchini et al., 2007) or ecological monitoring, elastic space coupling, and restoration techniques (Van Eetvelde and Christensen, 2023).In this sense, the CMR has, over centuries, closely engaged in a transformative relationship with the surrounding mountain and water systems.

Category 3 includes cultural landscapes connected to natural elements on an intangible or immaterial level (McBryde, 2014; Rössler and Lin, 2003; Taylor et al., 2014). These exogenous synergistic relationships with nature are non-material, and this research often focuses on religious, artistic, spiritual, symbolic, perceptive, cognitive, and ideological aspects. Previous studies on associative cultural landscapes have generally focused on contiguous or non-contiguous landscapes that have nature-cultural relevance (Taylor et al., 2014; Zhang and Li, 2024). The immaterial and intangible aspects that characterize Category 3 landscapes have been primarily studied using empirical research methods in anthropology (Chen, 2017), sociology (Bloemers, 2010), and history (Cosgrove, 2017). The construction of the CMR also represents the convergence of various cultural ideologies, such as indigenous Taoism. In summary, the CMR reflects various garden spatial design principles, a continuous transformation of a unique environmental land use shaped by human culture, and a fusion of different ethnic, religious, philosophical and other intangible influences. Indeed, previous research has largely focused on studying these three categories of cultural landscapes in isolation. However, there remains a gap in integrating these perspectives to capture the dynamic authenticity of all three categories of cultural landscapes together in complex cases such as the CMR, an approach that would provide a pathway for sustainable land management.

Apart from literature gap, the CMR faces various realistic challenges in management and policy. Since its designation as a World Heritage Site in 1994, the CMR has been integrated into more complex environment: crowded tourism and urban green space systems (HURPDI & CCPDI, 2008; Jun et al., 2019; Leung, 2001). However, local tourism policies, which reflect a limited understanding of its heritage value, may create imbalances between conservation and development in land management (Gullino et al., 2020; Leung, 2001).

Therefore, understanding the historic gardens of the CMR as a cultural landscape requires a holistic and chronological examination from a landscape-oriented perspective (Van Eetvelde & Antrop, 2009). This approach necessitates making greater use of the meaning of landscape mapping (Lian et al., 2024; Nijhuis et al., 2023; Simensen et al., 2018). Landscape mapping focuses on acquiring, recognizing, and proposing sustainable ecological land management strategies for integrated surface features (Lian et al., 2024; Lilley, 2018; Liu and Nijhuis, 2020; Simensen et al., 2018). In particular, the process-related dimension of landscape meaning should be characterized (Manolaki et al., 2019; Sahle and Saito, 2021; Schulp et al., 2019). By utilizing **landscape mapping**, this study not only shows how human activities manifest, adapt, change, and communicate across different temporal and spatial scales but also provides data-driven insights to inform policymakers' evaluations of land use changes.

Recent methodological advances show that landscape mapping and related spatial techniques can effectively document and analyze cultural landscapes (Simensen et al., 2018; Liu and Nijhuis, 2020; Lian et al., 2024). Yet most applications remain confined to Category 1 historic gardens, with limited integration of evolutionary land-use processes (Category 2) or intangible dimensions (Category 3). Existing studies also tend to apply such methods descriptively, rather than establishing a systematic analytical framework with clearly defined indicators that can be transferred across scales and contexts. While broader frameworks such as the European Landscape Convention (ELC) provide strategic direction (Reed et al., 2015; Van Eetvelde & Antrop, 2009), they lack operational tools for complex cases where all three UNESCO categories converge. Consequently, there remains a methodological gap in developing a coherent, indicator-based framework that connects spatial analysis with dynamic authenticity. This gap underpins the analytical framework and methodological pathway of the present study.

1.2. Research aim

This study aims to establish a holistic pathway for understanding the dynamic authenticity of the CMR's historic gardens within the context of cultural landscapes through the application of integrative landscape mapping. Based on this foundation, we propose an optimized sustainable management model to bridge the conceptual and methodological gaps between the three categories of the UNESCO cultural landscape system (Fig. 1).

Landscape mapping involves three steps: data acquisition, digital reconstruction, and characterization to determine dynamic authenticity. The first two steps focus on creating a web dynamic database, which establishes the environmental foundation for the management system. During the characterization of the CMR, four primary environmental

* The term "pathway" in this context refers to a holistic and universal research approach that is neither as broad and overarching as a "framework" nor as specific as an "approach" that denotes a particular method or technique.

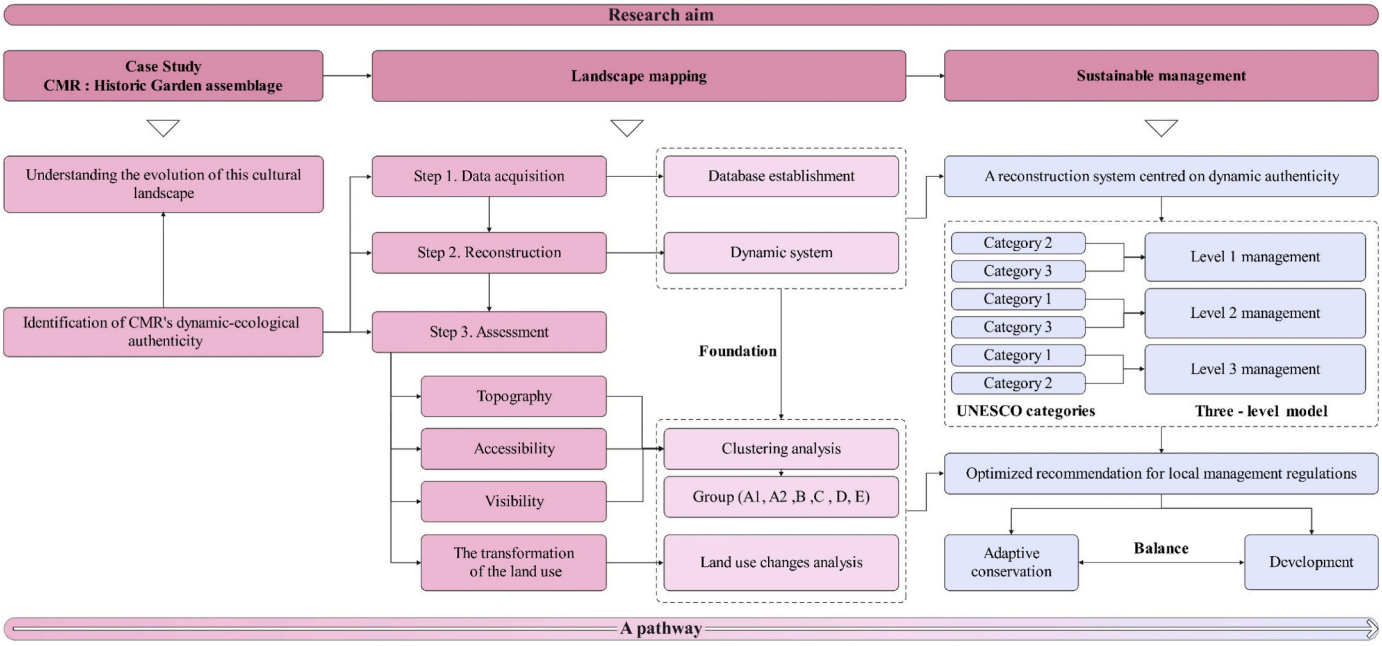

Fig. 1. The structural framework of this research.

factors were identified as the most representative: topography, accessibility, visibility, and land use. These factors were then converted into six specific quantitative indicators with corresponding metrics for clustering analysis. Through clustering and land use change analysis, we identified six groups with different characteristics and provided recommendations to optimize current local management policies.

Building upon the UNESCO classification of cultural landscapes and the strategic framework of the ELC, this study contributes to a practical three-level management model interactively influenced by three categories, which involves targeted physical strategies, land use zoning, and public engagement for local residents. By explicitly bridging environmental-adaptive heritage conservation with dynamic regional

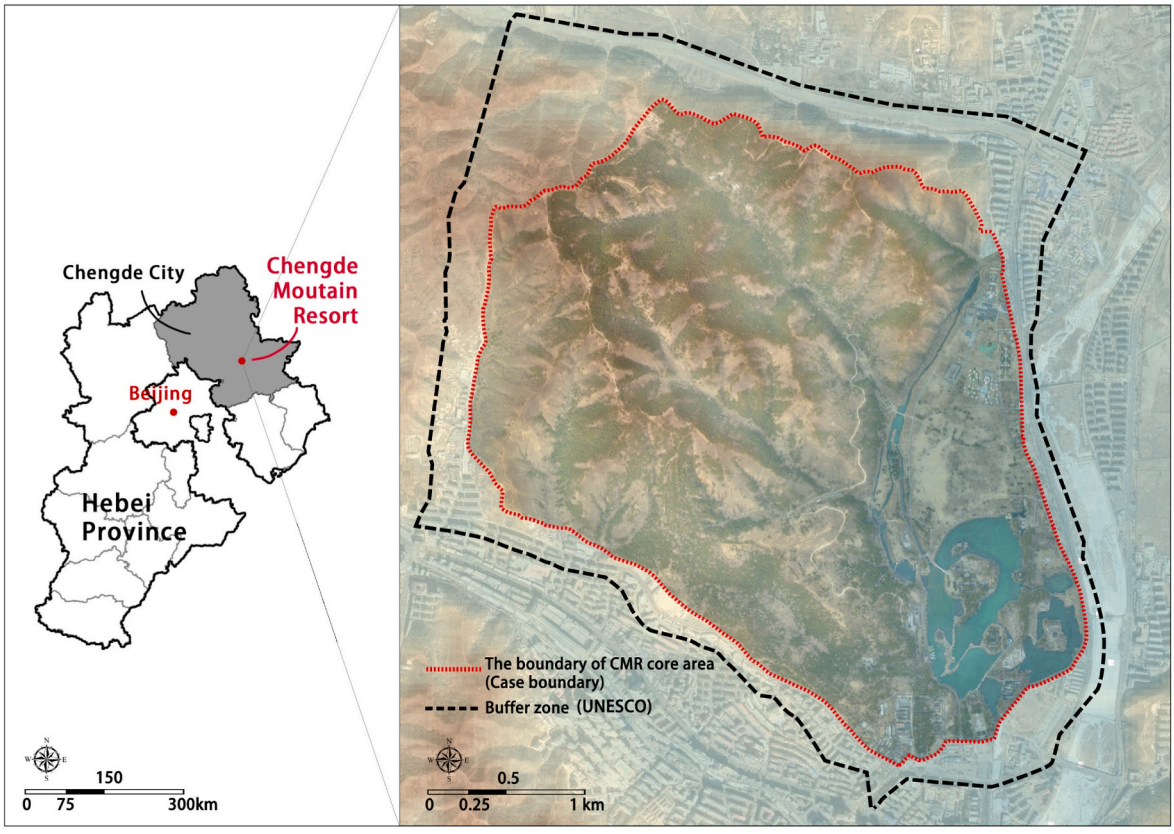

Fig. 2. The location of Chengde Mountain Resort. The boundary of the CMR core area is historically defined by the remains of the ancient wall, which also aligns with the boundary in the current official urban planning.

development goals, our approach not only aligns conservation actions with broader land governance but also provides a scalable tool for managing evolving cultural landscapes in urban and tourism-intensive environments.

2. Overview of the characteristics of the cultural landscapes in the CMR

This study employs mixed methods to analyze the CMR (5.64 km^2) as a cultural landscape. Built in 1703 in Hebei province, China (Fig. 2), the CMR comprises many smaller ***scenes,*** which reflect the ancient Chinese expression of imperial historic gardens and include views, buildings, courtyards, rockeries, waterscapes, and vegetation. We based our study on 144 representative scenes (named and numbered by the emperors) and four environmental factors: topography, accessibility, visibility, and land use changes. These four factors are derived from a synthesis of existing literature, considering the specific context of CMR.

First, many previous studies have shown that topography are key element in shaping the cultural landscape characteristics of CMR. This unique natural geography provided the ancient designers (emperors) with concepts for site planning (Whiteman, 2022; Zhang, 2023). Due to the diverse **topography** (in terms of **elevation** and **slope**), these two indicators were selected due to their critical role in shaping various relationships among scenes, influencing landscape fundamental frameworks, and affecting spatial experience such as accessibility and visibility (Whiteman, 2022; Zhang, 2023). They also align with historical design principles that emphasized the integration of natural terrain into the historic garden layout.

Second, as shown in previous studies, **accessibility** reflected in the organization of routes has been identified as a main driver of landscape change in historical planning, supporting evidence for spatial perception (Antrop, 2005; Whiteman, 2022), demonstrating various levels of continuous evolution shaped by human activities (Lieskovský et al., 2017), which aligns with our research aim. Specifically, we assess accessibility primarily in terms of movement from **scene to scene** and from **scene to water** (Lieskovský et al., 2017; H. Zhang et al., 2023; K. Zhang and Mingze, 2024; S. Zhou et al., 2022). Regarding the associative and intangible aspects of the CMR, the sophisticated spatial connections between the different scenes also reflect the convergence of spirituality across multiple religions and ethnic cultures in China (Forêt, 2000).

Third, the visual characteristics of the CMR—**exterior scene visibility and observed scene visibility—**concretize the holistic concept of *landscape*, functioning both as a mechanism and as an expression of spatial experience, perception, and technical craftsmanship with scientific practicality (Han, 2012; Keswick, 2003). This aligns with the core concept of *landscape* in the historical development of landscape architecture in China, which is rooted in the synthesis of multiple types of abstract cultural and spiritual media, such as poetry, painting, and religion (Varsano, P., 2013). These influences are embodied in visualized spatial experiences, reflected in spatial openness for exterior scene visibility and spatial privacy for observed scene visibility (Yu and Ostwald, 2018).

Fourth, **land use changes** have played a fundamental role in shaping the structure of the CMR. For instance, historical records suggest that *water* was the core element of land use in the establishment and development of the CMR, with the spatial arrangement of its elements initially emphasizing the significance of the lake (Whiteman, 2022).

In summary, accessibility, visibility, topography, and land use changes are considered in the literature as key environmental factors that influence the cultural landscape and interact with intangible elements in CMR: Topography defines the fundamental landscape structure, accessibility influences spatial organization, visibility shapes the perception of scenes, and land use changes reflect evolving cultural and ecological dynamics. In section 3.3, we quantify these factors and explore them in greater detail.

3. Methods

3.1. Data collection

Landscape mapping is a crucial tool for capturing data that reflects the inherent complexity of cultural landscapes, providing multi-scale spatial data while embedding geographical spatial information (Chiang et al., 2019; Van Lanen et al., 2022). It serves as the foundation for characterizing cultural landscapes in spatial analysis (Lian et al., 2024; Lilley, 2018; Liu and Nijhuis, 2020) and supports future sustainable land management (Simensen. T et al., 2018; Willemen et al., 2008).

To collect more precise data, a Matrice 300 RTK equipped with a DG4 Pro penta-lens camera was used for close-range photogrammetry in January of 2025. The photos, along with position and orientation system (POS) data, were then individually imported into Agisoft PhotoScan Pro vl.3.0.3772 and Agisoft Metashape Pro v1.7.4.12950. Finally, digital surface models (DSMs) and digital elevation models (DEMs) were generated from 3D point cloud data (.las format), incorporating vegetation, buildings, and other geo-elements. These models were further processed in ArcGIS Pro 3.3 for analysis. Key vegetation, such as old-growth trees, was mapped separately (see Supplementary Data A).

We also gathered a substantial amount of textual and graphical data, including written materials such as poems, research papers, traditional paintings, maps, mappings, and historical photographs. The multi-source data were collected by the *Chengde Cultural Heritage Bureau* and other collaborating authorities between 1988 and 2025. These materials were classified and summarized in tables according to scenes from the four historical phases (see Supplementary Data B). By assigning spatial coordinates to these materials, we were able to visually represent the level of attention given to heritage environment (Fig. 3, Table 1).

3.2. Creation of database

Many previous studies have suggested that using landscape mapping to reconstruct cultural landscapes facilitates the establishment of multifunctional data systems (Chen & Huang, 2020; Chiang et al., 2019; Lathouwers et al., 2023; Lian et al., 2024). We begin by using 3D modeling of point clouds as the geospatial-spatial foundation for our study (Fig. 4a). Next, we propose a systematic approach to rectifying historical information in cartometry (see Appendix A). This rectification process involves integrating historical maps to achieve precise transformations, correcting geometric distortions to align with current geospatial maps and improving their usability in spatial analysis (Nijhuis, 2015; Statuto et al., 2017). Additionally, we incorporate various graphic and textual datasets to interpret the characteristics and attributes of incomplete, lost, or missing landscape elements in historical cartographies (see Appendix B). Finally, the data are aggregated and managed by accurately matching coordinates on the updated Web-GIS platform for unified retrieval and management (Fig. 4b).

3.3. Data analysis

Landscape mapping as an approach enables multidimensional data processing and analysis of cultural landscapes (Schulp et al., 2019). As outlined in section 2, the factors were identified based on practical experience, expert consultations, a review of reliable literature, and an analysis of historical data. To enhance the credibility of the metrics, we have included a multi-source data comparison (see Appendix B).

Consequently, we identified accessibility, visibility, topography, and land use changes as the four most representative factors. The first three factors each correspond to two specific quantitative indicators with metrics (Table 2). These targeted indicators are as follows: for topography, elevation and slope; for accessibility, scene-to-water accessibility (SWTA) and scene-to-scene accessibility (STSA); for visibility, exterior scene visibility (ESV) and observed scene visibility (OSV) (see Supplementary Data C and D).These indicators were calculated using DEMs and

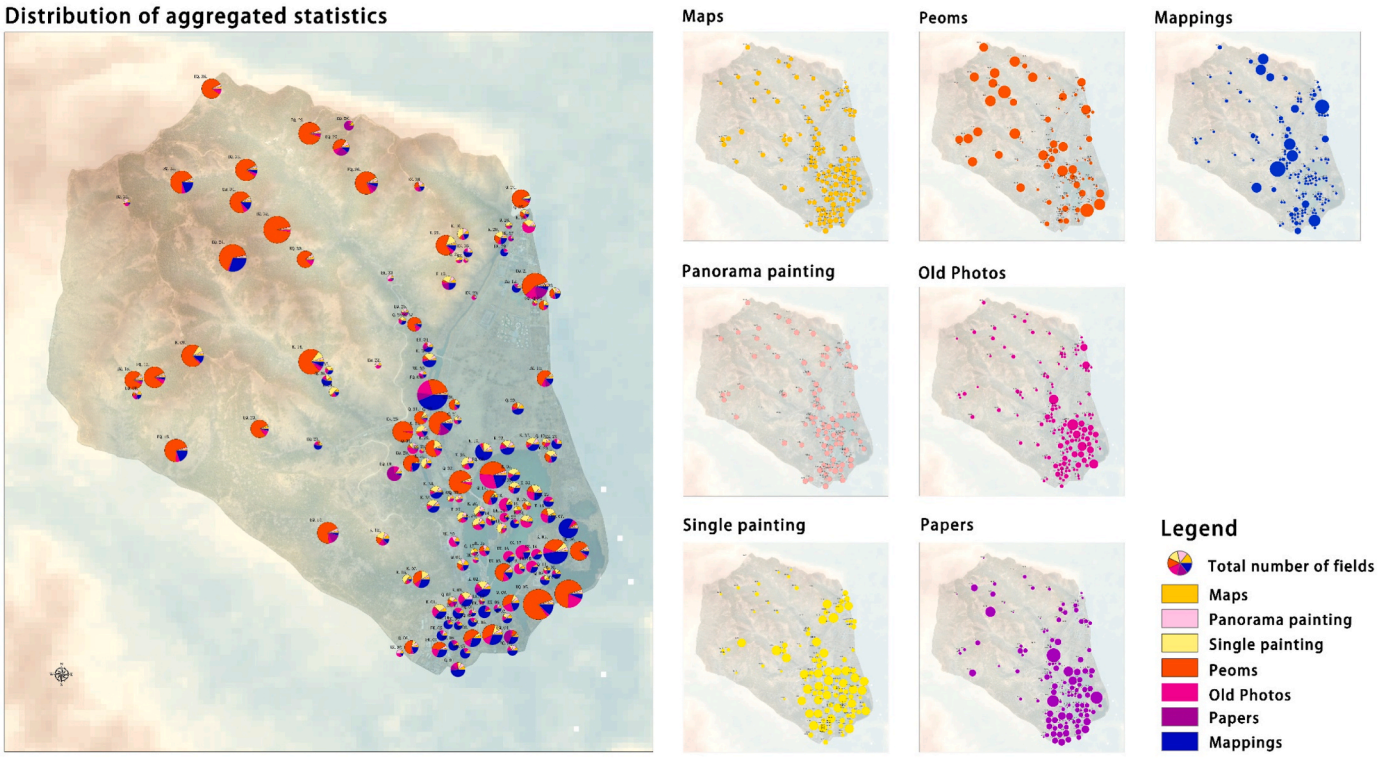

Fig. 3. The spatial distribution and frequency of various types of research data: Circle sizes in each subgraph are scaled relatively to indicate the level of entities and attention.

Table 1
Distribution of research data across four phases (P1 -4).

Category	P1	P2	P3	P4	Total
Maps	32	75	107	245	459
Panorama Painting	60	155	122	24	361
Single Painting	65	267	335	5	672
Poems	879	1137	1564	79	3659
Old Photos	124	117	385	458	1084
papers	343	244	785	357	1729
Mappings	54	153	137	61	405

DSMs in ArcGIS Pro and validated through statistical tests. This approach aligns with green building assessment frameworks (Saleh et al., 2024), where topography, accessibility, visibility, and land use are key to spatial performance. Similar to green site planning, our method integrates spatial structure and perceptual experience, providing a robust basis for landscape mapping, characterization and management.

Subsequently, we use the heatmap in R. 4.3.2. to perform agglomerative clustering, visualizing all the scenes as distinct groups based on the relevance of the six variables across different historical phases.

To assess the effectiveness of the selected environmental indicators, we conducted Kruskal-Wallis statistical tests, as the data was non-normally distributed after both the Levene test and Shapiro-Wilk test (see Supplementary Data E). The significant results with $p < 0.05$ indicate that these six indicators exhibit high discriminative power and scientific validity in the clustering analysis. We further tested the effectiveness of the grouping using the Calinski-Harabasz Index (CH Index) (Calinski and Harabasz, 1974; Halkidi et al., 2001), which measures inter-group separation and intra-group compactness, with higher values indicating better clustering (see Supplementary Data C).

Additionally, landscape mapping in cultural landscape studies emphasizes understanding the interactions between humans and the environment, as reflected in land use changes (Aimar, 2024; Schulp, 2019). To this end, we conducted a thorough investigation of the changes in land use in the CMR across four phases, using statistical analysis and visualization. This understanding of land use in the CMR provides an intuitive representation of the accumulation of historical layers, allowing for more accurate characterization of the evolution of its cultural landscapes.

4. Results

4.1. Reconstruction of the evolution of the CMR

We reconstructed the cultural landscape characteristics of four distinct historical phases of the CMR, based on changes in primary spatial attributes (e.g., construction process) and historical dynastic transitions at the site. Notably, Phases 1 through 3 belong to the historical period, while Phase 4 is distinct, falling within the modern era. The constituent elements considered in each phase include topography, river and lake systems, roads, individual buildings, and vegetation (Fig. 6).

Phase 1 (P1), which lasted from 1704 to 1708, marked the initial construction of the CMR. This phase was primarily characterized by the excavation of the lake to create hills, with 61 scenes constructed. The planning and design of roads and scenes were concentrated around the lake areas, exhibiting centripetal tendencies. During **Phase 2 (P2)**, from 1709 to 1713, the emperor expanded the bodies of water to the southeast and moved the palace walls eastward, resulting in the construction of additional independent buildings and roads. A total of 98 scenes were completed, with new buildings and sightseeing routes added in the lakeside and mountainous regions beyond the core area. **Phase 3 (P3)**, which lasted from 1740 to 1798, marked the peak of construction of the CMR, with 144 scenes completed. The southern palace, notable for its grand scale and monumental architecture, was constructed during this period. The scenes were intricate and richly developed in both lakeside and mountainous areas, while many religious buildings were added in the plains. **Phase 4 (P4)**, extending from 1798 to the present, saw a

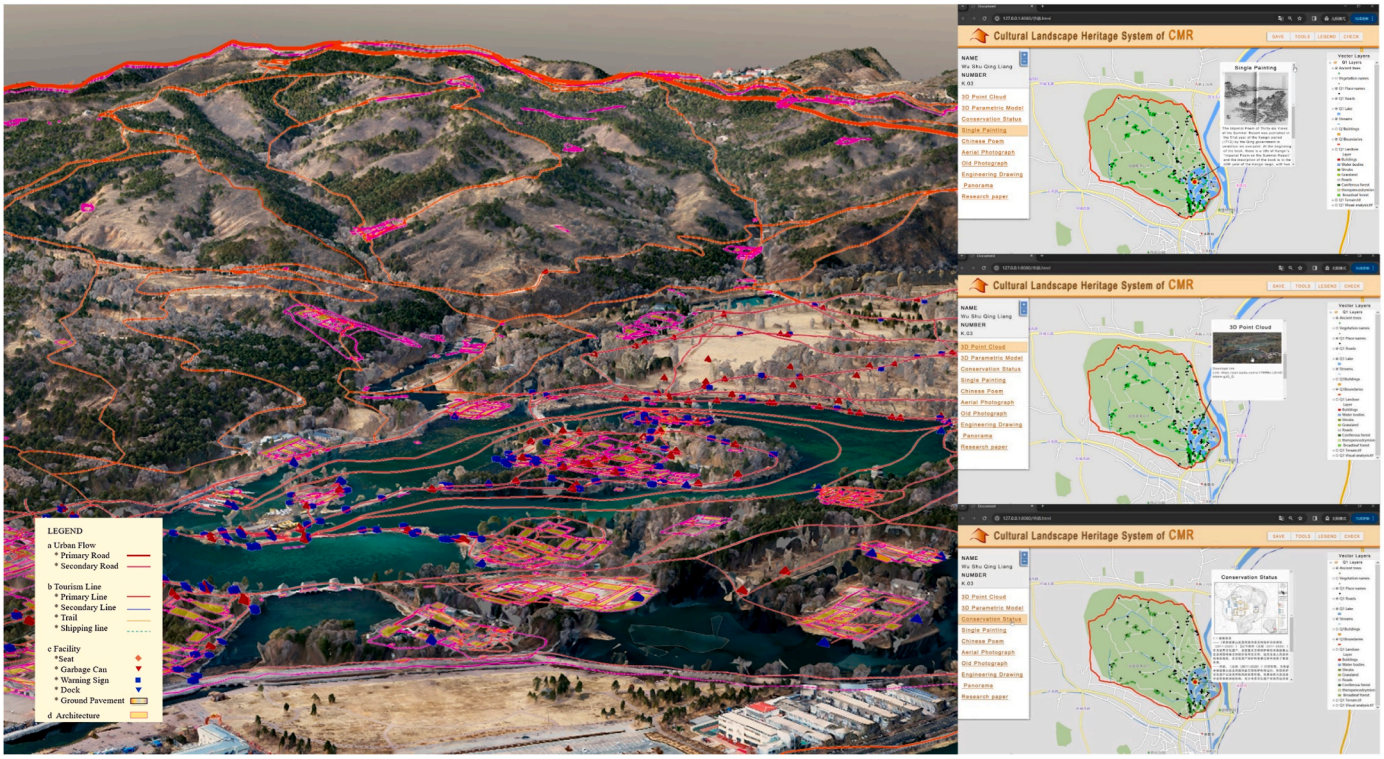

Fig. 4. [a]. Left: 3D modeling of point clouds in GIS used as the basis of our study. **[b] .** Right: Web-GIS platform for unified retrieval and management of the CMR.

Table 2
Six indicators for understanding the spatial characteristics of all scenes across four phases (Justification refers to the reasons for selecting that indicator, and The formula is in Supplementary Data D.

Criteria	Definition	Justification	Reference	Model
Elevation	The variation in elevations within the area of a single scene	The topography of the CMR exhibits significant elevation variations (265–477 m). Elevation significantly affects the spatial relationship among site scenes, shaping hierarchical landscape structures, which profoundly influence the characteristics of the cultural landscape.	Agapiou et al., 2016; Bunruamkaew and Murayam, 2011	DEMs
Slope	The varying degrees of terrain steepness within the area of a single scene	Slope is an important indicator for measuring the steepness of terrain. It influences the spatial enclosure type and occlusion relationship of scene distribution. From a landscape ecology perspective, slope also significantly impacts the ecological wind direction of the scene.	Bunruamkaew and Murayam, 2011; Wrbka et al., 2004	DEMs
Scene-to-water accessibility (STW)	The highest accessibility from the scene to the water's surface	According to historical records and related literature, the establishment and development of the CMR have been closely linked to changes in the water area. The distance from water influences the intrinsic functions of different scenes, including aesthetics, ecology, recreation, politics, and culture.	Lieskovský et al., 2017; S. Zhou et al., 2022	DEMs
Scene-to-scene accessibility (STSA)	The average accessibility between scenes	Moran's index and spatial autocorrelation tests reveal a significant inhomogeneous correlation between scenes, which reflects a distinctive narrative order in the spatial distribution of the landscape. This influences route selection, landscape visibility, and cultural experience, shaping the dynamic authenticity of the landscape and offering critical insights for planning policy.	H. Zhang et al., 2023; K. Zhang and Mingze, 2024	DEMs
Exterior scene visibility (ESV) (Fig. 5a)	The area of exterior visibility of a single scene (number of raster cells included in the viewshed)	According to historical naming traditions for scenes, the exterior view is an important aspect of cultural significance that reflects its level of spatial openness. This creates a rich network of visual connections between different scenes, shaping external spatial perception and highlighting the hierarchical prioritization of site selection in historic design principles.	Inglis et al., 2022; Lehto et al., 2024	DSMs
Observed scene visibility (OSV) (Fig. 5b)	The average number of times a single scene is observed along a tour route	Route plays a key role in the CMR by linking various scenes and shaping different tour experiences. This metric is used to assess the level of spatial privacy of each scene. From this passive observer perspective, the visual spatial perception of the scene's attractiveness can be effectively captured.	Chamberlain and Meitner, 2013; Wu et al., 2023	DSMs

reduction to 109 remaining scenes following modern warfare and abandonment. After the restoration undertaken as part of the *Chengde High-Quality Development Plan* (CHQDP) (CMG, 2022), most of the buildings, vegetation, and lake have been restored and reconstructed according to historical archives. However, many scenes remain as only remnants. Additionally, some new recreational and service facilities have been added.

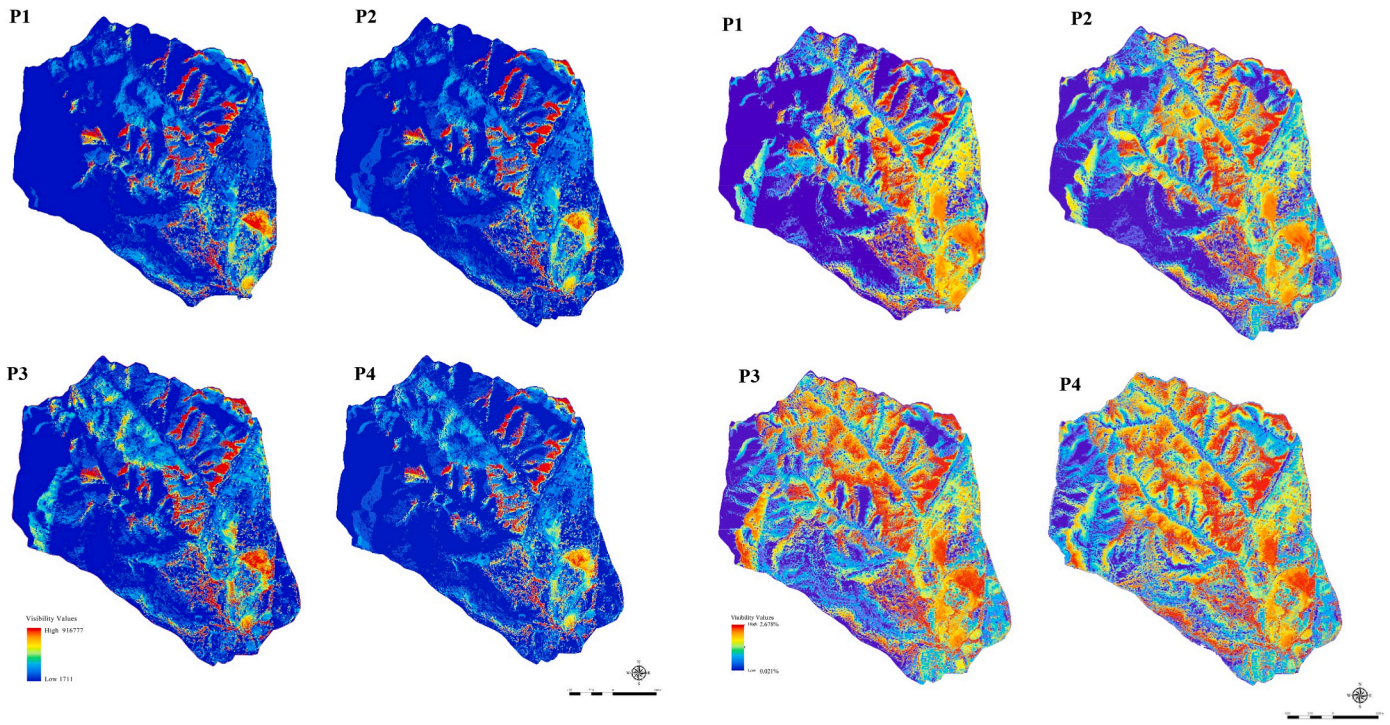

Fig. 5. [a]. Left 4 pics: ESV (scene's exterior visibility) across the four phases. **[b].** Right 4 pics: OSV (observed scene visibility) across the four phases.

4.2. Clustering results of the scenes

We clustered the scenes from the four phases using the six indicators proposed in section 3.3, with detailed values available in Supplementary Data C. The resulting clusters are shown below: 61 scenes are clustered into four groups in P1; 98 scenes are clustered into six groups in P2; 144 scenes are clustered into six groups in P3; and 119 scenes are clustered into six groups in P4 (Fig. 7). Table 3 explains the characteristics of different groups based on clustering analysis. We used the Calinski-Harabasz Index (CH Index) to assess grouping quality and validate its rationality. Based on the CH Index criteria, the four datasets scored between 23 and 31, classifying the clustering in the "good" category (see Supplementary Data C).

Fig. 8 illustrates the temporal trends of six key indicators across different groups from P1 through P4. ESV increased over time in all groups, with a particularly notable decline between P2 and P3 for Group A1. OSV peaked at P2 for Groups B and D but experienced a sharp decline afterward, reflecting adjustments in landscape visibility. STW and STS reached their highest values in P3 for Groups A1, B, and D, while the increase was less pronounced for Groups C and E; however, a general decline was observed in P4 for all groups, except for A2, indicating changes in landscape accessibility. Elevation showed a temporary increase in P2 for Groups B, C, and D, followed by a slight recovery of Group E in P4. Slope gradually decreased from P1 to P3 for all groups, with a notable increase in Group A2 between P2 and P3.

4.3. Land use changes

Based on the results of the reconstruction, we analyzed the changes in land use, which reflect the scale and rate of the evolution in the CMR across the four phases, presented as a Sankey diagram.

Overall, forestry areas dominated each phase. These included evergreen coniferous forests primarily composed of Chinese red pine[1] (35.07–36.02 %), deciduous broadleaf forests with dominant oak species[2] (21.65–22.88 %), and mixed forests (16.27–22.62 %) of Chinese elm,[3] Japanese pagoda trees,[4] poplar,[5] Chinese willow,[6] and Tilia.[7] These three land use types were the most common across all phases. Additionally, grasslands (6.85–8.09 %), shrub areas (5.42–5.6 %), and water (5.17–6.21 %) occupied significant proportions of the CMR across all phases. Buildings (0.38–1.54 %) and roads (1.84–5.77 %) account for the smallest proportions, with human-dominated spaces concealed among the mountains and forests (Table 4).

Viewed from a long-term perspective, the evolution of land use types varies significantly across different phases. Between P1 and P2, mixed coniferous and broadleaf forests were largely converted into other types of land uses, marking newly developed areas. Notably, a large portion of these areas were converted into bodies of water (23.09 %) and buildings (39.02 %) because of the eastern expansion. From P2 to P3, the largest increase in new buildings was on former grasslands (23.4 %). Furthermore, coniferous (21.1 %), broadleaf (8.5 %), and mixed forests (9.1 %) from P2 were used for the construction of buildings and roads in P3. By P4, buildings (35.6 %) were the main type of land converted into other land use types from P3. As a result of the development of tourism, the road area has increased considerably (49.8 %), as has modern functional infrastructure (Table 5., Fig. 9).

[1] Latin name: *Pinus tabuliformis*.

[2] Latin name: *Quercus variabilis*.

[3] Latin name: *Ulmus pumila* L.

[4] Latin name: *Styphnolobium japonicum (L.) Schott*.

[5] Latin name: *Populus cathayana*.

[6] Latin name: *Salix matsudana Koidz*.

[7] Latin name: *Tilia tuan Szyszyl*

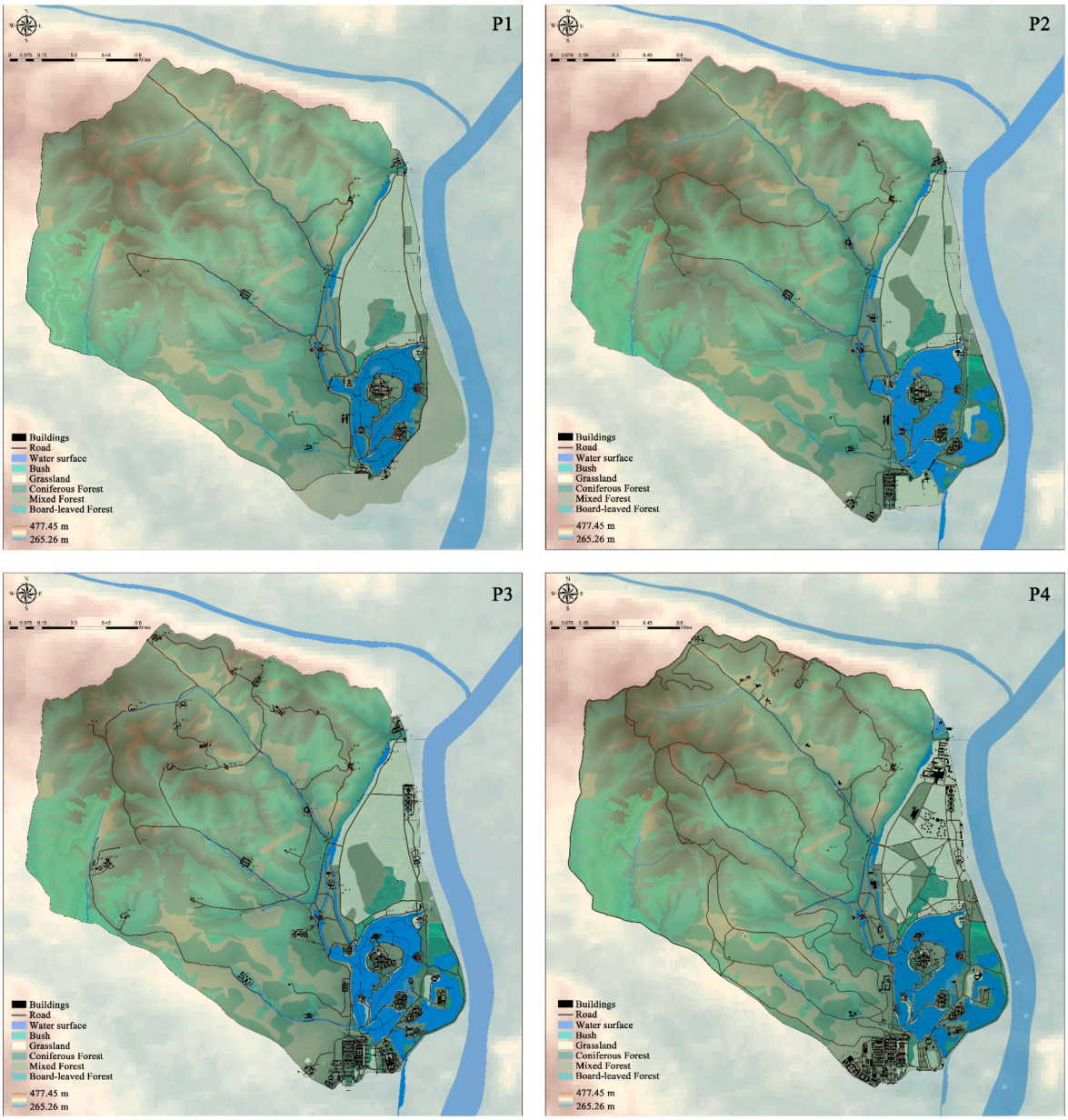

Fig. 6. Reconstruction of the evolution of the CMR from P1 to P4.

5. Three-level management model based on integrative characterization

5.1. Characterization of the CMR's evolution using UNESCO's three categories

1) Interdependencies between Categories 1 and 2

Categories 1 and 2 reflect an internal–external multi-scale relationship between historic gardens and land evolution. Traditional research emphasizes Category 1 through detailed, investigation-oriented spatial studies aimed at thoroughly identifying specific attributes and features of historic gardens (Gullino et al., 2020; Kümmerling and Müller, 2012; Yang and Han, 2020). However, this study expands the scope by anchoring an external, dynamic analytical process to incorporate the culturally, geographically, and ecologically driven evolving nature of a larger-scale external landscape (Category 2) (Aimar et al., 2021; Giannecchini et al., 2007; Marignani et al., 2008; Schulp et al., 2019; Van Lanen et al., 2022).

Specifically, we validated numerous historical studies and provided supporting evidence. From P1 to P3, the CMR was planned for imperial use, integrating mountain and water systems to reflect historic design principles while optimizing land use (Whiteman, 2020; Zhu et al., 2023). During P1–P2, the eastern expansion transformed mixed forests into water bodies, enhancing accessible spatial diversity, visual connectivity, and the accessibility of water-centered scenes in Group B (Mao, 2018; Zhu et al., 2023). Group D, initially isolated as the second center, gradually became visually and functionally linked to Group B, forming a landscape-scenic natural corridor that improved landscape permeability and ecological connectivity (IQHRUC, 1994). Meanwhile, low-visibility yet highly accessible scenes in Group C decentralized and integrated more closely with other clusters, adapting to changing political and service demands (Mao, 2018). Additionally, land use changes in mountainous areas have influenced the spatial atmosphere of the CMR's cultural landscape, characterized by rich elevation and slope variations with varying levels of openness. Scenes in Group A were

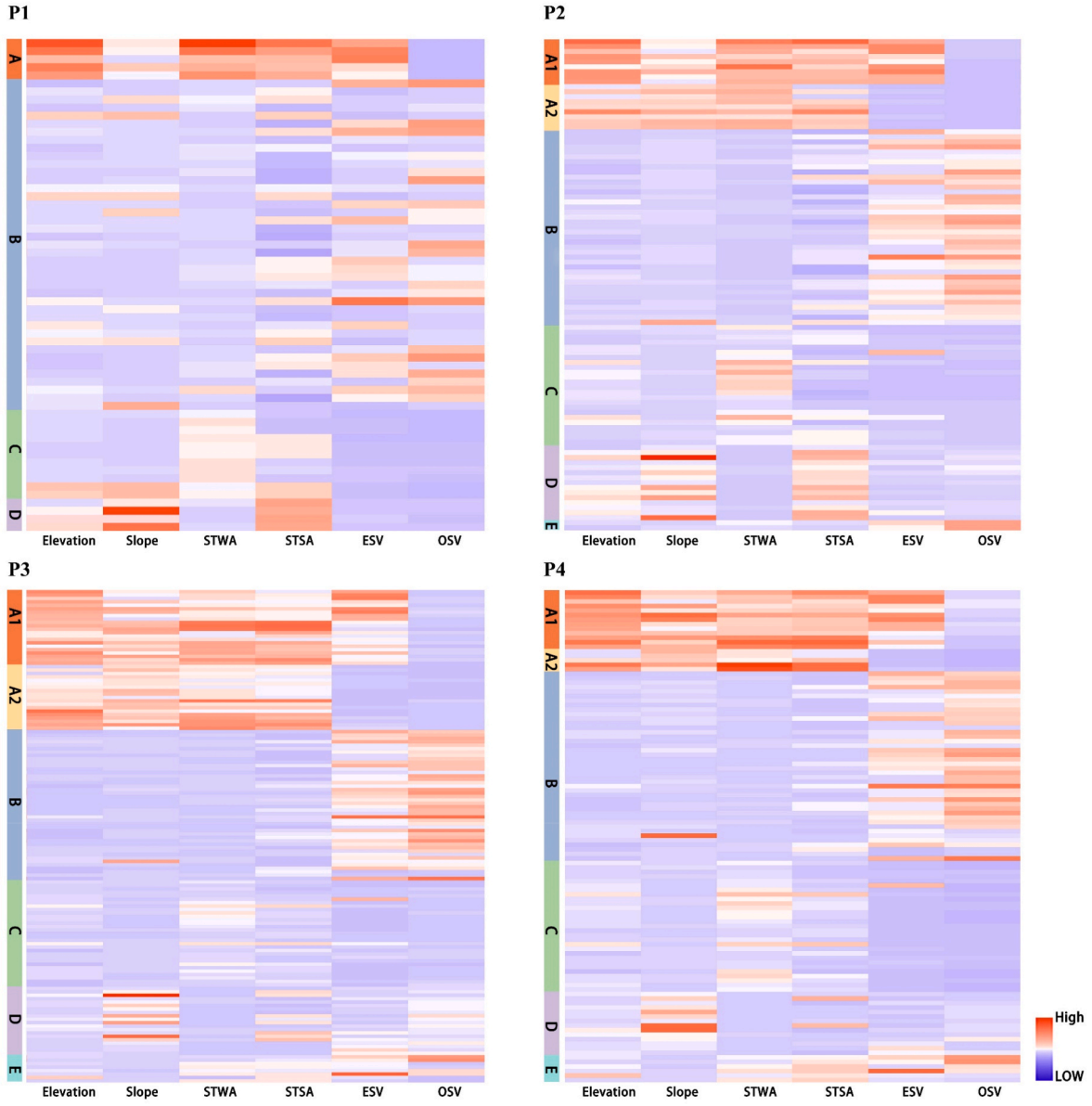

Fig. 7. The clustering of scenes across the four phases. Individual rows show the six indicators for each scene, while columns represent the specific indicators. To the left, bars indicate the clustered groups of scenes. Notably, higher values for STWA and STSA correspond to lower accessibility levels, as they reflect increased walking time.

initially converted from diversified forests into roads and buildings, particularly in A1 and A2. From P3 to P4, war, ecological degradation, and neglect of maintenance led to a significant loss of scenes in mountainous areas (Zhao, 2005). However, Group B remained spatially dominant, becoming an attractive point due to its strong landscape visibility and accessibility, supporting a more economic function through heritage tourism. Groups C, D, and E retained a spatial atmosphere similar to P3, although some scenes deteriorated into foundational remnants, which were replaced by grasslands for ecological regeneration.

This construction process shapes spatial privacy, aesthetic compositions, and sightline occlusions to serve both functional and visual purposes. However, the intentional transformation of surrounding land use, in turn, created a diverse and intricate network of scene-to-scene connections, significantly enhancing accessibility and visibility across different clusters.

2) The influence of Category 3 on Categories 1 and 2

Category 3, as a crucial factor for exploring intangible cultural-natural relationships, has had a profound impact on Categories 1 and 2 (Taylor et al., 2014). These exogenous synergistic relationships are often manifested in religious, artistic, spiritual, symbolic, perceptive, cognitive, and ideological aspects (Chen, 2017; Cosgrove, 2017; McBryde, 2014; P. Zhang and Li, 2023). However, these internal–external spatial and cultural dimensions are not separate domains. Our research bridges this gap by integrating quantitative indicators with qualitative cultural narratives.

On the one hand, we examine how intangible cultural concepts shape physical spaces in historic gardens (Category 1). We also validated numerous historical studies and provided supporting evidence. Unlike centralized structures, royal functional scenes (Group C) follow a homogenized spatial layout, differing from previous historical studies (Forêt, 2000; Whiteman, 2020; Zhu et al., 2023). This design prioritizes royal privilege and privacy, featuring low visibility for seclusion and high accessibility for convenience. On the other hand, we identify how deep cultural and spiritual ideology influence the evolution of

Table 3
Explanation of the characteristics of different clustering groups.

Group		Elevation	Slope	STWA	STSA	ESV	OSV	Explanation	
A	**A1**	High	High	Low	Low	High	Low	**Mountaintop viewing scenes**	Scenes located on hilltops or slopes offer excellent views and serve as observation platforms. However, they are not easily visible from the outside, have a dispersed spatial distribution, incur high travel costs, and are relatively far from water sources.
	A2	High	High	Low	Low	Low	Low	**Valley-enclosed scenes**	Scenes located in valleys are highly concealed and strongly influenced by Taoist concepts of harmony with nature. However, they have high travel costs and are relatively far from water sources.
B		Low	Low	High	High	High	High	**Water-centered viewing scenes**	Scenes distributed around water, with a dense concentration, are the core of the CMR. Historically, they were used for cooling off, leisure, and aesthetic appreciation of the landscape. They offer broad views and convenient access.
C		Low	Low	Low	High	Low	Low	**Royal functional scenes**	Scenes used for political and service functions feature enclosed spaces to ensure privacy. They are mostly distributed in inland areas but are conveniently connected to other scenic scenes.
D		Moderate	Moderate	High	Moderate	Moderate	High	**Ecological corridor scenes**	Scenes distributed linearly along narrow waterways create a unique, one-sided ecological landscape corridor. With mountains to the west, a water system in the middle, and plains to the east, they have high aesthetic value.
E		Low	Low	Low	Low	High	High	**Religious-cultural scenes**	Religious scenes in plain areas are mostly associated with Buddhism and regional ethnic cultures. They feature distinct landmark characteristics, offer broad spatial views, and are relatively distant from other scenes.

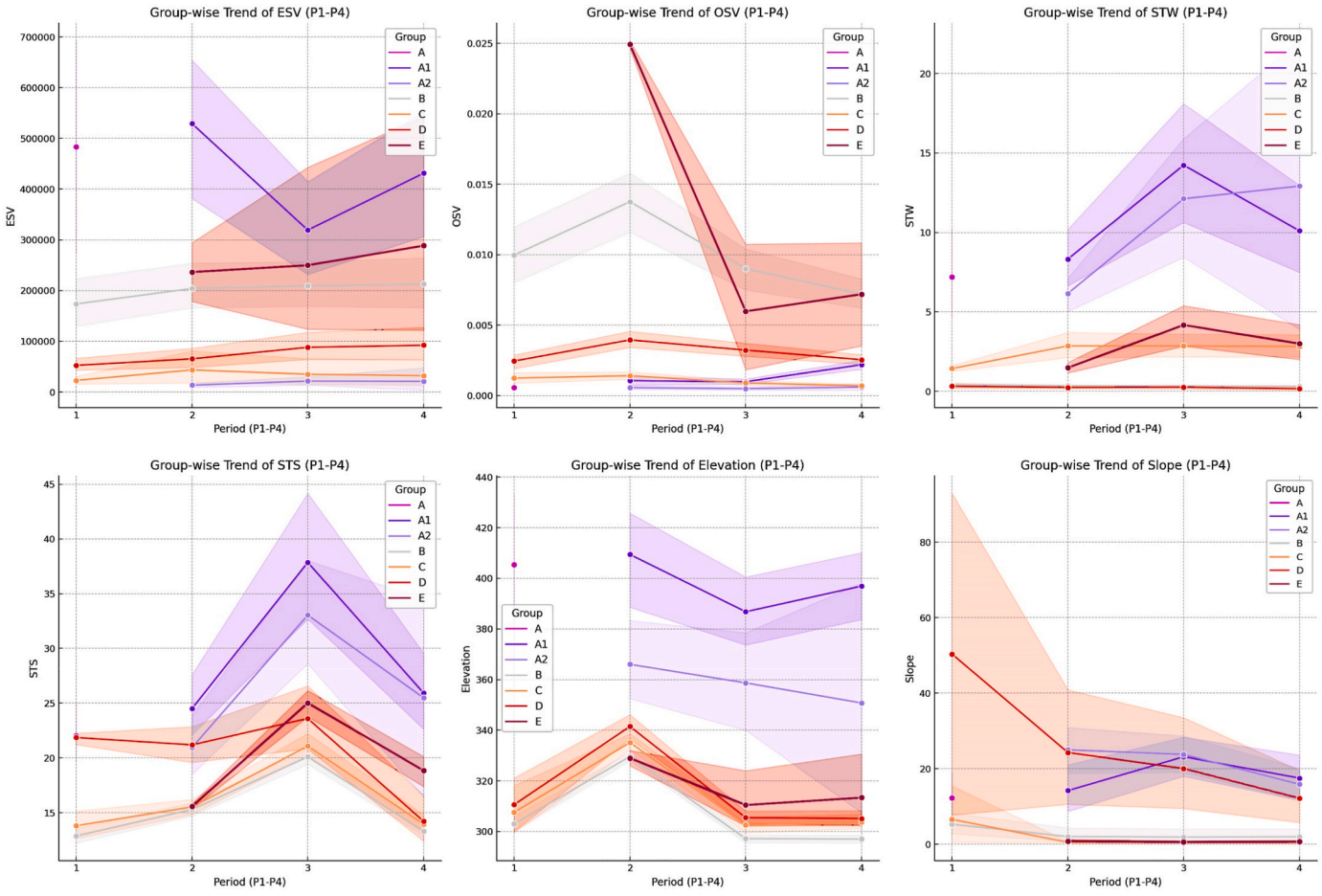

Fig. 8. Trends of indicators across groups during the four phases.

landscapes in the CMR (Category 2). For example, Taoist philosophy inspired land transformations by integrating human-made structures with environment, resulting in spatial layering with enclosures and progressive transitions at different levels (Forêt, 2000). Additionally, symbolizing cultural integration with ethnic groups, the CMR features a rare large grassland for hunting game, which is uncommon in Eastern historic gardens but reminiscent of those in the West.

Table 4
Sum of land use changes P1– P4.

Land Use Type	P1	P1 %	P2	P2 %	P3	P3 %	P4	P4 %
Buildings	20875.55	0.38 %	45028.23	0.83 %	84030.08	1.54 %	81569.53	1.50 %
Water	281555.1	5.17 %	338021.8	6.21 %	335104.3	6.16 %	333123.9	6.12 %
Shrub	294804.8	5.42 %	304867.2	5.60 %	304381.9	5.59 %	300957.6	5.53 %
Grassland	372829.2	6.85 %	419062.9	7.70 %	424466.6	7.80 %	440270.9	8.09 %
Road	100004.6	1.84 %	139461.9	2.56 %	209651.8	3.85 %	314091.9	5.77 %
Coniferous forest	1943577	35.71 %	1960485	36.02 %	1916734	35.22 %	1908625	35.07 %
Mixed forest	1230990	22.62 %	990619	18.20 %	939688.1	17.27 %	885740.5	16.27 %
Board-leaved forest	1197979	22.01 %	1245069	22.88 %	1228559	22.57 %	1178236	21.65 %
Grand Total	5442616	100 %	5442616	100 %	5442616	100 %	5442616	100 %

Table 5
Land use transfer matrix P1–P4.

Sum of the land use changes	P1								
P2	Buildings	Water	Shrub	Grassland	Road	Coniferous forest	Mixed forest	Board-leaved forest	Grand Total
Buildings	17570.87	700.68	11.29	4752.21	2309.96	838.07	*18109.5	735.65	45028.23
Water	110.86	259860.63	0	0	0.01	0	*78050.26	0	338021.76
Shrub	6.42	0	294146.62	0	0.35	0	10713.8	0	304867.19
Grassland	450.23	1775.95	0	366303.75	891.54	0	49641.42	0	419062.89
Road	1129.43	2848.5	646.87	1750.14	95569.78	8304.57	24823.63	4389.01	139461.93
Coniferous forest	294.29	0	0	0	341.23	1934434.8	25415.15	0	1960485.47
Mixed forest	889.15	16369.36	0	23.11	670.28	0	972638	29.07	990618.97
Board-leaved forest	424.3	0	0	0	221.44	0	51598.63	1192824.93	1245069.3
Grand Total	20875.55	281555.12	294804.78	372829.21	100004.59	1943577.44	1230990.39	1197978.66	5442615.74
Sum of the land use changes	**P2**								
P3	**Buildings**	**Water**	**Shrub**	**Grassland**	**Road**	**Coniferous forest**	**Mixed forest**	**Board-leaved forest**	**Grand Total**
Buildings	27182.05	308.18	45.49	*19668.7	4860.81	*12250.48	*14721.98	*4992.39	84030.08
Water	405.09	333205.08	0	0.05	1493.68	0.02	0.38	0	335104.3
Shrub	8.58	0	303826.94	0	546.36	0.32	30259.66	6.57	424466.64
Grassland	4945.98	0	0.05	383803.12	5450.94	0	0	0	419062.89
Road	4423.43	4508.47	994.71	15494.15	102635.51	*44364.84	*19255.77	*17974.9	209651.78
Coniferous forest	2166.41	0.01	0	0.7	10696.86	1903869.8	0	0.03	1916733.81
Mixed forest	4515.86	0.01	0	0.53	8790.76	0.01	926380.95	0	939688.12
Board-leaved forest	1380.83	0.01	0	95.64	4987.01	0	0.23	1222095.41	1228559.13
Grand Total	45028.23	338021.76	304867.19	419062.89	139461.93	1960485.47	990618.97	1245069.3	5442615.74
Sum of the land use changes	**P3**								
P4	**Buildings**	**Water**	**Shrub**	**Grassland**	**Road**	**Coniferous forest**	**Mixed forest**	**Board-leaved forest**	**Grand Total**
Buildings	54032.21	814.95	12.48	6177.9	6208.68	4869.81	7600.04	1853.46	81569.53
Water	101.6	330032.69	0	0	2989.56	0.01	0.01	0.01	333123.9
Shrub	20.76	0	299845.29	0	1091.58	0	0	0	300957.64
Grassland	6430.09	0.09	0.01	374890.02	9900.08	0.71	18409.78	30640.15	440270.9
Road	*7108.68	*4256.2	*4524.11	*43397.78	*120689.48	*49076.45	*51759.06	*33280.16	314091.91
Coniferous forest	5449.91	0.02	0	0.24	40388.05	1862786.8	0	0	1908625.03
Mixed forest	8305.46	0.36	0	0.67	15463	0.01	861919.22	51.77	885740.48
Board-leaved forest	2581.38	0	0	0.03	12921.35	0.03	0	1162733.58	1178236.37
Grand Total	84030.08	335104.3	304381.88	424466.64	209651.78	1916733.81	939688.12	1228559.13	5442615.74

5.2. Three-level management model

Although UNESCO's categorization of cultural landscapes provides a foundational framework, its practical implementation varies significantly across national and regional policies (Aimar, 2024; Rosalina et al., 2023). In China, the conservation of historic gardens and cultural landscapes follows the principles outlined in the *Law on the Protection of Cultural Relics* (NPC, 2017), which emphasizes static conservation over dynamic adaptation. Based on that, local policies like the CHQDP (CMG, 2022) lack differentiation, specificity, commonality, and dynamism regarding the implementation of CMR management. To address these issues, we propose a three-level management model (Table 6).

The three-level management model proposed above is UNESCO-oriented but also draws inspiration and insight from the ELC. As a significant method of ELC (Manolaki, 2020), landscape mapping combines dynamic authenticity with modern functionality (Schulp et al., 2019), fostering cultural landscapes' adaptive conservation (Aimar, 2024; Lopez Sanchez et al., 2021; Simensen et al., 2018; Taylor et al., 2014). This contributes to sustainable management by balancing environmental-adaptive conservation with development (Funsten et al., 2020; Wang et al., 2023).

First, Level 1 management is proposed for specific practical applications, as this study enables professional institutions to formulate more targeted and stratified conservation strategies (Bunruamkaew and Murayam, 2011; Gullino et al., 2020; Nijhuis et al., 2023). Influenced by the other two categories, the indicators and clustering results not only provide new data-driven perspectives on the physical conservation of historic gardens but also involve potential land use impacts such as urban encroachment and the decline of intangible heritage significance. This contributes to optimizing tourism design to enhance the experience of diversified travel routes while simultaneously promoting ecological protection and the public dissemination of heritage values.

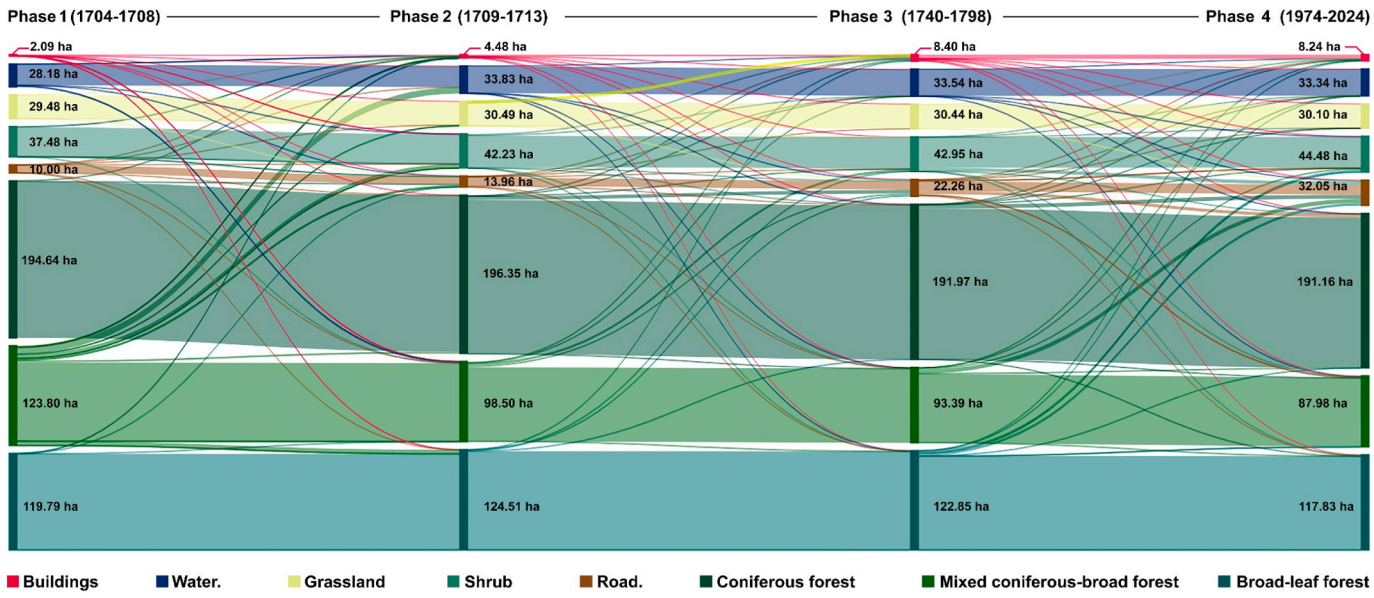

Fig. 9. Land use changes over the four phases. Each horizontal bar represents the area dedicated to different land uses over the four phases; the thickness of each bar indicates the area dedicated to that land use.

Table 6
Three-level management model.

Classification	Content	Object	Influenced by
Level 1 management, related to Category 1	Focuses on the strict conservation of historic gardens' physical structure, extending to the integrity of the surrounding land as well as the intangible value derived from it, rather than merely on the garden itself.	Historic gardens	Category 2 Category 3
Level 2 management, related to Category 2	Focuses on the dynamic evolution of the surrounding landscape, related to Category 2. However, it also identifies the continuous influence of land use on historic gardens, ensuring macro-level monitoring while allowing flexibility in land transformation, simultaneously promoting both social and ecological resilience.	Land use changes	Category 1 Category 3
Level 3 management, related to Category 3	Focuses on social strategies, encouraging public engagement in tourism activities centered around the cultural narratives of scenes and the environmental impact on land use.	Intangible cultural characteristics	Category 1 Category 2

Second, Level 2 management can be used to understand how external land use influences the primary attributes of historic gardens, enabling effective assessment of historic gardens in different areas at the macro-level (Cullotta and Barbera, 2011; Giannecchini et al., 2007; Lian et al., 2024). Influenced by the other two categories, Level 2 management aims to limit modern interventions and restrict certain land development activities that do not align with the heritage-integrated environment. This approach contributes to conserving the original authenticity of the historic gardens, including their ecological, physical, spiritual, and symbolic attributes, while maintaining the integrity of the surrounding environment. For areas needing physical intervention, low-impact soil stabilization methods like biopolymers or nanomaterials can enhance surface stability while preserving historical and ecological integrity (Bhagatkar and Lamba, 2024). The apparel industry's adoption of eco-efficient manufacturing and take-back programs highlights the value of lifecycle thinking, offering insights for land use management of cultural landscapes in terms of resource reuse, energy efficiency, and waste reduction (Pan et al., 2023). By analyzing historical land use transformations, policymakers can better prioritize conservation efforts, which can support the development of target zones for planning policies (Aimar, 2024; Nijhuis et al., 2023; Schulp et al., 2019; Van Eetvelde and Christensen, 2023).

Third, Level 3 management of the CMR requires public participation to balance heritage conservation, social inclusivity, and economic sustainability. Influenced by the other two categories, this approach integrates local knowledge of historic gardens' physical attributes into environmental-adaptive tourism strategies, such as ecological-educational zones, representative gardening techniques, traditional crafts, and religious-artistic workshops. This public-driven approach enhances social engagement (Cullotta and Barbera, 2011; Sánchez et al., 2020). Chengde's local employment policies under the CHQDP contribute to the economic viability of cultural landscapes while maintaining historical integrity (CMG, 2022; Gullino et al., 2020; HURPDI & CCPDI, 2008). Public participation can also improve information transparency, support local enterprises, and reduce pressure on decision-makers while minimizing environmental impact (Bunruamkaew and Murayam, 2011; Lieskovský et al., 2017). Embedding public governance into historic gardens' physical attributes and land use planning fosters long-term resilience, transforming historic gardens into socially and economically sustainable cultural landscapes (Van Lanen et al., 2022).

Consequently, this three-level management model demonstrates a high degree of replicability and universal applicability, as it selectively integrates the key principles of the ELC with quantitative analysis and qualitative narratives into a multi-scale cultural landscape rooted in Asian culture. This approach reflects a distinct perspective and the diverse interests of multiple stakeholders. Furthermore, it can serve as an effective communication intermediary among professional

conservation organizations, urban planners, government policymakers, developers, and tourists, facilitating the development of long-term, precisely targeted management strategies based on more comprehensive knowledge.

To summarize, our **key finding** is that the dynamic authenticity of historic gardens (Category 1) is deeply interconnected with surrounding land use (Category 2) and intangible associative components (Category 3), collectively shaping the evolution of an integrated cultural landscape. Existing international research lacks a holistic, integrated environment-oriented approach to cultural landscapes that encompasses all three UNESCO categories. This study presents the CMR as a representative case in which dynamic authenticity is central and all three categories coexist and interact. Based on this characterization, we propose a three-level model to improve cultural landscape management.

6. Discussion

6.1. Integrating dynamic authenticity into the reconstruction system

A reconstruction system is a fundamental step in cultural landscape research (Lathouwers et al., 2023). Through chronological layering and multimedia data synthesis, this system enables a more holistic understanding of historic gardens' dynamic authenticity within their broader cultural landscape context, aligning with UNESCO's long-term goal of sustainable management (Aimar, 2024; Funsten et al., 2020). Compared to the conventional descriptive outputs of historical archives and physical attributes in previous CHQDP policies (CMG, 2022) and other literature (Crumley et al., 2017; Marignani et al., 2008), the CMR highlights the foundational role of internal–external landscape structure, particularly in incorporating incomplete and missing components into its social-cultural land use dimensions. This tracking-based Web--GIS reconstruction platform provides policymakers with a tool to assess the effectiveness of land planning implementation in conserving, reproducing, restoring, and even regenerating cultural landscape values, addressing potential environmental threats and social pressures (Manolaki et al., 2019). Further, this platform can provide quantitative decision-making support, helping policymakers develop more scientifically grounded land management and conservation measures.

6.2. Recommendations for optimized implementation of local policies

From an implementation perspective, the local management policies encapsulated in the CHQDP (CMG, 2022) have not effectively characterized the ongoing transformation required for the succession, reproduction, and regeneration of heritage values. Additionally, they lack specificity and fail to systematically integrate zoning-based tourism planning with the land use transformation of the historic garden. Based on this three-level management model, we propose specific and practical recommendations for different groups of scenes to balance environmental-adaptive conservation and development (Table 7).

Table 7
Specific recommendations for each groups.

Clustering	Current statues	Future recommendations with three-level model
Group A1	They have a significant visibility advantage but poor accessibility. Currently, there is only one bus tourism route, leading to severe overcrowding of visitors and safety concerns on the slopes.	● Develop multiple-transportation-based (walking, bicycling, etc.) mountainous forestry tourism routes to disperse visitor pressure from popular scenes. ● Construct scenic viewpoints with platforms that leverage visibility advantages and designate land types for improved safety measures and facilities.
Group A2	Due to their location in the valley, the land is severely affected by water erosion, leading to the collapse and abandonment of many scenes. Some scenes remain in good condition, but their heritage value has not been given adequate attention.	● Preserve soil, water, and vegetation by designating the surrounding land use as an ecological protection zone, with short-term conservation measures and medium-to-long-term development plans. ● For areas with good physical conditions, create historically inspired Taoism rest and activity spaces to alleviate visitor pressure on nearby popular scenes.
Group B	They have excellent visibility and accessibility, with flat terrain, making it the current focus of development. However, the supporting infrastructure is inadequate and insufficient, and the tourism routes are disorganized and overlapping.	● Customize themed tourism routes based on different phases of royal history to showcase its historical evolution. ● The cultural significance of CMR lies in the fact that Group B served as a royal summer retreat. Enhancing infrastructure can help maximize its aesthetic value in relation to the surrounding water land use and its role in improving the microclimate for cooling.
Group C	Their visibility is poor, but accessibility is relatively good. However, many spaces are left unused and wasted, failing to leverage their accessibility to enhance the social dissemination of heritage value.	● Introduce more exhibitions and educational activities within the site. ● Establish clearer guiding and interpretative facilities to enhance its functional role in serving visitors, Improving public awareness of the cultural heritage value of CMR.
Group D	Although they have advantages in visibility and accessibility, the sites are linearly distributed rather than concentrated and are located far from the main entrance. As a result, visitor flow is low, ecological disturbance is minimal, and the ecological conditions remain excellent.	● Leverage the advantages of favorable ecological conditions by establishing a dedicated CMR floral and nursery cultivation center. ● Develop linear-themed tourism routes to enhance interaction with the ribbon-like water system and maximize the scenic value of the hilly terrain.
Group E	These areas feature expansive, open, and flat scenic spots with a strong religious atmosphere. However, the infrastructure is highly inadequate, leading to significant spatial underutilization and wastage of scenic areas.	● Enrich religious and social activities in large open scenic areas to enhance the social influence of CMR's cultural landscape. ● Introduce diverse outdoor cultural activities, such as horseback riding and other historically significant experiences, to boost urban vitality and engagement.

6.3. Limitations

Three aspects of our study require careful consideration when interpreting the results and data.

First, *the Mountain Resort and its Outlying Temples Chengde*, was included on UNESCO's World Cultural Heritage list in 1994. However, due to limitations in available data and spatial constraints, our research primarily focuses only on the core area of the heritage site, namely the Chengde Mountain Resort (CMR). Future studies could expand our analysis to include the entire site, including all of the outlying temples.

Second, there is some uncertainty in the vegetation data, particularly for P1 through P3, which correspond to more historical phases. Much of the vegetation was destroyed during modern periods due to warfare, abandonment, and ecological degradation. However, after five distinct periods of vegetation restoration (Table 8), the vegetation now largely reflects the original characteristics and appearance from those earlier periods, though significant gaps in authenticity and integrity remain.

Third, a small proportion of scenes (5 %) consist solely of foundational remains, which lack historical documentation and evidence for reconstruction. Although accurate, editable, and reliable surveying maps are available, their quantity is limited. While poems and paintings

Table 8
Different phases of restoration of vegetation in the CMR.

Phases	Time	Explanation
Reforestation	1940s–60s	To restore the vegetation at the CMR, a large-scale afforestation effort was undertaken. However, the initiative involved a single tree species with a low survival rate and did not consider the original landscape design.
Modernism landscape planning	1970s–90s	Gradually added many ornamental gardens, tree species. During this period, influenced by modernism and western landscape architecture, many foreign and modern gardening techniques were introduced. Thirty-Year Plan I
Preliminary theory-based restoration	1990s–2000	With the increased awareness of cultural heritage conservation and the need for tourism development, many academic works have been published, and the restoration of plants based on theoretical research have begun to develop. Thirty-Year Plan II
Landscape management	2000s	The focus of the vegetation of CMR has consistently been on improving the exterior environment, garden maintenance, scenes management, ancient tree protection, nursery construction, and forest area tending. During this period, large-scale cultivation of seedlings has been rare.
In-depth restoration	2010–2024	With the growing recognition in the field of domestic cultural relics and UNESCO World Heritage conservation, restoring the original appearance of the landscape at the CMR has become a necessary requirement for maintaining the "authenticity and integrity" of the resort. The focus of the vegetation work will shift to maintaining the original landscape, entering a period of adjustment and maintenance.

are more numerous, some lack precision and require secondary qualitative verification. As a result, these scenes have a degree of uncertainty. However, this small portion of uncertain scenes has not significantly impacted the results. To address this issue, we referred to other works from the same period and incorporated expert opinions into the reconstruction process.

7. Conclusion

This study provides a comprehensive pathway for understanding the dynamic authenticity of the CMR's historic gardens as a cultural landscape through integrative environment-oriented landscape mapping. By employing historical reconstruction and statistical characterization, this research provides empirical evidence of the evolution of the CMR, highlighting key transitions in spatial design, land use adaptation, and cultural significance. The identification of six targeted indicators for clustering analysis effectively combines quantitative spatial modeling with qualitative cultural narratives in heritage environment.

The findings enable us to propose a three-level management model with optimized policy recommendations aimed at bridging the conceptual and methodological gaps among the three categories in the UNESCO cultural landscape system. In terms of application, this study contributes to the broader discussion on heritage conservation by linking dynamic authenticity with modern functionality, inspired by the ELC and accounting for landscape transformations within environmental-social implementation frameworks. The landscape mapping approach facilitates a comprehensive land management and policy that incorporates physical interventions, land-use zoning policies, and public tourism engagement, balancing environmental-adaptive conservation with development.

As cultural landscapes continue to evolve in response to environmental-social and economic pressures, our research underscores the importance of integrative policymaking that can accommodate change while conserving heritage values. To further ensure the sustainable conservation and adaptive management of the cultural landscapes, future strategies should refine spatial zoning through clustering-derived typologies, enabling more targeted and responsive interventions. The six environmental indicators identified in this study can serve as a foundation for performance-based monitoring, and adaptive planning. Moreover, embedding intangible cultural narratives and community-based knowledge into governance practices can enhance participatory legitimacy and social resilience. These integrated measures not only operationalize the three-level management model but also provide transferable criteria for balancing heritage conservation and functionally transformed development amid growing environmental and societal pressures. Relevant research should continue to test and refine this approach through stakeholder-informed feedback, ensuring cultural landscapes remain both historically grounded and dynamically resilient.

CRediT authorship contribution statement

Jingsen Lian: Writing – original draft, Visualization, Validation, Software, Resources, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Steffen Nijhuis:** Supervision, Project administration. **Nan Bai:** Writing – review & editing. **Gregory Bracken:** Writing – review & editing, Supervision. **Haoxiang Zhang:** Writing – review & editing. **Xiangyan Wu:** Writing – review & editing. **Dong Chen:** Writing – review & editing, Data curation. **Jingyu Li:** Writing – review & editing.

Declaration of competing interest

This manuscript is original, has not been published, and is not under consideration elsewhere. All authors have approved the submission and declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. All authors have approved the submission and declare no conflicts of interest.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.indic.2025.100952.

Data availability

Data will be made available on request.

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