



A Landscape Approach to the Conservation and Development of Cultural Landscapes

Chengde Mountain Resort as a Case Study

Jingsen Lian

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Dedication

*To my grandmother, Mingying Han;
to my father, Zheng Lian, and my mother, Xiangqun Liu;
and to my wife and soulmate, Yuqing Hu.*

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List of Abbreviations

Abbreviation	Full term
BUD	Built-up urban density
BUE	Built-up urban area expansion rate
C1-6	Cluster 1-6
C-PHVP	Coupling Public Heritage Value Perception
CCHB	Chengde Cultural Heritage Bureau
CHCC	Cultural Heritage Conservation Center
CHI	Composite Index of Hazard Types and Frequencies
CHQDP	Chengde High-Quality Development Plan
CMR	Chengde Mountain Resort
CTD	Cultural Tourism Dependency (Share of GDP)
EDL	Education Level
ESV	Exterior scene visibility
GIS	Geographic Information System
GNNs	Graph Neural Networks
GRs	Greedy Routes
HEPLP	Hazard–Ecology–Perception Landscape Planning framework
HI	Heat Intensity
HSCs	Heritage Spatial Characteristics
LD	Landscape Design
LFI	Landscape Fragmentation Index
LGD	Ethno-linguistic and Language Diversity
LLMs	Large Language Models
LM	Landscape Mapping
LP	Landscape Planning
NDVI-T	NDVI Temporal Trend
NSGA-II	Non-dominated Sorting Genetic Algorithm II
NTL	Nighttime Light Intensity
OBH	Overlap of Biodiversity Hotspots
ORs	Official Routes
OSV	Observed Scene Visibility
PCA	Principal Component Analysis
PHVP	Public Heritage Value Perception

>>>

Abbreviation	Full term
PRs	PSLPM Routes
PSLPM	Perceptual–Spatial Landscape Planning Model
SOM	Self-Organizing Map
SSC	Social Structure and Cohesion Change
STSA	Scene-to-scene accessibility
STW	Scene-to-water accessibility
WHNUs	World Heritage Neighborhood Units

Summary

How can cultural landscape be conserved and developed through the landscape approach?

This thesis frames cultural landscapes as living systems in which landform, water, vegetation, settlement, mobility, governance, and everyday practices jointly produce heritage value across time and space. In such systems, heritage significance is not confined to monuments or isolated scenic elements, but emerges through the interaction of physical structure, ecological process, historical layering, and lived experience. But under accelerating climate change, ecological degradation, urban transformation, and tourism intensification, these systems are increasingly exposed to compound pressures that simultaneously threaten material stability, ecological function, cultural legibility, and management capacity. Because these pressures act across domains and scales, approaches that treat heritage as a bounded object or rely on single-domain solutions are no longer sufficient.

Within this proposition, landscape is treated as an integrative concept that links physical features, diverse functions, and socio-ecological processes. A landscape approach thus shifts conservation reasoning away from static object protection toward questions of evolution, relational structure, system performance, and future capacity. The thesis builds an integrated landscape approach including **landscape mapping** (characterization), **landscape planning** (conservation) and **landscape design** (development).

The first component, landscape mapping, addresses the characterization problem. The dissertation begins by synthesizing how landscape approaches have been used in research on historic gardens and related cultural landscapes and identifies a persistent gap between descriptive assessment and actionable intervention. It then uses Chengde Mountain Resort as the empirical anchor of the thesis and reconstructs it as an integrated cultural landscape through scene-based mapping, digital reconstruction, clustering, and land-use analysis. Through this process, the research makes long term evolution, persistent spatial structures, and scene-level attributes explicit and usable for management and decision making.

The second component, landscape planning, addresses the conservation problem by developing two complementary planning models. The first is the Hazard–Ecology–Perception Landscape Planning framework, which integrates hazards, ecological

sensitivity, and both expert and public heritage value perception into a unified workflow for cluster-targeted zoning, governance guidance, and conservation strategy. The second is the Perceptual–Spatial Landscape Planning Model, which responds to the growing gap between heritage spatial characteristics and public heritage value perception in complex cultural landscapes. Through large language model scoring, graph neural network coupling, and route optimization, PSLPM demonstrates how route-based interventions can reduce hotspot pressure, improve perceptual coherence, increase spatial diversity, and expand the coverage of marginal but meaningful scenes. In this sense, planning is treated not merely as zoning, but as an active mechanism for rebalancing use, interpretation, and spatial experience.

The third component, landscape design, addresses the development problem. Building on the evidence and planning outputs generated in the earlier stages, the dissertation extends from diagnosis and planning into development-oriented design. In the uploaded draft, this is framed through a Design-based Resilience Index for cultural landscapes and a clustering approach that translates comparative diagnosis into operational design grammar and cluster-specific toolkits. The purpose of this step is to convert abstract resilience patterns into concrete design variables and actionable rules, such as circulation restructuring, shading density, reversible construction strategies, material compatibility, ecological connectors, micro-retention measures, and visitor allocation principles. Design is therefore not treated as a final aesthetic layer, but as the stage at which conservation requirements become spatially operational. The design framework is further tested through Chengde Mountain Resort representation and scene-based experiments, bringing the thesis from documentation and interpretation to implementable design instruments.

Taken together, the thesis argues that cultural landscapes can be conserved and developed through a landscape approach only when characterization, conservation, and development are treated as parts of one integrated reasoning chain. Landscape mapping reveals how the system has evolved and where its persistent structures lie. Landscape planning identifies how current pressures, ecological constraints, and value perceptions interact and where targeted interventions are needed. Landscape design then translates these findings into auditable and site-responsive spatial actions. The overall contribution is therefore not a single model or tool, but an integrated framework that makes conservation decisions more defensible, more operational, and more responsive to change. By connecting historical reconstruction, planning intelligence, public perception, resilience diagnosis, and design translation, the dissertation offers a coherent pathway from diagnosis to implementable action for cultural landscapes understood as dynamic, relational, and governable heritage systems.

Samenvatting

Hoe kunnen cultuurlandschappen behouden en ontwikkeld worden vanuit een landschapsbenadering?

Deze dissertatie benadert cultuurlandschappen als levende systemen waarin reliëf, water, vegetatie, nederzettingsstructuren, mobiliteit, bestuur en alledaagse praktijken gezamenlijk erfgoedwaarde voortbrengen in tijd en ruimte. In dergelijke systemen ligt de betekenis van erfgoed niet besloten in monumenten of geïsoleerde landschappelijke elementen op zichzelf, maar ontstaat zij uit de wisselwerking tussen fysieke structuur, ecologische processen, historische gelaagdheid en geleefde ervaring. Onder de versnellende druk van klimaatverandering, ecologische achteruitgang, stedelijke transformatie en intensivering van toerisme worden deze systemen echter steeds sterker blootgesteld aan samengestelde drukfactoren die gelijktijdig de materiële stabiliteit, ecologische functie, culturele leesbaarheid en bestuurlijke capaciteit ondermijnen. Omdat deze drukfactoren zich uitstrekken over meerdere domeinen en schaalniveaus, volstaan benaderingen die erfgoed behandelen als een afgebakend object of steunen op oplossingen binnen één enkel domein niet langer.

Binnen deze these wordt landschap opgevat als een integrerend concept dat fysieke kenmerken, uiteenlopende functies en sociaal-ecologische processen met elkaar verbindt. Een landschapsbenadering verschuift het denken over behoud daarom van statische objectbescherming naar vragen van evolutie, relationele structuur, systeemprestaties en toekomstig aanpassingsvermogen. De dissertatie ontwikkelt een geïntegreerde landschapsbenadering die bestaat uit **landschapskartering** (karakterisering), **landschapsplanning** (behoud) en **landschapsontworp** (ontwikkeling).

De eerste component, landschapskartering, richt zich op het vraagstuk van karakterisering. De dissertatie begint met een synthese van de wijze waarop landschapsbenaderingen zijn toegepast in onderzoek naar historische tuinen en aanverwante cultuurlandschappen, en identificeert daarbij een hardnekkige kloof tussen beschrijvende beoordeling en handelingsgerichte interventie. Vervolgens gebruikt zij het Bergresort van Chengde als empirisch ankerpunt van de dissertatie en reconstrueert zij dit als een geïntegreerd cultuurlandschap door middel van scene-gebaseerde kartering, digitale reconstructie, clustering en landgebruiksanalyse. Via dit proces maakt het onderzoek langetermijnevolutie, blijvende ruimtelijke structuren en attributen op sceneniveau expliciet en bruikbaar voor beheer en besluitvorming.

De tweede component, landschapsplanning, behandelt het vraagstuk van behoud door de ontwikkeling van twee complementaire planningsmodellen. Het eerste is het Hazard–Ecology–Perception Landscape Planning-kader, dat gevaren, ecologische gevoeligheid en zowel deskundige als publieke percepties van erfgoedwaarde integreert in een samenhangende werkwijze voor clustergerichte zonering, bestuurlijke richtlijnen en behoudsstrategieën. Het tweede is het Perceptual–Spatial Landscape Planning Model, dat inspeelt op de groeiende kloof tussen ruimtelijke erfgoedkenmerken en publieke perceptie van erfgoedwaarde in complexe cultuurlandschappen. Door middel van scoring met grote taalmodellen, koppeling via graafneurale netwerken en route-optimalisatie laat PSLPM zien hoe routegebaseerde ingrepen hotspotdruk kunnen verminderen, perceptuele samenhang kunnen verbeteren, ruimtelijke diversiteit kunnen vergroten en de dekking van marginale maar betekenisvolle scènes kunnen uitbreiden. In die zin wordt planning niet louter opgevat als zonering, maar als een actief mechanisme om gebruik, interpretatie en ruimtelijke beleving opnieuw in evenwicht te brengen.

De derde component, landschapsontwerp, behandelt het ontwikkelingsvraagstuk. Voortbouwend op de evidentie en planningsuitkomsten die in de eerdere fasen zijn gegenereerd, strekt de dissertatie zich uit van diagnose en planning naar ontwikkelingsgericht ontwerp. In de geüploade conceptversie wordt dit uitgewerkt via een ontwerpgerichte veerkrachtindex voor cultuurlandschappen en een clusterbenadering die vergelijkende diagnose vertaalt naar een operationele ontwerpgrammatica en clusterspecifieke toolkits. Het doel van deze stap is om abstracte veerkrachtpatronen om te zetten in concrete ontwerpvariabelen en toepasbare regels, zoals herstructurering van circulatie, schaduwduchtheid, reversibele bouwstrategieën, materiaalcompatibiliteit, ecologische verbindingen, microretentiemaatregelen en principes voor bezoekersspreiding. Ontwerp wordt dus niet beschouwd als een laatste esthetische laag, maar als de fase waarin behoudseisen ruimtelijk operationeel worden gemaakt. Het ontwerp kader wordt verder getoetst via representaties van het Bergresort van Chengde en scene-gebaseerde experimenten, waardoor de dissertatie zich verplaatst van documentatie en interpretatie naar uitvoerbare ontwerpinstrumenten.

Alles bij elkaar betoogt deze dissertatie dat cultuurlandschappen alleen via een landschapsbenadering kunnen worden behouden en ontwikkeld wanneer karakterisering, behoud en ontwikkeling worden opgevat als onderdelen van één geïntegreerde redeneerlijn. Landschapskartering maakt zichtbaar hoe het systeem zich heeft ontwikkeld en waar de blijvende structuren ervan liggen. Landschapsplanning identificeert hoe huidige drukfactoren, ecologische beperkingen en waardepercepties op elkaar inwerken en waar gerichte interventies nodig zijn. Landschapsontwerp vertaalt deze bevindingen vervolgens naar controleerbare en

locatiespecifieke ruimtelijke ingrepen. De overkoepelende bijdrage ligt daarom niet in één enkel model of instrument, maar in een geïntegreerd kader dat beslissingen over behoud beter verdedigbaar, beter uitvoerbaar en beter responsief op verandering maakt. Door historische reconstructie, planningsintelligentie, publieke perceptie, veerkrachtdiagnose en ontwerpvertaling met elkaar te verbinden, biedt de dissertatie een samenhangend traject van diagnose naar implementeerbare actie voor cultuurlandschappen die worden begrepen als dynamische, relationele en bestuurbare erfgoedsystemen.



The Basics

Part A establishes the foundation of this dissertation by introducing research background, problem statements, objectives, and guiding questions, and by positioning the study through three connected landscape approaches: mapping, planning, and design. It then reviews the literature on historic garden research to clarify how these approaches have been used, what their main contributions and limitations are, and where important gaps remain. Together, these chapters prepare the reader for the following parts of the thesis by defining the conceptual basis, research direction, and analytical framework of development-oriented conservation.



1 Introduction

1.1 Background

Cultural landscapes are living systems where landform, water, vegetation, settlement, mobility, governance, and everyday practices jointly produce heritage value. They are not only shaped by historical intention and long-term evolution, but also continually reorganized by contemporary environmental stress and social change ([Antrop, 2006](#); [Bosher et al., 2020](#)). Under accelerating climate change, ecological degradation, and urban and tourism driven transformation, cultural landscapes face compounded pressures that threaten material stability, ecological function, and cultural legibility at the same time. These pressures act across scales and across domains, so responses that treat heritage as a bounded object and rely on single domain solutions often prove insufficient ([Connell, 2005](#); [Gothein & Wright, 2014](#)).

This dissertation advances a central proposition. Cultural landscape conservation must be development-oriented and design based. It should safeguard heritage integrity while steering change through traceable workflows that connect evidence to spatial decision making. Within this proposition, landscape is taken as an integrative concept that links physical features, diverse functions, and socio ecological processes across time and space. A landscape approach therefore places evolution, relational structure, and system performance at the core of conservation reasoning ([Arts, 2017](#); [Ginzarly et al., 2018](#); [Nijhuis, 2020](#); [Nijhuis, et al. 2023](#); [Rossignol, 1992](#)). It asks how persistent structures endure through long term change, how risks concentrate and propagate through landscape networks, how ecological limits shape feasible futures, and how perception and experience interact with spatial form. It also asks how to translate diagnosis into implementable planning and design actions rather than leaving assessment as an analytical endpoint ([Lassus, 1998](#); [Branton, 2009](#)).

Historic gardens are an important and sensitive subset within this broader cultural landscape field. They provide a revealing arena where designed scenes, ecological processes, and social meanings are tightly interwoven, and where the tension between protection and transformation becomes especially visible. Yet existing research has often developed along fragmented lines, with limited integration between mainstream conservation discourse and landscape approaches that could support actionable development-oriented conservation ([Millward, 2011](#); [Paiva, 2021](#); [Scazzosi, 2004](#)). This dissertation responds to that gap by building an integrated trajectory from mapping to planning to design, anchored in a deep case study and extended through global comparative analysis.

Chengde Mountain Resort (CMR) should be understood not simply as a historic garden or a collection of imperial relics, but as an integrated cultural landscape shaped by the long-term interaction of topography, water, vegetation, architecture, circulation, political intention, and everyday use ([Antrop, 2005](#); [Jones, 2003](#); [Scazzosi, 2004](#)). Its heritage value lies not only in individual scenic spots, but in the broader relational system formed by mountains, lakes, palaces, gardens, routes, and their wider setting. This perspective is especially important because CMR cannot be fully explained through a single heritage category. Although it was deliberately designed as an imperial landscape, its present condition also reflects environmental change, tourism development, land use transition, and evolving governance practices ([Forêt, 2000](#); [Gao & Jones, 2020](#); [Whiteman, 2020](#)). It should therefore be approached as a living heritage landscape, in which authenticity and integrity depend not only on material preservation but also on the continuity and legibility of spatial and temporal relationships ([Garcia-Esparza, 2018](#); [Nijhuis, 2020](#); [UNESCO, 2011](#)). Within this dissertation, CMR serves as the central case linking all chapters. In Part B, it is examined through landscape mapping to reconstruct its layered historical and spatial structure ([Crumley et al., 2017](#); [López Sánchez et al., 2021](#)). In Part C, it provides the basis for conservation-oriented planning under overlapping pressures such as hazards, ecological degradation, tourism, and management conflict ([Agapiou et al., 2016](#); [Bosher et al., 2020](#); [Sesana et al., 2019](#)). In Part D, this logic is translated into development oriented design, where diagnosis becomes operational strategies for integrity management, pressure control, and long term resilience ([Aimar, 2024](#); [Sánchez et al., 2020](#); [Von Haaren, 2002](#)). In this sense, CMR is both the case study and the integrative thread of the dissertation, connecting characterization, conservation, and development ([Lian et al., 2024](#); [Nijhuis, 2021](#); [UNESCO, 2023](#)).

The Chengde Mountain Resort functions as the empirical and methodological anchor of the thesis. It is a complex cultural landscape where multiple heritage dimensions and management logics coexist, and where evolution, land use dynamics, risk exposure, ecological sensitivity, and public experience interact in ways that challenge conventional single category interpretations ([Sevieri et al., 2020](#); [Tappeiner et al., 2021](#); [Connolly, 2020](#); [Hu et al., 2021](#); [Ferreira et al., 2023](#); [Rey-Pérez & Roders, 2020](#)). At the same time, a global dataset of near site neighborhood units provides a comparative horizon for design-oriented resilience thinking beyond a single case.

Across five parts, the dissertation develops a coherent chain of reasoning. It begins with a systematic literature review that clarifies how landscape approaches have been used in research on historic gardens and related cultural landscapes. It then reconstructs and characterizes a complex cultural landscape through landscape mapping and scene-based analysis. Next it develops planning frameworks that integrate hazards, ecology, and heritage value perception, including perception derived from large scale public text data supported by large language models. It then proposes a design-based resilience index and a cluster informed design grammar that translates comparative diagnosis into site specific spatial action. Finally, it synthesizes the outcomes, revisits the research questions, and identifies future directions. The overarching contribution is not a single tool. It is an integrated framework that makes conservation decisions more defensible by connecting data evidence, interpretive reasoning, and implementable spatial strategies.

Cultural landscapes are increasingly exposed to compound risks. Geographical hazards and climate related stress affect landform stability, hydrological regimes, and material decay ([Nguyen et al., 2022](#); [Ravankhah et al., 2021](#)). A landscape approach offers a way to meet this complexity. Conceptually, it reframes heritage as a relational system rather than a static object. Methodologically, it requires multiscale workflows that can connect long term evolution with fine grained spatial elements, connect expert knowledge with public perception, and connect assessment with planning and design decisions. This dissertation positions landscape mapping, landscape planning, and landscape design as an integrated ladder that supports development-oriented conservation.

1.2 Problem Statements

This dissertation is structured around three interconnected problems that correspond to the three steps of the integrated landscape approach. The thesis builds an integrated landscape approach including landscape mapping for characterization, landscape planning for conservation, and landscape design for development.

The first problem is a characterization problem ([Manolaki et al., 2019](#); [Sahle & Saito, 2021](#); [Schulp et al., 2019](#)). Cultural landscapes are often described through isolated heritage attributes or single scale descriptions, while their value and vulnerability emerge from long term evolution and cross scale interdependencies ([Cook et al., 2021](#); [Coombes & Viles, 2021](#); [Sesana et al., 2020](#)). In complex cases where designed scenes, land use dynamics, and associative meanings interact, existing approaches struggle to produce an integrative characterization that is comparable, interpretable, and useful for management. As a result, key questions remain unresolved, including which persistent structures organize the landscape, how change accumulates through time, and where vulnerability concentrates within the landscape system ([Lieskovský et al., 2017](#); [Antrop, 2005](#); [Whiteman, 2022](#)).

The second problem is a conservation planning problem. Cultural landscapes face compounded pressures from hazards, ecological degradation, and imbalanced expert and public value perceptions under climate change and urbanization, yet planning frameworks rarely integrate these dimensions, leading to fragmented and insufficient responses ([Bosher et al., 2020](#); [Julià & Ferreira, 2021](#); [Connolly, 2020](#)). This thesis addresses the gap with two models in CMR. The Hazard Ecology Perception Landscape Planning framework combines GIS based hazard and ecological sensitivity analysis with perception mapping from expert scoring and large language model supported public text analysis, producing cluster-based zoning and governance strategies that distinguish areas requiring complete conservation from areas needing careful tradeoffs. The Perceptual Spatial Landscape Planning Model tackles perception space mismatch by coupling perception scores from social media comments with a scene network and optimizing routes to reduce hotspot overconcentration while improving diversity and coherence.

The third problem is a development and design translation problem ([Fekete & Kollanyi, 2019](#); [Motloch, 2000](#); [Ornelas et al., 2016](#)). Even when diagnosis and clustering results are available, they often remain analytical outputs rather than actionable design knowledge. The missing link is a design-based mechanism that converts assessment into operational spatial rules, capacity thresholds, and reversible intervention principles ([Olivadese & Dindo, 2022](#)). Without this translation, development-oriented conservation cannot be executed in a defensible way, and resilience remains a general ambition rather than a spatially specific governance system that guides minimal intervention while safeguarding heritage integrity and landscape legibility ([Baster, 2022](#); [Garcia et al., 2017](#)).

1.3 Research Objective and Research Questions

The objective of this dissertation is to develop and validate an integrated landscape approach for development-oriented conservation of cultural landscapes. The approach links three sequential and interdependent components.

First, landscape mapping addresses characterization. It reconstructs evolution, identifies persistent structures, and produces scene level spatial evidence that makes cultural landscape dynamics legible. Second, landscape planning addresses conservation. It integrates hazards, ecological sensitivity, and heritage value perception into implementable planning guidance, so that conservation priorities and tradeoffs can be explicitly evaluated and translated into zoning and governance strategies. Third, landscape design addresses development. It translates diagnostic results into operational design variables, spatial rules, and minimal reversible intervention principles, enabling development and reuse that strengthen resilience while maintaining heritage integrity and landscape legibility.

Together these components form an integrated approach that bridges assessment and spatial action at both the site scale and the global comparative scale.

Based on this research objective, the dissertation is guided by the main question as:

- **How can cultural landscape be conserved and developed by landscape approach, with CMR as a case?**

And this main question can be elaborated into the following three sub research questions:

- 1 How can landscape mapping be used to characterize cultural landscapes by reconstructing their evolution, identifying persistent structures, and generating scene level spatial evidence of landscape dynamics?
- 2 How can landscape planning support development-oriented conservation by integrating hazards, ecological sensitivity, and heritage value perception into explicit planning priorities, zoning, and governance strategies?
- 3 How can landscape design translate diagnostic results into operational design variables, spatial rules, and reversible intervention principles that enable development and reuse while maintaining heritage integrity, landscape legibility, and resilience?

1.4 Research Approach

1.4.1 Landscape approach

How can a landscape approach support the characterization, conservation, and development of cultural landscapes through the integration of landscape mapping, landscape planning, and landscape design? It asks how landscape mapping can make long term evolution, persistent spatial structures, and scene level attributes explicit for management and decision making. It also asks how landscape planning can integrate hazards, ecological sensitivity, and heritage value perception to support targeted cluster conservation strategies, implementable zoning, and governance guidance. In addition, it examines how public heritage value perception can be quantified at scale and coupled with cultural landscape spatial characteristics so that route-based interventions improve perceptual coherence, spatial diversity, and coverage while reducing overconcentration and ecological pressure. Finally, it asks how landscape

design can translate characterization and planning results into actionable design toolboxes that guide development and reuse through auditable design variables, spatial rules, capacity thresholds, and minimal reversible interventions.

1.4.2

The structure of the research

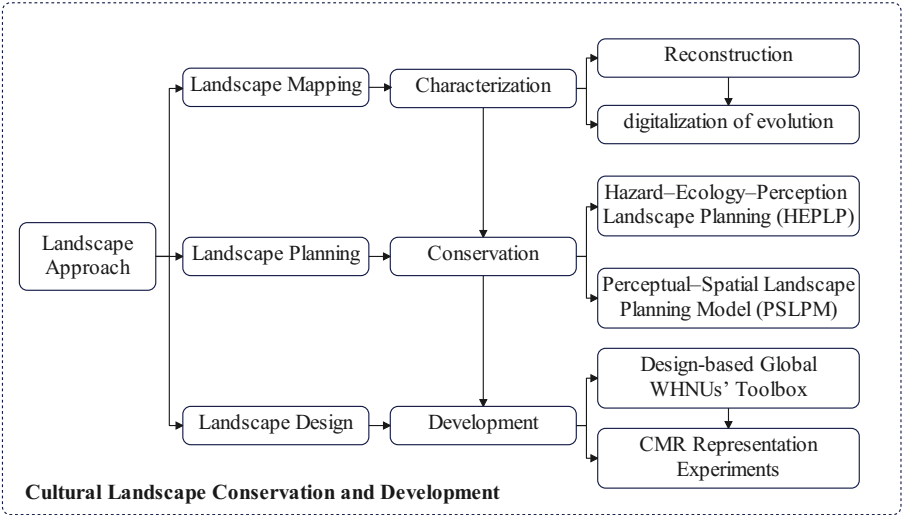


FIG. 1.1 Cultural Landscape Conservation and Development Framework.

The Fig 1.1 outlines an integrated framework for cultural landscape conservation and development under a Landscape Approach, organized around three coordinated strands: landscape mapping, landscape planning, and landscape design. Landscape Mapping leads to Characterization, which supports Reconstruction and the digitalization of landscape evolution, while also providing an evidence base that feeds into Conservation. Building on this input, Landscape Planning informs Conservation through two key outputs: the Hazard–Ecology–Perception Landscape Planning framework (HEPLP) and the Perceptual–Spatial Landscape Planning Model (PSLPM). Conservation in turn informs Development, ensuring that design decisions are grounded in conservation requirements; Landscape Design then contributes to Development, which produces a design-based toolbox for global World Heritage Neighborhood Units (WHNUs) and is further tested and communicated through CMR representation experiments, bringing the framework from documentation and interpretation to planning models and implementable design instruments.

1.4.3 Chengde Mountain Resort (CMR) as a cultural landscape

Chengde Mountain Resort should not be understood merely as a historic garden or a collection of isolated imperial relics, but as a complex cultural landscape shaped through the long term interaction of topography, water systems, vegetation, architectural composition, circulation, political intention, and everyday use. Its significance therefore lies not only in individual scenic spots or monuments, but in the broader relational system formed by mountains, lakes, palaces, gardens, routes, and surrounding settings ([Antrop, 2005](#); [Jones, 2003](#); [Scazzosi, 2004](#)). This perspective is also consistent with landscape approach scholarship, which treats heritage places as integrated socio ecological and spatial systems rather than static objects ([Arts et al., 2017](#); [Reed et al., 2020](#)).

This interpretation is especially important for CMR because the site cannot be adequately explained through a single fixed heritage category. While it clearly bears the characteristics of a deliberately designed imperial landscape, its present condition also reflects long term environmental change, tourism development, land use transition, and evolving governance practices ([Forêt, 2000](#); [Whiteman, 2020](#); [Gao & Jones, 2020](#)). CMR should therefore be approached as a living heritage landscape, in which authenticity and integrity are expressed not only through material preservation, but also through the continuity and legibility of relationships across time and space ([Garcia-Esparza, 2018](#); [Nijhuis, 2020](#); [UNESCO, 2011](#)).

Within this dissertation, CMR serves as the central case through which all chapters are connected. In Part B, it is examined through landscape mapping, where historical reconstruction and spatial analysis are used to reveal CMR as an integrated cultural landscape with layered temporal and spatial structures ([Crumley et al., 2017](#); [López Sánchez et al., 2021](#)). In Part C, it becomes the basis for conservation oriented planning, since cultural landscapes increasingly face overlapping pressures such as hazards, ecological degradation, tourism, and management conflict ([Agapiou et al., 2016](#); [Bosher et al., 2020](#); [Sesana et al., 2019](#)). In Part D, this logic is further translated into development oriented design, where diagnosis is converted into operational spatial strategies for integrity management, pressure control, and long term resilience ([Aimar, 2024](#); [Sánchez et al., 2020](#); [Von Haaren, 2002](#)).

Taken together, CMR is not only the case study of this dissertation, but also the integrative thread linking characterization, conservation, and development. As a cultural landscape, it demonstrates why landscape mapping is needed to reconstruct long term structure, why landscape planning is required to manage compound pressures, and why landscape design is essential for translating diagnosis into action ([Lian et al., 2024](#); [Nijhuis, 2021](#); [UNESCO, 2023](#)).

1.4.4 Conceptual hierarchy of the dissertation

This [Table 1.1](#) clarifies the conceptual hierarchy of the dissertation by organizing its main components from normative goal to applied case. It distinguishes the different levels at which the research is structured, including the overarching objective, the theoretical lens, the analytical workflow, the operational models, and the applied contexts of validation. In doing so, it shows how development-oriented conservation is translated from a general ambition into a coherent sequence of concepts, methods, tools, and case-based applications across the dissertation.

TABLE 1.1 Hierarchical relation between theory, method, tools, and application in the dissertation

Core concept / component	Level	Definition in this dissertation	Function	Corresponding chapter logic
Development-oriented conservation	Normative	A conservation position that seeks to maintain heritage integrity while allowing adaptive development, reuse, and resilience-building in cultural landscapes	States the dissertation's overarching aim and clarifies its overall objective.	Frames the overall objective of the thesis
Landscape approach	Theoretical	A way of understanding cultural landscapes as dynamic, relational, and multi-scalar systems in which history, ecology, perception, and spatial form interact	Clarifies how the problem is conceptualized and supports the thesis's core conceptual framing.	Part A, chapter 2
Landscape Mapping, Landscape Planning, Landscape Design	Analytical	A sequential analytical structure in which mapping characterizes the landscape, planning evaluates conservation priorities and trade-offs, and design translates diagnosis into development strategies	Defines how the research proceeds methodologically and structures the dissertation's three core logic.	Part A, chapter 1, 2
HEPLP	Operational	A planning-oriented model integrating hazard exposure, ecological sensitivity, and heritage value perception	Supports conservation and development tradeoffs planning and zoning decisions in the landscape planning stage.	Part C, chapter 4
PSLPM	Operational	A perceptual-spatial model linking scene structure, heritage perception, and landscape evidence	Supports perception-based landscape analysis and informs the transition from mapping to planning.	Part C, chapter 5

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TABLE 1.1 Hierarchical relation between theory, method, tools, and application in the dissertation

Core concept / component	Level	Definition in this dissertation	Function	Corresponding chapter logic
Resilience Index, spatial design, grammar, intervention principles	Operational	A set of design-oriented tools that translate analytical diagnosis into operational spatial strategies	Supports development, adaptive reuse, and reversible intervention in the landscape design stage.	Part D, chapter 6
Comparative, global application	Applied	The broader comparative dimension through which transferability is examined	Extends the framework beyond a single case and tests its broader applicability.	Part D, chapter 6
CMR case study	Applied	The principal testing ground of the dissertation	Demonstrates how the framework operates in a concrete cultural landscape and validates the approach at the site scale.	Part D, chapter 6

1.4.5 Overview of the methodological framework

This Table 1.2 provides an overview of the methodological framework of the dissertation. It summarizes how each part and chapter is structured in relation to its research approach, main research platforms and data sources, types of materials analyzed, and the models or algorithms applied. By bringing these elements together, the table clarifies the overall research logic of the dissertation, showing how the study moves from landscape approach and landscape mapping to landscape planning and landscape design, while integrating textual, visual, spatial, environmental, and user-generated data within a coherent analytical framework.

TABLE 1.2 Summary of Research Approaches, Data Sources, and Computational Methods

Research approach	Chapter	Research platform/ source	Type	Models / Algorithms.
Landscape approach	Part A Chapter 2	Web of Science/ Scholar/ Scopus	Textual	– VOSviewer – Pajek
Landscape mapping	Part B Chapter 3	Chengde Cultural Heritage Bureau (CCHB)	– 3D point cloud/ Orthophotography/ Photogrammetry/ – Textual – Visual materials	– Python – R studio

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TABLE 1.2 Summary of Research Approaches, Data Sources, and Computational Methods

Research approach	Chapter	Research platform/ source	Type	Models / Algorithms.
Landscape planning	Part C Chapter 4	– Chengde Cultural Heritage Bureau (CCHB) – Cultural Heritage Conservation Center (CHCC) of Beijing – Tsinghua Urban Planning & Design Institute (THUPDI) – China Geological Survey (CGS)	– Geographical hazards data – Shared data used in both hazard and ecological sensitivity analyses – Ecological sensitivity – Heritage value perception data	– Large Language Models (LLMs) – Python – ArcPy
	Part C Chapter 5	– Chengde Cultural Heritage Bureau (CCHB) – Social media	– Cultural landscape spatial data -User-generated content from social media data (same as above)	– Large Language Models (LLMs) – Python – Graph Neural Networks (GNNs)
Landscape design	Part D Chapter 6	– Chengde Cultural Heritage Bureau (CCHB) – VIIRS VNL annual composite from NASA and NOAA – United Nations World Tourism Organization (UNWTO) – Armed Conflict Location and Event Data Project (ACLED) – Centre d'Études Prospectives et d'Informations Internationales (CEPII) – Global Data Lab (GDL) – ESA WorldCover – Global Human Settlement Layer – The International Disaster Database – NASA LP DAAC – Critical Ecosystem Partnership Fund – ESA WorldCover – WorldClim v2.1	– Social Vulnerability – Historical Fabric and Urban Morphology – Composite Geo-Environmental Stressor Index – Geo-Contextual – Spatial base data – Field monitoring – Hydrological and ecological analysis data – Terrain and environmental analysis data	– Self-Organizing Map (SOM) – Python

1.5 Scientific and Societal Relevance

This dissertation is scientifically relevant because it advances cultural landscape research from fragmented assessment toward an integrated approach that connects characterization, conservation, and development in one coherent chain of reasoning. Instead of treating mapping, planning, and design as separate professional domains, the thesis positions them as interdependent steps that can be reproduced, audited, and transferred across cases. It contributes to a methodological structure that makes cultural landscape knowledge operational, meaning that evidence can be translated into management decisions, planning guidance, and design action without losing interpretability.

Scientifically, the thesis contributes in three ways that align with its integrated landscape approach. First, it strengthens landscape mapping as characterization by demonstrating how long-term evolution and persistent spatial structures can be reconstructed and expressed through scene level attributes that are usable for management. This supports dynamic understanding of authenticity and integrity by showing how heritage legibility is produced through evolving relationships rather than fixed snapshots. Second, it advances landscape planning as conservation through an integrated workflow that links hazards, ecological sensitivity, and heritage value perception. By combining GIS based environmental diagnosis with perception mapping derived from both experts and large-scale public text, the thesis expands planning from single dimension protection toward explicit trade off management and cluster targeted zoning logic. It also demonstrates perception space coupling and route-based planning as a planning instrument, not only as an evaluation tool, thereby adding spatial intelligence to cultural landscape governance. Third, it advances landscape design as development by proposing a design-oriented resilience translation that converts comparative clustering results into operational design toolboxes. In this translation, resilience becomes a set of auditable design variables, spatial rules, capacity thresholds, and minimal reversible intervention principles, enabling development and reuse to be guided by measurable constraints and clear decision logic.

The dissertation is socially relevant because it addresses urgent governance dilemmas faced by cultural landscapes worldwide under climate stress, ecological limits, and tourism pressure. Many heritage sites are trapped between two unsatisfactory options, either freezing change in ways that weaken living functions, or allowing development that erodes integrity and landscape legibility. The integrated approach proposed in this thesis offers a third path. It supports risk

informed conservation that prioritizes where complete protection is necessary, while identifying where carefully guided development is feasible and beneficial. It provides a defensible basis for negotiating conflicts between ecological sensitivity and public demand by making both dimensions visible and comparable in planning. It also offers route-based strategies that redistribute visitor pressure away from hotspots, improve experiential continuity, and bring marginal yet meaningful scenes into a broader interpretive sequence, which can support local economies while reducing ecological and spatial overload.

Finally, the societal contribution lies in transferability and accountability. Because the thesis links diagnosis to action through explicit variables and rules, it can support transparent communication among policymakers, practitioners, and the public. It provides a way to justify why certain zones require strict conservation, why others can host adaptive reuse, and how interventions can remain minimal and reversible while still improving resilience. In this sense, the dissertation reframes cultural landscape conservation as spatial governance that is evidence based, design oriented, and capable of steering development without sacrificing heritage integrity.

2 Literature Review

Although there have been numerous studies on the heritage attributes, characteristics, and values of the historic garden as a special category of cultural heritage, the **question** is that a comprehensive review that combines mainstream historic garden conservation with ways of understanding the garden in a landscape context has not been conducted. Landscape is an integrative concept that combines physical features and the diversity of functions with social and ecological process throughout the scales of time and space. Therefore, this landscape context means applying the landscape approach to explore the organic connection between the scale of evolution and the architectonic elements in relation to each other. To elaborate, instead of viewing the garden as an object in one specific temporal-spatial frame, such an approach focuses on the evolution of the site in order to identify persistent structures and other values. For **method**, through paper coding as qualitative analysis combined with bibliometric visualization software, we reviewed 162 studies to explore the interconnections between the historic garden and landscape approach. The **result** is that there are three correspondences between landscape approaches and different stages of historic garden's conservation and development: studies identifying the historic garden's characteristics using landscape mapping, studies demonstrating historic gardens' conservation based on landscape planning, and studies exploring the potential of development and reuse by means of landscape design. Finally, we **discuss** the research gaps and outline an action framework for the conservation and development of heritage gardens in a landscape context.

Lian, J., Nijhuis, S., Bracken, G., Wu, X., Wu, X., & Chen, D. (2024). Conservation and development of the historic garden in a landscape context: A systematic literature review. *Landscape and Urban Planning*, 246, 105027. <https://doi.org/10.1016/j.landurbplan.2024.105027>

2.1 Introduction

Historic Garden is an important category of cultural heritage, which is identified as a dynamic living system rather than a simple composition assembling distinct heritage elements, as defined by the [Florence Charter \(1981\)](#), and it is also listed in the [UNESCO operational guidelines \(1992\)](#) as a special type of cultural landscape (item 1): as an example of human intentional creation and design of nature. Under this perspective, the historic garden's values lie precisely in their diverse heritage attributes which show a succession of transformation of special natural environment conducted by human culture and address different scales of time and space ([Connell, 2005](#); [Gothein & Wright, 2014](#)).

To understand historic gardens as a cultural landscape we need to look at them in a more comprehensive and sustainable way, specifically in a landscape context ([Antrop, 2006](#)), which means we should make more use of the connotation and meaning of the landscape approach ([Arts, 2017](#); [Ginzarly et al., 2018](#); [Nijhuis, 2020](#); [Nijhuis, et al. 2023](#); [Rossignol, 1992](#)). Landscape as an approach, emphasizes the acquisition, recognition, and sustainable management of surface features ([Freeman, 2015](#); [Reed, 2016](#)), which is a means of spatial perception and serves territorial and regional planning and design ([De Fries, 2010](#)). Its concern for ecological evolution and cultural transformations aligns with the multifaceted attributes of the historic garden, encompassing both unique application scenarios and universally applicable principles ([Lassus, 1998](#); [Branton, 2009](#)). However, most heritage landscape conservation theories and methodologies focus on the historic garden as 'fixed' objects addressing a specific scale, or architectural features without including relational and contextual aspects, such as the relation among garden clusters and the urban or rural context ([Millward, 2011](#); [Paiva, 2021](#); [Scazzosi, 2004](#)). The introduction of a landscape approach to conservation and development in the historic garden has compensated for the lack of systematization, weak integration, and poor dynamics of architectonic heritage conservation methods ([Harvey, 2015](#); [Sayer et al., 2013](#)). In view of international conventions and previous research, one of the most relative angles associated with this introduction to the field of the historic garden is that it will end up not merely focusing on employing conventional methods to acquire intact conservation results for each element under restrictive conservation criteria, but rather establish a cyclical process that applies the adaptive strategy to support conservation effectively ([Obad Šćitaroci et al., 2019](#); [Girard, 2013](#)).

In addition, it is, firstly, an approach to the historic garden that provides a long-term chronological vision to articulate the initial design logic in the past, which involves revealing the territorial collection memory and identity, grasping the ancient wisdom in response to the changes in the natural environment (Funsten, 2020; Nijhuis, 2015). Secondly, it makes this continuous succession more feasible and practical, to convert all these principles into present use, developing new functions with multiple interventions (Liu & Nijhuis, 2020; Czałczyńska, 2014). Thirdly, these heritage values are cognized, reinterpreted, and reused progressively in a sustainable way, which will benefit the next generation in the future (Benfield, 2013; Gullino et al., 2019).

This study attempts to propose the possibilities and potentials of using a landscape approach for the conservation and development of the historic garden reflecting the outcomes from design and planning (Fig 2.1). Hence, the following question will be answered in this research to address the issue mentioned above: What is the current research focus and gaps in the literature about landscape approaches used for historic garden's conservation and development and how to improve this landscape approach?

2.2 Bibliometric Analysis and Visualization

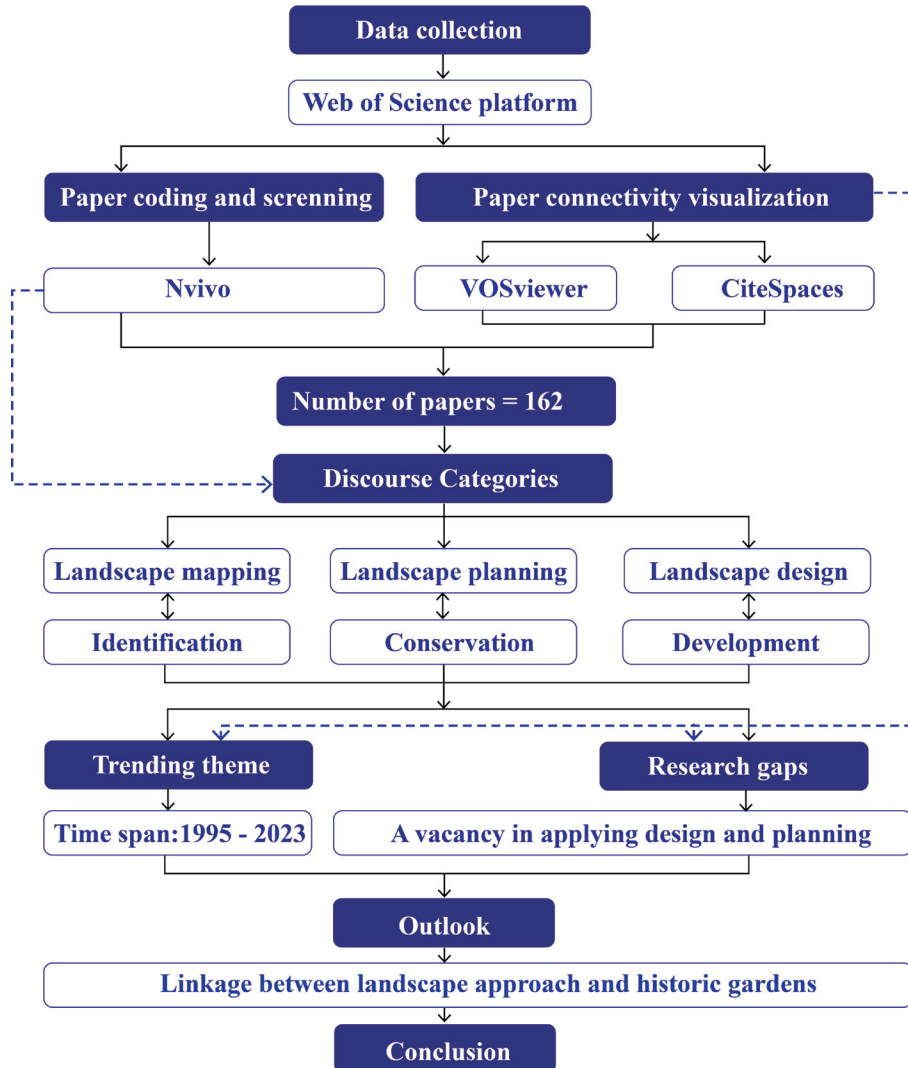


FIG. 2.1 The flow diagram for literature review.

The method of literature analysis is broken down into two parts: firstly, we use Nvivo, based on paper coding and statistical methods, to visually obtain a direct overview of the paper's basic information such as the number published each year and site coverage. We also use Nvivo to establish multiple criteria to classify and identify the specific content of the target literature in a detailed way. Secondly, we use VOSviewer and Citespace to show and simulate the scientometric network between research literature in a macro sense so that we can have a more integrated understanding of the academic gaps and tendency of research, and particularly find the vacancies in the present study field.

Web of Science (WOS) offers diverse accessible databases for publications that explicitly articulate and use landscape approaches to conserve and develop the historic garden from multiple disciplines, including humanities and social science as well as natural science. Moreover, the Conference Proceedings Citation Index-Social Science & Humanities (CPCI-SSH), Emerging Sources Citation Index (ESCI), Conference Proceedings Citation Index-Science (CPCI-S), Science Citation Index Expanded (SCI-E), Social Sciences Citation Index (SSCI), and Arts & Humanities Citation Index (A&HCI) were all decided upon as data sources for the present research. We divided the topic into three main categories as obligatory terms: "landscape approach", "conservation and development", and "the historic garden", with each of them having a set of keywords for their related concepts.

- 1 **Landscape approach:** $TS_1 = (\text{"landscape approach" OR "landscape method" OR "landscape planning" OR "landscape design"})$
- 2 **Conservation and development:** $TS_2 = (\text{"conservation" OR "protection" OR "preservation" OR "maintenance" OR "restoration" OR "adaptive reuse" OR "utilization" OR "regeneration" OR "rehabilitation" OR "renovation" OR "intervention"})$
- 3 **The historic garden:** $TS_3 = (\text{"historic* garden" OR "garden heritage" OR "historic* park" OR "park heritage" OR "botanic* garden"})$
- 4 $(TS_1) \text{ AND } (TS_2) \text{ AND } (TS_3)$

We will then match these three groups of keywords with each. The time span was set from 1995 to 2023.

According to the PRISMA statement (2020) (Page et al., 2021) (Fig 2.2), the results yielded 476 documents from the Web of Science, and 2 duplicated papers and 68 non-English papers were removed before screening. 5 previous review papers were excluded according to the PRISMA flow diagram and 1 paper doesn't have the main content. The second screening of the remaining studies (n = 400), and 190 articles were excluded due to their lack of focus on using the historic garden as the research subject. A further 48 papers were excluded because the literature did not address the application of the "landscape approach" as a research method or tool, or provide relevant workflows from a landscape perspective, finally leaving (n = 162) articles as the final set of references used for writing (Suppl. Data 1)

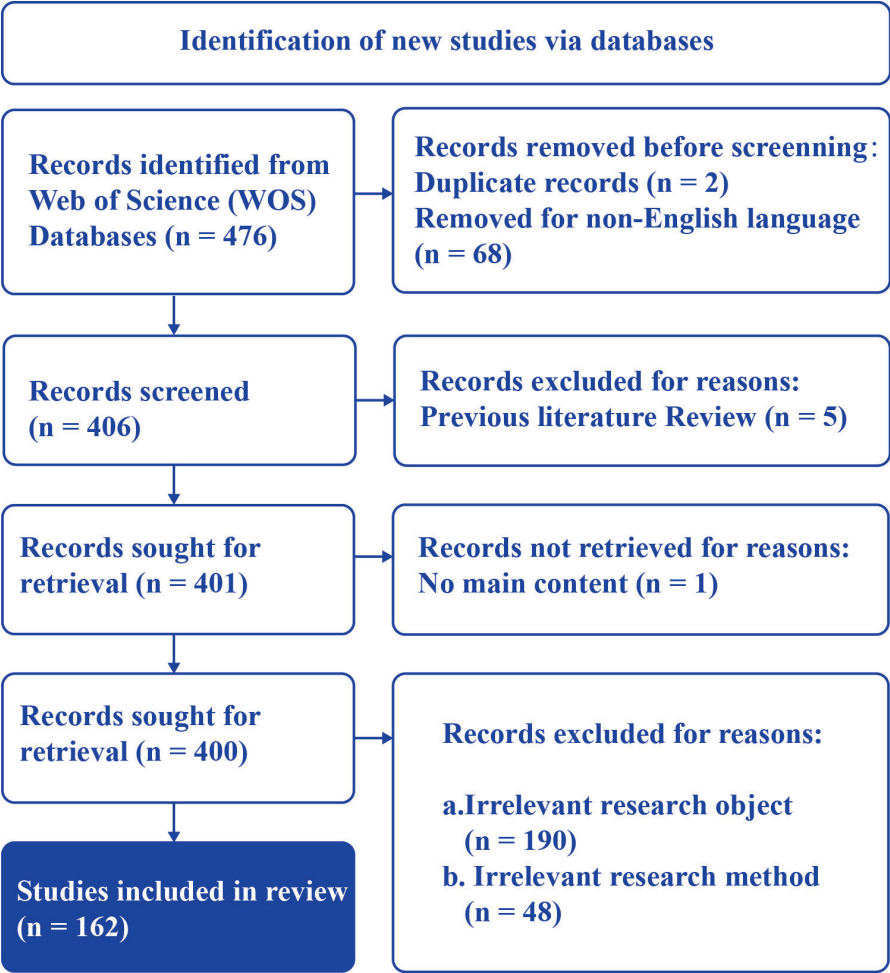


FIG. 2.2 The PRISMA flow diagram for paper screening.

We used paper coding to categorize the literature for statistical and qualitative analyses (Finfeld, 2018; Jensen & Allen, 1996). Regarding the coding logic, we drew inspiration from [Onwuegbuzie et al. \(2012\)](#) and their work on taxonomic analysis and theme analysis in qualitative research techniques. Firstly, with reference to the elements of taxonomic analysis, we redefined the classification system for the papers, which includes the following 6 items: research design, study questions, research objectives, (mixed) qualitative and quantitative data, analysis techniques, and findings. After repeatedly reading the papers, we systematically deconstructed the content based on these criteria. This process allowed us to create a comprehensive classification system for a more organized and efficient analysis of the papers. Furthermore, through theme analysis, we attempt to extract the various domains of different papers and conduct constant comparison analysis to identify similarities among them. These findings are then summarized into distinct headings, serving as group names for the purpose of clustering.

In the process of paper coding and analysis, the software *NVivo Version 20 1.7.1.153* was employed in this research. Nvivo offers a method for paper coding that involves identifying key topics in the papers and linking them to nodes. The node system allows for the efficient management of complex data records, enabling researchers to explore patterns and connections between concepts within a broader discussion ([Phillips & Lu, 2018](#)). After multiple authors discussed and established grouping criteria and applied the two analysis methods mentioned earlier, the first author unified the coding process in NVivo and performed the categorization and organization.

VOSviewer and Citespace are two prominent and widely used software. They are used for bibliometric analysis, visualizing a wide range of connectivity (clusters) between different papers, which indicates the intrinsic meaning of the paper database. As many papers as possible should be collected to make sure of obtaining a complete database of relevant papers for further screening and analysis. These Java-based programs enable the creation of bibliographic data maps that are color-coded and provide an insightful representation of the underlying data. ([Waltman et al., 2010](#); [H. Zhang et al., 2022](#)). Additionally, CiteSpace stands out for its capacity to extensively utilize co-citation and co-occurrence analysis. This analysis identifies clusters of co-cited references and creates networks of co-occurring keywords. As a result, critical keywords in papers can be revealed, along with trending topics and concepts throughout the entire research field. ([Chen, 2006](#)).

2.3 Landscape-Oriented Insights from the Literature

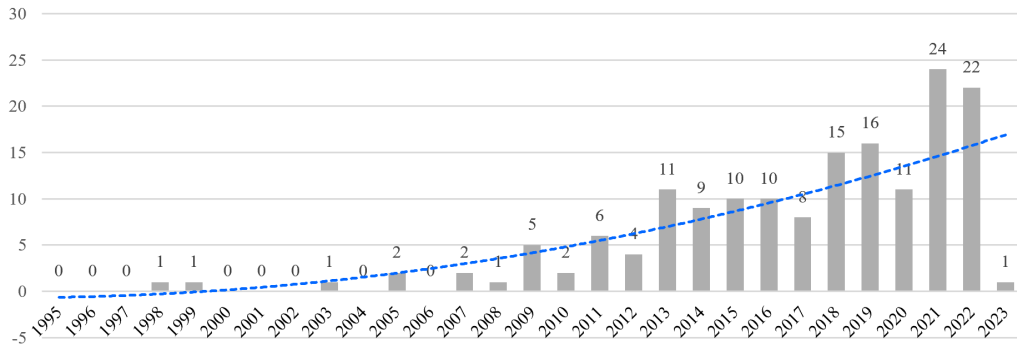


FIG. 2.3 Annual distribution of the studies.

Figure 2.3 shows the number of papers screened in section 2.2, related to research on the historic garden and published between 1995 and 2023 in the WoSCC database. In the early stages (1995 - 2008), only eight were published in this period, which indicates that the historic garden as a special type of heritage did not receive much attention from researchers. However, from 2009 onwards, this research field increasingly attracted attention, and the number of publications gradually increased. Although there were fluctuations, the number of documents increased rapidly from 5 to 23 from 2009 to 2022, with an annual growth rate of 12.58%.

We also counted other different attributes of the paper cases, such as the largest proportion of studies in Europe due to the application of ELC (Fig 2.4); more case studies in urban context than in suburban and mixed areas (Fig 2.5); cases that are not part of the conservation system receives less attention than national heritage and world heritage (Fig 2.6).

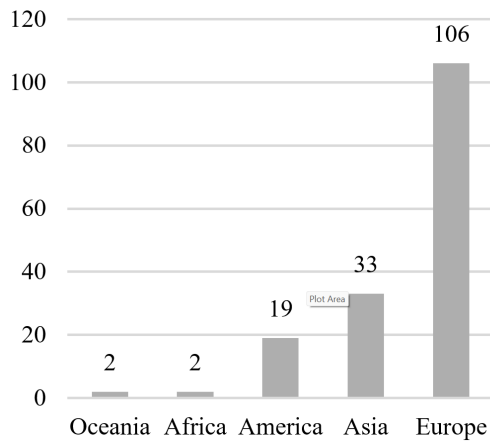


FIG. 2.4 Continental distribution of the academic institution.

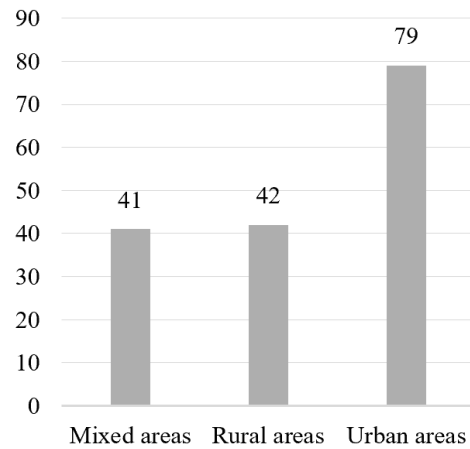


FIG. 2.5 Types of landscape environment historic gardens.

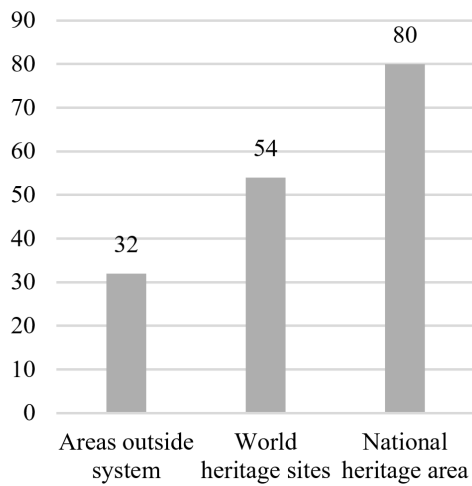


FIG. 2.6 Level of heritage conservation in the case studies.

Demonstrated by VOS-viewer, four clusters emerged, with the four keywords showing the highest co-occurrence: “cultural landscape,” “conservation,” “landscape,” and “sustainable development” (Fig 2.8A). Furthermore, the historic garden only shows the connection with the “restoration”, “preservation” and “sustainable development” (Fig 2.8B). When using “design” and “landscape” as connecting words to show relevance, the historic garden was established as a vacant position (The part framed in red) (Fig 2.8C, 8D).

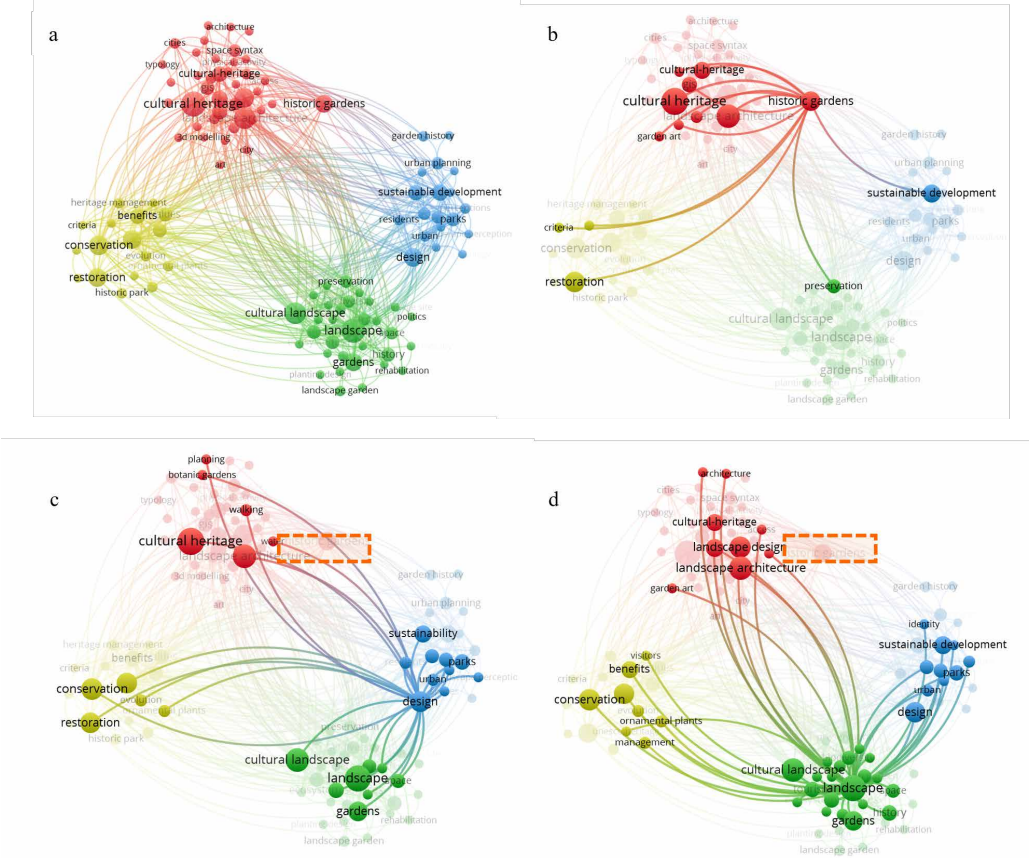


FIG. 2.8 Connectivity of keyword co-occurrence frequency processed in VOS-viewer. **A:** Keyword co-occurrence clustering; **B:** Related research links for ‘historic garden’; **C:** Historic Garden is vacant in the ‘Design’ related literature link; **D:** Historic Garden is vacant in the ‘Landscape approach’ related literature link.

2.4 Discourses in Conservation and Development of the Historic Garden

We have entered all the conservation and development principles and tactics found in each document as coded references in the NVivo program to extract the key discourses ([Table 2.1](#)).

Overall, **landscape mapping (LM)** focuses on the acquisition and interpretation of various human-nature interactive forms of information related to surface spatial characteristics ([Lilley, 2018](#); [Soini, 2001](#)). Utilizing the advantages of this approach, we clustered papers related to the analysis of the historic garden characteristics and attempted to form group A. [Von Haaren \(2014\)](#) compared **Landscape Planning (LP)** and **Landscape Design (LD)** in terms of their responses to substantive and process values facing landscape change. He pointed out that LP is more capable of providing systematic support for the protection of multiscale spaces (more substantive value), while LD contributes more to offering innovative intervention based on development for specific issues (more process value). As a result, we attempt to establish the connection between LP and historic garden conservation (group B), and the connection between LD and historic garden development (group C). These three relationships are in sequential order of different phases of the whole conservation and development process of the historic garden ([Fig 2. 9](#)).

Firstly, for group A, a series of international conventions and charters have defined the conservation of the historic garden as being based on the core of pluralistic values, and the determination of these values requires the identification of heritage characteristics ([De la Torre, 2013](#)). Although landscape mapping originated from geography and ecology, its practical application has gradually proven advantageous in precisely categorizing surface patterns and demonstrated a close association with characterization ([Blasi et al., 2014](#)). It provides advanced technical support and comprehensive application tools for identifying, visualizing, synthesizing, interpreting, and understanding the spatial characteristics of a special site, and it has been used in the historic garden research for many years ([Liu & Nijhuis, 2020](#)). This constitutes the key reason for clustering our first discourse. The sub-groups have been commonly applied from landscape mapping for identifying the heritage values of the historic garden, including basic research on the historical materials (A1, 22%), various digital techniques utilization for recording values (A2, 10%), landscape assessment modeling (A3, 7%) and landscape indicators for capturing changes (A4, 12.5%).

Secondly, for group B, the conservation of the historic garden is essentially a regional concept concerned with the protection of the territory environment (Scazzosi, 2004), and inclusion of integrity is one of the most crucial criteria employed by UNESCO to determine the value of cultural heritage. Meanwhile, landscape planning involves the comprehensive formulation of territorial management strategies in a long-term vision, emphasizing the multifaceted attributes of the site, with a primary goal of promoting sustainable land use practices (Von Haaren, 2002), which aligns with the purpose of the historic garden serving the integrative values for future generations. Additionally, on the social aspect, landscape planning is a result of collective efforts involving multiple stakeholders to address multifunctional issues. This facilitates the achievement of consensus among various interested parties and helps resolve conflicts that may arise during the implementation of conservation agreements (Ryan, 2011). These subgroups are methods used to conserve the integrity of the historic garden with landscape planning, including policy-making and legislation (B1, 3%), territorial management (B2, 10.5%), multiple stakeholders (B3, 3%), and a holistic toolbox to analyze conservation status (B4, 10%).

Thirdly, for group C, the development and reuse of historic gardens mean retaining their original values while opening up new possibilities for their sustainable enhancement, bringing the heritage with a fresh life distinct from (more than) its original purpose (Hotimah et al., 2015). Unlike “conservation” methods that have matured paradigms, given that the historic garden is a fragile type of cultural heritage, their development and reuse require timely updates and consideration of new intervention methods (Sharma, 2007). The significance of landscape design lies in seeking spatial language that can reveal deeper and richer meanings for a specific “place”, creating new visions and values within various scales of ecological or social-cultural processes (Von Haaren et al., 2014). It is considered an intentionally and newly crafted and envisioned “built intervention” to foster and enhance the existing experiences of a place (Treib, 2001). Indeed, this enduring visibility and practicality of landscape design are beneficial in establishing harmony between the essence of the historic garden and its future users. These subgroups are methods used to develop and reuse the historic garden with landscape design, including establishing intervention standards of design (C1, 8.5%), sustainable development protocol connecting conservation and reuse (C2, 8.5%), and pluralistic tourism model (C3, 5%).

TABLE 2.1 Eleven guidelines involved by historic gardens studies on landscape approach

Application of landscape approach	Number of studies	Referenced studies (Appendix A)	Previous related approach & concept
A. Studies to identify the historic gardens' characteristics using Landscape mapping			
A1. Historical research and achieves organization of historic gardens	36	10; 15; 16; 18; 23; 33; 39; 40; 41; 46; 53; 56; 61; 62; 67; 69; 76; 78; 81; 82; 87; 99; 104; 108; 115; 122; 125; 126; 129; 132; 144; 146; 153; 156; 159; 162	Landscape archeology; Cultural landscape
A2. Digital techniques to capture and record the heritage data	16	01; 13; 22; 37; 44; 70; 75; 84; 97; 102; 103; 116; 120; 121; 139; 145	Digital landscape modeling (DLM); Landscape information model (LIM)
A3. Using the landscape assessment model to evaluate the heritage status	11	21; 32; 35; 55; 64; 80; 91; 92; 114; 123; 124	Landscape character assessment
A4. Landscape indicators used for monitoring the changes in heritage	20	09; 34; 38; 45; 47; 51; 66; 83; 90; 95; 100; 112; 117; 128; 135; 137; 147; 151; 155; 157	Landscape biography; landscape mapping
B. Studies demonstrating historic gardens' conservation based on landscape planning			
B1. Elaborated landscape inclusion in policy-making and legislation	5	19; 24; 30; 59; 113	the Florence Charter; European landscape convention (ELC)
B2. Landscape as territorial management of heritage site	17	06; 27; 48; 54; 57; 71; 85; 86; 93; 96; 130; 131; 136; 141; 150; 152; 161	European landscape convention (ELC)
B3. Promoting multiple stakeholder participation in the conservation process	5	05; 11; 25; 29; 74	Historic urban landscape (HUL)
B4. Landscape as a holistic toolbox to analyze the conservation status	16	03; 08; 20; 26; 31; 42; 58; 60; 63; 88; 89; 98; 106; 142; 149; 160	Landscape management; landscape planning
C. Studies exploring potentials of development and reuse by means of landscape design			
C1. Establishing landscape-centered intervention standards of design	14	04; 12; 17; 36; 49; 72; 79; 110; 111; 118; 119; 133; 140; 143	Cultural landscape
C2. A sustainable development protocol connecting conservation and reuse	14	02; 07; 14; 43; 52; 65; 77; 94; 101; 107; 127; 134; 148; 154	Landscape suitability evaluation (LSE)
C3. Designing a pluralistic tourism model to convert the heritage values	8	28; 50; 68; 73; 105; 109; 138; 158	Landscape tourism

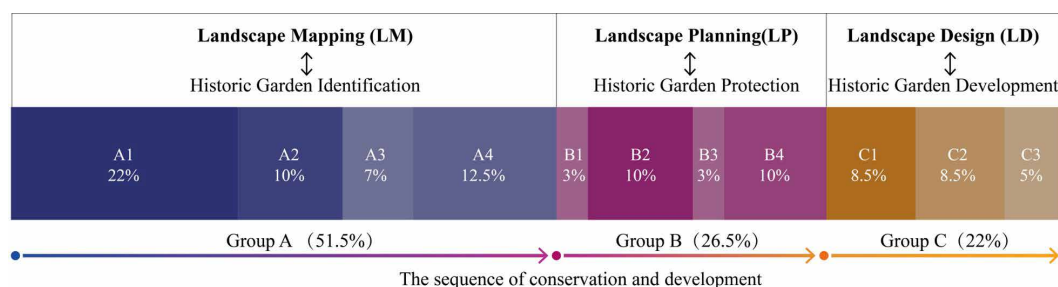


FIG. 2.9 The distribution of the percentage of each category of landscape research in the historic garden conservation-development sequence.

However, compared to group C (22%), group A (51.5%) and group B (26.5%) clearly dominate with a larger proportion, which indicates a more pronounced focus from the academic community on the identification of historic garden characteristics, rather than development and reuse. This imbalance can be considered a gap in the current academic field, and the future development and reuse of the historic garden has a lot of potential for exploration.

2.4.1 Studies of characterization using landscape mapping (Group A)

Historical research is the starting point for the historic garden's conservation and development, this is due to the rearrangement and comparison of historical materials that will contribute to determining the degree of conservation, restoration, and maintenance of heritage elements and compositional linkages in historic gardens (A1) (Baster, 2022; Szilágyi et al., 2020). The objective of conducting historical research on primary and secondary sources, such as archives, museum documents, map and library collections, specialized bibliography reviews, and internet sources, is to gain a comprehensive understanding of the construction and evolution of gardens (Gullino et al., 2019; Halbrooks, 2005; Shojae & Zarei, 2016). Additionally, landscape archeology as an interdisciplinary field provides many insights into how to apply landscape mapping to the study and analysis of historic gardens (Kluiving & Guttman-Bond, 2012). Many studied cases involving historic gardens show that landscape archeology is conducted for the restoration-based purpose of revealing the cultural forces and ideologies behind each phase of development (Jacques, 1997; Klagyivik, 2011).

Digital technology is increasingly important in historic garden research and practice **(A2)** (Counsell, 2001; P. Gullino et al., 2020). Its rapid development has improved how heritage information is recorded, stored, and disseminated, leading to significant advances in the representation of integrative landscape environment information (Liang et al., 2018; C. Yang, 2015). The London Charter (2012) proposes that digital recording research for specific heritage types is currently the focus of this field and, in recent years, digital research on the historic garden has increased (Denard, 2016). Capturing the combination of fundamental man-made or natural elements, and other social or cognitive properties in historic gardens, is the core of landscape heritage recording work (Alberta Cazzani et al., 2022; Malinverni et al., 2019). Even though most of these scanning and mapping methods are carried out with GIS as the core of the database, many auxiliary technologies and plug-in functions have been derived (Malinverni et al., 2019; Shevlyakova & Atkina, 2019). This mainly reflects the recording of information on the dynamic evolution of historic gardens. On the basis of the records, some studies are trying to simulate and reproduce the historical-spatial features of historic gardens based on mathematical models with parametric systems (Li & Li, 2016; Yu et al., 2018), which are more challenging because the natural elements in historic gardens are more dynamic, even though many heritage features have been destroyed and no longer exist.

In the identification of landscape values, landscape character assessment (LCA) has been increasingly used in many studies to discuss historic garden conservation as a perceived entity in recent years **(A3)** (Gkoltsiou & Paraskevopoulou, 2021). LCA is seen as essential to implementing the ELC and as a highly useful instrument for researchers to assess the landscape character of the historic garden (Tudor, 2014). It emphasizes achieving an overall assessment of the historic garden's geographic-physical and social-perception condition through issue definition (Fairclough et al., 2018; Swanwick, 2002), setting criteria, building a conceptual framework for documenting the spatial particularities with the goal of addressing all stakeholders' needs and interests but also identify the threats to both heritage and users. On the one hand, it is necessary to conduct a field survey to record the environmental information on the surface of the land, and to assign specific indicators to the different zones according to their internal components, i.e. landscape character type (LCT). On the other hand, after the information is obtained, different levels of the strengths, or sensitivity vulnerabilities of each heritage type are analyzed (S. Turner, 2018).

The dynamic concept of the landscape approach is used to monitor changes in the heritage elements of historic gardens **(A4)** (Carneiro, 2012; Malinverni et al., 2019; Morar et al., 2019). Several studies have shown that a multifaceted study of species in historic gardens can aid in the introduction of more precise conservation and development guidelines as well as technical office action (Del Curto et al., 2022), and it seems most attention is paid to the growth state and community succession of historical vegetation, hydrological studies related to changes in the water system, as well as distribution and alignment of routes (Carrari et al., 2022; P. Gullino et al., 2020; Hüttel et al., 2019). The purpose of employing landscape monitoring is to sustain its existing integrity, with emphasis on the continual maintenance and restoration of historical materials (Halbrooks, 2005). We can also identify a close correlation between the internal logic of landscape monitoring in historic gardens and landscape biography theory (Sánchez et al., 2020). This concept promotes a wide chronological analysis of the single remnant and their relationship, which contributes to putting the historic garden within a framework of spatial and temporal coherence (Kolen & Renes, 2015; Roymans et al., 2009). In this way, the landscape monitoring tools are not only for the control of the physical environment but also for the purpose of reinforcing the local identity of the site.

2.4.2 Studies of conservation based on landscape planning (Group B)

Many countries inevitably invoke references to the Florence Charter and other international conventions when developing legislation or policies regarding the conservation of their historic gardens. Despite the fact that it does not represent a legal act but only a series of recommendations, it has had a profound impact on the conservation activities performed in historic gardens **(B1)** (Araoz, 2013; M. Jagiełło, 2021). Despite those principles being adopted by a large number of countries, actually, only a few countries have tried to progressively incorporate those universal guidelines with very specific consideration (Athanasiadou, 2019). On the contrary, most other nations arbitrarily adopt them without comprehensive thinking due to static, independent, and conventional heritage conservation concepts which, unavoidably, causes excessive commercial development and tourism encroachment on local communities (Caust & Vecco, 2017; Pyykkönen, 2012).

The application of the landscape approach to the conservation phase of historic gardens is reflected in territorial management **(B2)** (Del Curto et al., 2022; Funsten et al., 2020). To be specific, the overall conservation of historic gardens can be seen as a management of the territory's various special resources, based on ecological considerations, and can lead to beneficial value cycles (Carneiro, 2012). However, it has been pointed out that the unjustified and loose territorial management aimed at economic exploitation leads to the degradation of natural resources, even causing them to disappear (Cianci, 2013). This can be seen particularly in the conflict between protected zones and newly developed alteration areas in terms of ecology, sight lines, aesthetic atmosphere, as well as the changes in topography and river banks (Nagpal & Sinha, 2009). In this respect, the U.S. national park management system is experienced in managing such large-scale historic gardens, which is seen as a service system, namely to make the different sociocultural and natural contexts better understood and utilized with full respect for their historical and environmental values (Catron & Eaddy, 2018). In the European context, the ELC also advocates an integrated landscape management approach based on territorial governance, which is also very applicable to the conservation of historic gardens in a holistic and integrated manner (Scazzosi, 2004).

The landscape approach facilitates the participation of multiple stakeholders in the conservation of the historic garden through participatory behavior and raising awareness, which is based on the community as the main organizational unit **(B3)** (Muir, 1999; Wahurwagh & Dongre, 2015; Wang, 2023). Some scholars point out that the historic garden is a social space where the interaction between different interested parties and users happens, satisfying the capacity of individuals to include physical activity in their daily routines (Khalilnezhad et al., 2021). In order to better utilize the public social value of historic gardens, scholars advocate establishing precise behavioral measures and guidelines, which means a highly efficient communication network should be established among knowledgeable gardeners, civic organizations, environmentally conscious residents, relevant institutions, and local authorities (A. A. Andrianou & Papaioannou, 2017; Minelli et al., 2016). Some scholars point out that the strength of the concept of landscape narrative can be used to enhance residents' sense of empowerment to achieve the preservation of heritage (Guilfoyle et al., 2019; Guimarães et al., 2015), and will also work toward the realization of this common vision. This concept harmoniously integrates a bottom-up approach, rooted in landscape-related perspectives, with expert scientific knowledge, facilitating the cultivation of a culture founded on mutual trust and collaboration concerning the historic garden. Reflecting the form-related concept of HUL, it also fosters a collective commitment to engage the public in the practice of promoting conflict resolution through deliberation. (D. Sikora & Kaczynska, 2022; Feng et al., 2021; Nurme et al., 2014).

The landscape is not only an object of study and perspective, but it also provides a holistic toolbox for analyzing the conservation status of historic gardens **(B4)** (Aşur & Alp, 2020; Dobrescu & Raducu-Lefter, 2012; Lassus, 1998; Muir, 1999). The primary application scenario entails the integration of historic garden preservation within their environs, elucidating the interconnections between the internal constituents of these gardens and their immediate surroundings. Due to the fact that the historic garden is the representation of place attachment, coherence, and a withheld identity in the collective unconscious of the area's inhabitants (Carneiro, 2012; Garcia et al., 2017), they have been proven to effectively tackle the social-ecological challenges of locality posed by the processes of globalization (Jakobsson & Dewaelheyns, 2018). This relationship is often projected onto the integrated connections between the various elements within historic gardens and the external natural and cultural environments, such as the use of water, path accessibility, plants' composition, productive areas, and buildings' view, to analyze and test whether they are all in a harmonious cohesion (Gullino et al., 2019; Nagpal & Sinha, 2009; Vanni Accarigi & Crosby, 2019). For related concepts, "landscape planning" and "landscape management" have established a complete system at the level of geography, ecology, and social science, providing a reference and foundation for creating a toolbox for historic garden conservation. (Sánchez et al., 2020).

2.4.3 Studies of development and reuse by means of landscape design (Group C)

Landscape design is an important method for bridging conservation and development, placing appropriate interventions into the historic garden site to activate its potential, which prioritizes compatible conservation and development simultaneously **(C1)** (Fekete & Kollanyi, 2019; Motloch, 2000). The concept of intervention was born out of a discussion in the cultural heritage community about the appropriate way to maximize the preservation of heritage (Ornelas et al., 2016), and was later introduced to the existing landscape and historic gardens by Lassus in conjunction with the concept of design practice (Lassus, 1998). It now considers every situation as an opportunity, as if fixing certain problems might improve the heritage environment as a whole (Olivadese & Dindo, 2022). They play a constructive role by providing valuable guidance for designers, enabling them to introduce changes that align with the cultural heritage and cater to the demands of the present era (Baster, 2022; Garcia et al., 2017).

This means of intervention emphasizes the implantation of new functions of the site, for the economy, and for public service. This approach partly overlaps with certain concepts of “revitalization” or “regeneration” (Nagpal & Sinha, 2009). This type of intervention is mainly reflected in the installation of infrastructure, equipment, and facilities including guided wayfinding, lighting, audio commentary, parking, entrances and exits, retail, exhibitions, sculpture, bins, toilets, etc. (Edensor & Bille, 2019; Rostami et al., 2016). The methodology of this aspect of the papers mainly employs a qualitative study with questionnaires and a mathematical statistical model to analyze the data, intending to test the environmental impact of intervention in the historic garden sites, including popularity, perceptibility, distribution rationality, public acceptability, and environmental hazards. On this basis, it is possible to optimize the design and planning of interventions (A. A. Andrianou & Papaioannou, 2017; Romero, 2011; Rostami et al., 2016). Actually, in terms of the related concept, the historic garden is an important component of cultural landscapes. Scholars argue from this perspective that landscape architectonic intervention (Indira, 2017), as a landscape design approach, is an important means to promote the conservation and development of the historic garden, which is based on adaptability to ecological, social, economic, and human environments (Page et al., 1998). They have proposed various alternative solutions to address site-specific issues to maintain the characteristics of the cultural landscape (Parsizadeh et al., 2015).

A sustainable conservation and development protocol is particularly important for the conservation of historic gardens and essentially proposes a collaborative and shared governance model of work (C2) Andrianou & Papaioannou, 2019; Gullino et al., 2018). This plays a pivotal role in the sustainable revitalization of landscapes, as it is intricately connected to environmental preservation, economic viability, and the availability of resources for both current and future generations (Wahurwagh & Dongre, 2015). There are many case studies that show that conservation and development projects in historic gardens need to be integrated into a planning and design framework of public open space or green infrastructure, creating a cultural and physical environment that promotes social interaction and good health (Cameron et al., 2012; Connell, 2005; Paraskevopoulou et al., 2020). Given the intricacy involved in this undertaking, it becomes imperative to adopt a regional standpoint to fully grasp the interconnections among distinct heritage sites, thereby establishing a unified foundation for collaborative endeavors (Nijhuis, 2021). This approach actively preserves the traditional landscape by integrating productive functions with ethical, artistic, historical, educational, and recreational functions (Cilona & Ala, 2018). From a conceptual point of view, the landscape suitability assessment based on multicriteria evaluation proposes to clarify the value rating of the heritage site and the crisis it faces. Through overlaying various suitability maps, combined with AHP analysis, an optimal protocol will be generated that takes into account the balance between the conservation and development of the historic garden (Bunruamkaew & Murayam, 2011, Lan-Ling et al., 2016).

Designing a multifaceted and pluralistic landscape tourism model can effectively convert the heritage value of historic gardens **(C3)** (Benfield, 2013; Czałczyńska-Podolska, 2014; Hristov et al., 2018). The demand for visiting gardens and landscapes has witnessed a notable upswing, (Backhaus & Murungi, 2009). Given this context, there has been a growing trend to actively promote “heritage experiences” and emphasize the significance of engaging the senses and emotions as essential components of the tourism product (Hristov et al., 2018). This call for the adoption of new approaches to interpreting values to visitors through mixed media of text, images, and audio commentary, aims at highlighting the reproduction of “site memory” (Cheng et al., 2014), through which ancient and historical material culture is reshaped, reproduced, and reused in historic gardens of very different scales and functions (Williams, 2014). Some cases accomplished maximizing visitor engagement by integrating a variety of alleys, guided tours, routes, and pathways, continually altering angles and visual perspectives, and dynamically adjusting the distribution of natural elements like plants and waterscapes to align with specific visibility objectives (Badami, 2021; Fornaris et al., 2011; Korotun et al., 2021). Some studies focus on the type of visitor activity compared to the historical designer’s original design intent, which facilitates the assessment of historic garden changes in tourism development and reflects the mutual influence of garden elements and visitors (Connell, 2005; Zhu et al., 2022).

However, most historic gardens were initially designed as private spaces and later transitioned to public areas, therefore, the development of measures to address the issue of damage to heritage features due to excessive visitor carrying capacity has received attention. (Yoon & Kwon, 2010). In terms of related concepts, “landscape tourism” is not yet a recognized term, but it has been much discussed recently in both the geography and tourism fields. This mode of temporary movement of subjects in the landscape is considered to play an important role in preserving the stability of ecosystems, cross-cultural exchange, sustainable economic growth, and the cognitive construction of local identity (Burger, 2000; Knudsen, 2008).

2.5 Interpretation of Findings and Research Implications

2.5.1 Trending themes in current research and research frontiers

According to the results presented by Citespace, which reflected a conventional research paradigm that treated historic gardens as mere “historical landmark” artifacts. However, a noticeable shift from 2000 onwards as evidenced by the emergence of “communities”, “residents”, and “identity” as prominent research themes, suggests a growing interest in exploring the role of historic gardens in urban development. This signifies a heightened recognition of the contribution of historic gardens in fostering community development and providing essential services for urban residents, underscoring the importance of studying the historic garden within the broader urban development context. It also attests to the fact that contemporary habitat life concepts have played a significant role in shaping research efforts related to the historic garden. Besides, the existence of “Landscape Architecture” spans a long period which is a testament to the applicability and usefulness of landscape as an approach.

2.5.2 Research gap: a vacancy in applying landscape design

Indeed, landscape design is regarded as an essential practice to link the physical systems and immaterial characteristics of heritage sites in a more integrative landscape spectrum from an external perspective ([Dobrescu, 2013](#); [Fekete & Kollanyi, 2019](#)). Nevertheless, there are few studies that demonstrate how the landscape approach can be to identify the pluralistic values of the historic garden in the context of specific cases and application scenarios (vacant position in [Fig 8c, 8d](#)).

Additionally, the term “historic garden” shows more connection to “preservation” and “restoration”, which implies the current research mainly focuses on conserving the garden heritage based on historical methods. Even though this historical study is the starting point for heritage research, we also need regard for on-site values which can be used for development and reuse ([Dobrescu & Raducu-Lefter, 2012](#); [Hosseini & Caneva, 2022](#)). As many case studies indicated, historic gardens are increasingly treated as parts of urban public green spaces ([Rostami et al., 2016](#)), but due to the lack of effective interpretation, their on-site values in social and cultural aspects are

not recognized by visitors at the same level as other more visible and substantial values, such as aesthetics. In response to this issue, many studies have proved that the landscape approach, especially landscape design, has this particular “interpretation” attribute (Meinig, 1979), making the landscape a widely used tool that can provide planners and designers an overview of site continuity and entity on one hand, and simultaneously reveal the complexity for users and visitors on special purposes, like perception and education, on the other (Motloch, 2000). The historic garden is not an exception to this approach, however, the research gap can be identified that further and more detailed research on how to take advantage of landscape interpretation to equally conserve and develop the historic garden is still lacking (Hristov et al., 2018).

2.5.3 Toward a landscape design-based framework

Based on the literature review and paper analysis, it can be observed that there is limited research on the application of landscape design methods in the conservation and development of the historic garden. Consequently, we are going to propose assumptions and basic concepts about building a framework to establish a linkage between the landscape and the historic garden for addressing or resolving these gaps.

We found that the potential for applying landscape design in the development and reuse of historic gardens is only realized when they are considered as integral parts of the overall cultural landscape (Dobrescu, 2013; Fekete & Kollanyi, 2019). This subordinate relationship can be recognized through the determination of “layers” that convey various heritage elements (M. Antrop, 1998; Crofts, 1975). Therefore, in the framework presented below:

On the one hand, we attempted to establish the closely connected projected relationship that historic gardens have from multiple types of related elements of the landscape background through “layers”, to identify the landscape design origin possessed by historic gardens (Fig 2.10A). Previous research has established a comprehensive spatial-analytical model for landscape architecture through “layers”, providing a more intuitive and reliable research framework (Motloch, 2000; Gazvoda, 2002), especially for the study of landscape design (Booth, 1989; Nijhuis, 2016). In these cases, based on the dissection and reassembly of layers, it is possible to technically and functionally generate redesigned principles from broader landscape scope for each independent architectonic element of historic gardens in the vertical dimension (Fig 2.10A). They struck a balance between “restoration,” “reconstruction,” and “renewal,” to enhance the authenticity of intrinsic structure for conservation and promoted sustainable solutions for historic gardens’ development (Altincekic et al., 2016; Fekete, 2021; Bálint & Nagy, 2022; Kuśmierski, 2022).

On the other hand, utilizing this projected relationship, we have proposed and compared three landscape design-based approaches (C1, C2, C3) to foster positive interaction, collaboration, and symbiosis of the historic garden's development and reuse in a higher-dimensional landscape context (Fig 2.10B).

1 Landscape-centered intervention

Compared to other two operational guidelines (C2, C3), it's a more concrete approach that explores the design logic and ideology behind the original landscape heritage by reproducing the diachrony of ancient imagination, characteristics, and phenomena (Zhang & Chen, 2014; Abdel-Rahman, 2016). Specifically, the objective is to transform diverse heritage layers (Fig 2.10A) and values by employing appropriate and precisely graded interventions to achieve the adaptability of the historic garden to ecological, cultural, social, economic, and human environments (Page et al., 1998; Indira, 2017).

2 A sustainable protocol

Compared to the other two operational guidelines (C1, C3), this approach focuses more on the application of landscape design to establish a systematically collaborative model for the development and reuse of historic gardens within multilevel surroundings (Gullino et al., 2018, Andrianou & Papaioannou, 2019). This broader-scope design framework serves as a significant effort to achieve a balance between land-use changes and specific heritage functions (Nijhuis, 2021). Positioning historic gardens as the core of broader landscape development and reuse, this sustainable conservation protocol, based on the concept of “design”, more effectively breaks free from the constraints of static and singular preservation management (Cilona & Ala, 2018).

3 Landscape tourism model

Compared to the other two operational guidelines (C1, C2), the landscape tourism model emphasizes the importance of the role of the “user”, which revolves around the subjective perspective rather than the objective historic garden heritage itself (C1) (Hristov et al., 2018). The modern user is one of the key factors in the development and reuse of the historic garden heritage (Connell, 2005). Therefore, applying landscape design enhances visitors' interpretation, engagement, and experience of the value of historic garden heritage, encompassing both tangible and intangible aspects (Cheng et al., 2014; Korotun, 2021; Ana & Vladimir, 2022), which can help to promote the development and reuse of historic gardens from the perspective of the public.

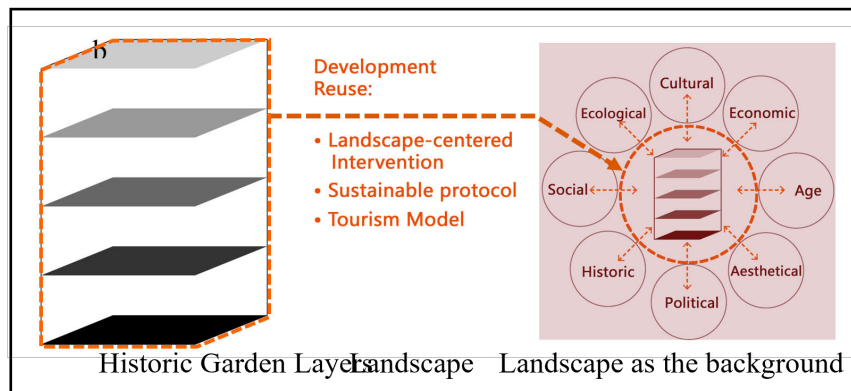
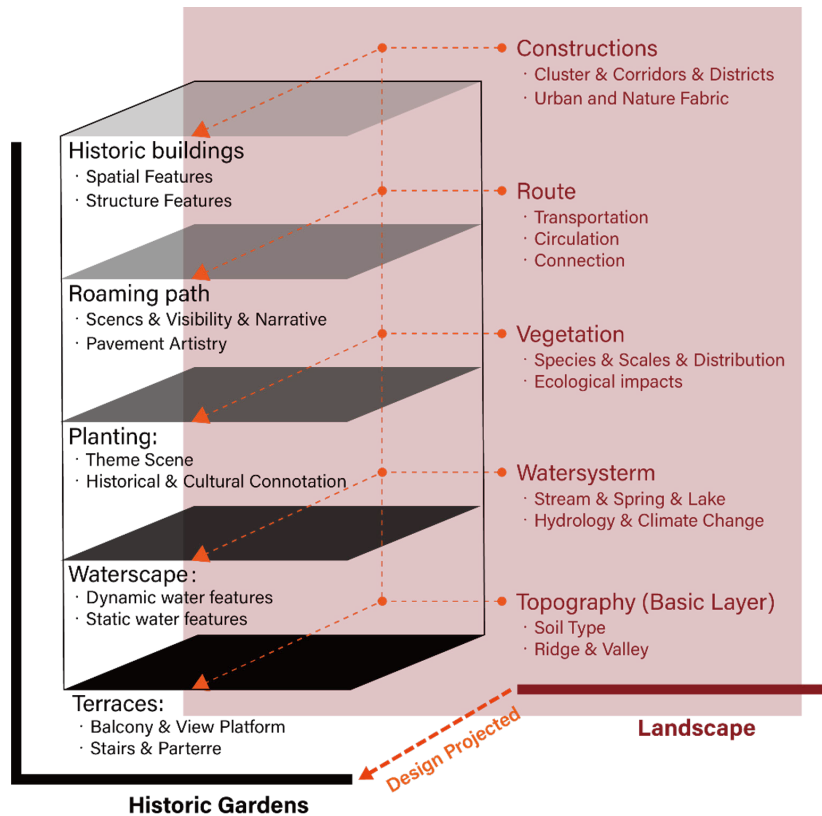


FIG. 2.10 A: Design projection relationship between landscape elements and the historic garden's layers; **B:** Three operational guidelines of landscape design to be applied for the development and reuse of the historic garden.

Finally, [Silva \(2012\)](#) proposes eight dimensions based on UNESCO's classification of heritage values and impact and we used it as a reference for assessing the relationship between historic gardens and cultural landscapes ([Fig2.10b](#)).

In addition, the landscape approach, because it places more emphasis on the processual analysis of “landscape” ([Muir, 1999](#)), will focus on natural systems overlayed by human-conscious activities ([Lowenthal, 1993](#)). Therefore, the consistent process of the landscape offers a chronological pattern as a spectrum containing the historic garden's evolution ([M. Antrop, 1998](#)). In terms of timeline, a coordinate is built with time (x-axis), values (y-axis), and layers (z-axis) ([Fig 2.11](#)). Firstly, when we look backward and reconstruct the historic garden's layers from different historical periods, various principles in relation to the heritage values ([Silva, 2012](#)), could be recognized by comparative analysis, reflecting the remained logic behind the spatial changes ([Bell, 2012; Motloch, 2000](#)). Moreover, previous research applied typology to classify heritage values closely linked to distinct attributes, which can be considered as architectonic elements in the framework ([Fig 2.10A](#)), indicating the key cultural significance ([Mason, 2002; Silva, 2012](#)). This makes it more operational, practical, and straightforward to develop value-based management and social impact assessment of heritage by identifying heritage characteristics ([Pereira, 2011](#)). In contrast, if we look forward to following the positive sequence, we can identify many potentials to make use of those heritage values relying on the understanding of the progressive changes of the landscape pattern, ensuring optimum conservation and development of these historic gardens for future generations ([Dreij, 2012](#)).

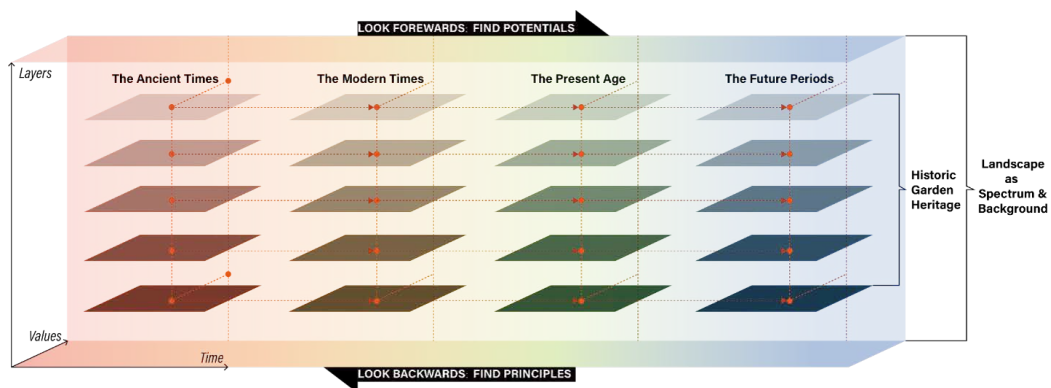


FIG. 2.11 Landscape as Spectrum & Background of historic garden heritage in a chronological evolution.

2.5.4 Limitations

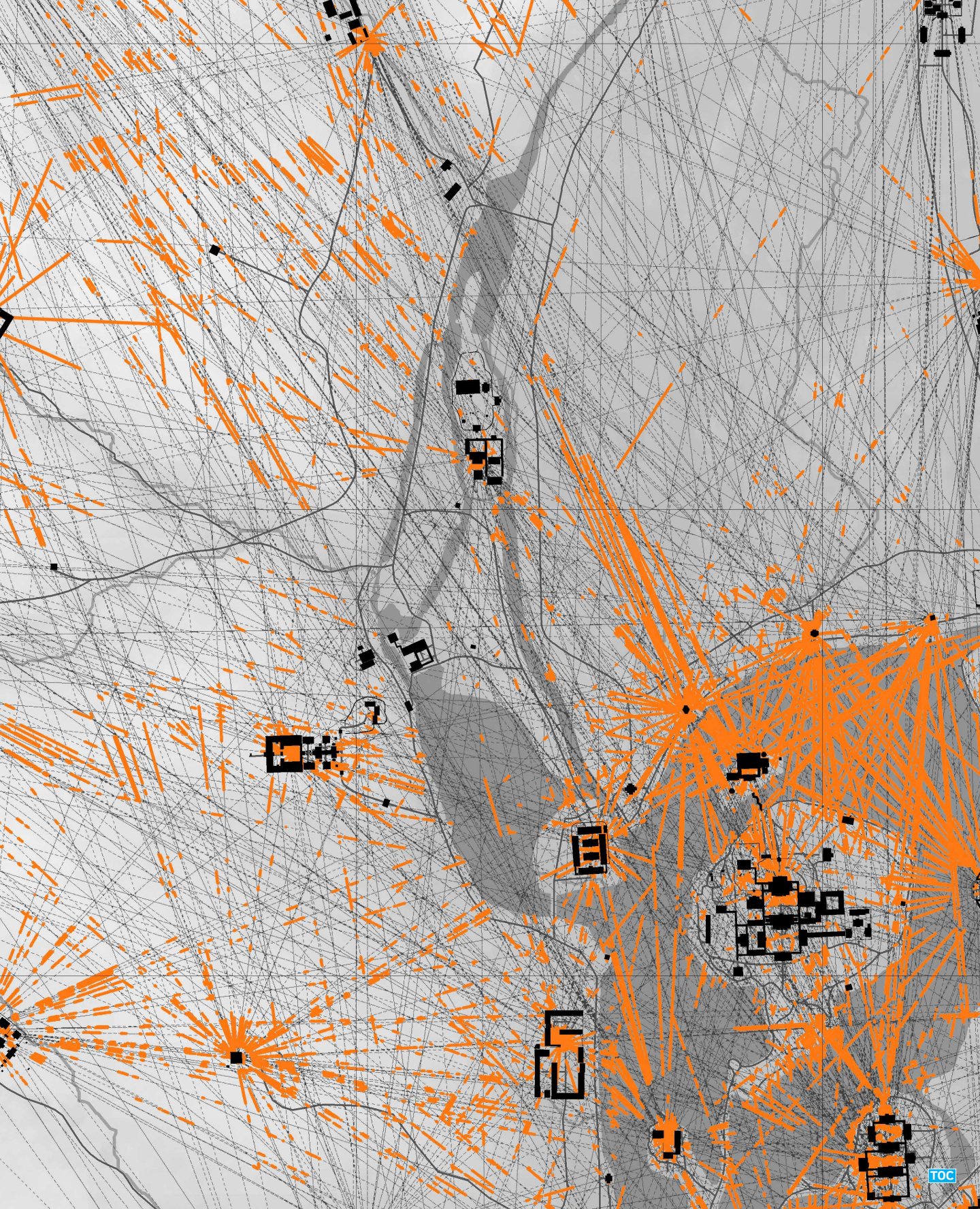
Admittedly, the main limitation is the potential inaccuracies of using visualization-based literature analysis software. The literature clustering used to identify research gaps is automatically generated by the software's built-in algorithm and lacks sufficient subjective selection and intervention, which may result in revealing major contradictions but lacking specificity. Apart from that, some of the data on "landscape architecture" is presented in the form of project reports and other types of printed materials which were published in the early years and not in the English version. They are important for the scope of this research but often not included in the core dataset of Web of Science, and this may result in data sample sizes that are not very adequate.

2.6 Conclusion

A systematic review of the literature in the field of the historic garden that tackles concerns linked to employing landscape as a study approach was conducted, with an emphasis on the contributions of knowledge for conservation and development. The bibliometric visualization was made to affirm the potential inherent in the relationship between the historic garden and the landscape approach. This paper strongly emphasizes the importance of establishing integrative operational frameworks, wherein studies on the historic garden from various disciplines, influenced by their respective landscape approaches and theoretical foundations, can mutually support their conservation and development efforts.

Basically, all the papers are grouped into three different research discussion categories, namely, heritage characteristics identification based on landscape mapping, heritage integrative conservation based on landscape planning, and heritage development and reuse based on landscape design. These three subgroups correspond to the pre-, middle-, and post-phases of the entire conservation and development process of the historic garden. Afterward, we summarized the research gap in applying landscape design for conservation and development. Given that research gap, we proposed a landscape design-based framework to establish a closely projected connection between the landscape background and the historic garden through the "layers".

Consequently, we also compared the three operational guidelines discussed in Group C on different specific scenarios to deeply elaborate their strength on the implementation aspect and articulated their heritage value impact in different dimensions. In addition, the continuity of the historic garden is derived from the evolution of the landscape spectrum and background through the reconstruction and comparative analysis of the “layers”, based on which we further proposed that the intention of conservation and development of heritage values in two chronological directions. The main goal of this paper is to provide a landscape approach as a foundational concept and method that can contribute to the sustainable conservation and development of the historic garden, enabling better recognition and reuse of their heritage value.



Landscape mapping

Following the conceptual and literature foundation established in Part A, Part B introduces landscape mapping as the first analytical step of the dissertation. This chapter addresses the characterization problem by showing how a complex historic garden can be understood as an integrated cultural landscape rather than as a set of isolated heritage elements. Using the Chengde Mountain Resort as the main case, Chapter 3 reconstructs long-term landscape evolution, identifies persistent spatial structures, and establishes scene-level evidence that makes the cultural landscape legible for management. In this way, landscape mapping provides the interpretive and spatial basis for the following chapters: it supports Part C by supplying the characterization needed for conservation planning, and it supports Part D by providing the diagnostic foundation for design translation and development-oriented intervention.

Lian, J., Nijhuis, S., Bai, N., Bracken, G., Zhang, H., Wu, X., Chen, D., & Li, J. (2025). Understanding historic gardens for the sustainable land management of cultural landscapes: Chengde Mountain Resort (CMR) as a case study. *Environmental and Sustainability Indicators*, 28, 100952. <https://doi.org/10.1016/j.indic.2025.100952>



3 Mapping Chengde Mountain Resort (CMR) as a Cultural Landscape

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 ([ICOMOS, 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 sustainable interaction of heritage with contemporary surroundings ([Gao & Jones, 2020](#); [Garcia, E & Juan, 2018](#)). As for practices, these are closely linked to sustainable land management and policies ([Shen & Chou, 2021](#); [Wang et al., 2023](#); [Yi et al., 2021](#)), as improper urban expansion and tourism-driven land conversion can threaten heritage integrity ([Aimar, 2024](#)). Understanding this dynamic integration requires a methodological

pathway¹ 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 & 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 & 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 & Christensen, 2023).

¹ 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.

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 & 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 & 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 CMR's 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 (Antrop & Van Eetvelde, 2018). This approach necessitates making greater use of the meaning of landscape mapping (Lian, 2024; Nijhuis et al., 2023; Simensen.T 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 & Nijhuis, 2020; Simensen.T et al., 2018). In particular, the process-related dimension of landscape meaning should be characterized (Manolaki et al., 2019; Sahle & 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.

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 3.1).

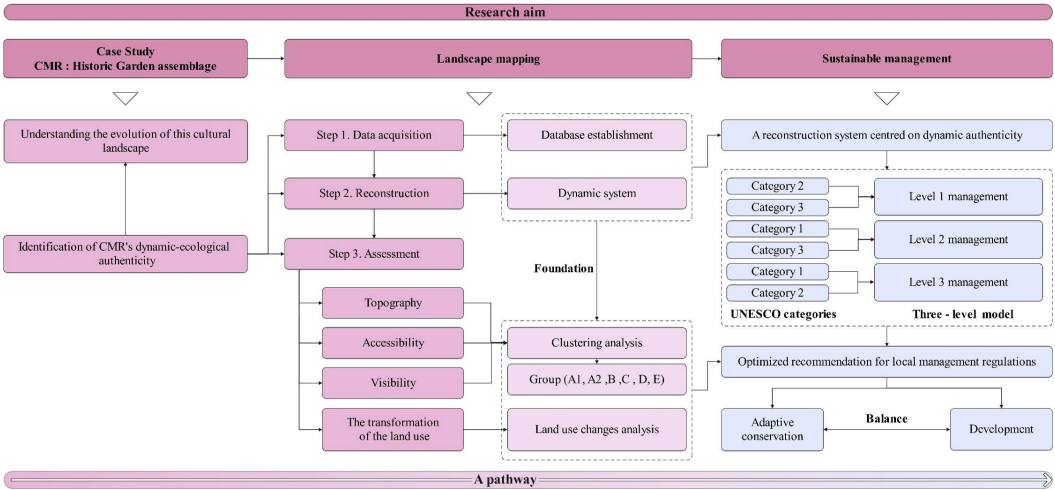


FIG. 3.1 The structural framework of this research.

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 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 European Landscape Convention (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 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.

3.1 Overview of the Characteristics of the Cultural Landscapes in the CMR

This study employs mixed methods to analyze the CMR (5.64 km²) as a cultural landscape. Built in 1703 in Hebei province, China ([Fig 3.2](#)), 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 is 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.

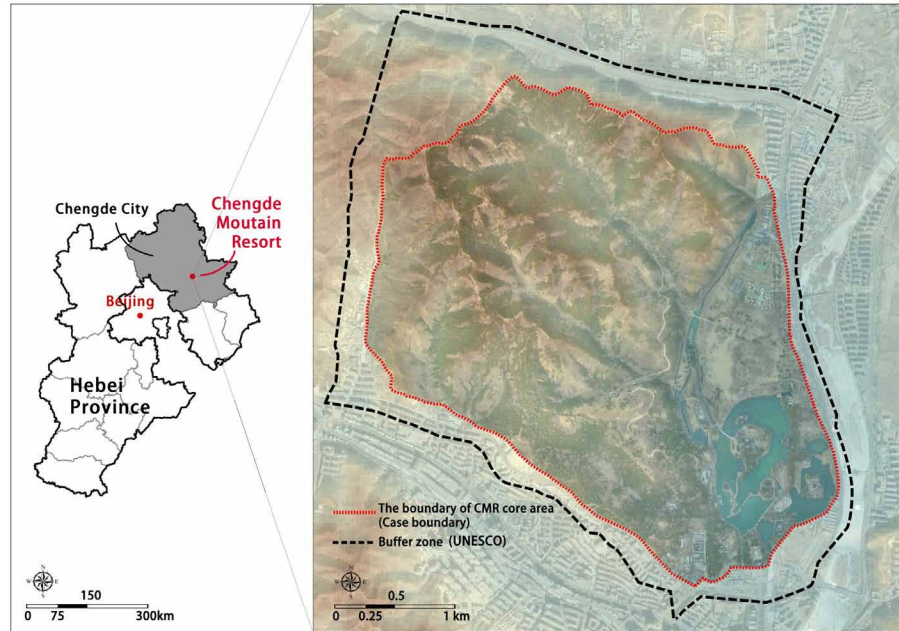


FIG. 3.2 The location of Chengde Mountain Resort.

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 & 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 & 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.

3.1.1 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 & 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. The photos, along with position and orientation system (POS) data, were then individually imported into Agisoft PhotoScan Pro v1.3.0.3772 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.

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. These materials were classified and summarized in tables according to scenes from the four historical phases. By assigning spatial coordinates to these materials, we were able to visually represent the level of attention given to heritage environment (Fig 3.3, Table 3.1).

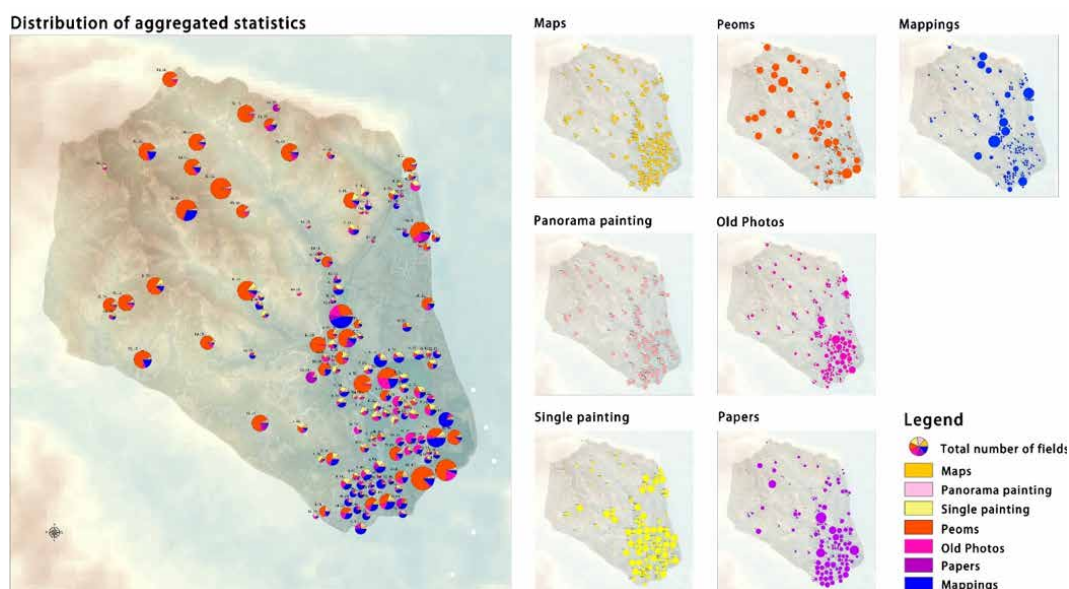


FIG. 3.3 The spatial distribution and frequency of various types of research data: Circle sizes in each subgraph are scaled relatively to indicate the level of entities and attention.

TABLE 3.1 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

3.1.2 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 3.4A). Next, we propose a systematic approach to rectifying historical information in cartometry (see Appendix B). 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 3. 4B).



FIG. 3.4 **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.

3.1.3 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 3.2). 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). These indicators were calculated using DEMs and 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 Appendix B). 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 & Harabasz, 1974; Halkidi et al., 2001), which measures inter-group separation and intra-group compactness, with higher values indicating better clustering (see Appendix B.2).

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.

TABLE 3.2 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 Appendix B.

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 & 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 & 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 & Mingze, 2024	DEMs
Exterior scene visibility (ESV) (Fig 3.5A)	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 3. 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 & Meitner, 2013; Wu et al., 2023	DSMs

3.2 Reconstruction of the Evolution of 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 3.5).

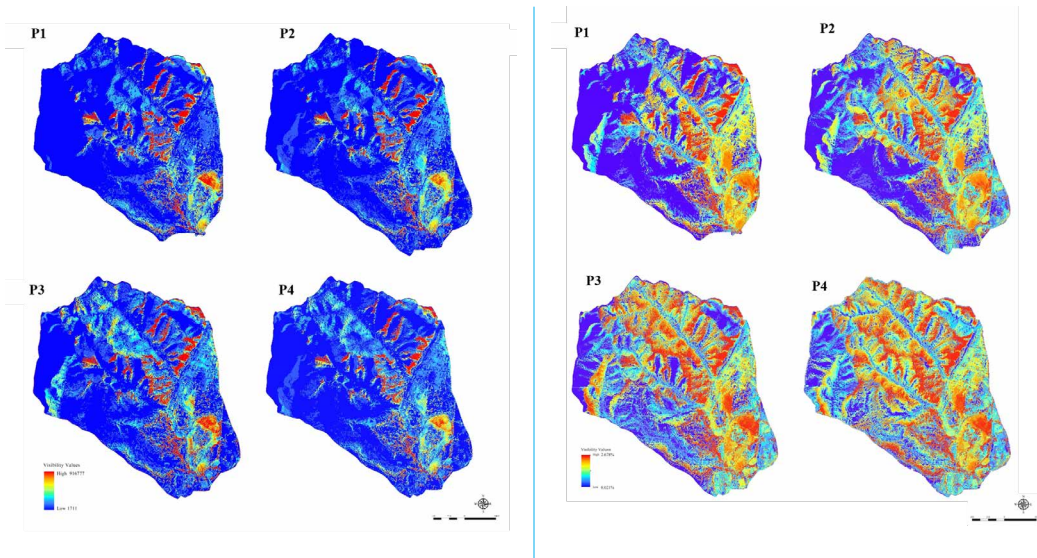


FIG. 3.5 A (left): ESV (scene's exterior visibility) across the four phases; B (right): OSV (observed scene visibility) across the four phases.

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 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.

3.3 Characterization of CMR

3.3.1 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 [Appendix B](#). 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 3.6](#)). [Table 3.3](#) 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 [Appendix B.2](#)).

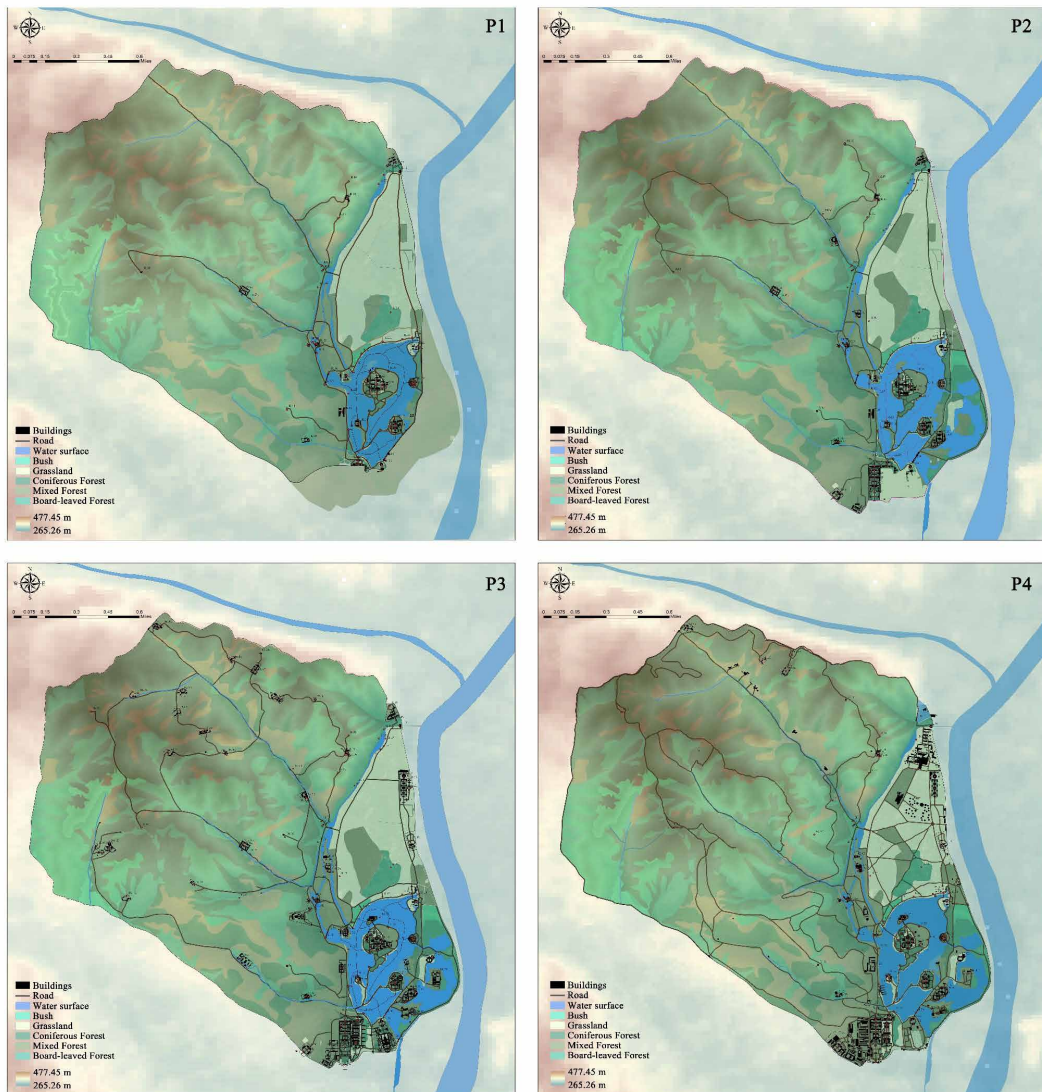


FIG. 3.6 Reconstruction of the evolution of the CMR from P1 to P4

TABLE 3.3 Explanation of the characteristics of different clustering groups

Group		Elev.	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		Mod- erate	Mod- erate	High	Mod- erate	Mod- erate	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.

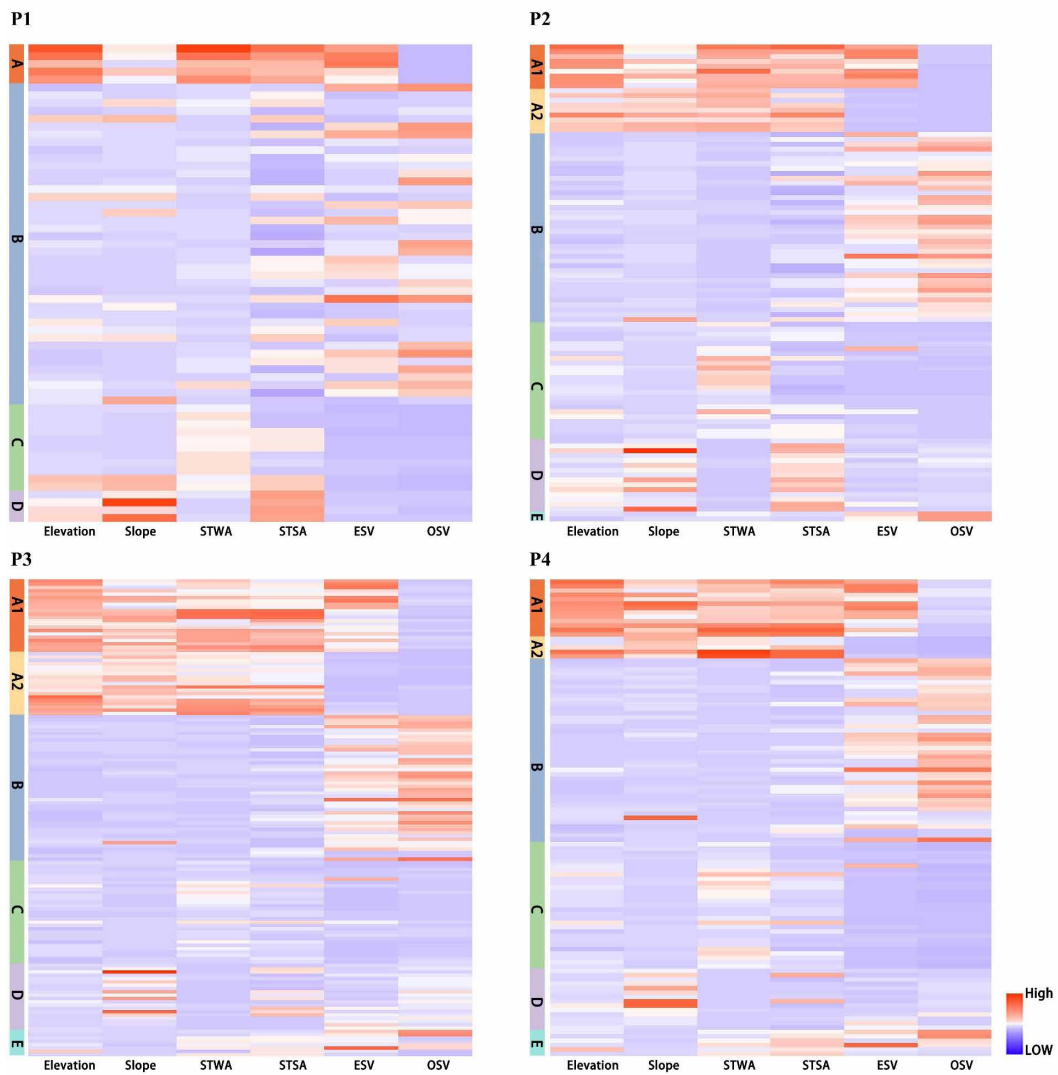


FIG. 3.7 The clustering of scenes across the four phases. Individual rows show the six indicators for each scene, while columns represent the specific indicators. To the left, bars indicate the clustered groups of scenes. Notably, higher values for STWA and STSA correspond to lower accessibility levels, as they reflect increased walking time.

Figure 3.7 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 in 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.

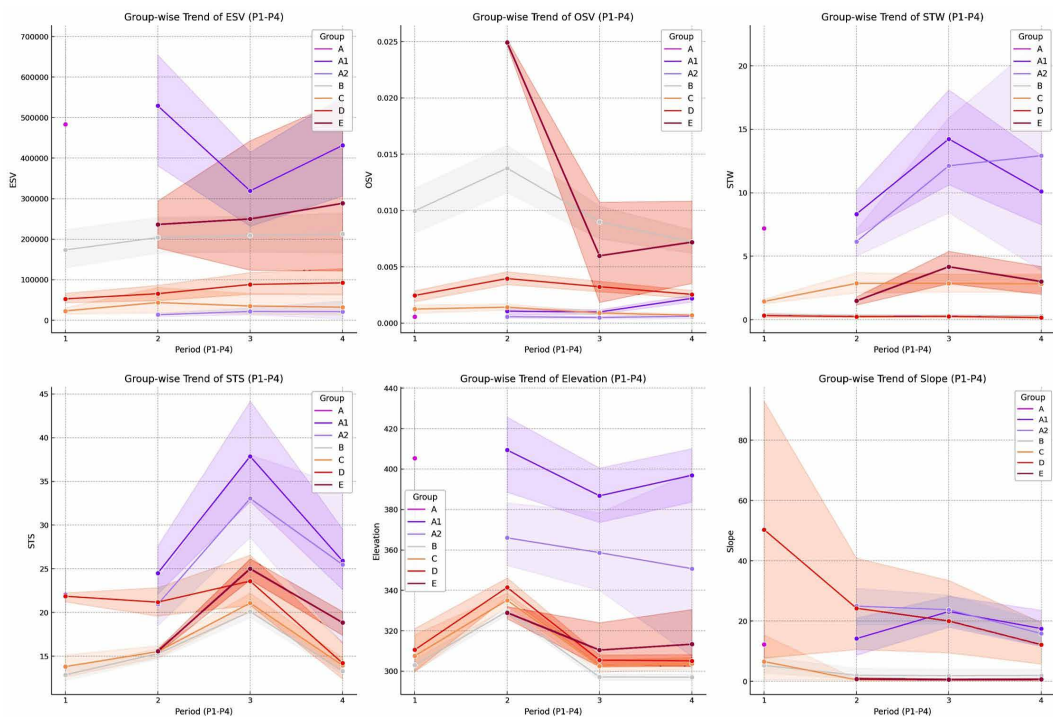


FIG. 3.8 Trends of indicators across groups during the four phases.

3.3.2 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 pine² (35.07-36.02%), deciduous broadleaf forests with dominant oak species³ (21.65-22.88 %), and mixed forests (16.27-22.62%) of Chinese elm,⁴ Japanese pagoda trees,⁵ poplar,⁶ Chinese willow,⁷ and Tilia.⁸ 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 3.4).

TABLE 3.4 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 %

² Latin name: *Pinus tabuliformis*

³ Latin name: *Quercus variabilis*

⁴ Latin name: *Ulmus pumila* L.

⁵ Latin name: *Styphnolobium japonicum* (L.) Schott

⁶ Latin name: *Populus cathayana*

⁷ Latin name: *Salix matsudana* Koidz

⁸ Latin name: *Tilia tuan* Szyszyl

TABLE 3.5 Land use transfer matrix P1–P4

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

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

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TABLE 3.5 Land use transfer matrix P1–P4

P4 \ P3	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

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 3.5, Fig 3.8).

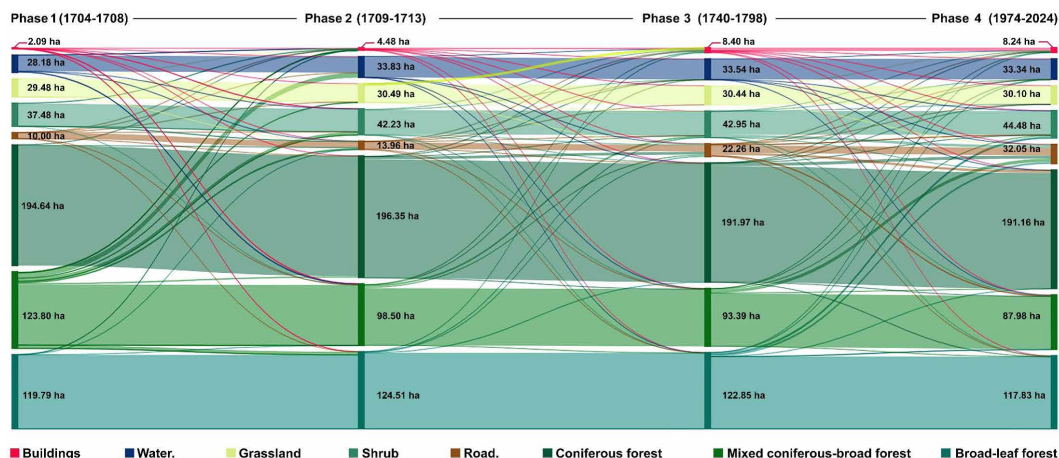


FIG. 3.9 Land use changes over the four phases. Each horizontal bar represents the area dedicated to different land uses over the four phases; the thickness of each bar indicates the area dedicated to that land use.

3.4 Three-Level Management Model Based on Integrative Characterization

3.4.1 CMR 's evolution in UNESCO 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 & Müller, 2012; Yang & 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, 2019; Van Lanen et al., 2022).

Specifically, 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 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 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 & 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). 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 landscapes in the CMR (Category 2). For example, Taoist philosophy inspired land transformations by integrating human-made structures with nature, 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.

3.4.2 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 3.6).

TABLE 3.6 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

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, 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 & 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.

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 & 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 & 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, 2019; Van Eetvelde & 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 & 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 & 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.

3.5 Theoretical Implications and Future Recommendations

3.5.1 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 site management ([Aimar, 2024](#); [Funsten et al., 2020](#)). Compared to the conventional descriptive outputs of historical archives and physical attributes in previous CHQDP regulations ([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.

3.5.2 Strategic implementation of management

TABLE 3.7 Specific recommendations for each groups.

Clustering	Current status	Future recommendations based on the 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 and safety concerns on the slopes.	– Develop multiple-transportation-based routes (walking, bicycling, etc.) in the mountainous forestry areas to relieve visitor pressure from popular scenes. – Construct scenic viewpoints with platforms to 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, causing many scenes to collapse and be abandoned. While some scenes remain in good condition, their heritage value has not been adequately recognized.	– Preserve soil, water, and vegetation by designating the surrounding land as an ecological protection zone, with short-term conservation measures and medium-to-long-term development plans. – In areas with favorable 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 due to their flat terrain, making them the current focus of development. However, the supporting infrastructure is insufficient, and 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 the CMR is rooted in Group B's role as a royal summer retreat. Enhancing infrastructure can help maximize its aesthetic value in relation to surrounding water systems and its role in improving the microclimate for cooling.
Group C	These scenes have poor visibility but relatively good accessibility. However, many spaces remain unused, failing to leverage their accessibility to enhance the social dissemination of their heritage value.	– Introduce more exhibitions and educational activities within the site. – Establish clearer guiding and interpretative facilities to enhance the site's functional role in serving visitors and improve public awareness of the cultural heritage value of the CMR.
Group D	Although these scenes have good visibility and accessibility, the sites are linearly distributed and located far from the main entrance. This has resulted in low visitor flow, minimal ecological disturbance, and well-preserved ecological conditions.	– Leverage the favorable ecological conditions by establishing a dedicated CMR floral and nursery cultivation center. – Develop linear tourism routes to enhance interaction with the ribbon-like water system and maximize the scenic value of the hilly terrain.
Group E	These are expansive, open, and flat scenic areas with a strong religious atmosphere. However, the infrastructure is highly inadequate, leading to significant spatial underutilization and wasted scenic potential.	– Enrich religious and social activities in large open scenic areas to enhance the social influence of the CMR's cultural landscape. – Introduce diverse outdoor cultural activities, such as horseback riding and other historically significant experiences, to boost urban vitality and engagement.

From an implementation perspective, the local management regulations 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 3.7).

3.5.3 Limitation

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.

TABLE 3.8 Different phases of restoration of vegetation in the CMR		
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.

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 3.8), 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 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.

3.6 Conclusions

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.

Landscape planning

How can landscape planning be applied to the conservation and development of cultural landscapes?

Part C develops landscape planning as the intermediate step between characterization and design. Building on the spatial evidence produced through landscape mapping in Part B, it shows how cultural landscapes can be guided through planning frameworks that address conservation priorities, development pressures, and spatial trade-offs. The two chapters (Chapter 4, 5) in this part are complementary: one focuses on the integration of hazard, ecology, and heritage value perception into planning and zoning, while the other focuses on perceptual-spatial relationships and route-based planning. Together, they translate diagnosis into implementable planning guidance and prepare the transition to the design-oriented discussions in Part D.

Lian, J., Nijhuis, S., Shan, X., & Bracken, G. (2026a). An integrative hazard-ecology-perception framework for cultural landscape planning. *Ecological Indicators*, 183, 114681. <https://doi.org/10.1016/j.ecolind.2026.114681>

Lian, J., Nijhuis, S., Bracken, G., Bai, N., & Zhang, H. (2025). Introducing a Perceptual-Spatial Landscape Planning Model (PSLPM) for cultural landscapes' route optimization: The case of Chengde Mountain Resort. *Frontiers of Architectural Research*. <https://doi.org/10.1016/j.foar.2025.10.004>



4 Hazard–Ecology– Perception Landscape Planning (HEPLP)

Cultural landscapes are increasingly vulnerable to the compounded effects of geographical risks, ecological degradation, and imbalanced heritage value perceptions under intensifying climate change and global urbanization pressure. However, planning frameworks rarely integrate geographical hazards, ecological sensitivity, and both expert and public heritage value perceptions, often leading to insufficient planning responses. This study proposes a Hazard-Ecology-Perception Landscape Planning (HEPLP) framework that links these three dimensions for cultural landscape planning and evaluates it through a case study of Chengde Mountain Resort. A GIS-based approach is used to analyze geographical hazards and ecological sensitivity, while heritage value perceptions are derived from expert scoring and large language model analysis. The results identify one cluster where the high-risk geological hazards require complete conservation. Another eight clusters are also identified where trade-offs between ecological sensitivity and heritage value perception are carefully balanced, revealing that public perceptions conflict with ecological limits, or that clusters with low ecological sensitivity hold undervalued potential for development. Building on these insights, HEPLP delivers cluster-targeted conservation and development strategies that can be directly translated into practical zoning guidelines, as well as policy implications at both local and international level. Conceptually, unlike previous frameworks that focused on single or dual dimensions, HEPLP theoretically advances and extends landscape planning as an integrative tool for sustainable cultural landscape conservation and development under environmental and social challenges.



As a process, it encodes geomorphological evolution, ecosystem dynamics, and the progression of social perceptions within landscape forms. As a carrier, it materializes socially constructed elements such as cultural memory, place identity, and disaster experiences. As a mediating interface, the landscape harmonizes ecological processes and human behaviors, serving as a junction of risk governance and cultural transmission (Freeman et al., 2015; Reed et al., 2020). Grounded in its interdisciplinary functionality of landscape, landscape planning provides practical pathways for translating substantive theories into implementable strategies for conservation and development of cultural landscape (Lian et al., 2024; Sánchez et al., 2020). It enables the identification of mismatches between perceived landscape values and the vulnerabilities of environmental systems. At the same time, it reveals how the heritage values of overlooked sustainable cultural landscapes are often marginalized in both experts' and public's perception, thereby contributing to the reconstruction of the social foundations of cultural landscape (Sánchez et al., 2020; Tappeiner et al., 2021). This study refers to the application of landscape planning in cultural landscapes as cultural landscape planning.

However, few existing theoretical frameworks have yet integrated the interactions and coordinated analysis of geographical hazards, ecological sensitivity, and heritage value perception into cultural landscape planning (Fig 4.1).

These aspects have largely been investigated in individual dimensions. Hazard-centered frameworks such as the Indicator-Based Risk Assessment quantify cascading chain effects among indicators (Nguyen et al., 2022; Ravankhah et al., 2021). The Multi-Hazard Risk Prioritization Framework integrates multiple hazards through correlation spatial matrices (Sevieri et al., 2020), identifying overlapping hazard zones at different priority levels (Julià & Ferreira, 2021) to inform targeted conservation strategies (Lombardo et al., 2020). Ecological related research rooted in landscape ecology emphasizes the interaction between spatial configurations and ecological processes, offering a foundation for assessing connectivity and sustainability in cultural landscapes (Tappeiner et al., 2021). Extending this perspective, Nature-Based Solutions embed ecology within spatial design to align multifunctional systems activating cultural values (Coombes & Viles, 2021), while Urban Political Ecology exposes power-driven environmental injustices and calls for more equitable ecological governance (Connolly, 2020). Perception-oriented frameworks, including the Historic Urban Landscape and Cultural Landscape Gene Theory, emphasize how cultural perceptions shape historical layers and evolutionary patterns (Hu et al., 2021; Ferreira et al., 2023; Rey-Pérez & Roders, 2020). Complementing this, Environmental Psychology examines spatial behavior, experience, and emotion, underscoring psychological structures that influence heritage value perception (Hussein et al., 2020). However, few studies have integrated both expert and public perspectives in examining heritage value perception.

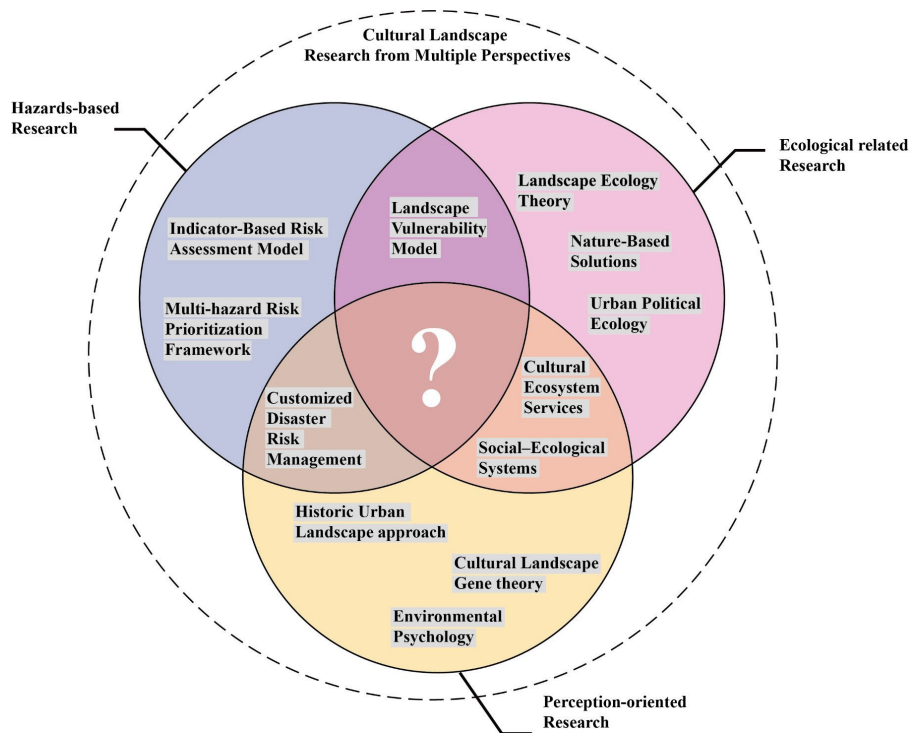


FIG. 4.1 A critical overview of relevant theoretical frontiers: multidiscipline, overlap, and research gap.

Beyond single-dimensional analyses above, several studies introduce two intersecting theoretical perspectives. For example, the Landscape Vulnerability Model combines external environmental stressors with internal ecosystem disturbances, including soil, vegetation, and hydrological processes, together with potential hazard exposure, to generate a unified and functionally coupled index of vulnerability (Chen et al., 2023; Cook et al., 2021; Sesana et al., 2020). A Customized Disaster Risk Management framework has been proposed to align responses to climate change with the diverse perceptions of heritage values across regions (Bosher et al., 2020). This approach reshapes stakeholder governance mechanisms, enhances the adaptive capacity of unconventional hazard buffer zones, and embeds participatory strategies that are rooted in community practices (Bosher et al., 2020; Durrant et al., 2023). The Cultural Ecosystem Services framework, grounded in ecosystem functioning, highlights how ecological processes support the formation of cultural identity, collective interests, and shared visions embedded within cultural landscapes (Csurgó & Smith, 2021). In addition, Social-Ecological Systems framework emphasizes the dynamic coupling between ecological disturbances and socio-cultural structures, focusing on feedback-driven governance and mechanisms for adaptive resilience

([Heslinga et al., 2017](#)). Overall, despite partial overlaps, a comprehensive integration of hazard, ecology, and perception dimensions in cultural landscape planning research remains largely absent, leaving a critical gap that this study aims to address.

This study investigates how cultural landscapes can be systematically characterized under the combined pressures of geographical hazards, ecological sensitivity, and heritage value perception by developing the Hazard-Ecology-Perception Landscape Planning (HEPLP) framework. Using a GIS-based methodology that integrates entropy and Analytic Hierarchy Process for hazard and ecological analysis, together with expert scoring and public content analysis for value perception, the study constructs a spatially explicit decision system for cultural landscape planning. Our innovation focuses on unifying expert and public heritage value perceptions with geographical hazard and ecological assessments, advancing and optimizing cultural landscape planning from isolated analyses toward an integrative and predictive framework for resilience and continuity.

This study analyzes the Chengde Mountain Resort (CMR), which is a typical cultural landscape case for other universal applications. Built in 1703 in Hebei province, China ([Fig 4.2](#)), the CMR has an area of 5.64 km² which comprises 144 smaller **scenes**, which reflect the historic scenic spots like other cultural landscapes, including fantastic views, buildings, courtyards, rockeries, waterscapes, and vegetation. In total, 144 representative scenes are used (named and numbered by the design emperors) in this study.

CMR was inscribed on the UNESCO World Heritage List in 1994. It embodies a distinctive spatial expression of understanding landscape order. Integrating political, religious, ecological, and aesthetic values ([UNESCO, 1994](#)), CMR represents a concentrated manifestation of the philosophical concept of harmony between humans and nature. Its heritage significance is not only tied to national historical memory and identity but also offers the international community a unique perspective on oriental culture ([UNESCO, 1994](#)).

CMR faces challenges related to geographical hazards, the degradation of ecological sensitivity, and imbalances in heritage value perception, which critically undermine the authenticity, integrity, and sustainability of the CMR ([Jun, 2020](#); [Pan et al., 2024](#); [Shi et al., 2025](#)). CMR is located in the transitional fault belt in the North China Plain, an area historically prone to seismic fault activity and characterized by complex geological conditions ([Shi et al., 2025](#)). The intersections between mountainous terrain and historic structures are particularly susceptible to landslides and collapses ([Fig 4.2A-B](#)). CMR also experienced ecological degradation due to climate change and anthropogenic disturbances, including soil erosion, vegetation decline,

and siltation and shrinkage of water systems (Fig 4.2C-D, Pan et al., 2024). Public attention is predominantly concentrated on the core imperial architecture, while more remote areas which are rich in ecological, religious, and historical significance are largely neglected (Fig 4.2E-F). This imbalance in perception narrows public understanding of the cultural landscape's full value and results in an unequal allocation of conservation resources (Jun, 2020).

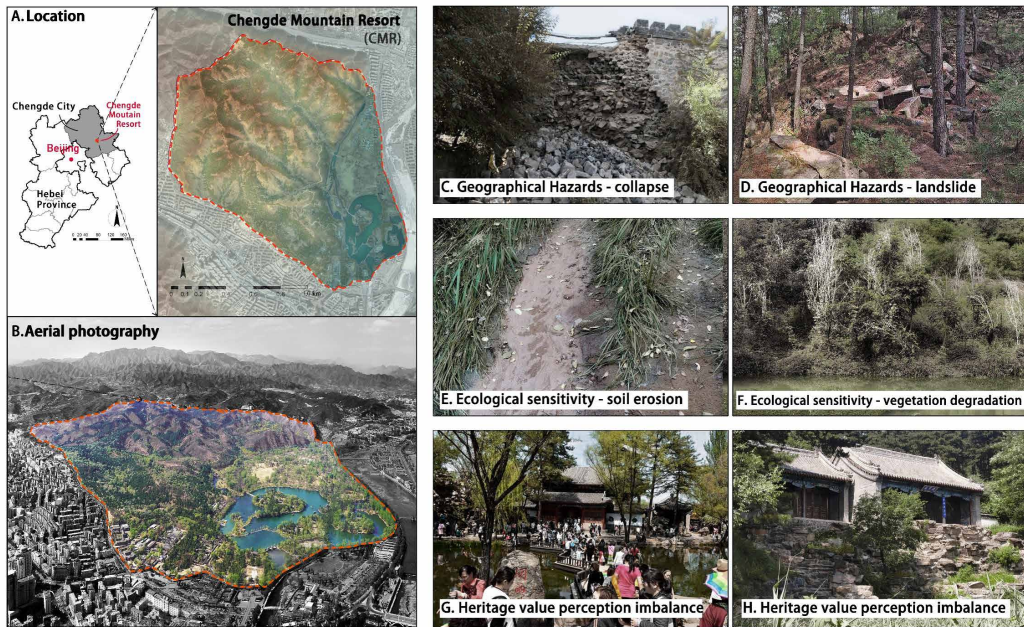


FIG. 4.2 Multi-Dimensional challenges in CMR: **A-B:** geographical hazards; **C-D:** ecological sensitivity; **E-F:** and heritage value perception imbalance.

4.2 Data Collection

Our research data consists of three components: (1) geographical hazards data, used for risk assessment and determination of conservation levels; (2) ecological sensitivity data, applied to ecological zoning analysis of CMR; and (3) heritage value perception data, used to evaluate both expert and public perceptions of different scenes. Details are listed in [Figure 4.3](#) and [Table 4.1](#).

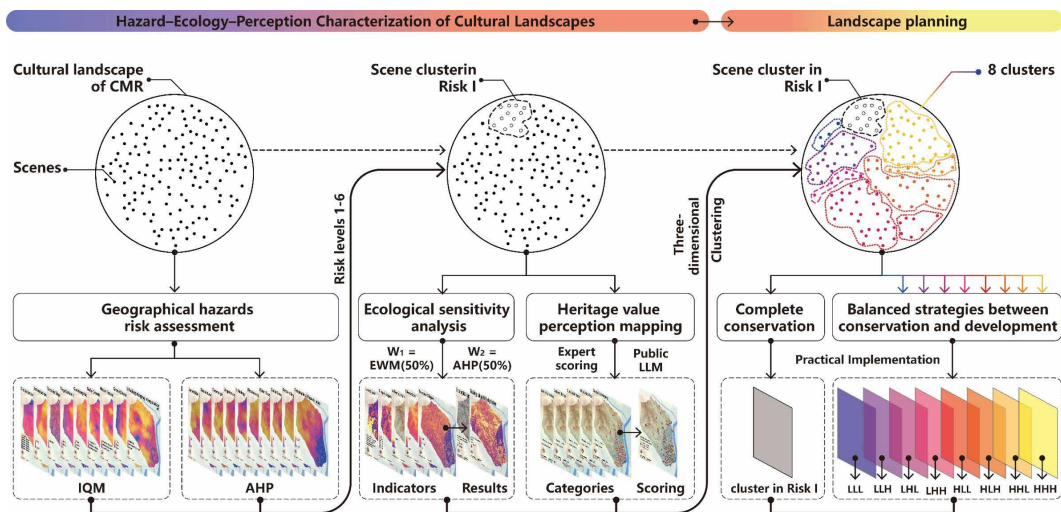


FIG. 4.3 HEPLP Framework: from Hazard-Ecology-Perception characterization to landscape planning.

TABLE 4.1 The three categories of data

Data category	Data type	Data format	Data source
Geographical hazards data	Landslide and rockfall occurrence points	Vector points	– Official Plan for the Overall Conservation of the Ancient Ruins of the CMR from Chengde Cultural Heritage Bureau (CCHB) – The Mapping and investigation team from the Cultural Heritage Conservation Center (CHCC) of Beijing Tsinghua Urban Planning & Design Institute (THUPDI)
	Lithology	Raster data	
	Groundwater Level		
	Gully Development		
	Water Erosion		
	Geomorphic Unit		
	Distance to faults		
Shared data (used in both hazard and ecological sensitivity analyses)	Coniferous and broadleaf mixed forest (land use)	Vector polygon to raster data	– CMR vegetation database (Total station field digital coding with RTK for each single tree) from Chengde Cultural Heritage Bureau (CCHB)
	Coniferous Forest (land use)		
	Broadleaf Forest (land use)		– Official Plan for the Overall Conservation of the Ancient Ruins of the CMR from Chengde Cultural Heritage Bureau (CCHB) – The Mapping and investigation team from the Cultural Heritage Conservation Center (CHCC) of Beijing Tsinghua Urban Planning & Design Institute (THUPDI)
	Grassland (land use)		
	Water body (land use)		
	Slope (topography)		
	Construction Land (land use)		
Ecological sensitivity data	Distance from Roads (Anthropogenic factors)	Raster data	– CMR close-range photogrammetry database from Chengde Cultural Heritage Bureau (CCHB). – High-quality cloud points generated from M300rtk with a DG4 pro-penta-lens camera.
	Distance between Scenes (Anthropogenic factors)		
	Elevation (topography)		
	Slope Direction (topography)		
Heritage value perception data	Expert scoring of heritage value	Number table	– Scoring from five senior experts (professor-level engineers with 30 years of experience) from the Chengde Mountain Resort’s conservation and planning departments participated in the consultation.(Appendix C)
	User-generated content	59852 comments	– CMR-themed search and retrieve content under restricted access from Dianping, Ctrip, Fliggy, Baidu Maps, and Agoda. All comments were parsed to identify pre-defined scene names.

* Several types of data are employed in both hazard assessment and ecological sensitivity analysis, but with distinct conceptual roles: in the hazard model they act as conditioning indicators for geological hazard events, while in ecological analysis they represent the different levels of sensitivity and adaptive capacity of ecosystems.

4.3 Hazard–Ecology–Perception Analysis

4.3.1 Geographic hazards analysis and risk level identification

A circle with a radius of 50 m is selected as the basic environmental unit, and statistical analysis is conducted on the data within the unit ([García-Grajales et al., 2023](#); [Shi & Zhang, 2022](#)). The study is based on the Information Quantity Model (IQM), and its theoretical foundation is information theory ([Ash, 1966](#)), which uses the reduction of entropy during the occurrence of geological hazards to represent the likelihood of an event. The equation of IQM follows:

$$I = \sum_i^n I(X_i, D) = \sum_i^n \ln \frac{S_i / A_i}{S / A} \quad (4.1)$$

In formula (4.1), where D denotes the occurrence of geological hazards in the study area; $I(X_i, D)$ represents the information value of factor class X_i for hazard occurrence; S_i is the number of hazard scenes within factor class X_i ; A_i is the total number of scenes belonging to factor class X_i ; S is the total number of hazard scenes in the study area; and A is the total number of scenes in the study area. This model quantifies the relative contribution of different factor classes to geological hazard occurrence and supports the identification of areas with higher hazard susceptibility ([Lin et al., 2021](#); [Zhang et al., 2023](#)) in formula (1). It should be noted that D is implicitly embedded in the hazard occurrence frequencies S_i and S , which are used to estimate the conditional probability of hazard occurrence within factor class X_i and the background probability in the study area. It offers a higher level of usability and ease of implementation compared to the artificial neural network method ([Lin et al., 2021](#)).

In addition, to fully utilize expert knowledge, the Analytic Hierarchy Process (AHP) was applied to evaluate the risks of geographic hazard. An indicator system was established based on expert assessments, and a corresponding weighting matrix was formulated ([Appendix C](#)). The Jaccard Index was employed to quantify the degree of overlap between IQM and AHP. It is defined as the ratio of the intersection to the union of two sets, ranging from 0 (no overlap) to 1 (complete overlap). This allows us to evaluate the consistency and divergence between two datasets.

The index data of eight factors were evaluated using the IQM. The generated information quantity index and its ranking are shown in [Table 4.2](#) and [Fig 4](#) to assess the risks for geological hazards in CMR. The results are divided into six levels using the natural-break method ([Table 4.3](#)). In terms of AHP analysis based on the composite scores and weights ([Appendix C](#)), six different risk levels of geographic hazards are identified using the natural breaks method ([Table 4.3](#)).

TABLE 4.2 Index system of geological hazards assessment based on IQM

Index	Segmentation standards	Information quantity	Order	Index	Segmentation standards	Information quantity	Order
Lithology	Bedrock	0.63	9	Vegetation Coverage (%)	<40%	0.17	11
	Sedimentary Rock	- 0.36	20		40-70%	- 0.06	14
	Loess	0.12	12		>70%	- 0.08	15
Groundwater Level(m)	< -1m	- 0.18	16	Terrain Slope (°)	<5	- 0.79	22
	0 ~ -1m	0.12	12		5-30	0.6	10
	0m (Surface)	0.72	8		>30	0.77	7
Gully Development	Shallow Gully	- 0.26	18	Distance to the faults(m)	>5000 m	N/A	N/A
	Moderate Gully	- 0.38	21		5000-5500m	- 0.83	23
	Deep Gully	1.25	3		4500-5000m	- 1.19	24
Water Erosion	Low Erosion	- 0.23	17		4000-4500m	0.07	13
	Moderate Erosion	- 0.27	19		3500-4000m	0.98	5
	Frequent Erosion	1.15	4		3000-3500m	1.3	2
Geomorphic Unit	Plain	- 0.83	23		2500-3000m	1.41	1
	Valley	0.6	10				
	Slope	0.78	6				

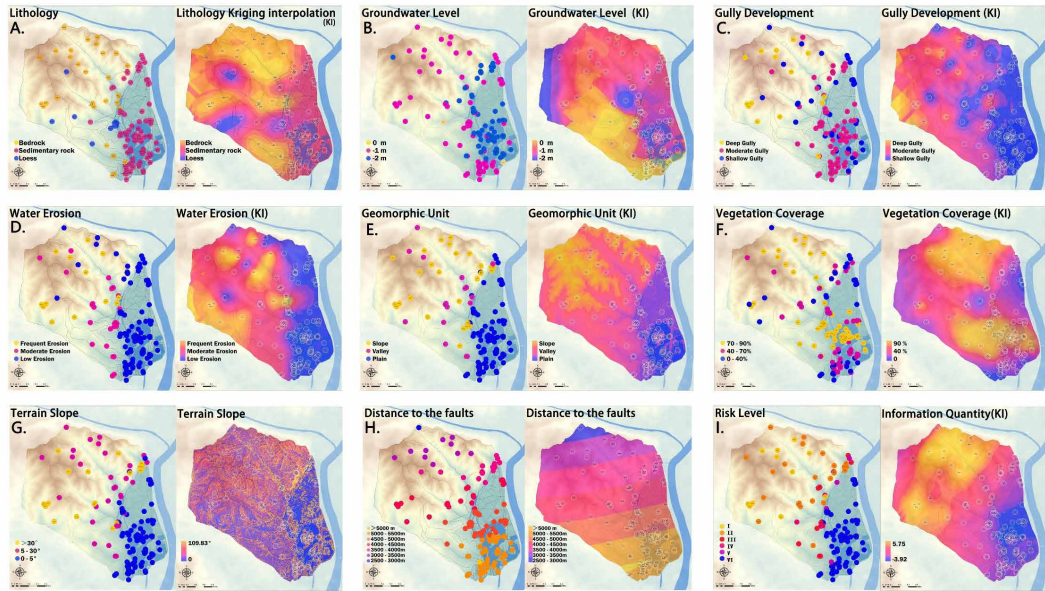


FIG. 4.4 A-I: The visualization of each Geographic hazards' indicators of 144 scenes with R-50m units in CMR.

The spatial distribution of geographical hazards reveals a clear northwest-southeast gradient, with higher risks concentrated in the northwestern sector of the CMR. This pattern is consistent with the frequent gully development and steeper terrain in this area (Fig 4.4.C, E, G), which elevate the likelihood of landslides and collapses. In contrast, the southeastern sector exhibits relatively lower hazard levels despite having comparable vegetation coverage, likely due to gentler slopes and more stable lithological conditions (Fig 4.4A, F, G). It is interesting to note that certain hazard indicators show partial inconsistency: for example, because of human-driven forest exploitation, water erosion hotspots are not fully correlated with areas of high groundwater levels (Fig 4.4B, D), as the latter are predominantly located in the southwest. Vegetation coverage is generally denser in both the north and the south (Fig 4.4F), yet hazard risks are higher in the north, underscoring the slope and geomorphic conditions as more controlling factors (Fig 4.4E, G). These findings demonstrate the necessity of using multi-source geospatial indicators to capture compound hazards, rather than relying on a single dataset, which emphasizes the multidimensionality of heritage landscape risks.

TABLE 4.3 Six geographic hazard risk levels based on IQM and AHP

Risk level	Definition	Number of scenes (IQM)	Number of scenes (AHP)
I	Extremely High Risk	13	16
II	High Risk	24	16
III	Moderately High Risk	10	15
IV	Moderate Risk	14	19
V	Moderately Low Risk	15	22
VI	Low Risk	62	56

To further validate and compare the classification outcomes, we conducted a Jaccard Index intersection analysis between the AHP results and those derived from the IQM. The Jaccard Index between the two datasets was calculated to be 70.5%, indicating a relatively high degree of similarity. This comparative approach enabled us to identify a consistent set of extremely high-risk areas (Risk Level I) with 12 scenes for complete conservation. Thus, they are excluded from the subsequent overlay-based clustering procedure in [section 4.2.4](#).

4.3.2 Ecological sensitivity analysis and integrated weight overlap

This study employed the entropy weight method (EWM) as an analysis method, which is a commonly used objective weighting approach in ecological sensitivity analysis. Based on information entropy theory, it determines the weight of each indicator (positive and negative) by calculating the degree of dispersion in the data, effectively reflecting the amount of information each variable contributes to the system ([Appendix C](#)). It is designed to determine objective indicator weights for ecological sensitivity, whereas IQM quantifies the probabilistic relationship between hazard occurrences and conditioning factors. This data-driven weighting mechanism avoids the interference of subjective human judgment, enhancing both the scientific rigor and objectivity of the evaluation process. The main equations of IQM follow:

$$e_j = -\frac{1}{\ln(n)} \sum_{i=1}^n \left(\frac{x'_{ij}}{\sum_{i=1}^n x'_{ij}} \cdot \ln \left(\frac{x'_{ij}}{\sum_{i=1}^n x'_{ij}} \right) \right) \quad (4.2)$$

$$w_j = \frac{1 - e_j}{\sum_{j=1}^m (1 - e_j)} \quad (4.3)$$

In formula (4.2, 4.3), where x'_{ij} is the normalized value of the original data for the i -th sample under the j -th indicator, used to eliminate the influence of differing units or dimensions. n represents total number of samples (i.e., the number of evaluated objects), and m means total number of indicators. $\ln$ is natural logarithm function used for calculating information entropy, and e_j represents the information entropy of the j -th indicator, which measures the uncertainty in the distribution of this indicator across all scenes. w_j is the final weight of the j -th indicator, representing its relative importance in the overall evaluation.

Furthermore, we conducted weight calculations using the AHP (Appendix C) and developed the associated judgment matrix. Finally, we integrated the two methods by averaging their respective weights to obtain the final weights. The final average weight of the EWM and AHP Weight Analysis is shown in following table (Table 4.4).

TABLE 4.4 A combined weighting approach using EWM and AHP

Indicator	EWM	AHP	Combined	Order
Water Body	0.129	0.283	0.206	1
Broadleaf Forest	0.188	0.15	0.168	2
Mixed Forest (Coniferous and Broadleaf)	0.089	0.184	0.137	3
Coniferous Forest	0.142	0.108	0.125	4
Slope	0.185	0.045	0.115	5
Grassland	0.13	0.064	0.097	6
Elevation	0.083	0.036	0.06	7
Distance from Roads	0.002	0.083	0.042	8
Slope Direction	0.035	0.014	0.025	9
Distance Between Scenes	0.008	0.023	0.015	10
Construction Land	0.01	0.01	0.01	11

For each scene (Fig 4.5), we calculated the mean ecological sensitivity index within the same unit and used this average value to assign corresponding levels of ecological sensitivity index (Appendix C). Fig 4.5A shows a clear gradient of ecological sensitivity, with higher values in the northwestern mountains dominated by steep slopes and forests, and construction land is relatively sparse. On the contrary, lower values appear in the southern and eastern plains with concentrated construction land, gentle terrain, and grassland. Usually erosion-prone slopes and fragmented forests are the most sensitive elements, but at the scene-unit scale (Fig 4.5B): some eastern river-adjacent scenes show high sensitivity despite moderate slopes, and certain northern scenes record low values due to homogeneous vegetation and proximity to construction land. These spatial variations underscore the importance of integrating multiple indicators in ecological sensitivity assessment rather than relying on any single indicator.

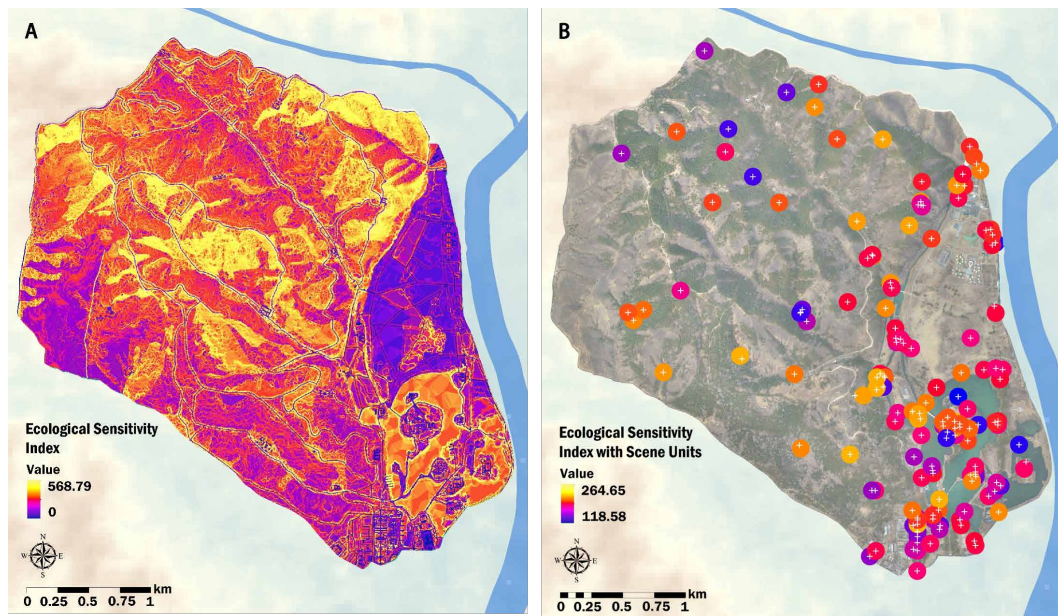


FIG. 4.5 A Map of Ecological Sensitivity Index , B. Map of Index with Scene Units. ArcGIS Pro 3.4.3 is used to conduct a weighted overlay analysis to derive the ecological sensitivity index across different regions.

4.3.3 Use of large language models for perception scoring

This dissertation incorporates large language models (LLMs) as a method for deriving public heritage value perception from large-scale textual data, such as social media content. The use of LLMs responds to a key methodological challenge in cultural landscape research: while expert-based evaluations are well established, capturing public perception at scale remains difficult due to the volume, diversity, and unstructured nature of available data (Silva & Roders, 2012; Arts et al., 2017; Freeman et al., 2015; Luo et al., 2025).

To ensure methodological transparency, the LLM-based perception scoring is implemented through a structured prompt engineering process, in which heritage value dimensions are explicitly defined and consistently applied across all inputs. This approach allows qualitative textual expressions to be translated into comparable quantitative scores, enabling integration with spatial and ecological datasets (Luo et al., 2025; Lian et al., 2024).

However, the use of LLMs also introduces potential limitations that must be acknowledged. These include sensitivity to prompt design, the risk of embedded biases in training data and language representation, and challenges related to reproducibility across model versions and input variations. To address these issues, the dissertation adopts a standardized prompting framework, documents the scoring procedure, and evaluates model outputs through robustness testing and comparison with baseline methods. In addition, the results are interpreted as indicative patterns rather than exact measurements and are used in combination with spatial and ecological indicators (Luo et al., 2025).

While full equivalence with human interpretation cannot be assumed, the LLM results are treated as a complementary layer of perception analysis rather than a replacement for expert judgment. In this sense, LLM-derived scores function as proxies for aggregated public discourse, capturing relative differences in perception across space rather than definitive evaluations of heritage value (Silva & Roders, 2012; Csurgó & Smith, 2021; Hussein et al., 2020).

Within this framework, LLMs function as an enabling tool that makes large-scale perception data operational for landscape planning. Their use allows perception to be incorporated as a dynamic and spatially explicit variable, thereby supporting more inclusive and responsive conservation strategies that account for both expert knowledge and public experience (Arts et al., 2017; Freeman et al., 2015; Reed et al., 2020; Sánchez et al., 2020; Lian et al., 2024).

4.3.4 Experts' and publics' heritage value perception mapping

We invited five experts from the cultural relics management team of the CMR, each with over 30 years of experience and holding the title of professor-level senior engineer. Two of them are affiliated with the heritage conservation and research department, and three are from the cultural landscape planning department. Each expert independently evaluated the 5 different heritage value categories as historical, cultural, scientific, social, artistic, using the Heritage Value Assessment Matrix (Appendix C) (CHCC&CMACH, 2023; Silva & Roders, 2012; UNESCO, 1994). The scoring follows a standardized 1–5 scale, where 1 represents “Very Low” and five represents “Very High.” Experts completed the assessments individually using an Excel-based scoring matrix, drawing on their professional knowledge, extensive research experience, and their understanding of the physical and cultural characteristics of each scene in CMR.

In this study, we adopted the few-shot learning approach for Large Language Model (LLMs) as proposed by [Luo et al. \(2025\)](#) to enhance performance in the AI model-based analysis of user-generated content. Their comparative study assessed the performance of multiple LLMs (*GLM*, *ERNIE*, *Moonshot*) in analyzing Chinese user-generated content for cultural perception, while *Moonshot-v1* demonstrated superior performance than other similar models in both micro- and macro-averaged precision. Specifically, we utilized the *Moonshot-v1-128k* version to analyze 59,852 comments from various social medias, incorporating structured prompt engineering inputs that included (1) task instructions, (2) definitions of heritage value categories, (3) background information on CMR, and (4) expert scoring examples for 144 scenes ([Table 4.5](#)).

Finally, to conduct a comprehensive analysis, we performed Principal Component Analysis (PCA) on the scores of five value categories (historical, cultural, scientific, social, and artistic), resulting in integrated scores for both expert evaluations and public evaluations.

To synthesize the experts' scoring, we first calculated the average scores from five independent experts across five heritage value categories and subsequently conducted a PCA. The first principal component accounted for 89.76% of the total variance, indicating a high degree of internal consistency among expert assessments. In parallel, we performed PCA on the public heritage value ratings derived through few-shot prompting using an LLM, where the first principal component explained 92.34% of the variance. These two sets of PCA-derived scores were then integrated in a spatial mapping analysis that reflects respectively expert-informed and publicly perceived heritage significance ([Fig 4.6](#)). Fig 6 shows heritage value scores of 144 scenes, where expert ratings remain consistent while public perceptions are more polarized, concentrating on core areas and overlooking peripheral sites.

This study acknowledges the spatial imbalance of heritage value scoring, particularly in the northwestern area where fewer sample points increase uncertainty. To mitigate this, we integrated both expert and public evaluations, ensuring a more balanced representation and reducing the potential bias in decision-making.

TABLE 4.5 The four prompt engineering process of LLM

Prompt Component	Description	Data Source / Reference	Function
Task Instructions	The model was instructed to identify five distinct categories of heritage value—historical, cultural, scientific, social, and artistic—reflected in social media comments related to the CMR. Each category was to be rated on a scale from 1 (lowest) to 5 (highest) according to its significance.	This task instruction was adapted from existing research (Luo et al., 2025) and aligns with an expert discussion framework.	Providing clear task instructions can significantly improve the effectiveness of few-shot learning by ensuring the model adheres to a uniform evaluation criterion.
Definition of 5 categories	The heritage value perception spans five categories: historical (political and ethnic integration), cultural (traditional diversity and synthesis), scientific (site selection and construction techniques), social (education, tourism, religion, and civic life), and artistic (aesthetic landscape and spatial design).	(Silva & Roders, 2012) (UNESCO, 1994) (CHCC & CMACH, 2013)	These definitions served as label explanations or output templates in the few-shot examples, assisting the model in accurately identifying and evaluating each category. This, in turn, supports targeted comment analysis and enables precise classification and scoring.
Background: Introduction to CMR	We indexed 2520 academic articles from the CNKI platform published over the past 30 years related to CMR. Following the basic PRISMA methodology and using abstracts, keywords, and titles, we screened and selected 290 articles with direct relevance. After conducting a literature review, a 3,000-character background document was generated.	CNKI	This section clearly establishes CMR as the study subject and, grounded in academic literature, enhances the scientific rigor, credibility, and validity of the overall task.
Expert Scoring Examples for Scenes	Relevant documentation for 144 scenes was evaluated by five senior experts across five heritage value categories. Of these, 115 scenes (80%) were used for model context construction, and 29 scenes (20%) for testing. The LLM predictions showed strong alignment with expert scores, achieving a Pearson correlation of 0.771, recall of 0.976, and precision of 0.825.	Collection of historical archives / Expert scoring	This process built a representative labeled dataset that enabled the model to learn diverse and accurate scoring patterns, serving as a reliable reference for the evaluation task. The reserved test set ensured an objective assessment of the model's performance.

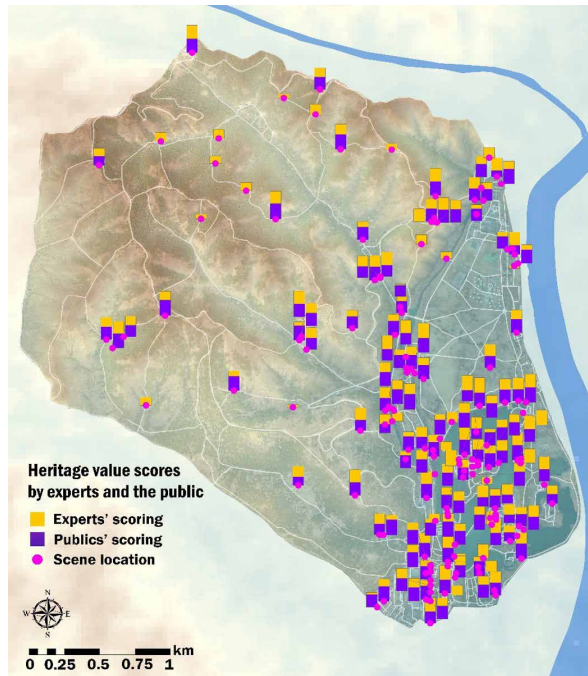


FIG. 4.6 The visualization of heritage value scoring.

4.3.5 Three-dimensional comprehensive analysis

As mentioned in [Section 4.3.1](#), we excluded the scenes located in Risk Level I of geographical hazards. For the remaining scenes, we conducted a three-dimensional comprehensive analysis and applied pairwise clustering, resulting in a total of eight distinct clusters ([Fig 4.7A](#)).

To evaluate the robustness of the clustering framework, we introduced threshold adjustments of ± 0.01 , ± 0.02 , and ± 0.05 to the classification boundaries of the three input dimensions, namely geographical hazards, ecological sensitivity, and heritage value perception. These adjustments simulate small to relatively large perturbations in the threshold settings and allow us to examine whether the clustering structure remains stable under different parameter conditions. For each adjustment level, the clustering results were recalculated and compared with the original classification. Robustness was assessed using the coefficient of variation (CV), which is defined as the ratio of the standard deviation to the mean. CV was used here to measure the relative variation in cluster size under different threshold perturbations. Lower CV values indicate higher stability and lower sensitivity to threshold changes.

Table 4.6 shows that under ± 0.01 , all clusters yield extremely low CV values (ranging from 0.014 to 0.043), indicating minor variation in group sizes. With ± 0.02 adjustments, the CVs range from 0.058 to 0.151, providing a moderate but stable window to test robustness. Even under the larger ± 0.05 adjustments, the system remained structurally consistent, with no evidence of category collapse or abnormal inflation (CVs between 0.09 and 0.174). These findings confirm that the clustering framework is not overly sensitive to threshold selection, and that ± 0.02 serves as a representative and meaningful perturbation scale for robustness evaluation.

TABLE 4.6 Robustness test of clustering results under breakpoint perturbations

Order	Clusters	± 0.01			± 0.02			± 0.05		
		Mean	Std	CV	Mean	Std	CV	Mean	Std	CV
1	High-High-High	34.33	0.481	**0.014	34.44	1.998	**0.058	35	3.150	**0.09
2	High-High-Low	9.67	0.280	**0.029	9.56	0.707	**0.074	9.67	0.948	**0.098
3	High-Low-High	21.67	0.477	**0.022	21.56	1.660	**0.077	20.67	3.597	*0.174
4	High-Low-Low	7.33	0.249	**0.034	7.44	0.707	**0.095	7.33	0.946	*0.129
5	Low-High-High	30.67	0.951	**0.031	30.67	4.079	*0.133	30.33	5.065	*0.167
6	Low-High-Low	4.67	0.173	**0.037	4.89	0.484	**0.099	5	0.815	*0.163
7	Low-Low-High	19.67	0.472	**0.024	19.67	2.970	*0.151	20.33	3.334	*0.164
8	Low-Low-Low	4	0.172	**0.043	3.78	0.556	*0.147	3.67	0.576	*0.157

*Values marked with ** denote very low variation ($CV < 0.10$), and * denotes moderate variation ($CV < 0.2$).

Hence, by integrating the layers of geographical hazards, ecological sensitivity, and heritage value perception, we identified nine distinct clusters of landscape scenes through HEPLP framework (Fig 4.7A-B).

Fig 4.7A shows the three-dimensional clustering of ecological sensitivity, expert scoring, and public scoring. The divergence along the public scoring axis is clearly greater than along the other two dimensions, indicating higher variability in public perceptions. Fig 4.7B further confirms this pattern, as the ecological sensitivity index exhibits a bi-peak distribution, suggesting that scenes are concentrated in both low-sensitivity plains and high-sensitivity mountainous areas. This is reflected in the coexistence of very low values, such as EQ.07. (0.009), and Q.15. (0.010), and very high values, such as K.12. (0.941), and K.01. (0.920). Expert scoring follows a near-normal distribution, with most values clustered around the middle range, indicating relatively strong consistency among experts. For example, many scenes fall close to the central band, including EK.13 (0.514), EQ.10. (0.600) although a limited number of scenes still reach very high values, such as Q.29. (0.965).

In contrast, public scoring shows a much more polarized pattern. A substantial number of scenes received no public score at all, such as EK.06 (0.00), whereas a small number of scenes were scored extremely highly, including EK.26 (0.99), Q.17. (0.97). This contrast reflects the spatial imbalance of public comments, where a limited number of highly visible or popular scenes attract disproportionate attention, while many peripheral scenes remain scarcely evaluated. Some of the low values may reflect the absence of public ratings rather than genuinely low public evaluation.

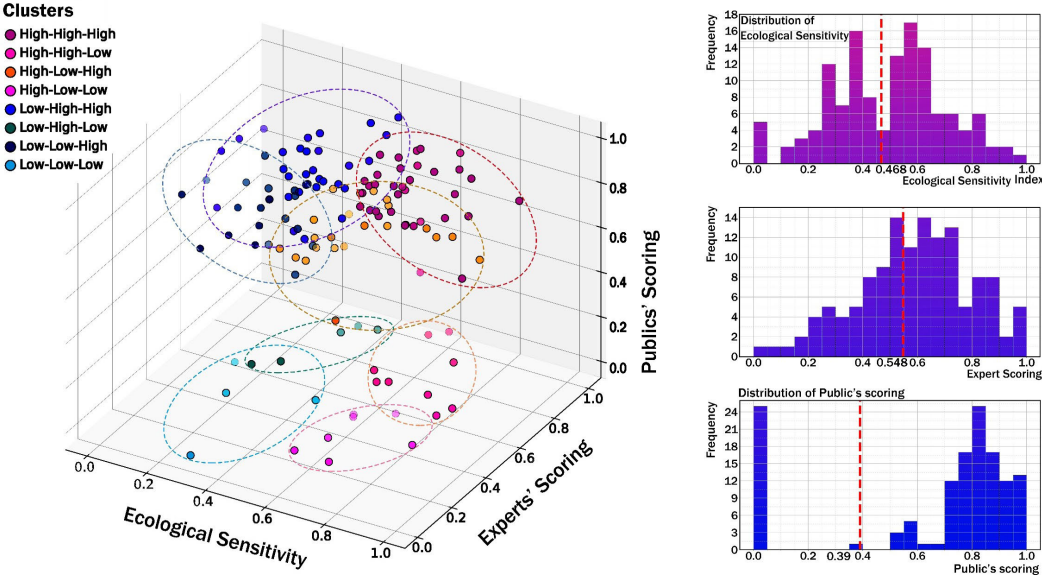


FIG. 4.7 A: Three-dimensional clustering and eight clusters; **B:** Distributions of ecological sensitivity, expert scoring, and public scoring.

4.4 The Practical Implementation and Strategic Landscape Planning

The HEPLP comprehensive analysis integrates multidimensional data, encompassing geographical hazards, ecological sensitivity, and heritage value perception data. It defines cluster of complete conservation based on scenes identified as having the highest geographical hazard risks (Risk level I), establishing a foundational spatial boundary for controllable conservation. Building upon this, the approach clusters the scenes by normalizing the ecological sensitivity, experts' scoring, and publics scoring to eliminate dimensional inconsistencies. Using the natural breaks classification method, each category was categorized into “high” and “low” levels, resulting in eight matched clusters.

The breakpoint values above were automatically identified using the Natural Breaks method in ArcGIS. They also visually correspond to the distribution of scenes, enhancing their interpretability. To ensure robustness of clustering, we conducted a sensitivity analysis of the classification boundaries by slightly adjusting the breakpoint values. A micro-adjustment of ± 0.02 was applied, corresponding to a 4.3% to 5.1% change in the original breakpoints. Given that the variables were normalized to a $[0, 1]$ scale, this represents a 2% shift in unit terms, providing a moderate and reasonable analysis that does not fundamentally alter the classification system, but is sufficient to test its sensitivity. To further strengthen the robustness assessment, additional tests (± 0.01 and ± 0.05 of breakpoint) were also conducted, capturing both fine-grained and more extensive perturbations. Finally, the CV is calculated to quantify the stability of each category combination during the breakpoint adjustment process.

These distinct clusters enable the formulation of differentiated intervention and guidance strategies. Finally, the method emphasizes the role of local multi-stakeholder participation, fostering collaborative planning, governance, and institutional innovation under the tripartite coupling of hazard, ecology, and perception.

4.4.1 Risk-based complete conservation practices

All scenes falling within Risk Level I of the geographical hazard assessment were designated for complete conservation, as shown by the white circles in [Fig 4.9](#), [Table 4.6](#). This designation reflects a threshold-based and spatially explicit rationale aligned with UNESCO's relevant operational guidelines ([UNESCO, 2010](#)), which state that areas exposed to the highest levels of risk, such as landslide or rockfall zones ([Fig 4.8A](#)), exceed the limits of manageable intervention and must be excluded from any short-term development. The proposed model formalizes this logic by providing a quantifiable basis for zoning severely vulnerable areas as minimal intervention zones, forming the foundation for bottom-line conservation strategies.



FIG. 4.8 Site-specific conservation interventions in Risk Level I cluster.

For instance, targeted measures have been implemented at the CMR to mitigate geographical hazards recently. Select key vegetation within core zones has been supported and reinforced to enhance soil stability and reduce the risk of surface erosion ([Fig 4.8B](#)). In addition, reversible structural bracing has been applied to heritage walls adjacent to unstable slopes to prevent collapse due to terrain movement ([Fig 4.8C](#)). Finally, protective shelters have been constructed over areas prone to rockfall to shield vulnerable remains from further damage ([Fig 4.8D](#)).

The Risk Level I cluster serves as a pre-emptive control mechanism, acting as an intelligent switch: when geographical hazard intensity surpasses a defined threshold, the model automatically initiates a complete conservation protocol, prohibiting inappropriate development, infrastructure construction, and tourism activity. It safeguards the ecological and cultural integrity of the site. Moreover, this risk-based mechanism is structurally compatible with broader territorial governance systems. It can be seamlessly embedded into national and regional landscape planning frameworks, providing a scientifically robust and administratively actionable tool for excluding the most risk heritage sites from land use or transformation. Its application is particularly relevant for cultural landscapes located in high-risk seismic belts, cyclone-exposed coastal zones, or geologically unstable mountain environments (Fig. 4.9).

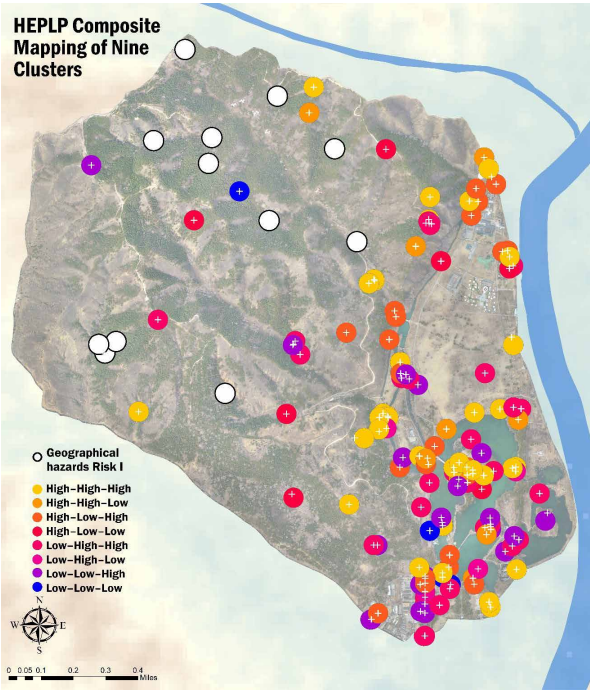


FIG. 4.9 HEPLP composite mapping of nine clusters.

4.4.2 Practices based on integrated ecological and perception analysis

For the remaining scenes, we conducted an overlay analysis in Section 4.3.4 (Table 4.6). Each group was assigned a tailored strategy of intervention, balancing conservation priorities with appropriate forms of sustainable development (Table 4.7). This approach aims to align protection measures with both the ecological sensitivity and the perceived heritage significance of each site, thereby ensuring context-sensitive and value-driven landscape planning.

TABLE 4.7 Balanced conservation and development strategic implementation of landscape planning

Cluster No.	Ecological Sensitivity	Experts' Scoring	Public Scoring	Conservation and Development Strategy
1	High	High	High	Conservation is the priority, but gradual long-term development can be implemented, with visitor flows controlled during operational periods.
2	High	High	Low	Conservation is the priority, combined with various degrees of professional and technical restoration and maintenance. Long-term exhibitions are organized to enhance public awareness and perception
3	High	Low	High	Limit on-site visits, supplemented by online exhibitions to reduce the physical damage caused by on-site displays
4	High	Low	Low	Conservation should remain the long-term focus, with no consideration for short-term development, and establishing archaeological backfilling for ecological restoration.
5	Low	High	High	Development is the priority, incorporating modern interventions for adaptive reuse, focusing on exhibitions to promote the dissemination of heritage value.
6	Low	High	Low	Reconstruction can be carried out to reproduce heritage value, and specific exhibitions can enhance public heritage education, heritage value perception and social engagement.
7	Low	Low	High	Significant intervention and renovation can be undertaken, with the addition of more recreational infrastructure that integrates modern functions.
8	Low	Low	Low	Serve as a buffer zone for conservation and development, functioning as storage space for equipment or temporary activities service spaces.

In summary, areas with high ecological sensitivity are typically prioritized for conservation over development, as complex ecosystems are integral to cultural meaning. Their disturbances cause irreversible damage and suffer substantial restoration costs, eroding the heritage values embedded in cultural landscapes. However, these clusters may overlap with scenes of strong public heritage perception, as popular scenes attract disproportionate attention and carry symbolic or aesthetic meanings. Such overlap creates tensions between ecological conservation and social expectations. Resolving such conflicts calls for collaborative, multi-stakeholder governance anchored in a long-term vision for sustainable landscape planning.

In Cluster 1, conservation takes precedence when development with clearly defined intervention and restoration limits is permitted. [Fig 4.10A1-2](#) illustrates the popular tourist dock and the restoration work conducted by engineers at the same scene. However, Cluster 2 is often marginalized or overlooked, which presents more potential to utilize expert knowledge and technical expertise for restorative interventions and ongoing maintenance in areas of high heritage value as shown in [Fig 4.10B1-2](#). Such efforts can help unlock latent potential, rearticulate long-term significance, and ultimately enhance public recognition and appreciation ([Ferreira et al., 2023](#)). Cluster 3 reflects a paradoxical case where ecologically vulnerable scenes, though rated low in expert-assigned heritage value, are popularly recognized by the public, requiring restricted on-site access and the use of virtual exhibitions to balance ecological conservation with symbolic engagement ([Wu et al., 2021](#)) ([Fig 4.10C1-2](#)). The scenes in Cluster 4 are currently planned for the archaeological backfilling and ecological restoration, due to their high ecological sensitivity and relatively low perception of both experts and the public ([Pijpers, 2024](#)) ([Fig 4.10D1-2](#)). This long-term initiative supports the conservation of the enduring natural environment evolution that underpins the sustainability and the living characteristics of the cultural landscape.

On the contrary, when ecological sensitivity is relatively low, these clusters offer considerable potential for strategic landscape planning and targeted interventions. Cluster 5 is highly appreciated from the perspective of heritage value perception. Therefore, development based on adaptive reuse becomes a priority, with the goal of revitalizing the functional role of heritage such as commercialized commemorative site leasing and culturally creative products ([Wang et al., 2023](#)) ([Fig 4.10E1-2](#)). Due to its ecological stability, Cluster 6 holds potential for expert reconstruction efforts. Physical interventions through reconstruction with specific exhibitions can help reproduce the characteristics and values of heritage, restore the cultural context, and promote public heritage education, social perception, and engagement ([Lucchi, 2023](#)) ([Fig 4.10F1-2](#)). For Cluster 7, the management strategy can focus on functional renovation centered on public popularity and everyday value. Given the absence of ecological constraints, the introduction of modern recreational facilities and cultural and religious gathering spaces can endow this area with renewed social significance ([Yenin et al., 2020](#)) ([Fig 4.10 G1-2](#)). Cluster 8 serves as a buffer between conservation and development, functioning as equipment storage or a temporary activity space. While not part of core conservation, it supports overall landscape planning by easing pressure on other key clusters and improving operational flexibility ([Fig 4.10.H1-2](#)).

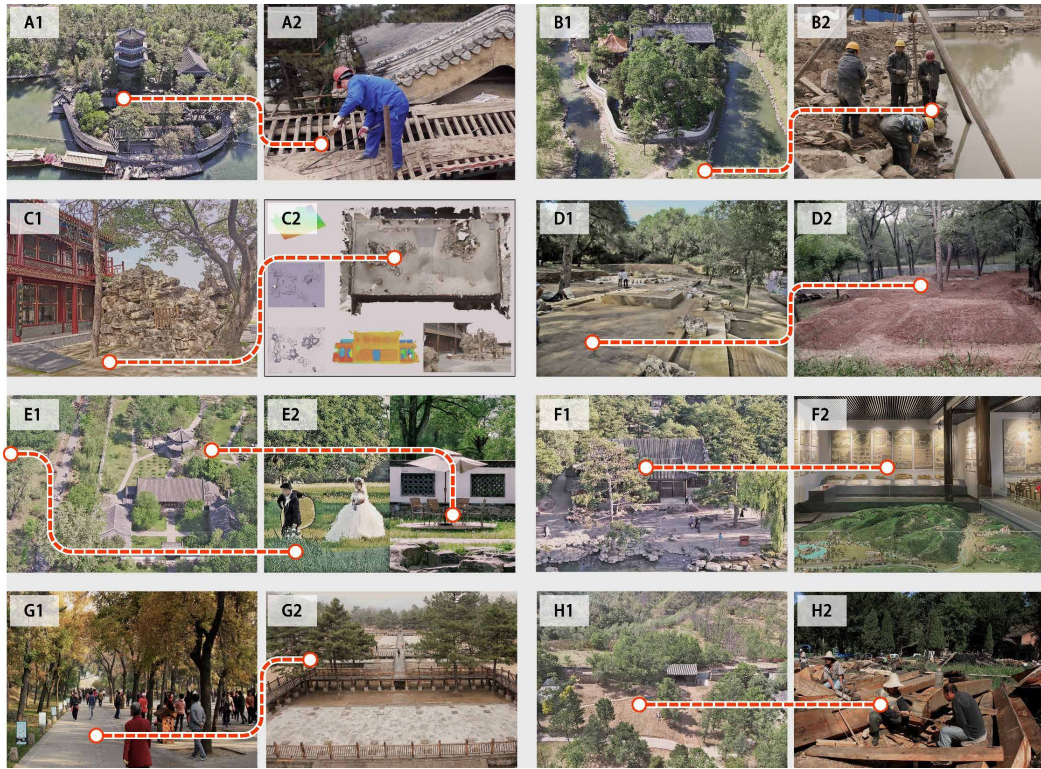


FIG. 4.10 Strategic conservation and development practices for each of the eight clusters.

4.4.3 Theoretical contribution of HEPLP

This study makes three key theoretical contributions to the field of landscape planning, especially for the heritage issue. First, it introduces the HEPLP framework as a spatially explicit, integrative model that systematically incorporates geographical hazards, ecological sensitivity, and heritage value perception, domains that have traditionally been examined in isolation. For instance, while Landscape Vulnerability Model (Cook et al., 2021; Sesana et al., 2020) and Social-Ecological Systems Framework (Heslinga et al., 2017) have addressed geographical hazards and ecological resilience, they didn't pay much attention to perceptual dimensions and corresponding spatial resolution. Building upon their research, HEPLP bridges this gap through a GIS-based, multi-criteria approach that enables zone-based intervention grounded in both environmental risk and cultural valuation.

Furthermore, this study systematically integrates both expert and public heritage value perceptions, extending beyond the qualitative orientation of frameworks such as the Historic Urban Landscape (Rey-Pérez & Roders, 2020; Ferreira et al., 2023). Through the structured LLM content analysis, HEPLP offers a replicable method for capturing value pluralism and implementing it into strategic landscape planning.

TABLE 4.8 Comparison of HEPLP with related frameworks.

Framework	Focus	Limitations	HEPLP Contribution
Landscape Vulnerability Model (Cook et al., 2021; Sesana et al., 2020)	Integrates external stressors with internal ecosystem disturbances into a vulnerability index.	Strong on geographical-ecological assessment but neglects heritage value perceptions and governance interfaces.	Extends vulnerability analysis by embedding perception mapping and zoning conservation-development tradeoffs.
Customizable Disaster Risk Management Framework (Bosher et al., 2020; Durrant et al., 2023)	Aligns heritage value perceptions with disaster risk governance across regional contexts.	Conceptually broad, limited spatially social-ecological explicitness and operational details.	Operationalizes heritage disaster-perception linkages with multi-level ecological integration and clustering.
Cultural Ecosystem Services Framework (Csurgó & Smith, 2021); Social-Ecological Systems framework (Heslinga et al., 2017)	Highlights how ecological processes underpin cultural identity, collective interests, and shared visions.	Captures perception values but remains descriptive and ecosystem-function centric lacking the integration with hazards.	Bridges these theories by aligning geographical hazard layers, enabling conflict identification and adaptive alignments.
HEPLP	Hazard–Ecology–Perception Landscape Planning	Unifies hazard, ecology, and perception into one framework	Provides a integrated, spatially explicit tool that supports precisely targeted strategies and resilience-oriented landscape planning

Meanwhile, it extends the conceptual reach of existing framework such as Cultural Ecosystem Services (Csurgó & Smith, 2021) by aligning intangible values with geographical hazard and ecological layers, facilitating conflict identification and adaptive trade-offs. HEPLP reconceptualizes the landscape as not merely a passive backdrop, but an active governance interface for resilience, sustainability, and inclusiveness, supporting more efficient policy making and providing a robust foundation for long-term cultural landscape planning.

Moreover, several existing frameworks have attempted to link various dimensions, yet each remains partial in scope. Table .4.8 compares three of the closest approaches with the HEPLP framework, highlighting how HEPLP advances beyond their limitations by integrating hazards, ecology, and perception into a spatially explicit landscape planning tool .

4.4.4 Policy and governance implications

The HEPLP framework carries direct policy relevance by functioning as a decision-support tool that can be embedded into different levels of existing governance systems. At the site level, cultural heritage managers can apply the cluster-based zoning results to set conservation priorities, guide maintenance schedules, and allocate limited resources more efficiently. At the regional level, planning authorities can integrate HEPLP outputs into spatial plans, ecological restoration projects, and land-use policies, ensuring that development aligns with both cultural and environmental objectives. At the international level, UNESCO and its advisory bodies such as *International Council on Monuments and Sites* (ICOMOS) and *International Union for Conservation of Nature* (IUCN) can use HEPLP as a standardized methodology for risk-informed monitoring, management reporting, and evaluation of buffer zones.

Implementation can be done through three main pathways. One approach is to incorporate HEPLP maps into management plans and risk preparedness frameworks. Another would be applying its results to buffer zone designation and adaptive reuse policies in areas where ecological sensitivity and public heritage value perception overlap. A further step is to embed HEPLP into national disaster risk management and spatial planning systems to promote cross-sectoral collaboration between cultural heritage authorities, environmental agencies, and tourism departments. By doing so, HEPLP moves beyond a conceptual model and becomes an operational governance instrument for building the long-term resilience of cultural landscapes.

4.4.5 Validation, robustness, and replicability of the HEPLP framework

To ensure that the HEPLP framework functions as more than a model that merely produces zoning results, this study explicitly evaluated its robustness, validity, and replicability through weighting comparison, cluster stability testing, expert-based verification, and methodological transparency. For geographical hazard analysis, the IQM was complemented by the AHP as an expert-informed comparative method, and the Jaccard Index between the two classifications reached 70.5%, indicating a relatively high degree of agreement. For ecological sensitivity analysis, indicator weights were calculated using both the entropy weight method and AHP, and then integrated through averaging, thereby reducing reliance on either purely objective or purely subjective weighting logic. In addition, the stability of the three-dimensional clustering framework was tested through breakpoint perturbations of ± 0.01 , ± 0.02 , and ± 0.05 . The resulting coefficient of variation values remained

consistently low, with no category collapse or abnormal inflation across the eight cluster combinations, indicating that the clustering structure is stable and not overly sensitive to minor classification changes.

The LLM-based public heritage value perception analysis was likewise subjected to explicit verification and methodological justification. Rather than being used as a black-box substitute for expert judgement, the LLM was employed as a scalable analytical tool for interpreting large volumes of user-generated content within a transparent few-shot prompting framework. The prompt design consisted of four clearly defined components, namely task instructions, category definitions, a literature-based background text on the Chengde Mountain Resort, and expert scoring examples, which together constrained the interpretive scope of the model and improved procedural transparency. Of the 144 scenes with expert-evaluated heritage value profiles, 115 were used as contextual examples and 29 were reserved for testing, and the resulting predictions showed strong agreement with expert scoring, with a Pearson correlation of 0.771, recall of 0.976, and precision of 0.825. The framework is also broadly replicable, as its principal procedures, including weighting, prompting, PCA integration, and threshold-based clustering, are explicitly defined. Nevertheless, the study acknowledges that online comments are unevenly distributed across platforms, locations, and user groups, and may therefore reflect bias related to digital visibility and participation. Accordingly, low public scores should not always be interpreted as genuinely low heritage appreciation, but may in some cases indicate limited online attention. For this reason, public perception results were interpreted in combination with expert assessment rather than as an independent substitute for it.

4.4.6 Limitation

While the HEPLP framework provides a structured integration of hazard, ecology, and perception dimensions, there remain some limitations. First, the scoring of public heritage value perception is based on secondary data from social media sources, which may not fully capture the diversity of local or less digitally active voices. Future work could incorporate field-based methods such as interviews or participatory mapping to improve inclusiveness, because HEPLP may need adaptation in cultural landscapes without strong digital footprints. While the LLM-based analysis offers valuable insights, online comments are unevenly distributed and may carry bias. We mitigated this by data cleaning and balanced sampling, and cross-validated results with expert scores using kappa statistics and a confusion matrix, which confirmed substantial agreement. Second, the clustering of ecological sensitivity and heritage value perception, though supported by sensitivity tests, may oversimplify complex gradients. More refined

clustering approaches could improve the model's responsiveness to subtle differences across sites. Third, the framework emphasizes spatial clustering but pays limited attention to temporal dynamics. Geographical hazards, ecological sensitivity, and heritage value perceptions all evolve over time. Integrating temporal scenarios or monitoring data would support more adaptive planning strategies.

4.5 Conclusion

This study introduces a novel HEPLP framework that systematically integrates multi-dimensional geographical hazard assessment, ecological sensitivity analysis, and heritage value perception mapping for landscape planning. Through a case study of CMR, the framework demonstrates how a composite spatial decision pathway informs differentiated conservation and development strategies grounded in both expert knowledge and public engagement. The integration of multi-source data enables spatially explicit and functionally coupled cultural landscape clusters. Specifically, nine clusters were identified, ranging from ecologically sensitive yet highly valued sites to low-sensitivity areas with limited recognition, thereby revealing both synergies and conflicts among hazard, ecology, and perception dimensions. The findings reveal that high-risk areas require complete conservation, while the remaining clusters present nuanced trade-offs between ecological sensitivity and heritage value perception, necessitating tailored implementations of landscape planning.

Beyond its empirical application, the HEPLP framework provides a theoretical advancement by bridging multidisciplinary boundaries across landscape hazard, ecology, perception, and spatial planning. It operationalizes the landscape as both a methodological and governance interface, supporting a data-driven process that transcends static planning approaches. Moreover, the inclusion of public heritage value by LLM, which is often overlooked in formal planning, enhances the social engagement of conservation and development strategies and facilitates an inclusive framework. Future work is needed to address monitoring feedback from the implementations, as well as temporal dynamics and participatory methodologies. Finally, this study reveals the complexity of cultural landscapes and the widespread challenges they face. The proposed HEPLP framework offers a replicable and adaptable planning tool for the sustainable management of cultural landscapes under increasing climatic and anthropogenic pressures, and it can be extended to diverse contexts such as urban cultural landscapes and coastal heritage, supporting broader regional and global applications.

5 Perceptual– Spatial Landscape Planning Model (PSLPM)

As cultural landscapes increasingly evolve within urban environments, a persistent gap has emerged between their heritage spatial characteristics and public heritage value perception, undermining urban identity and sustainability. This study introduces the Perceptual–Spatial Landscape Planning Model, an integrative framework that positions route optimization as a strategic planning intervention to bridge this gap. Taking Chengde Mountain Resort as a case, we constructed a spatial network of 144 scenes and collected 43,879 user-generated social media comments to quantify public perception. We achieved perceptual–spatial coupling through: 1). A few-shot learning paradigm based on a large language model generates five distinct perception scores of each scene; 2). The resulting scores are then integrated with heritage spatial characteristics in graph neural networks using graph attention networks and deep graph infomax. Based on the coupling process, the optimized routes were generated by a multi-objective evolutionary algorithm. The optimized routes outperformed official and greedy baselines, achieving higher spatial diversity, perceptual coherence, lower variance, and broader coverage of marginal yet meaningful scenes. These routes avoided overconcentration in perceptual hotspots as conventional tourism planning while enhancing interpretive richness across various spaces. This model provides strong contextual transferability, offering interpretable framework for integrating public perception into cultural landscape planning, thereby advancing both the methodological rigor and spatial intelligence of cultural landscapes' development in urban environments.

5.1 Introduction

Cultural landscapes are increasingly recognized as dynamic spaces shaped by human perception, identity, experience, and meaning (Sahle & Saito, 2021; Singh et al., 2023). As urbanization accelerates, many cultural landscapes embedded in urban environments are facing significant challenges (Bornioli et al., 2023; J. Liu et al., 2022), particularly a growing divergence between their **Heritage Spatial Characteristics (HSCs)**, understood in this study as the spatial configuration, material features, and landscape elements through which heritage significance is physically expressed (J. Liu et al., 2022), and **Public Heritage Value Perception (PHVP)**, defined here as the ways in which the public recognizes, experiences, and evaluates that significance (Tena et al., 2025).. This divergence makes cultural landscapes more vulnerable to marginalization in urban renewal processes, where pressures from tourism development, planning inertia, or commercial logic may dilute contextual meaning and gradually erode heritage values and characteristics. As a result, public awareness and emotional connection to cultural landscapes may weaken, undermining sustainability and contributing to the loss of urban identity and cultural continuity (Soyer & Tunca, 2025).

To address this, a mediating mechanism is needed to link HSCs with PHVP. Route optimization can serve as such a bridge between cultural landscapes, the city, and the public, functioning as a perception-oriented medium that transcends the limitations of purely physical-spatial connectivity (Liang et al., 2024). The spatial complexity of many cultural landscapes does not always correspond to their heritage value perception (e.g., secluded palaces vs. open squares); yet, route optimization offers the potential to reconcile spatial connectivity with perceptual sequencing without compromising the underlying cultural logic (Öztürk & Aktan, 2024; Ryan, 2020). As debates over the conservation and development of cultural landscapes intensify, route optimization offers a strategic intervention to balance conservation policy with contemporary urban demands (Smith, 2023). It can mitigate congestion, relieve tourism pressure, and redistribute value across space, enabling visitors to engage with the cultural landscape in a sequential, value-driven manner aligned with public interest (Lin et al., 2024).

A critical research gap remains in cultural landscapes' route optimization: The disconnection between HSCs and PHVP. On the one hand, existing studies have emphasized the identification of objective spatial structural features, but few have conducted in-depth analyses of how these spatial factors influence PHVP. Previous studies have focused more on the impact of spatial visibility, movement patterns,

transition probabilities, accessibility, connectivity, and specific points of interest on tourist behaviour (Jamhawi et al., 2023; Zhang et al., 2023). However, overemphasis on objective spatial factors while neglecting users' subjective preferences (Liu et al., 2022) has led to suboptimal value alignment in tour routes and unsatisfactory user experiences (Liang et al., 2024; Vansteenwegen et al., 2011). On the other hand, some studies have explored the integration of various AI techniques to analyze public perception with user-generated content, revealing the potential of social media data (Bai et al., 2023) to capture comprehensive perceptions of heritage (Ai et al., 2024; B. Wang et al., 2024; Xu et al., 2024), but these applications have mainly focused on textual understanding, narrative generation, and personalized interaction, without integrating such insights into spatial-practical route optimization (Trichopoulos, 2023). They focus more on functional tool-oriented development (Wong et al., 2023), with limited efforts toward jointly holistic modeling and quantitatively identifying the relationship between cultural landscapes' HSCs and PHVP. As a result, route optimization lacks multi-dimensional perceptual alignment, which needs more precision and perceptual-spatial relevance (Liang et al., 2024).

As an integrative approach that combines spatial organization with the communication of value perception, landscape planning fundamentally aims to facilitate the transformation of place-based cultural meanings through spatial configuration (Lian et al., 2024; Ryan, 2011; Sánchez et al., 2020). In a cultural landscape, spatial forms are not neutral containers but carriers of embedded narratives, historical references, and symbolic meanings (Henning et al., 2021; Von Haaren, 2002). Landscape planning as an approach draws upon this spatial characteristic to align physical structures with intangible heritage value perception of the public (Ducci et al., 2023), transforming landscape into a medium of cultural communication (Bohnet et al., 2022).

In this study, the proposed Perceptual-Spatial Landscape Planning Model (PSLPM) is grounded in the core logic of landscape planning. PSLPM employs spatial indicators to delineate landscape structure, while simultaneously incorporating public perception to establish a route optimization mechanism. Specifically, PSLPM combines few-shot learning from large language models to extract multidimensional heritage value perception, graph neural networks to embed perceptual-spatial complexity, and a multi-objective evolutionary algorithm to generate optimized routes that balance spatial diversity with perceptual coherence. Rather than offering a purely technical solution, PSLPM contributes to a strategic framework that embodies planning principles and addresses issues of spatial management and sustainability, extending beyond the enhancement of tourist experiences to include the broader goal of improving the perceptual quality. By bridging theoretical principles with AI-driven input, PSLPM advances communicative efficacy of cultural landscapes through practical planning interventions.

5.2 Data Collection

The framework of PSLPM is illustrated in Fig 5.1. This diagram illustrates a streamlined framework for optimizing cultural landscape routes based on public perception and spatial features. Social media comments (43,879) are scored by LLMs into five PHVP categories. These are the same used in Chapter 4. GIS-based analysis generates two HSC layers, integrated through principal component analysis (PCA). A Graph Neural Network (GNN) with Deep Graph Infomax learns 32D spatial embeddings. These data are coupled and optimized using a Multi-Objective Evolutionary Algorithm (NSGA-II) to generate five routes. Two baseline methods (greedy algorithm and official routes) are included for comparison. Final analyses assess PHVP and HSC differences across routes.

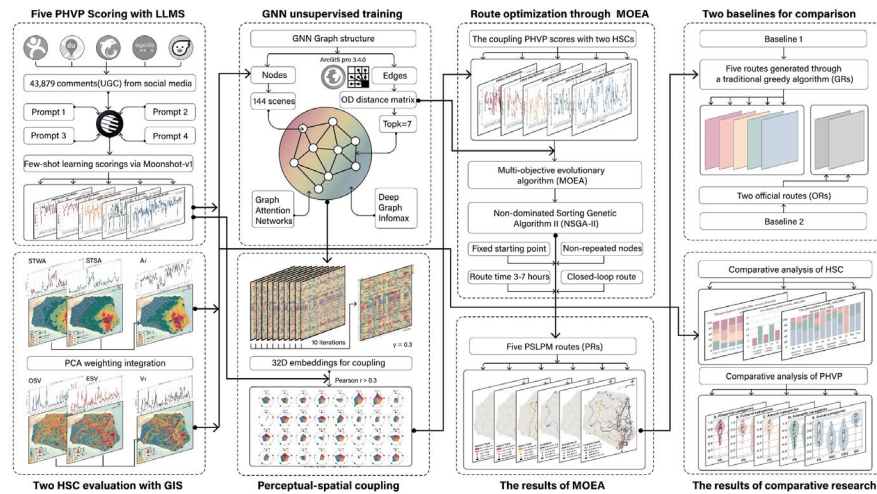


FIG. 5.1 The framework of PSLPM route optimization.

All data used in this study were classified into two categories: (1) cultural landscape spatial data, employed to characterize the spatial attributes of the CMR; and (2) user-generated content from social media platforms, used to identify public perceptions of heritage values (Table 5.1).

TABLE 5.1 The two categories of data

Data category	Type/ format	Capture tools	Data source
Cultural landscape spatial data	3D cloud points (.las format)	Matrice 300 Real Time Kinematic equipped with a DG4 Pro penta-lens camera	Close-range photogrammetry conducted by the Chengde Cultural Heritage Bureau
	0.5m digital surface models (DSMs) including vegetation	Agisoft PhotoScan Pro v1.3.0.3772 and Agisoft Metashape Pro v1.7.4.12950	
User-generated content from social media data	From an initial total of 59,852 comments, 43,879 were retained after filtering.	These data span a ten-year period from January 2015 to March 2025 and were retrieved through publicly accessible interfaces using a keyword-based search strategy. Specifically, we employed the official names, aliases, and spatial identifiers of the 144 predefined scenes in the CMR as query terms. The distribution of comments across platforms was as follows: Dianping (20,367), Ctrip (13,918), Fliggy (8,633), Baidu Maps (11,057), and Agoda (5,877).	Dianping, Ctrip, Fliggy, Baidu Maps, and Agoda

The selected platforms represent different user communities and functions. Dianping focuses on attraction reviews, Ctrip, Fliggy, and Agoda emphasizes itinerary sharing and user ratings, while Baidu Maps provides mapping-based spatial tagging. This combination ensures comprehensive and diversified perception coverage. To ensure data quality and heritage relevance, a two-step filtering protocol was applied: (1) only comments that explicitly referenced one or more of the 144 scenes were retained; (2) exact duplicates were identified and removed by comparing SHA-256 values, where SHA-256 is a secure hash algorithm in the SHA-2 family standardized by the U.S. [National Institute of Standards and Technology \(2015\)](#) that maps input data of arbitrary length to a fixed 256-bit message digest; near-duplicate content was filtered using sentence-level BERT embeddings with a cosine similarity threshold of 0.95. This ensured that retained comments were both unique and semantically relevant to specific cultural scenes. After filtering, a total of 43,879 unique and scene-relevant comments were retained ([Appendix C](#)).

5.3 Perceptual–Spatial Analysis

5.3.1 Cultural landscape spatial characterization

The spatial characterization of the CMR is closely related to two key indicators: accessibility and visibility. These two indicators not only reflect the functional organization of the site but also embody its cultural, symbolic, and experiential significance:

Accessibility can be further divided into Scene-to-Water Accessibility (STWA) and Scene-to-Scene Accessibility (STSA). STWA was included to capture the proximity of scenes to water bodies of CMR. Water is recognized as a typical compositional element that plays a critical spatial and symbolic role in many cultural landscapes, shaping a scene's aesthetic, ecological, recreational, and symbolic functions. (Balcan et al., 2024; Wallach, 2005; Zhang & Taylor, 2020). STSA, on the other hand, reflects the degree of movement and spatial connectivity among different scenes. It relates to the narrative and experiential continuity of the landscape, as evidenced by spatial autocorrelation patterns, and plays a key role in shaping spatial perceptions and cultural engagement across the site (Liao & Liang, 2025; Wu & Chen, 2022). Visibility can be further divided into Observed Scene Visibility (OSV) and Exterior Scene Visibility (ESV). OSV measures how frequently a scene is encountered along visitor routes, thereby indicating its visual exposure and spatial privacy. This passive visual perception dimension is essential for understanding how often and from where a scene contributes to the overall experiential structure (Domingo et al., 2020; Kim et al., 2020). ESV quantifies the visual openness of a scene's exterior, reflecting spatial prominence and symbolic hierarchy embedded in the cultural landscape. High ESV values indicate landmark-like roles, while low values suggest enclosed, introspective spatial character (Lee, 2023; Salerno, 2023).

We used ArcGIS Pro 3.4.0 to extract the values of STWA, STSA, OSV, and ESV based on a DSM-derived spatial model. Afterwards, PCA was conducted to integrate the accessibility and visibility attributes of the CMR into composite spatial characterization indicators for further analysis:

$$\begin{aligned} A_i &= w_1 \cdot STWA_i + w_2 \cdot STSA_i \quad \text{and} \quad V_i = w_3 \cdot OSV_i + w_4 \cdot ESV_i \\ S_i &= w_5 \cdot A_i + w_6 \cdot V_i \end{aligned} \quad (5.1)$$

In formula (5.1), where A_i represents the composite accessibility index of scene i ; V_i represents the composite visibility index of scene i ; S_i represents the composite spatial characterization index of scene i . The PCA weighting factors w_1 , w_2 , w_3 , w_4 , w_5 , w_6 determine the relative importance of each component. They are derived from the first principal component of each indicator group, using the corresponding explained variance as the weighting coefficient.

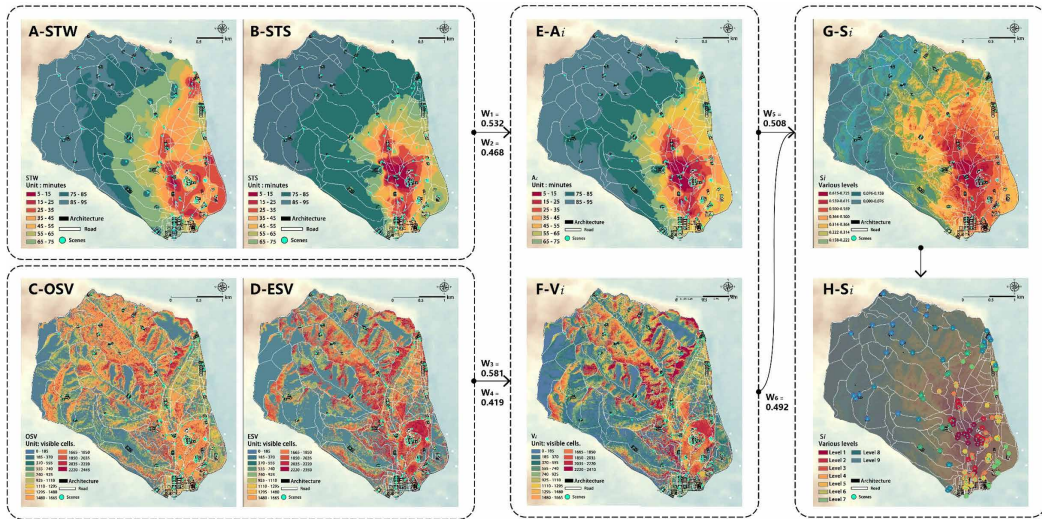


FIG. 5.2 Both accessibility and visibility were derived through a dimensionality reduction process based on PCA-weighted integration in Formula 5.1. **A:** Scene-to-Water Accessibility (STWA); **B:** Scene-to-Scene Accessibility (STSA); **C:** Observed Scene Visibility (OSV); **D:** Exterior Scene Visibility (ESV); **E:** Composite accessibility index (A_i), derived from STWA and STSA; **F:** Composite visibility index (V_i), derived from OSV and ESV; **G:** Composite spatial characterization index (S_i), integrating accessibility and visibility; **H:** Classification of 144 scenes into nine levels based on , showing an uneven spatial distribution across the CMR, with higher values concentrated in the southeastern lake area and lower values mainly located in the western and northern mountainous areas.

We found that within the same scene in the CMR, there are substantial differences between STWA, STSA, ESV, and OSV indicators (Fig. 5.2A-D), articulating these scenes exhibit substantial differences in both visibility and accessibility. The composite accessibility (A_i) was derived by integrating the STWA () and STSA () (Fig. 5.2E), while the first principal component alone accounted for 94.35% of the total variance by PCA. And composite visibility (V_i) was combined with OSV () and ESV (), while the first principal component explained 89.37% of the total variance (Fig. 5.2F). Furthermore, we applied the natural breaks method to classify all 144 scenes according to A_i (0.549) and V_i (0.268) into four distinct categories (Table 5.2):

TABLE 5.2 The four categories of scenes clustered by A_i and V_i

Category	A_i (composite accessibility)	V_i (Composite visibility)	No.	Description
H-H	High (0.549 - 1)	High (0.268 - 1)	62	Scenes with both high A_i and V_i , predominantly located around the southeastern lakes. These include a cluster of scenic and recreational heritage buildings.
H-L	High (0.549 - 1)	Low (0 - 0.268)	36	Scene characterized by high A_i but limited V_i . This group mainly comprises enclosed historical royal functional structures, such as interior sections of political palaces.
L-H	Low (0 - 0.549)	High (0.268 - 1)	25	Scenes with low A_i but high V_i , typically situated on elevated terrain in mountainous areas. Most are pavilions intended for viewing the landscape.
L-L	Low (0 - 0.549)	Low (0 - 0.268)	21	Scenes with both low A_i and low V_i , often located in the western and northern zones, far from the main entrance. These are predominantly religious buildings.

In general, the spatial distribution of the composite spatial index (S_i) across scenes in CMR is notably uneven, which was combined with A_i () and V_i (), while the first principal component accounted for 92.19% of the total variance (Fig 5.2G-H). Fig 5.2G shows the composite spatial characterization index (S_i) for each scene by integrating accessibility and visibility, whereas Fig 5.2H presents the classification of these S_i values into nine levels and their spatial distribution across the CMR. Scenes classified as Level 1–3, characterized by high accessibility and visibility, are predominantly located in the southeastern lake area. Those with medium values (Level 4–6) are mainly situated in the transitional plains extending from the southeast toward the northern zone. In contrast, scenes within the mountainous areas tend to have lower S_i values and are largely concentrated in Levels 7–9.

5.3.2 Five Heritage Value Perception scores generated through large language models

In this study, we adopted the few-shot learning approach using Large Language Model (LLM) as proposed by Luo et al. (2025) to analyze the large number of user-generated content. Their comparative study assessed the performance of multiple LLM (Glm/ Ernie/ Moonshot) in analyzing Chinese user-generated content for cultural perception, while Moonshot-v1 demonstrated superior performance than other similar models in both micro- and macro-averaged precision. Specifically, we

utilized the *moonshot-v1-128k* model, incorporating structured prompt engineering inputs that included (1) task instructions, (2) definitions of heritage value categories, (3) background information on CMR, and (4) expert scoring examples for 144 scenes (Table 4.5). This part is also applied to Section 4.3.3 with similar purpose.

By embedding these examples into the model prompt, we effectively simulate the decision-making process of human evaluators within a specific context. This structure allows the model to perform controllable dimension-wise scoring under limited supervision by emulating expert evaluation logic embedded in structured prompts.

$$y_i^{(k)} = \sum_{l=1}^5 \pi_l^{(k)} \cdot I \left[\phi^{(k)} \left(\mathcal{F}_{LLM} \left(c_i \mid \mathcal{P}_{\text{task}}, \mathcal{P}_{\text{def}}, \mathcal{P}_{\text{bg}}, \mathcal{P}_{\text{ex}} \right) \right) \in R_l \right] \quad (5.2)$$

In formula (5.2), where $y_i^{(k)}$ is the score for comment c_i on PHVP category k ; $\mathcal{F}_{LLM}$ denotes the LLM function guided by structured prompts $\mathcal{P}_{\text{task}}, \mathcal{P}_{\text{def}}, \mathcal{P}_{\text{bg}}, \mathcal{P}_{\text{ex}}$; $\phi^{(k)}(\cdot)$ extracts the semantic content related to PHVP category k ; R_l is the semantic rule for rating level l , it denotes the predefined semantic criterion associated with rating level l for a given PHVP category. Specifically, each R_l represents a set of qualitative descriptions and judgment cues embedded in the prompt, which specify how expressions in a comment should be interpreted as level 1 to level 5 within that dimension; $\pi_l^{(k)} = l \in \{1, 2, 3, 4, 5\}$ is the corresponding score, it denotes the numerical score associated with rating level l . In this study, the five rating levels are directly mapped to ordinal scores from 1 to 5, such that the score assigned to level l equals l ; and $I[\cdot]$ is the indicator function that returns 1 if the model output matches level l , and 0 otherwise.

5.3.3 The perceptual-spatial embeddings for coupling

The two HSCs and the five PHVP scores were incorporated into the structural embedding framework based on GNN with two-layer graph attention networks as attributes of the nodes (scenes). The connectivity edges among the 144 scenes were constructed using GIS-based OD (Origin-Destination) data in ArcGIS Pro 3.4.0 as the links. To ensure a meaningful yet computationally efficient network, we applied a classical local neighbourhood coverage criterion, retaining the top- k nearest neighbours (KNN) with ≈ 7 as the k .

$$\pm_{ij}^{\text{CMR}} = \frac{\exp \left(\text{LeakyReLU} \left(\mathbf{a}^\top [\mathbf{W}\mathbf{h}_i \parallel \mathbf{W}\mathbf{h}_j] + \gamma \cdot \text{sim}_{\text{percept}}(i, j) \right) \right)}{\sum_{k \in \mathcal{N}(i)} \exp \left(\text{LeakyReLU} \left(\mathbf{a}^\top [\mathbf{W}\mathbf{h}_i \parallel \mathbf{W}\mathbf{h}_k] + \gamma \cdot \text{sim}_{\text{percept}}(i, k) \right) \right)} \quad (5.3)$$

In formula (5.3), Where α_{ij}^{CMR} is the perception-modulated attention weight from node i to node j . $\mathbf{h}_i, \mathbf{h}_j \in \mathbb{R}^d$ are the node feature vectors, with $d = 7$, including two HSC variables and five PHVP scores. $N(i)$ denotes the set of the top- k spatial neighbors of node i based on GIS proximity ($k \mid 7$), and $\mathbf{h}_k \in \mathbb{R}^d$ is the feature vector of neighbor k . $\mathbf{W} \in \mathbb{R}^{d \times d}$ is a shared learnable transformation, producing $\mathbf{W}\mathbf{h}_i, \mathbf{W}\mathbf{h}_j \in \mathbb{R}^d$, and $\mathbf{a} \in \mathbb{R}^{2d'}$ is the trainable attention vector. $\parallel$ denotes concatenation, and $\text{LeakyReLU}(\cdot)$ is the activation function. $\text{sim}_{\text{percept}}(i, j)$ is the cosine similarity between perceptual vectors $\mathbf{p}_i, \mathbf{p}_j \in \mathbb{R}^5$, representing the five PHVP scores of nodes i and j . γ is a positive hyperparameter controlling the contribution of perceptual similarity, set to 0.3 in this study. We set the perceptual similarity weight $\gamma = 0.3$ following prior practices in perceptual attention (Zhou et al., 2024). This value has been demonstrated to be robust in practice, particularly in applications where semantic-structural integration is the primary objective.

In addition, Deep Graph Infomax was employed to encode perceptual-spatial complexity through representation learning to reflect meaningful scene relationships rather than superficial co-occurrences. Following (Velickovic et al., 2017), the unsupervised training objective was to maximize mutual information between $\mathbf{h}_v$ and $\mathbf{s}$ while distinguishing real nodes from corrupted counterparts:

$$\mathcal{L}_{\text{PSLPM}} = -\sum_{v \in V} \log \sigma(\mathbf{h}_v^\top \cdot \mathbf{s}) - \sum_{\tilde{v} \in \tilde{V}} \log \sigma(-\mathbf{h}_{\tilde{v}}^\top \cdot \mathbf{s}) \quad (5.4)$$

In formula (5.4), where $\tilde{v} \in \tilde{V}$ is a corrupted negative node obtained by randomly shuffling input features. $\sigma(\cdot)$ is the sigmoid activation function. $\mathbf{s}$ is the graph-level summary vector derived from a readout operation over all node embeddings in the network. It provides a compact representation of the overall perceptual-spatial context of the CMR scene graph, rather than the attributes of any individual node. In the contrastive objective, $\mathbf{s}$ functions as the global reference representation, allowing the model to maximize agreement between genuine node embeddings and the holistic graph context while minimizing agreement between corrupted node embeddings and the same context. $\mathbf{h}_v$ is the embedding of node v , representing the perceptual-spatial characteristics of an individual scene. This contrastive loss encourages the embeddings $\mathbf{h}_v$ to align with the overall graph context $\mathbf{s}$, while reducing the alignment between corrupted node embeddings and the same global summary, thereby improving the context-awareness and robustness of the learned representations.

In terms of **coupling**, this process yielded 32D embeddings using Graph Attention Networks and Deep Graph Infomax that effectively capture two HSCs and five PHVP (7-dimensional input) for coupling them together. Rather than a merely trivial

expansion from this original 7-dimensional input, this transformation served as semantic fusion: re-encoding heterogeneous attributes through cross-feature interaction and structural context to reflect scene topology (Ye et al., 2024). Given the weak heterogeneity of the input, higher dimensional embeddings are essential for sufficient representational capacity to capture structural and semantic complexity (Qiang et al., 2025). Prior studies have shown that dimensional expansion enhances representational capacity for knowledge prediction and alignment (Liu et al., 2023; Luo et al., 2021; Tran & Park, 2024). Moreover, appropriate higher dimensional embeddings help to better separate noise and extract latent patterns (Dai et al., 2022; Yu et al., 2023).

In contrast, using the original 7-dimensional data in linear models such as traditional regression, which doesn't fully capture the sequential effects of heritage-related spatial and perceptual characteristics along visitor trajectories. With 144 nodes representing a moderate-scale network, 32D embeddings provide a widely adopted and empirically supported middle ground, balancing complexity, representational capacity, robustness, and generalization (Cao et al., 2024; K. Wang et al., 2024). For the scale of scenes (nodes) in CMR, lower-dimensional (e.g., 16D) embeddings would lack expressive power and struggle to capture interaction structures in weakly heterogeneous data (Gu et al., 2021), while excessively high dimensions—with far more parameters than nodes (eg.64 or 128D)—may lead to overfitting (Xu et al., 2023).

The node embeddings h_v were aligned with PHVP through correlation-weighted interpretable reconstruction to ensure semantic coherence, reduce redundancy, and improve interpretability (Z. Liu et al., 2022). Pearson correlation was used to weight and align each embedding with the five PHVP. For each PHVP category k , all 32D embeddings were ranked by the absolute correlation with k , and categories with Pearson's $r > 0.3$ were selected as its dominant representation dimensions (positively correlated). The selected coupling PHVP (**C-PHVP**) categories, representing enhanced versions of the original LLM-derived PHVP scores with two embedded HSCs' influences (Pearson's $|r| > 0.3$), both positively and negatively correlated), reflect a common *post hoc attribution* strategy—where GNN embeddings are associated with task-specific variables to identify semantically aligned and interpretable dimensions (Pope et al., 2019; Ying et al., 2019). Using Pearson correlation to align embeddings with the five C-PHVP serves as a targeted attribution method—ensuring task relevance and reducing noise, rather than relying on unsupervised dimensionality reduction. We calculated a perception-weighted C-PHVP score based on the selected embeddings:

$$(C-PHVP \text{ Score Definition}) s_i^{(k,C-PHVP)} = \sum_{d \in D_k} w_d^{(k)} \cdot z_{i,d}, \quad \text{with} \quad w_d^{(k)} = \frac{\rho_d^{(k)}}{\sum_{d' \in D_k} |\rho_{d'}^{(k)}|} \quad (5.5)$$

In formula (5.5), Where $z_{i,d}$ denotes the value of the d -th embeddings for node i ; $w_d^{(k)}$ is the normalized weight derived from the Pearson correlation between the d -th embeddings and the k -th PHVP category, restricted to the subset $D_k = \{d \mid |\rho_d^{(k)}| > 0.3\}$, when the D_k includes all embedding d for which the absolute value of the Pearson correlation coefficient $r = (\rho_d^{(k)})$ between the d -th embedding and k -th PHVP category is greater than 0.3; and $s_i^{(k,C-PHVP)}$ represents the final C-PHVP score of node i with respect to PHVP category k .

5.3.4 The optimized tourism routes and baseline comparison

The final five C-PHVP scores of each scene (node) and the pairwise OD distance matrix were jointly incorporated into a multi-objective evolutionary algorithm (MOEA) framework (Deb et al., 2002). We employed the Non-dominated Sorting Genetic Algorithm II (Deb et al., 2002) to simultaneously optimize for two objectives: maximizing the average five C-PHVP scores and minimizing the total route distance.

To ensure logical and feasible route structures, we imposed classical constraints, including (1) non-repetition of nodes, (2) fixed starting points (entrance and exit), (3) closed-loop route configurations, and (4) a specified tour time (3–7 hours) for the route. The algorithm was configured with standard yet context-specific settings: population size = 100, number of generations = 200, crossover probability = 0.9, and mutation probability = 0.05. The population refers to the set of candidate routes maintained in each generation of the evolutionary search, where each individual represents one feasible route composed of a sequence of scenes. Thus, a population size of 100 means that 100 candidate routes were retained, evaluated, and evolved in each generation. These values were selected not only based on established evolutionary optimization literature (Deb et al., 2002; Zhang, 2024), but also in consideration of the structural characteristics of the CMR graph—a medium-sized network of 144 nodes with moderate connectivity and high perceptual heterogeneity. This setup ensured sufficient search space coverage and solution diversity, without incurring excessive computational cost.

$$\text{maximize: } F(R) = [S^{\text{his}}(R), S^{\text{cul}}(R), S^{\text{art}}(R), S^{\text{sci}}(R), S^{\text{soc}}(R)], \quad \text{with} \quad S^{(k)}(R) = \frac{1}{|R|} \sum_{v \in R} S^{(k)}(v) \quad (5.6)$$

$$\text{minimize: } D(R) = \sum_{t=1}^{T-1} \text{dist}(v_t, v_{t+1}), \quad \text{with} \quad \text{dist}(i, j) = D_{ij} \quad \text{from distance matrix } D \quad (5.7)$$

$$R_{t+1} = \text{Select}(\text{Nondominated-Sort}(R_t \cup \text{Crossover}_{\text{route}}(R_t) \cup \text{Mutation}_{\text{PHVP}}(R_t))) \quad (5.8)$$

Subject to the following constraints

(a) Non – repetition of nodes : $v_i \neq v_j, \forall i \neq j, v_i, v_j \in R$

(b) Fixed-starting-point : $v_1 = v_{\text{entrance and exit}}$

(c) Closed-loop path : $v_T = v_1$

$$(d) \text{Travel-time: } f_{\text{time}}(R) = \frac{D(R)}{4} + \sum_{i=1}^T t_{\text{stop}}(v_i) \in [3, 7] \text{ hours} \quad (5.9)$$

These three formulas describe the multi-objective route optimization process, through which candidate routes of different lengths were iteratively generated and evaluated. Since the route was constrained by a feasible tour time of 3 to 7 hours rather than by a fixed number of nodes, the optimization allowed flexible route structures ranging from shorter, more selective itineraries to longer routes with broader scene coverage. In this way, the algorithm explicitly accommodated both short and long routes while ensuring their logical continuity, spatial feasibility, and temporal realism. In formula (5.6), the route $R = [v_1, v_2, \dots, v_T]$ represents a sequence of scenes (nodes), and the objective is to maximize the five C-PHVP scores $F(P) = [S^{\text{his}}(R), S^{\text{cul}}(R), S^{\text{art}}(R), S^{\text{sci}}(R), S^{\text{soc}}(R)]$, where each category score $S^{(k)}(R)$ is the average of the corresponding scores of all nodes along the route. Formula (5.7) aims to minimize the total travel distance $D(R) = \sum_{t=1}^{T-1} \text{dist}(v_t, v_{t+1})$, with distances derived from the entries D_{ij} of the distance matrix D . Formula (5.8) describes the iterative population of candidate routes update process where the current population R_t undergoes route-structure-based $\text{Crossover}_{\text{route}}(R_t)$ and PHVP mutation $\text{Mutation}_{\text{PHVP}}(R_t)$ to generate offspring. Here, $\text{Crossover}_{\text{route}}(R_t)$ denotes a route-structure-based crossover operator applied to two parent routes. Specifically, an ordered subsequence is first selected from one parent and preserved, after which the remaining non-duplicated nodes are filled in according to their order in the other parent. This design follows the logic of permutation-preserving crossover commonly used in route and traveling-salesman-type genetic algorithms (Goldberg & Lingle, 1985; Potvin, 1996);

$\text{Mutation}_{\text{PHVP}}(R_i)$ is a PHVP-guided mutation operator designed for this study. For a selected offspring route, one or more internal nodes are probabilistically perturbed through replacement, swap, or local reordering among feasible candidate scenes. The perturbation is guided by the C-PHVP profile of the route, so that nodes contributing relatively less to underperforming perceptual objectives are more likely to be modified. In this way, the mutation operator not only introduces stochastic variation, as in classical evolutionary search, but also steers the route toward better perceptual balance and diversity (Radu et al., 2013); These offspring are merged with the current population, after which all candidate routes are ranked using fast *Non-dominated* sorting and *Selected* according to nondomination rank and crowding distance to form the next generation R_{i+1} , thereby maintaining a Pareto-efficient balance across multiple objectives. Formula (5.9) represents the total travel time $f_{\text{time}}(R)$ within 3-7 hours includes the walking duration—estimated as $D(R)/4$ based on an average walk speed of 4 km/h—and the cumulative stop time at each node (10 minutes).

In this study, we established two representative **baselines** to comprehensively evaluate the relative advantages and applicability of our PSLPM routes (PRs). The first baseline is two Official Routes (ORs), namely the two officially recommended routes explicitly displayed on the guide boards at the entrance of CMR. These routes are primarily designed along linear spatial axes and link major landmarks (some scenes), reflecting a managerial logic grounded in spatial structure and connectivity of iconic scenes. The second baseline comprises five theme-based routes generated through a greedy algorithm (GRs), each corresponding to one of the five PHVP. These routes connect the highest-scoring scenes within each PHVP category. This type of route planning exemplifies existing approaches that only focus on preference-driven optimization while overlooking spatial structural balance.

5.4 The Application of PSLPM

5.4.1 PHVP analysis based on LLM and GNN

Based on four sets of prompts, we derived 1–5 scores for five PHVP categories using LLM. These five PHVP scores were subsequently visualized in a spatial-geographical mapping (Fig 5.3). Using a Graph Attention Networks and Deep Graph Infomax system, we conducted 10 iterations of unsupervised learning, resulting in a heatmap of 32D embeddings averaged across all scenes (Fig 5.4).

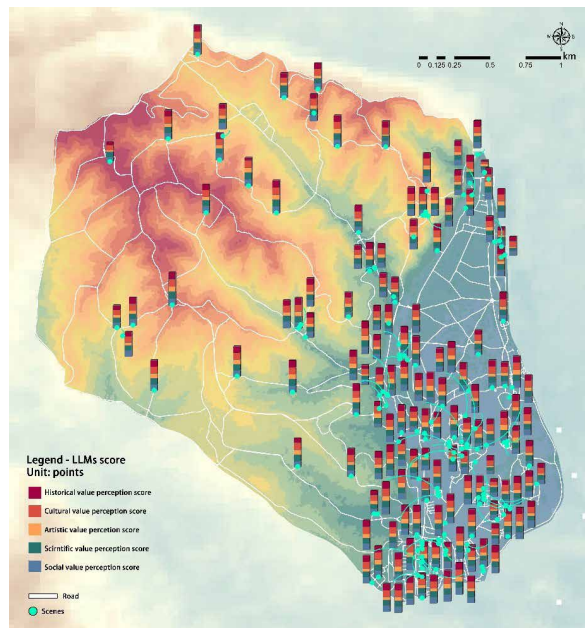


FIG. 5.3 The spatial-geographical mapping of LLM-generated scores.

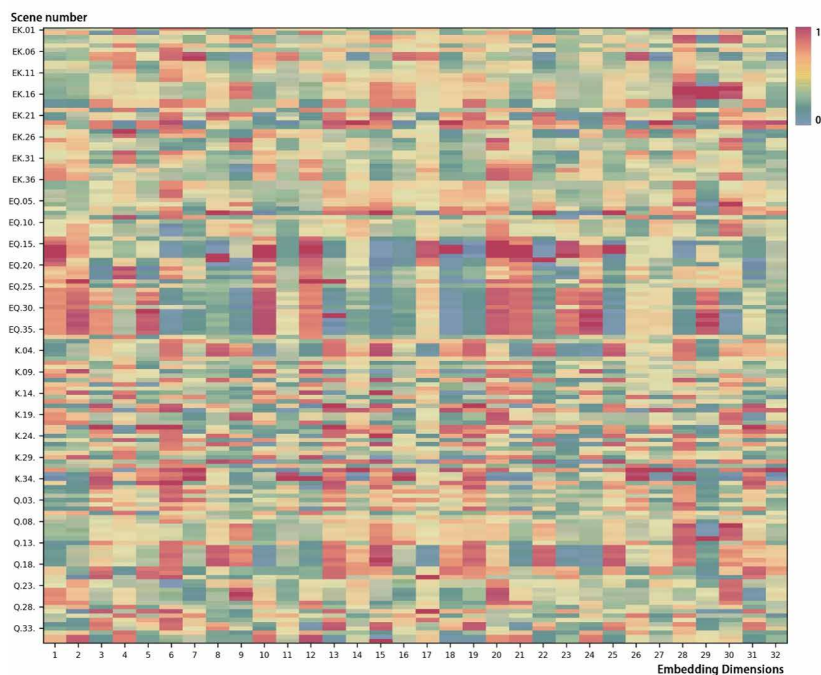


FIG. 5.4 The heatmap of 32D embeddings averaged across all 144 scenes.

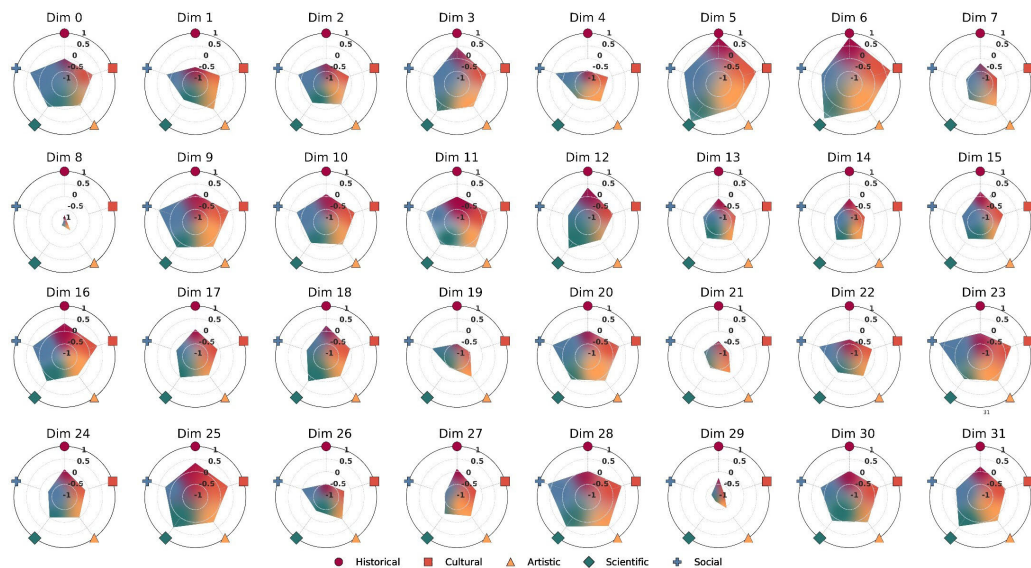


FIG. 5.5 Pearson correlation coefficients between the 32-dimensional embeddings and the five public heritage value perception categories.

The relationships between the 32D embeddings and the five PHVP categories vary significantly. We visualized their Pearson correlation coefficients and identified the most relevant embeddings of each PHVP category (Pearson's $r > 0.3$, positively correlated) (Fig 5.5, Table.5.4) . Their correlations with two HSCs (A_i and V_i) ranged from 0.489 to 0.935 (also Pearson's $|r| > 0.3$, positively and negatively correlated), indicating moderate to robust associations. These were subsequently used in a weighted analysis to derive the final spatial–perceptual C-PHVP scores. To validate the contribution of GNN-based embeddings, we conducted an ablation experiment comparing raw input features (7D) with Graph Attention Networks embeddings of varying dimensions (16D, 32D, 64D) (Table 5.4). The 32D embedding achieved the highest average perceptual score (0.723), the lowest perceptual variance (0.089), and a reasonable computational cost. These results support the choice of 32D as the main configuration, balancing semantic expressiveness and perceptual stability.

TABLE 5.3 Top Pearson correlation coefficients ($r > 0.3$) between the 32D embeddings and five PHVP categories, their two HSCs index ($|r| > 0.3$).

Dim	Historical value	Cultural value	Artistic value	Scientific value	Social value	A_i	V_i
0	− 0.019	0.132	0.036	0.088	*0.390	− 0.574	− 0.490
1	− 0.299	0.010	*0.326	− 0.207	*0.307	− 0.459	− 0.618
3	*0.431	0.177	0.073	0.262	− 0.026	0.536	− 0.513
5	**0.819	**0.547	0.136	**0.827	0.252	0.935	0.857
6	**0.807	**0.684	**0.358	**0.671	0.129	0.662	− 0.721
9	0.087	*0.345	0.159	0.195	*0.439	− 0.373	− 0.547
12	*0.335	0.029	− 0.127	0.228	− 0.168	0.627	0.705
16	0.258	*0.344	− 0.094	0.152	0.258	− 0.764	− 0.892
20	0.013	0.246	0.141	0.082	*0.426	− 0.844	− 0.602
23	− 0.076	0.231	0.149	0.064	**0.555	− 0.715	− 0.766
25	*0.33	0.289	0.181	*0.459	0.204	0.611	− 0.493
28	0.015	*0.34	**0.607	0.268	**0.541	− 0.815	− 0.674
30	0.016	0.163	*0.313	0.124	0.156	0.489	0.544
31	0.159	0.034	0.122	*0.412	− 0.005	0.506	0.486

** indicates strong correlation, with $r > 0.5$; * indicates moderate correlation, with $r > 0.3$

TABLE 5.4 Model Input Settings and Performance Comparison on PHVP Tasks

Feature Setting	Feature Type	Dimension	Avg. PHVP	Std. Dev. (diversity)	Runtime (s)NVIDIA RTX 3090)	Explanation
Raw input (baseline)	2 HSCs+ 5PHVP scores	7	0.445	0.125	24.3	No GNN semantic fusion; insufficient alignment with PHVP
Graph Attention Networks+Deep Graph Infomax embedding	GNN-based embedding	16	0.571	0.114	35.2	Lower expressive power; Embedding too shallow; limited perceptual generalization
Graph Attention Networks+Deep Graph Infomax embedding	GNN-based embedding	*32	*0.723	*0.089	*37.8	Best trade-off between value expression, balance, and cost
Graph Attention Networks+Deep Graph Infomax embedding	GNN-based embedding	64	0.684	0.127	45.9	Overfitting risk; Marginal gain in value, but increased noise and cost

*Indicates the optimal setting across all evaluation metrics.

5.4.2 Thematic and multi-layered route design

We obtained the final perceptual-spatial C-PHVP scores for all 144 scenes, along with their spatial connectivity attributes derived from GIS. After the MOEA process, five PSLPM distinct route outputs were obtained each emphasizing a specific theme (Fig 5.6, Table 5.5). For each theme, both long-route and short-route variants were generated. Meanwhile, many scenes exhibit high composite indicators and thus play multiple roles. We grouped these into a composite route.

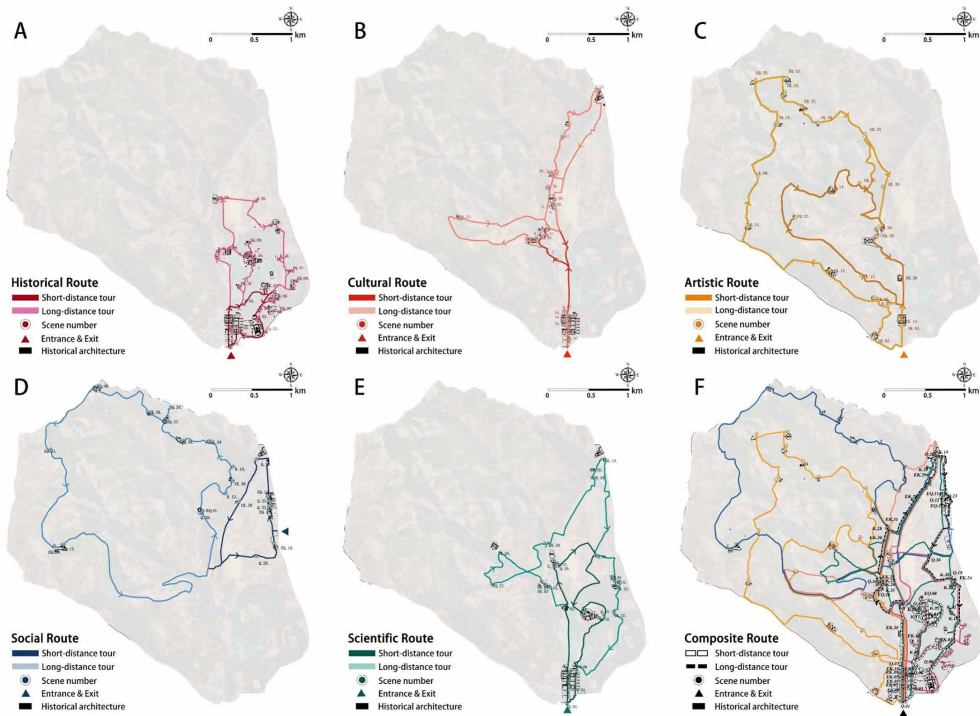


FIG. 5.6 The five PSLPM routes and a composite route generated from MOEA.

TABLE 5.5 The attributes of five thematic routes and a composite route.

Theme route	Number of scenes	Historical scores	Cultural scores	Artistic scores	Scientific scores	Social scores	Short tour distance (m)	Long tour Distance (m)
Historical route	28	*0.720	0.389	0.267	0.542	0.437	2051.15	4278.34
Cultural route	22	0.599	*0.758	0.641	0.562	0.537	2975.19	4193.37
Artistic route	24	0.361	0.663	*0.784	0.493	0.573	3192.46	5496.07
Scientific route	27	0.539	0.495	0.514	*0.672	0.375	3218.83	5016.97
Social route	22	0.360	0.459	0.576	0.224	*0.682	2933.43	9739.704
Composite route	49	0.565	0.457	0.665	0.559	0.532	3640.244	4090.95

*Indicates the highest perception score among all routes in the corresponding category.

5.4.3 Comparative research of two baselines

Using the historical-themed route as an example, we included all scenes from the PR, GR, and OR routes to construct spatial image collages. The horizontal axis represents the distance of each scene from the entrance as well as the distances between scenes, while the vertical axis indicates the normalized C-PHVP scores. Colours denote different spatial categories. This visualization reveals the overall PHVP level of each route, along with the extent of coverage and richness of variation across the four spatial types (Fig 5.7).

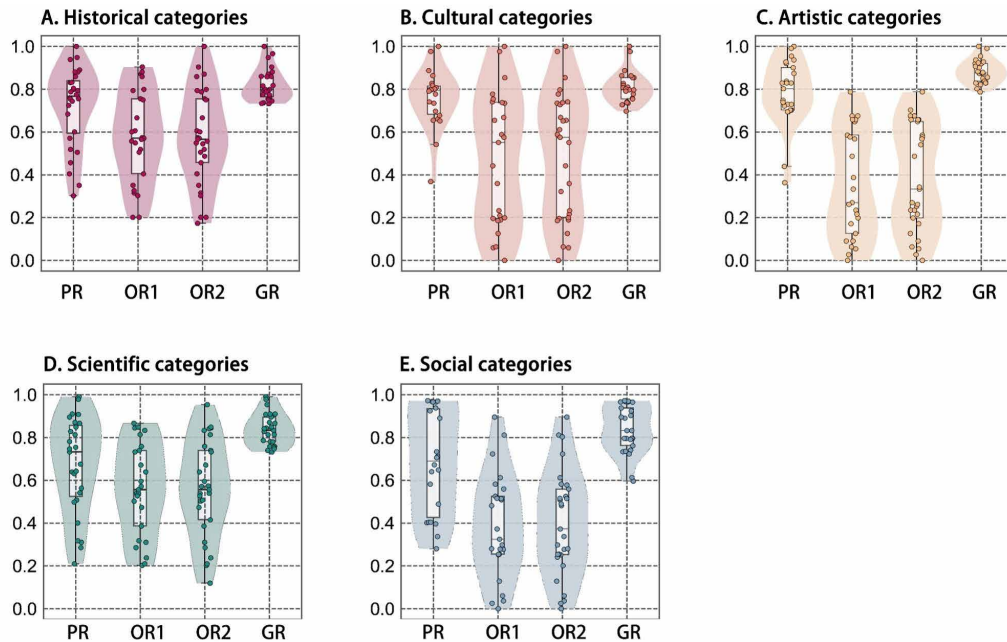


FIG. 5.7 Comparative Distribution of Spatial Categories and Historical C-PHVP Scores Along PR, GR, and OR. Here, HH, HL, LH, and LL denote the four spatial categories derived from the binary combination of the two core spatial dimensions introduced earlier, namely accessibility and visibility. Specifically, HH indicates high accessibility and high visibility, HL indicates high accessibility and low visibility, LH indicates low accessibility and high visibility, and LL indicates low accessibility and low visibility.

5.5 The Application of PSLPM

5.5.1 Practical reflection from PSLPM

This study proposes the PSLPM as a systematic response to an issue in cultural landscape practice: the gap between HSCs and PHVP. Such misalignment not only weakens the cultural carrying capacity of landscapes under rapid urbanization but also creates a disconnect between heritage spatial governance and public experience (Qi et al., 2022). As a result, sites with rich cultural connotations but inconspicuous spatial structures are often marginalized, undermining the cultural landscapes' integrity, continuity and sustainability (Khalaf, 2021).

Compared with GRs and ORs, PSLPM couples spatial accessibility and visibility in HSCs with PHVP to generate PRs that exhibit greater structural penetration, spatial diversity, and balanced layout. These PRs encompass a broader range of HSC-defined areas while maintaining high levels of perceived value, effectively avoiding the spatial bias seen in GRs and ORs that tend to overconcentrate on perceptual hotspots or visually dominant nodes. Such biases exacerbate congestion in core areas and diminish opportunities for cognitive engagement with marginalized scenes (both low accessibility and visibility), ultimately impeding comprehensive heritage value communication. The lengths of PRs are also constrained within a practical range, ensuring accessibility while enhancing perceptual engagement. This spatial pattern not only improves visitor mobility experience but also reactivates the cultural potential of marginalized zones, reinforcing the narrative coherence of cultural landscapes and offering a supportive reference for developing more inclusive intelligent navigation systems.

More importantly, PSLPM's construction relies on standardized spatial indicators and modular perception scoring mechanisms, giving the model strong contextual transferability. It is not bound to any specific cultural landscape typology. By simply adapting the source corpus and perceptual dimensions to local heritage contexts, PSLPM can be applied across diverse route optimization practices, where previous research has primarily emphasized circulation efficiency or expert-driven, single-objective linear planning such as historical districts and industrial heritage sites (Balcan et al., 2024; Pei et al., 2022). In addition, PSLPM offers a unified yet flexible analytical framework for communicating cultural values under varying spatial conditions, thereby expanding the theoretical and methodological boundaries of global cultural landscapes' planning practice.

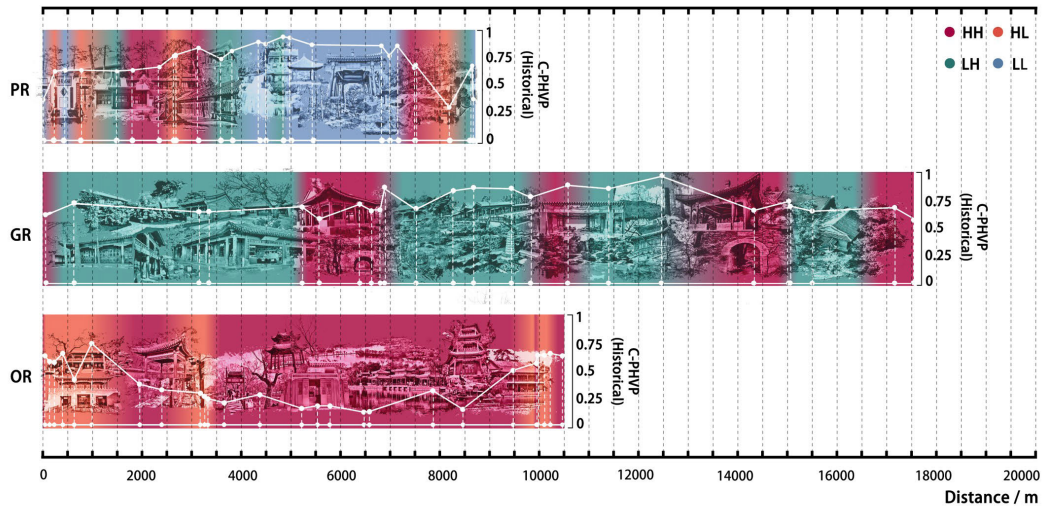


FIG. 5.8 Comparative Distribution of Spatial Categories and Historical C-PHP Scores Along PR, GR, and OR

5.5.2 Theoretical implications of PSLPM

Current studies of cultural landscapes in urban environments have largely consolidated around a perceptual–spatial duality, as reflected in the interdisciplinary studies across human geography, environmental psychology, urban perception theory, and governance research (Bornioli et al., 2023; Singh et al., 2023; Soyer & Tunca, 2025; Liu et al., 2022). Frameworks such as UNESCO’s *Historic Urban Landscape* emphasize their role as spatial carriers of urban public memory and identity, while the *European Landscape Convention* stresses individual perception, place attachment, embodied experience of cultural landscapes. However, when the theoretical framework was applied into practice, a persistent disconnection remains between spatial models and perceptual meanings. (Qi et al., 2022; Jamhawi et al., 2023; Zhang et al., 2023; H. Liu et al., 2022). To fill this gap, we draw upon landscape planning as an interdisciplinary integrative approach that aligns cultural landscape physical structures with the intangible public perception (Lian et al., 2024; Ryan, 2011; Sánchez et al., 2020). Building on this foundation, we introduce the PSLPM route optimization as an intervention that utilizes recent advances in social media–based semantic mining and AI-driven perception modeling to deepen the integrative coupling between spatial structure and perceptual meaning.

Methodologically, the study lays the foundation for perceptual computing and the advancement of urban spatial intelligence for cultural landscape planning and management. By embedding semantically derived scores from LLM into GNN structures, PSLPM demonstrates how distributed perceptual data can be translated into structurally expressive embeddings, thereby enhancing the interpretability of high-dimensional spatial representations (Luo et al., 2025; Liu et al., 2022; Pope et al., 2019). While not fully resolving the black-box nature of GNNs, the proposed correlation-based attribution mechanism offers an interpretable interface that links latent graph representations with domain-specific semantic dimensions, providing a replicable, transparent, and generalizable template for explainable spatial intelligence (Z. Liu et al., 2022; Ying et al., 2019). Building on this, PSLPM advances a MOEA that balances spatial diversity, perceptual equity, and experiential coherence (Deb et al., 2002; Zhang, 2024), transcending prior models that rely solely on spatial hierarchy or perceptual hotspots (Smith, 2023; Von Haaren, 2002). This approach supports perceptual value-informed landscape planning and responds to the governance and management challenges of cultural landscapes under the pressure from urban environments.

5.5.3 Validation, robustness, and replicability of the PSLPM

To ensure that PSLPM is not presented merely as a result-producing workflow, its methodological credibility was further examined through validation, robustness assessment, and replicability analysis. First, the validity of the LLM-based PHVP scoring was evaluated against expert judgement. The perception scoring process was based on 59,852 user-generated comments linked to 144 scenes, and was guided by four structured prompt components, including task instructions, PHVP category definitions, CMR background information, and expert-scoring examples. Of the 144 scenes, 115 scenes (80%) were used for model context construction, and 29 scenes (20%) were reserved for testing. The LLM outputs showed strong agreement with expert evaluation, achieving a Pearson correlation of 0.771, a recall of 0.976, and a precision of 0.825. These results indicate that the LLM did not function as an unconstrained generative system, but as a structured scoring instrument capable of transforming large-scale textual comments into interpretable and domain-relevant PHVP values.

Second, the robustness of the perceptual-spatial coupling process was assessed through ablation and parameter-based comparison. The GNN component was constructed on a graph of 144 scene nodes using GIS-based OD relationships, with top-k = 7 nearest neighbors and a perceptual similarity weight of $\gamma = 0.3$. To test

whether the results depended on an arbitrary embedding configuration, the raw 7D input was compared with 16D, 32D, and 64D embeddings. The 32D setting achieved the highest average perceptual score (0.723), the lowest variance (0.089), and a moderate runtime cost (37.8 s), outperforming both the raw baseline (0.445, 0.125, 24.3 s) and the 64D setting (0.684, 0.127, 45.9 s). This indicates that 32D provides the best trade-off between semantic expressiveness, stability, and computational efficiency. In addition, the selected embedding dimensions showed moderate to strong associations with both PHVP categories and HSC indicators, with Pearson coefficients ranging from 0.489 to 0.935, supporting the interpretability of the correlation-weighted C-PHVP reconstruction rather than treating the GNN as a purely black-box operation.

Third, robustness was also examined at the route-output level through comparison with baseline strategies. Across all thematic categories, the PSLPM routes covered all four spatial types, with HH accounting for 32%–59.26%, HL for 24%–36.36%, LH for 3.45%–24%, and LL for 3.45%–20%, whereas the official routes were entirely concentrated in HH and HL areas and the greedy routes showed no LL coverage at all. The PSLPM route lengths ranged from 6.329 to 12.673 km, while the greedy routes were much longer, ranging from 14.536 to 21.053 km. In perception terms, the PSLPM routes achieved mean values of 0.739, 0.682, 0.784, 0.783, and 0.688 across the five PHVP categories, remaining lower than the highly concentrated greedy routes but consistently higher and more coherent than the official routes. This suggests that PSLPM does not simply maximize perceptual hotspots but produces route structures that are more balanced in their integration of spatial diversity, perceptual coherence, and practical accessibility.

Finally, the replicability of the PSLPM is strengthened by the explicit specification of its full modelling pipeline, including the source and filtering of 59,852 comments, the four-part prompt structure, the 115/29 expert comparison design, the graph construction rules, the top-k = 7 neighborhood setting, the perceptual similarity weight $\gamma = 0.3$, the Pearson threshold of $r > 0.3$ for embedding attribution, and the NSGA-II optimization parameters of population size = 100, generations = 200, crossover probability = 0.9, and mutation probability = 0.05. Together, these details make the framework substantially more transparent and reproducible than a purely descriptive route recommendation process. At the same time, some limitations remain. The LLM-based scoring may still be influenced by platform bias, prompt dependency, and uneven comment distribution, while the GNN embeddings, although partially interpreted through correlation-based attribution, remain a simplified representation of complex perceptual-spatial relationships. PSLPM should therefore be understood not as a deterministic decision-making system, but as a reproducible and interpretable planning support framework.

5.5.4 Limitations

First, *Mountain Resort and its Outlying Temples, Chengde* was included on UNESCO's World Cultural Heritage list in 1994. However, considering the limitations of available data and spatial constraints, our research primarily focuses on the core part of the heritage site, namely the Chengde Mountain Resort (CMR).

Although this study constructs a multidimensional perception scoring system based on user-generated content, effectively capturing public value perception comments in real-world contexts, certain limitations related to data source bias remain. User-generated content collected is subject to platform recommendation algorithms and the composition of user groups, which may lead to the underrepresentation of specific value types, due to lower expression frequency or stylistic divergence.

In addition, while weighted-correlation was used to enhance the post hoc interpretability of GNN embeddings, the model still exhibits inherent *black-box* characteristics. Therefore, the newly planned routes need to be checked and evaluated by local administrators and experts. Furthermore, the current modeling assumes relatively stable landscape structures and perception patterns over time, without accounting for dynamic contextual shifts such as real-time tracking of newly planned routes as feedback, aiming for further improvements and simulation studies. This may limit the model's applicability in scenarios involving real-time navigation, adaptive management, or personalized recommendation.

5.6 Conclusion

PSLPM fundamentally enhances cultural landscape route optimization by transcending purely technical approaches. Through the integration of LLM and GNN, it establishes a value-informed spatial strategy that explicitly bridges the gap between objective HSCs and subjective PHVP. This coupling ensures that experiential sequencing aligns with collective cultural perception. Built upon standardized spatial indicators (accessibility, visibility) and a modular perception scoring mechanism (adaptable LLM prompts for different PHVP dimensions), PSLPM exhibits strong transferability. It can be adapted to diverse cultural landscape typologies by tailoring the source corpus and perceptual categories to local heritage contexts.

For landscape planning managers and heritage governance, PSLPM provides a powerful, data-driven tool sensitive to public perception. It supports strategic objectives such as rebalancing visitor flows to alleviate congestion; enabling more inclusive landscape interpretation by highlighting marginalized areas; informing the development of intelligent navigation systems; and mediating between the inherent spatial logic of landscapes and evolving public cultural meanings. Integration into planning workflows, participatory processes, or smart tourism platforms facilitates more equitable, perceptually resonant, and sustainable cultural landscape development. Thus, PSLPM effectively bridges the persistent gap between spatial structure and perceptual significance, offering a robust pathway for enhancing the cultural landscapes within contemporary urban environments.

Landscape Design

How can landscape design contribute to enhancing the resilience of global cultural landscapes?

PART D shifts the focus from planning to design translation. While Part C established how landscape planning can diagnose risks, ecological constraints, and perception-based spatial demands through HEPLP and PSLPM, planning alone does not yet specify how these findings can be converted into actionable spatial interventions. The next step, therefore, is landscape design. Here, the emphasis moves from identifying where conservation and development pressures occur to defining how design can respond to them through operational toolboxes, spatial rules, and reversible intervention principles. By introducing a design-based resilience index and cluster-informed design grammar, Part D extends the thesis from site-specific planning toward transferable design strategies for global cultural landscapes, while also testing their applicability through the Chengde Mountain Resort as a design translation case.

Lian, J., Nijhuis, S., Peng, Y., Bai, N., Roders, A., Bracken, G., Wu, Z. (2026). Global understanding and preventive actions for urban and peri-urban World Heritage (submitted)



6 Design-based Index for Cultural Landscape

6.1 Introduction

World Heritage conservation is increasingly a question of urban governance ([Coimbra et al., 2025](#); [UNESCO, 2023](#); [UNESCO, 2011](#)). Many cultural and mixed World Heritage properties are embedded in dense historic cores, peri urban transitional belts, and cultural landscapes that are simultaneously exposed to redevelopment cycles, tourism economies, infrastructure expansion, and accelerating climate stress ([Coimbra et al., 2025](#); [UNESCO, 2023](#); [Adie & Amore, 2019](#); [Chen et al., 2024](#)). In such settings, deterioration rarely follows a single cause. Instead, risks accumulate through coupled processes ([Saha et al., 2021](#); [Aboukhater et al., 2023](#)). Gradual morphological change, including densification, encroachment, and land fragmentation, can amplify heat and water impacts ([Loibl et al., 2021](#); [Pham et al., 2021](#); [Jiang et al., 2023](#); [Jimenez et al., 2022](#)), while ecological decline can erode landscape buffering and adaptive capacity ([Saura et al., 2017](#); [Cimatti et al., 2025](#)). Climate related hazards are also intensifying, including extreme weather events and sea level rise that are projected to expand exposure for heritage properties in coming decades ([Ciantelli et al., 2018](#); [Reimann et al., 2018](#); [Vousdoukas et al., 2022](#); [Chen et al., 2024](#)). Social vulnerability can interrupt routine maintenance, weaken enforcement, and reduce the capacity to respond when shocks occur, especially under instability or conflict related disruption ([UNESCO, 2021](#); [Tandon, 2018](#); [Gerstenblith, 2018](#); [Schipper, 2022](#); [Aboukhater et al., 2023](#); [Elayah et al., 2022](#)). These coupled mechanisms mean that heritage integrity is shaped not only by conservation practice, but also by the broader neighbourhood systems in which a heritage property is situated ([UNESCO, 2011](#); [UNESCO, 2023](#); [Coimbra et al., 2025](#)).

UNESCO's monitoring instruments, including State of Conservation reporting, reactive monitoring missions, and the List of World Heritage in Danger, remain essential for international accountability (UNESCO, 2023; UNESCO, 2024). However, they are often mobilized only after pressures have already become visible or politically salient (UNESCO, 2024; UNESCO World Heritage Centre, 2023). For urban and regional decision makers, a recurring challenge is anticipatory governance: how to detect when a heritage property is drifting toward an endangered context, and which preventive interventions are most likely to work before integrity loss becomes difficult to reverse (UNESCO & ICCROM, 2022; UNESCO, 2023). A second challenge is comparability. UNESCO documentation provides rich and contextual diagnoses, but drivers of endangerment are frequently described narratively and unevenly across properties, limiting consistent cross site monitoring and early warning at a global scale (UNESCO, 2023; UNESCO, 2024). Evidence from World Heritage documentation also suggests persistent gaps between climate awareness and on the ground action (Chen et al., 2025), underscoring the need for operational approaches that are both comparable and spatially actionable (UNESCO & ICCROM, 2022).

Recent advances in remote sensing and global open data have improved the ability to monitor urban growth, thermal exposure, and ecosystem change (Khalil & Kumar, 2025; Jiang et al., 2023; Jimenez et al., 2022), but two gaps remain. First, the analytic units of governance and assessment are frequently mismatched. Many threats to heritage originate not inside the property boundary, but in the surrounding urban fabric and landscape interfaces where planning is actually negotiated and implemented (UNESCO, 2011; UNESCO, 2023). Second, quantitative monitoring frameworks often privilege environmental hazards while under representing social and institutional constraints, particularly where routine maintenance capacity is fragile or disrupted (UNESCO, 2021; UNESCO, 2023; Coimbra et al., 2025; Aboukhater et al., 2023; Yu et al., 2025). Together, these gaps leave monitoring efforts hazard centred, often missing neighbourhood level drivers and rarely capturing governance capacity, which limits their usefulness for preventive urban planning (UNESCO, 2011; Coimbra et al., 2025; Xu et al., 2024).

Here we address these challenges by reframing World Heritage risk as a coupled neighbourhood system and translating recurrent danger drivers into a globally auditable indicator framework aligned with UNESCO guidance and impact assessment practice (UNESCO & ICCROM, 2022; UNESCO, 2023; UNESCO, 2011). We ask three questions: how can widely available global datasets be integrated into an interpretable typology of World Heritage properties that captures the joint roles of social vulnerability, urban morphology, and geo environmental stress (UNESCO, 2021; Loibl et al., 2021; Aboukhater et al., 2023; Saha et al., 2021)? Which dimensions tend to worsen for endangered properties within each cluster, and

how does this configuration differ across clusters ([UNESCO, 2024](#); [UNESCO World Heritage Centre, 2023](#))? How does environmental context shape these dimensions across climate zones and coastal inland settings, and what implications does this have for preventive management at urban and peri urban scales ([Ciantelli et al., 2018](#); [Reimann et al., 2018](#); [Vousdoukas et al., 2022](#); [Chen et al., 2024](#))?

To answer these questions, we construct standardized World Heritage near site analysis units as neighbourhood systems centred on UNESCO site coordinates, enabling globally comparable measurement of surrounding urban landscape pressures ([UNESCO, 2023](#)). Our harmonized evidence base covers 1,013 cultural and mixed properties. We compile 12 indicators grouped into three dimensions: social vulnerability, including human activity intensity and capital proxies, education level, and social instability; historical fabric and urban morphology, including built up density and built up expansion; and geo environmental stressors, including multi hazard exposure, vegetation trend, heat intensity, biodiversity sensitivity, and landscape fragmentation ([UNESCO, 2021](#); [Loibl et al., 2021](#); [Saha et al., 2021](#); [Saura et al., 2017](#); [Cimatti et al., 2025](#)). Dynamic components are summarized over 2015 to 2025 to reduce sensitivity to single year anomalies and to better reflect chronic and cumulative processes ([Saha et al., 2021](#); [Jiang et al., 2023](#); [Khalil & Kumar, 2025](#)).

We then derive a data driven typology using a hybrid self organizing map and Gaussian mixture model clustering framework designed for non linear coupling and heterogeneous density patterns in multi source indicators ([Chen et al., 2021](#); [Olszewski, 2021](#); [Vesanto & Alhoniemi, 2000](#); [Kohonen, 2012](#)). The resulting typology identifies six clusters, each representing a distinct configuration of physical and social characteristics. Importantly, endangered WHNUs do not simply underperform uniformly across all indicators. Instead, they show larger deviations on the indicators that define each cluster, producing interpretable escalation signatures. These escalation signatures capture cluster specific endangerment mechanisms, as individual indicators become more extreme and coupled indicators deteriorate in recurring and synchronized patterns when WHNUs shift from normal to endangered status. The expansion heat mechanism aligns with established evidence linking densification to urban microclimate impacts ([Loibl et al., 2021](#); [Khalil & Kumar, 2025](#)). The hazard ecology stress mechanism reflects compounding hazard exposure and ecosystem stressors that can undermine buffering capacity ([Saha et al., 2021](#); [Saura et al., 2017](#); [Cimatti et al., 2025](#)). The socio environmental conflict mechanism is consistent with documented capacity constraints and crisis related disruption in conservation governance ([UNESCO, 2021](#); [Tandon, 2018](#); [Gerstenblieth, 2018](#); [Schipper, 2022](#); [Aboukhater et al., 2023](#); [Elayah et al., 2022](#)). The urban rural transitional mechanism reflects the cumulative effects of landscape

transformation and fragmentation in heritage linked cultural landscapes ([Pham et al., 2021](#); [Jiang et al., 2023](#)). Cluster wise distributions and association tests further show that climate zones and coastal inland settings condition both normal and endangered states, and that these associations become stronger once properties enter endangered status.

Within this typological framework, the Chengde Mountain Resort is classified as Cluster 6, a stability oriented profile characterized by high dependence on cultural industry and tourism, relatively stable educational and multicultural conditions, low density and limited spatial expansion, a positive NDVI trend, low fragmentation, and moderate heat stress. Positioning CMR in Cluster 6 does not imply an absence of risk. Rather, it clarifies that the main planning task differs from crisis oriented recovery. In this case, the priority is not post event repair, but integrity and capacity management: converting relative prosperity into long term preventive conservation capability, institutionalizing routine maintenance, and managing visitor and landscape pressures before they accumulate into structural degradation.

At the same time, a stability oriented cluster is not pressure free. In Cluster 6 contexts, risk more often appears as localized accumulation rather than systemic breakdown. Typical expressions include route and node congestion, heat stress concentrated in microclimatic hotspots, increased sensitivity of shoreline and slope soil and water processes under extreme rainfall, and perceptual dilution of landscape experience caused by commercial spillover. Because these pressures represent monitorable risk pathways rather than a change in typological identity, cross cluster borrowing becomes methodologically justified. What is transferred is not the claim that CMR should be reclassified by importing external problems, but that recurrent mechanisms and design levers identified elsewhere can be selectively mobilized through modular grammars to address local threshold exceedance while preserving the baseline objectives of Cluster 6.

To make such transfer reproducible rather than ad hoc, this study adopts a pressure tool matching logic. The main typological identity remains Cluster 6, so the baseline planning toolkit is organized around an integrity envelope and capacity budgeting, including spatial integrity constraints, tourism load budgeting and allocation, maintenance reinvestment through tourism revenue loops, blue green continuity as a process-based substrate, and a heat response protocol. Localized pressures are then addressed through modular calls to other cluster grammars once monitoring indicators or point cloud derived parameters exceed predefined thresholds. For example, congestion, commercial spillover, and rising nighttime light pressure may activate modules associated with auditable permitting thresholds and shade based preventive infrastructure. Heat accumulation in narrow corridors or core nodes

may call for heat budget controls and a more breathable microclimatic skeleton. Slope runoff concentration, shoreline erosion, or extreme rainfall sensitivity may trigger stormwater path design and soft boundary strategies with thicker buffers. Peripheral fragmentation or service facility expansion may require fragmentation control combined with maintenance reinvestment logic. In this framework, point cloud data serve not merely as descriptive documentation, but as a way to translate spatial experience and morphological constraints into computable parameters for diagnosing localized pressures, selecting representative scene assemblages, and specifying geometrically enforceable indicators and permitting conditions.

Accordingly, the case study does not treat a single scenic spot as the experimental unit. Instead, it uses scene combinations as transferable spatial prototypes. This is because key pressures in CMR typically emerge in chained patterns along visitor routes and terrain driven processes, meaning that a single point cannot adequately represent crowd spillover, cumulative heat load, or convergent runoff and erosion. Methodologically, point cloud data are used to cluster the site into reproducible spatial groups across five dimensions: openness, canopy cover, slope and flow accumulation potential, route accessibility, and dwelling capacity. One representative combination is then selected from each group and structured through a node, transition, and background logic, so that each prototype captures both localized dwelling impacts and process based propagation. In this way, the framework links typological diagnosis, modular planning response, and transferable design grammar, allowing CMR to function not as an exceptional case, but as a demonstrative application of how globally derived mechanisms can inform site specific preventive conservation.

By converting recurrent endangerment drivers into individual indicators and coupled mechanisms within an auditable and spatially consistent evidence chain, our approach complements UNESCO's narrative monitoring with a comparative neighbourhood lens that is actionable for cities ([UNESCO & ICCROM, 2022](#); [UNESCO, 2023](#)). The typology supports screening and early warning, preventive governance design, and transfer of experience across properties, enabling cities facing similar coupled pressures to adapt strategies without assuming that all heritage risks are locally unique ([UNESCO & ICCROM, 2022](#); [UNESCO, 2023](#); [Coimbra et al., 2025](#)).

6.2 Dataset and Analytical Framework

6.2.1 Research object and definition

In this study we focus on the cultural segment of the List together with mixed properties, which are highly visible and highly valued yet managed under constant tension between conservation and development. Our harmonized evidence base covers 1,013 inscribed sites, of which 972 are cultural and 41 are mixed, enabling a consistent analysis at the site scale.

To enable globally comparable spatial analysis, we used a widely-adopted spatial proxy approach by constructing fixed radius buffers as circular polygons centered on the coordinate points provided by the UNESCO World Heritage Centre database. These buffers serve as standardized analysis units and have been shown to capture integrated signals of heritage sites and their immediate landscape context in studies of environmental exposure, urbanization gradients and cultural landscape accessibility ([Jimenez et al., 2022](#); [Sakhvidi et al., 2025](#)). Buffer radius was selected to balance the spatial resolution of multi-source indicators and noise control. Since many geospatial dataset are available at 500 m resolution, small buffers yield too few pixels for stable estimates, whereas large buffers are more likely to incorporate non-heritage surroundings ([Jimenez et al., 2022](#); [Sakhvidi et al., 2025](#)). We therefore used $r = 5$ km, typically covering about 80 to 150 pixels, to retain local relevance while maintaining statistical stability.

To assess spatial independence among the neighborhood units, we examined the pairwise distance distribution of heritage center points. In total, 99.988% of point pairs were separated by more than 15 km and only 0.004% were within 5 km, indicating that overlap among $r = 5$ km buffers is negligible at the global scale. We refer to these standardized neighborhoods as World Heritage near-site analysis units (WHNU) to define the object of this research.

6.2.2 Data and indicator system

Following the UNESCO official List of World Heritage in Danger (UNESCO, 2024), we translate narrative drivers into a computable, auditable indicator system that accumulates and transforms open-source data, and supports comparison across heritage properties while holding data sources, temporal windows, and spatial sampling scales constant (UNESCO, 2024). These indicators are not intended to replace site specific heritage interpretation. Instead, they operationalize the recurrent pressure chains documented by UNESCO as proxy variables that can be quantified at the property scale (UNESCO, 2024; UNESCO & ICCROM, 2022; UNESCO, 2023), enabling subsequent association testing, clustering, and threshold-based management discussions. To reduce misclassification from single year anomalies, dynamic social and hazard variables are compiled over a ten-year window from 2015 to 2025. Morphological and ecological remote sensing variables are extracted primarily at a 500-meter grid resolution within each heritage property polygon, and then integrated into a GIS platform, producing a traceable spatial evidence chain.

To capture the multi-dimensional conditions that shape heritage vulnerability at the World Heritage neighbourhood scale, this study organizes the indicator system into three major categories: **Social Vulnerability**, **Historical Fabric and Urban Morphology**, and **Composite Geo-environmental Stressors**. These categories reflect three interrelated dimensions of risk formation. Social Vulnerability addresses whether the surrounding social and institutional context has the capacity to absorb pressure, sustain routine maintenance, and coordinate responses to disturbance. Historical Fabric and Urban Morphology focus on whether ongoing urbanization and spatial transformation are compressing the physical legibility, integrity, and landscape structure of heritage settings. Composite Geo-environmental Stressors examine whether hazard exposure and ecological change are intensifying material deterioration, environmental instability, and long-term management burdens. Together, the three categories move beyond single-hazard assessment by capturing the coupled social, spatial, and environmental processes through which World Heritage properties shift from manageable pressure to endangered conditions. To capture the multi-dimensional conditions that shape heritage vulnerability at the World Heritage neighborhood scale, this study organizes the indicator system into three major categories: Social Vulnerability, Historical Fabric and Urban Morphology, and Composite Geo-environmental Stressors. These categories reflect three interrelated dimensions of risk formation. Social Vulnerability addresses whether the surrounding social and institutional context has the capacity to absorb pressure, sustain routine maintenance, and coordinate responses to disturbance. Historical Fabric and Urban Morphology focus on whether ongoing urbanization

and spatial transformation are compressing the physical legibility, integrity, and landscape structure of heritage settings. Composite Geo-environmental Stressors examine whether hazard exposure and ecological change are intensifying material deterioration, environmental instability, and long-term management burdens. Together, the three categories move beyond single-hazard assessment by capturing the coupled social, spatial, and environmental processes through which World Heritage properties shift from manageable pressure to endangered conditions.

For Social Vulnerability, we operationalize UNESCO referenced drivers such as governance failure, limited maintenance capacity, social instability, and tourism-driven commercial pressures into five quantitative indicators that capture the coupled effects of human activity intensity and societal stress ([UNESCO, 2024](#)). Nighttime Light Intensity is derived from annual composites produced by the National Aeronautics and Space Administration (NASA) and the National Oceanic and Atmospheric Administration using the Visible Infrared Imaging Radiometer Suite (VIIRS) and is extracted at 500-meter resolution for each WHNUs. The ten-year series capture both persistent and seasonal loads of population and economic activity, aligning with UNESCO descriptions of sustained anthropogenic pressure associated with urban expansion, extended operating hours, and informal commerce competing for management resources ([UNESCO, 2024](#); [UNESCO & ICCROM, 2022](#); [UNESCO, 2023](#)). Cultural Tourism Dependency Share of GDP is matched to the heritage property scale using disaggregated statistics from the United Nations World Tourism Organization (UNWTO) and national statistical agencies, representing structural exposure to a single sector and peak season congestion risks, consistent with pathways where over-reliance on tourism revenue destabilizes conservation investment and prioritizes commercial retrofitting over long-term care ([Adie & Amore, 2019](#); [Coimbra et al., 2025](#)). Social Structure and Cohesion Change is built on event-level data on conflict and demonstrations from the Armed Conflict Location and Event Data project (ACLED), capturing fluctuations in social order and governance capacity that constrain routine inspection, mobilization of minor repair funds, and coordinated emergency response, echoing UNESCO concerns about weak management systems, limited enforcement, and escalating illegal occupation or damaging uses ([UNESCO, 2024](#); [UNESCO & ICCROM, 2022](#)). Language Diversity draws on diversity indices from the Centre d'Études Prospectives et d'Informations Internationales (CEPII), treating communication and consensus costs as a management constraint. In multi-actor participation, cross-level decision making, and risk communication settings, information friction and coordination costs can translate into delayed implementation and fragmented governance ([Adie & Amore, 2019](#); [UNESCO, 2024](#)). Finally, Education Level uses the education index from Global Data Lab as a proxy for human capital and technology absorption capacity, which conditions the effectiveness of restoration, monitoring, material and

craft compatibility, regulatory enforcement, and training systems, reflecting UNESCO narratives where limited technical capacity allows small disturbances to accumulate into major deterioration (Coimbra et al., 2025; UNESCO, 2024).

For Historical Fabric and Urban Morphology, we translate urban development and modification pressures into three spatial structure indicators that emphasize cumulative compression of legibility and integrity (Coimbra et al., 2025; UNESCO, 2023; UNESCO & ICCROM, 2022). Built-Up Urban Density is calculated from the European Space Agency World Cover land cover product at 10-metre resolution and summarized within WHNUs for the 2025 cross section, capturing volume accumulation and fine-grain scale shifts that pressure skylines, street networks, plot rhythm, and view corridor structure, consistent with repeated UNESCO warnings about uncontrolled development, volumetric intrusion, visual disturbance, and dilution of historic form (Coimbra et al., 2025; Loibl et al., 2021; UNESCO, 2011; UNESCO, 2023; UNESCO, 2024; UNESCO & ICCROM, 2022). Built-Up Urban Area Expansion Rate is derived from the Global Human Settlement Layer at 10-metre resolution over 2015 to 2025, quantifying the speed and magnitude of encroachment into buffer zones and transition belts. This indicator is designed to detect the passive contraction of ventilation corridors, drainage systems, and landscape gradients, as well as secondary development cascades triggered by outward extension of roads and utilities in UNESCO documents (Coimbra et al., 2025; UNESCO, 2011; UNESCO, 2023; UNESCO, 2024; UNESCO & ICCROM, 2022).

For Composite Geo-Environmental Stressor Index, we use five indicators to capture coupled hazard and ecological stress pathways, highlighting how multi-hazard overlap and ecological process change jointly affect heritage materials, geomorphic stability, and operational maintenance calendars (Chen et al., 2024; UNESCO, 2024). Composite Index of Hazard Types and Frequencies is constructed from the Emergency Events Database by compiling the types and occurrence frequencies of hazards such as earthquakes, extreme rainfall and flooding, and storm surge over 2015 to 2025, providing a baseline for repeated or compound shock conditions and supporting alignment between UNESCO reinforcement planning and the local threat spectrum (Ciantelli et al., 2018; Reimann et al., 2018; Saha et al., 2021; UNESCO, 2023; Vousdoukas et al., 2022). Normalized Difference Vegetation Index Temporal Trend (NDVI) is estimated from the National Aeronautics and Space Administration Land Processes Distributed Active Archive Center (NASA LP DAAC) Moderate Resolution Imaging Spectroradiometer (MODIS) vegetation products at 500-metre resolution, using ten-year trend estimation within each WHNU. It detects risks from vegetation degradation that destabilizes substrates and accelerates erosion, while also identifying the inverse risk where excessive growth or invasive expansion increases shading, moisture retention, and loss of visibility of

heritage attributes, thereby elevating ecological change from short-term variability to a prioritized intervention timeline (Chen et al., 2024; UNESCO, 2024). Heat Intensity is derived from the National Aeronautics and NASA LP DAAC daily land surface temperature and emissivity products, summarized at 500-metre scale to reflect heat driven material ageing, contraction of workable maintenance windows, and reductions in thermal comfort that affect visitor carrying capacity and routine upkeep schedules, consistent with UNESCO attention to climate related deterioration and adaptation gaps (Chen, Y., Wang, et al., 2025; Cimatti et al., 2025; Ciantelli et al., 2018; Loibl et al., 2021; UNESCO, 2023). Overlap of Biodiversity Hotspots is assessed through spatial intersection with biodiversity hotspot boundaries defined by the Critical Ecosystem Partnership Fund, identifying zones where ecological sensitivity constraints may conflict with heritage use and management, and where weak boundaries and rule design can indirectly amplify deterioration through habitat disturbance and insufficient control (Chen et al., 2024; Jiang et al., 2023; UNESCO, 2023). Landscape Fragmentation Index is computed from the European Space Agency World Cover dataset at 10-metre resolution by deriving multiple fragmentation measures and integrating them through principal component analysis, yielding a single index that reflects connectivity loss, buffer system weakening, and corridor disappearance. This makes the cumulative impacts of infrastructure severance, dispersed development, and landscape patchwork legible within permitting conditions and threshold based cumulative ledgers (UNESCO, 2011; UNESCO, 2023; UNESCO, 2024; UNESCO & ICCROM, 2022).

Indicators originated from heterogeneous spatial resolutions, temporal windows, and data formats, so harmonization converged all metrics to the WHNU level through spatial, temporal, and statistical integration. Raster indicators were aggregated via polygon-based zonal statistics to WHNU-level means or majority classes, vector ecological layers were intersected and converted into binary or ordinal attributes, and socio-economic tabular indicators were geocoded and linked using area-weighted or buffer-based matching. Temporal heterogeneity was reduced by expressing gradual processes as linear trends, chronic exposure and socio-economic context as multi-year means for 2015 to 2025, and climate, language, education, and built environment as 2025 snapshots. Statistical standardization used z-score scaling for continuous variables and min-max scaling for bounded ones. Composite indexes were generated after standardization to balance component influence. Categorical context variables such as coastal setting and climate zone were kept for stratified interpretation. Further methodological details are provided in the Supplementary Data.

6.2.3 Clustering approaches

To assess potential redundancy among the candidate indicators and to avoid multicollinearity driven information duplication in subsequent clustering and resilience modelling, we conducted a pairwise correlation screening across all indicators prior to model building. Because the indicators originate from heterogeneous sources and exhibit non-normal distributions and potential nonlinear monotonic relationships, we employed Spearman's rank correlation coefficient (Spearman's ρ) to quantify the strength and direction of bivariate associations. All indicators were harmonized to a comparable site-level analytical unit before the correlation test. We inspected the distribution of pairwise correlation coefficients to identify statistically and substantively high correlations that could signal redundancy. Following common practice in indicator system construction, pairs with $|\rho| \geq 0.8$ were treated as potentially redundant and were examined further for conceptual overlap.

Only Nighttime Light Intensity and Built environment density correlate (Spearman's $\rho \approx 0.51$). As they represent different categories, removing either indicator would weaken the interpretation, thus both variables are retained. Other correlations are weak (-0.3 – 0.3), indicating low redundancy. Thus 12 indicators capture complementary social, urban morphological, and environmental dimensions.

Our indicator system comprises 12 indicators, exhibiting nonlinear coupling and locally heterogeneous density patterns. To characterize a continuous spectrum of heritage types while preserving topological continuity, we adopted a hybrid clustering framework combining a self-organizing map (SOM) with a Gaussian mixture model (GMM). Specifically, the SOM performs nonlinear manifold unfolding by projecting high-dimensional relationships onto a low dimensional grid while preserving neighborhood structure, which improves cluster separability and reduces the cluster merging or artificial splitting that can arise from linear dimensionality reduction (Kohonen, 2012; Vesanto & Alhoniemi, 2000). We then applied a GMM in the SOM representation space to conduct probabilistic clustering, yielding posterior membership probabilities for each sample. This avoids boundary artefacts introduced by hard assignments and provides an operational measure of uncertainty that supports probability threshold-based identification of transitional cases, risk stratification and priority setting. The combined approach leverages the structural fidelity of SOM and the probabilistic expressiveness of GMM (Kohonen, 2012), making it well-suited to the complex coupling among social, morphological and environmental factors in heritage data.

To reduce path dependence in algorithm choice and to strengthen methodological reproducibility, we conducted a comparative evaluation of clustering methods under the same dataset and consistent preprocessing, benchmarking SOM-GMM against common alternatives including K-means, standalone GMM and HDBSCAN. All methods were assessed using a consistent set of internal validity metrics and information criteria, jointly considering cluster separation, within cluster compactness and model complexity, and the final approach was selected on this basis. K-means peaks at $k=4$ (Silhouette=0.458, Calinski–Harabasz=855.57, Davies–Bouldin=0.812) but assumes spherical equal-variance clusters and misses nonlinear gradients. Gaussian Mixture Model yields low and unstable Silhouette values (0.216 to 0.342) and the BIC-best solution at $k=11$ (Bayesian Information Criterion=11482.17) risks overfitting with blurred boundaries. HDBSCAN performs best at $k=12$ (Silhouette=0.380, Calinski–Harabasz=666.45, Davies–Bouldin=0.731) but is parameter-sensitive, produces many small clusters, and undermines interpretability. However, SOM-GMM excels at $k=6$: Silhouette=0.497, Calinski–Harabasz=837.40, Davies–Bouldin=0.743, BIC=11426.50, yielding compact, well-separated, parsimonious clusters.

For implementation, we parameterized SOM training to ensure reproducibility, fixed the random seed, and trained for 28,000 iterations with $\sigma = 0.33$ and learning rate = 0.1542 (Chen et al., 2021; Olszewski, 2021). After SOM training, we used the best matching unit coordinates together with features capturing local topological variation as inputs to the GMM, and systematically searched across covariance structures and candidate numbers of clusters k . The choice of k followed a two-step decision rule: we first screened candidate solutions using thresholds of Silhouette ≥ 0.35 and Davies Bouldin ≤ 1.00 , and then integrated the Calinski Harabasz index and BIC to make the final selection, resulting in $k = 6$ for the main analysis. We further performed sensitivity analyses by varying SOM grid size within a reasonable range (for example, 9×9 to 13×13), applying small perturbations to σ and learning rate, and repeating experiments with different random seeds and bootstrap resampling.

6.2.4 From characterization to design toolboxes

The six cluster typologies create a structured pathway for converting diagnostic characterization into operational design toolboxes. By distinguishing different resilience pressures such as social vulnerability, morphological compression, thermal stress, ecological decline, tourism dependence and hazard exposure, the clustering results identify the main leverage points available for spatial intervention. Methodologically, this enables abstract resilience dimensions to be translated into concrete design variables, including shading density, circulation restructuring, reversible construction strategies, material compatibility rules, micro retention systems, biodiversity connectors and visitor allocation principles. This step links analytical outputs with design practice by clarifying which spatial, ecological or governance parameters can be shaped through design to buffer risks or reinforce heritage continuity. In this study, resilience does not refer to the maximization of generalized urban performance or tourism growth. It is defined as the capacity of a World Heritage neighbourhood system to maintain heritage integrity, landscape legibility, ecological buffering, and routine governance capability under cumulative social, morphological, and environmental pressures.

The typology also provides a systematic basis for forming cluster specific toolboxes. Rather than proposing a single design response for all cultural landscapes, each cluster becomes a pattern that guides differentiated intervention. Social tourism clusters prioritize visitor regulation, micro climate conditioning and service infrastructure. Morphology driven clusters emphasize volumetric control, fine grain upgrading and safeguards for material authenticity. Ecology oriented clusters rely on water and soil micro infrastructures and continuity of ecological networks. Hazard and fragmentation clusters require spatial buffers, setback rules and landscape configuration control. In this way, the clustering framework moves beyond classification and establishes a method for identifying which design levers correspond to each resilience profile, supporting the development of targeted design grammars in subsequent sections.

6.3 Resilience Patterns for Landscape Design Practice

6.3.1 The characterization of six resilience clusters

Fig 6.1 provides a global overview of the WHNUs, showing the spatial distribution of the six clusters and the locations of endangered WHNUs. This joint display links neighbourhood types to their geographic context and prefaces the cluster comparisons that follow.

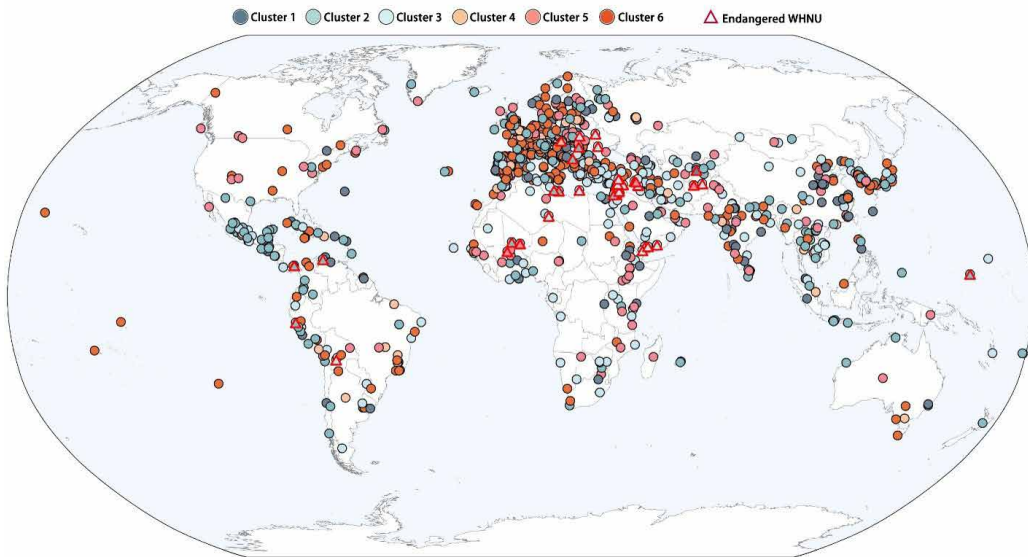


FIG. 6.1 Global spatial distribution of the six clusters, with endangered WHNU highlighted.

Cluster 1 (C1, WHNU with **Rapid Urban Expansion**) is defined with the following indicators (Fig 6.2A): In social terms, moderately high Nighttime Light Intensity ($Mdn=2.84$; $M=3.01$) points to a pronounced urbanized setting, while Cultural Tourism Dependency is also moderately elevated ($Mdn=1.08$; $M=1.23$), indicating that tourism provides a meaningful share of local economic activity. On urban morphological

aspect, Cluster 1 shows moderately high Built environment density ($Mdn=0.35$; $M=0.56$) and the highest Built up Urban Expansion Rate ($Mdn=-0.11$; $M=0.38$) among all clusters, capturing an intense and ongoing process of urban growth. Environmentally, Heat Intensity is very high ($Mdn=2.61$; $M=2.87$), reflecting a marked urban heat island effect. Overall, accelerated urban growth and tourism together with heat island intensification form the main characteristics of Cluster 1. Within this cluster, *Historic Cairo* and *the Historic Areas of Istanbul* as the typical cases. Significantly, the endangered sites exhibit an intensified urbanisation profile, reflected in elevated Nighttime Light Intensity ($Mdn=3.05$, $M=3.46$), high Built-up Urban Density ($Mdn=2.35$, $M=2.47$), accelerated Built-up Urban Expansion Rate ($Mdn=2.78$, $M=2.86$), and strong Heat Intensity ($Mdn=3.43$, $M=3.40$), signalling severe and persistent urban development pressure. For instance, *the Ancient City of Damascus*, *the Historic Centre of Shakhriyabz* and *the Old City of Jerusalem and its Walls*.

Cluster 2 (C2, WHNU with **Hazard and Ecological Sensitivity**) is defined by its environmental setting (Fig. 6.2B). The Composite Index of Hazard Types and Frequencies is clearly elevated ($Mdn=0.928$; $M=1.02$), indicating substantial multi-hazard exposure. The NDVI Temporal Trend is predominantly negative ($Mdn=-1.23$; $M=-0.71$), suggesting recent declines in vegetation condition. The Overlap of Biodiversity Hotspots ($Mdn=0.58$; $M=0.27$) shows that many sites are embedded in high-value ecological zones, which heightens the sensitivity of their conservation context. A positive Landscape Fragmentation Index ($Mdn=1.58$; $M=1.53$) points to moderately to highly fragmented surrounding landscapes, with potential to further erode ecosystem integrity. Within C2, Cluster 2, the endangered sites reveal an acutely vulnerable environmental configuration, characterised by a markedly elevated Composite Index of Hazard Types and Frequencies ($Mdn=2.82$, $M=3.11$), pronounced vegetation decline captured by the NDVI Temporal Trend ($Mdn=-2.72$, $M=-2.55$), strong ecological sensitivity indicated by the Overlap of Biodiversity Hotspots ($Mdn=2.05$, $M=1.81$), and substantial Landscape Fragmentation Index values ($Mdn=3.22$, $M=1.94$), together signalling extreme multi-hazard exposure and compromised ecosystem integrity, for instance, *Fortifications on the Caribbean Side of Panama* and *Peru's Chan Chan Archaeological Zone*.

Cluster 3 (C3, WHNU with **Social-Vulnerable Settlement**) represents cultural landscapes where social and cultural systems remain persistently simple, volatile or structurally vulnerable (Fig 6.2C). The socio-economic profile is characterised by very low to moderate Nighttime Light Intensity ($Mdn=-0.11$; $M=0.08$), indicating weak or uneven urban development. Cultural Tourism Dependency is generally low ($Mdn=-0.48$; $M=-0.54$). Social Structure and Cohesion shows substantial fluctuation ($Mdn=1.35$; $M=1.58$), suggesting persistent disruption, adjustment or systemic stress. Language Diversity is notably low ($Mdn=-0.86$;

$M=-0.75$), reflecting homogeneous communities, while Education Level is also low ($Mdn=-0.50$; $M=-0.68$), indicating limited human capital foundations. On urban morphological aspect, Built up Urban Density remains low overall ($Mdn=-0.67$; $M=-0.26$), and Built-up Urban Expansion Rate is slow or stagnant ($Mdn=-0.37$; $M=-0.25$). Those cases such as *the M'Zab Valley and Koutammakou*. C3 danger sites exhibit a clear social-vulnerability profile, defined by extremely low Cultural Tourism Dependency ($Mdn=-2.10$, $M=-1.79$), strong volatility in Social Structure and Cohesion ($Mdn=2.77$, $M=2.68$), markedly low Language Diversity ($Mdn=-0.83$, $M=-0.96$) and Education Level ($Mdn=-2.77$, $M=-2.59$), together with weak and stagnant urban form reflected in low Built-up Urban Density ($Mdn=-0.58$, $M=-0.18$) and slow Built-up Urban Expansion Rate ($Mdn=-0.34$, $M=-0.31$). For instance, *Samarra Archaeological City* and the *Old City of Sana'a* illustrate this pattern, where social structures undergo substantial and complex shifts driven by high population mobility and persistent community disruption.

Cluster 4 (C4, WHNU with **Compact Historic Urban Core**) is defined with the following indicators (Fig. 6.2D): Nighttime Light Intensity is markedly high, indicating that Cluster 4 sites are concentrated in mature, high-brightness urban cores ($Mdn=2.13$; $M=2.27$), while Cultural Tourism Dependency is high ($Mdn=1.02$; $M=0.91$). Education Level is distinctly high, reflecting elite urban cores with strong concentrations of highly educated populations ($Mdn=1.22$; $M=0.80$). In terms of urban morphology, Built-up Urban Density is substantially above average ($Mdn=0.38$; $M=0.76$), but Built-up Urban Expansion Rate is strongly negative ($Mdn=-1.24$; $M=-0.95$). This pattern suggests that Cluster 4 does not represent outward-growing urban frontiers but instead dense, growth-stagnating or even mildly contracting historical core areas shaped by long-established street fabrics. On environmental aspect, Heat Intensity is exceptionally pronounced ($Mdn=2.03$; $M=2.00$), forming one of the dominant pressures on this cluster and aligning closely with dense impervious surfaces and compact urban block structures. Within Cluster 4, WHNUs are typically located in the oldest and most spatially constrained urban cores. Examples such as the *Historic Centre of Kraków* and the *Old Town of Tallinn* show dense street fabrics and strong metropolitan core characteristics. The *Historic Centre of Vienna* is particularly notable as a WHNU in Danger, where extremely high Nighttime Light Intensity (Mdn , $M=4.12$), Built-up Urban Density (Mdn , $M=3.34$) and Heat Intensity (Mdn , $M=4.91$) illustrate the severe pressures faced by compact historic cores under intense urban context.

Cluster 5 (C5, WHNU with **Rural-Urban Transitional Fragmentation**) is defined with the following indicators (Fig. 6.2E): Urban economy is low, reflected in weak Nighttime Light Intensity ($Mdn=-2.00$; $M=-1.29$) and limited Cultural Tourism Dependency ($Mdn=-0.83$; $M=-0.70$). Social Structure and Cohesion remains

slightly below average but stable ($Mdn = -0.33$; $M = -0.11$), Language Diversity is modest ($Mdn = -0.58$; $M = -0.28$), and Education Level is low ($Mdn = -0.35$; $M = -0.67$). The urban form is weak, with markedly low Built-up Urban Density ($Mdn = -1.51$; $M = -1.32$) and slow or stagnant Built-up Urban Expansion Rate ($Mdn = -0.46$; $M = -0.54$), indicating that most sites lie outside active urban growth zones. The defining environmental characteristic is high Landscape Fragmentation Index ($Mdn = 0.77$; $M = 0.72$), resulting in a patchwork of farmland, roads and dispersed small-scale developments. This pattern typifies a rural-urban transitional setting shaped by fragmented spatial structure and uneven development such as *Konso Cultural and the Jesuit Missions of the Chiquitos*. C5 danger sites show very weak urban economic activity, reflected in low Nighttime Light Intensity ($Mdn = -2.56$, $M = -2.01$) and low Cultural Tourism Dependency ($Mdn = -1.40$, $M = -1.16$), together with limited social and human-capital foundations such as low Education Level ($Mdn = -4.17$, $M = -3.59$). Their spatial structure is defined by low Built-up Urban Density ($Mdn = -1.74$, $M = -1.96$) and a distinctly high Landscape Fragmentation Index ($Mdn = 2.09$, $M = 1.93$), forming a heterogeneous rural-urban mosaic rather than a coherent urban fabric, such as *Old Towns of Djenné and Tomb of Askia*.

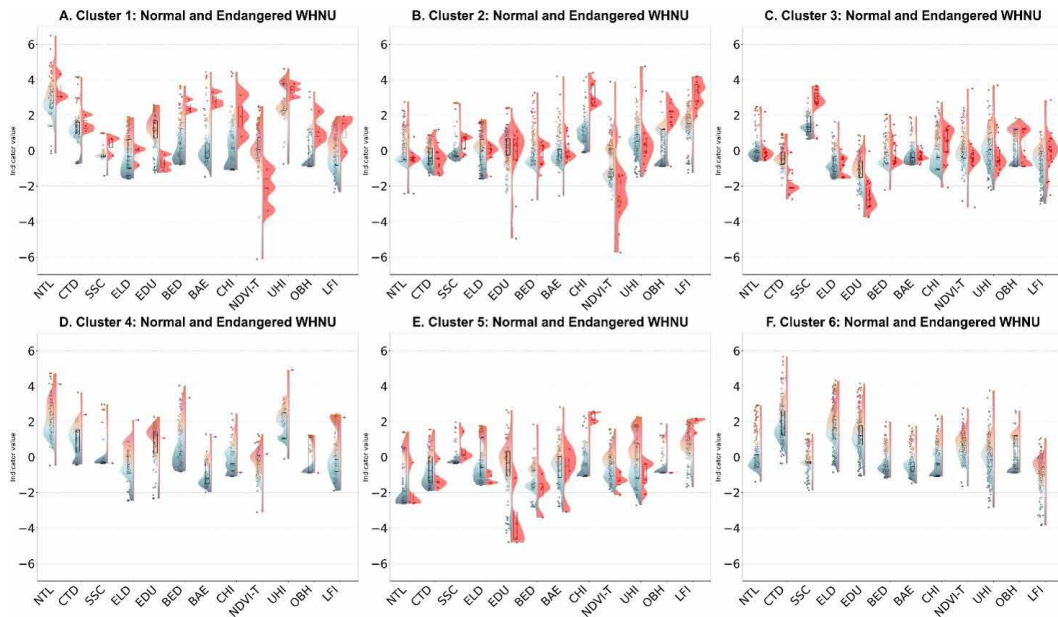


FIG. 6.2 12 Indicator distributions for Normal and Endangered WHNU across the six clusters.

Cluster 6 (C6, WHNU with **Stable Cultural Diversity**) is defined with the following indicators (Fig. 6.2F): The consistently high Cultural Tourism Dependency ($Mdn=1.60$; $M=1.92$) indicates a strong tourism-driven economic structure that aligns closely with elevated Ethno-linguistic and Language Diversity ($Mdn=1.66$; $M=1.66$) and similarly high Education Level ($Mdn=1.21$; $M=1.29$). Social Structure and Cohesion ($Mdn=-0.33$; $M=-0.26$) is slightly negative, suggesting gentle adjustment or mild contraction rather than systemic disturbance, forming a socio-economic profile characterised by high cultural diversity, high educational attainment and tourism- or culture-oriented development. The urban form remains weakly urbanised, with both Built-up Urban Density ($Mdn=-0.55$; $M=-0.38$) and Built-up Urban Expansion Rate ($Mdn=-0.53$; $M=-0.47$) clearly below the global average, indicating low-density and slow-expansion settlement structures. Environmentally, the Composite Index of Hazard Types and Frequencies ($Mdn=-0.38$; $M=-0.16$) is slightly below average, while the NDVI Temporal Trend ($Mdn=0.65$; $M=0.63$) is distinctly positive, reflecting general vegetation improvement. Heat Intensity ($Mdn=0.09$; $M=0.04$) remains close to zero, suggesting moderate heat-island stress with occasional high values. Meanwhile, the Landscape Fragmentation Index ($Mdn=-0.59$; $M=-0.74$) is relatively low, indicating that C6 sites tend to be embedded within more integrated and cohesive landscape matrices. Cluster 6 is largely represented by sites characterised by medium-scale urban settings, strong culture- and tourism-driven economies and stable social and educational structures. Examples include the *Historic Centre of Brugge*, *Old City of Berne*, *City of Luxembourg* and *City of Graz*, where rich historical landscapes and mature cultural industries support long-standing, self-reinforcing development patterns.

6.3.2 The clusters with climate and coastal-inland context

Fig 6.3 compares the climate subtype and coastal-inland distributions of WHNU under normal versus endangered context, showing a diverse pattern in the normal set but a pronounced convergence toward specific climate zones and predominantly inland settings in the endangered subset.

In C1, normal samples are Temperate-dominated (43.7%) with a mixed climatic profile. Endangered properties concentrate in Temperate, Dry and Hot Summer (100%). Spatially, endangered concentrates fully inland (Inland 100%) while normal properties show a balance (Coastal 45.6%, Inland 54.3%) (Fig 6.4A). In C2, Normal samples are Temperate-dominated (43.5%) but climatically diverse. On endangered aspects, Arid rises to 50% and coastal share increases to 66.6% (Normal Coastal 43.5%). Endangered C2 properties concentrate in hot-arid and

coastal settings, where aridification and coastal exposure amplify risk (Fig 6.4B). In C3, Normal samples are already arid-dominated (Arid 41.2%). Endangered properties concentrate further into desert and steppe types, with arid-related climates reaching 63.1% and Tropical dropping to 0%. Inland dominance also strengthens (Normal Inland 68.2%, endangered Inland 78.9%). Endangered C3 properties cluster in dry interior regions where aridity aligns with instability (Fig 6.4C). In C4, Normal samples are Temperate-dominated (58.3%), typical of dense historic cities. All endangered properties converge in Temperate (100%) and shift fully inland (Inland 100% vs Normal 63.2%) (Fig 6.4D). In C5, Normal samples are climatically mixed, led by Cold (31.7%) with substantial Temperate and Arid shares. On endangered aspects, climate contracts to Arid (75%), dominated by Arid, Steppe, Hot (50%). Spatially, properties are inland-dominated (Normal Inland 77.5%) and become fully inland in endangered (Inland 100%). Therefore, C5 exhibits a predominantly mixed inland spatial structure in cold and Arid transition zones (Fig 6.4E). In C6, Normal samples are strongly Temperate (58.6%), defining a stable cultural-tourism climate profile. Spatially, properties are quasi-balanced with a high coastal share (Coastal 46.7%, Inland 53.3%). C6 shows stable temperate conditions with no emerging endangered properties (Fig 6.4F).

Understanding of six clusters and representative cases requires moving beyond statistical differentiation to interpret how hazard exposure, ecological sensitivity, socio economic attributes, and heritage system conditions coalesce into coherent governance profiles. The following sections synthesize the defining characteristics of each cluster and summarize representative WHNUs that exemplify their internal logic and pressure configurations.

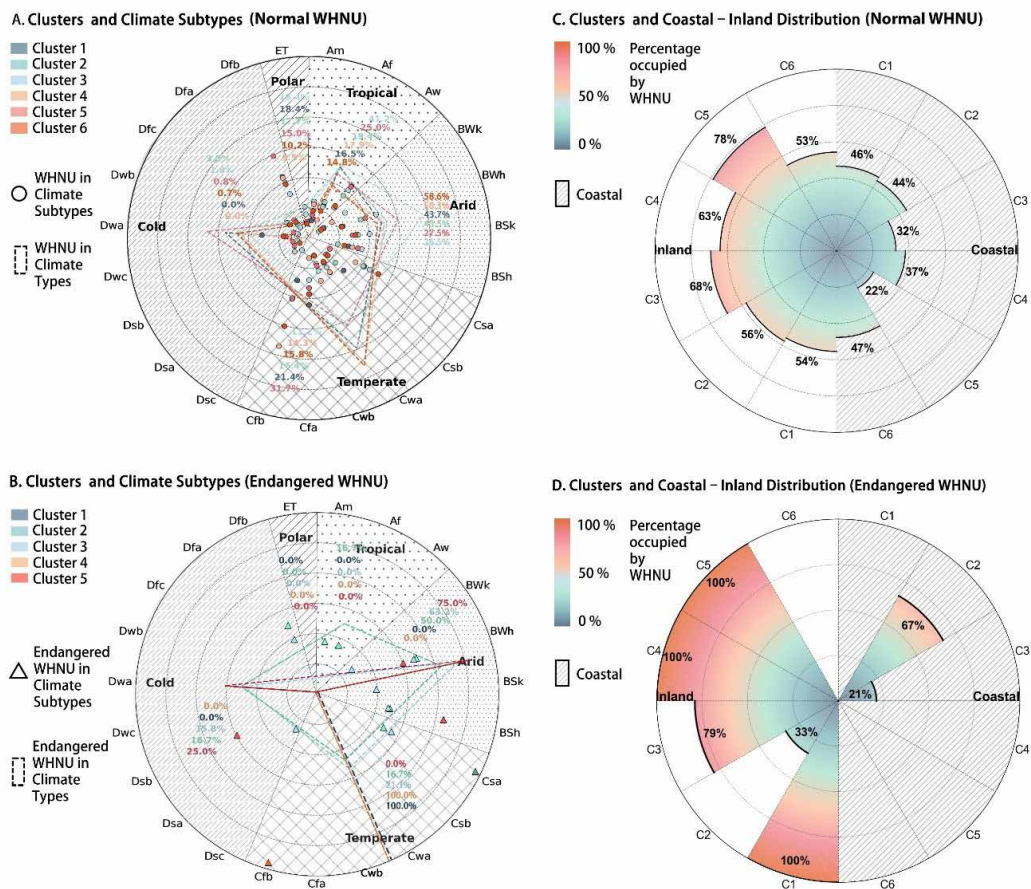


FIG. 6.3 Cluster specific climatic and geographic distributions under Normal and Endangered WHNU. **A:** Under Normal WHNU conditions, the six clusters show clear climatic differentiation. C1 and C2 follow mixed climatic profiles dominated by the Temperate zone (> 40%). C3 is strongly arid-driven with Arid regions exceeding 41%. C4 and C6 display pronounced Temperate concentration, each reaching or exceeding 58%, forming the most distinctly temperate-urbanized types. C5 presents an interlaced structure shaped by Cold (32%), Temperate and Arid zones; **B:** In the endangered subset, climatic biases become highly directional: endangered sites in C1 and C4 occur almost exclusively in Temperate settings, while endangered properties in C2, C3 and C5 concentrate strongly in Arid environments, reflecting the risk-amplifying nature of dryland conditions; **C:** Under Normal conditions, all clusters are inland-dominated, with only C1, C2 and C6 showing coastal shares between 44% and 47%; **D:** In the endangered subset, a sharp spatial convergence emerges. C1, C4 and C5 each reach 100% inland, and C3 reaches 79% inland. C2 is the only contrasting case, with 66.7% of endangered properties located in coastal zones.

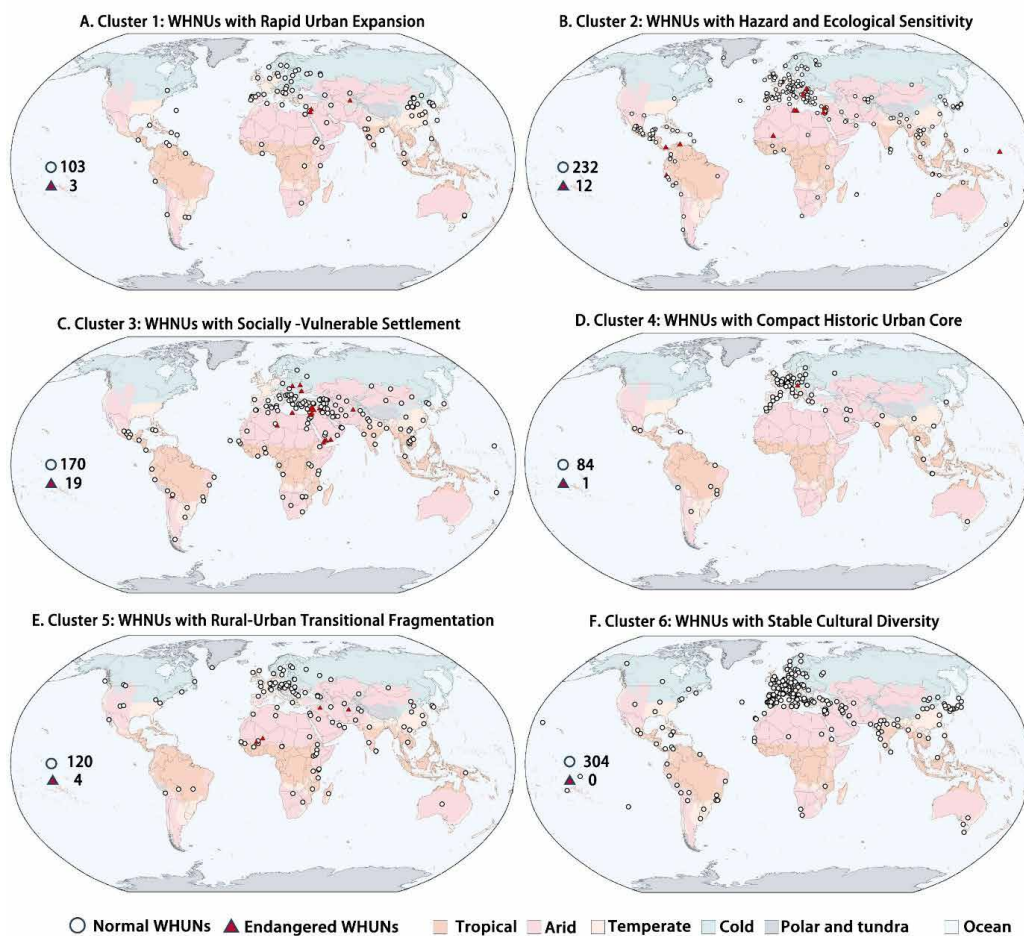


FIG. 6.4 Global mapping of WHNUs across six clusters (normal and endangered) and climate zones. **A–F:** the mapped locations, allowing a visual comparison of how six clusters co-occur with broad climatic contexts.

C1 captures WHNUs embedded in rapidly expanding urban systems, pressured by sustained urbanization, spatial compression and worsening thermal conditions. Infill development and outward capital expansion impose long-term structural compression, enlarging impervious surfaces while green areas lag, and dense population intensify heat accumulation, generating pronounced urban heat that undermines material stability and structural integrity. WHNUs concentrate in temperate conditions, but all endangered WHNUs occur in temperate dry and hot summer climates, all being inland urban context, showing high density growth plus thermal accumulation brings in vulnerability (UNESCO, 2023). The endangered C1 WHNUs exhibit elevated nighttime light intensity, built environment density, expansion rates and heat intensity, evidencing systemic pressures eroding historic fabric (UNESCO, 2024).

C2 is typically located in environments where multiple hazards overlap, ecosystems are highly sensitive, and degradation is already evident. The co-occurrence of biodiversity hotspots and landscape fragmentation is particularly challenging. Endangered WHNUs in C2 also concentrate in hot-arid climates and shift toward coastal settings, consistent with elevated climate-warming risks tied to water-resource variability, coastal erosion, and more frequent extreme rainfall (UNESCO, 2023; Voudoukas et al., 2022; UNESCO, 2025; Reimann et al., 2018). The endangered WHNUs illustrate long-term impacts from environmental factors such as shoreline erosion, and they are highly vulnerable to extreme rainfall and flooding, with climate change likely worsening environmental instability (UNESCO, 2024). Statistically, C2 contains one of the highest shares of endangered coastal WHNUs among clusters.

C3 reveals vulnerabilities embedded in social systems, where cultural and educational attainment is limited, human capital is insufficient, and institutional support has not yet fully materialized. The reliance on intergenerational transmission, together with restricted education and employment, drives out-migration, creates gaps in craftsmanship, and weakens heritage meaning (Cissé, 2020). These WHNUs are largely in arid and semi-arid inland regions with persistent water scarcity, inadequate infrastructure, and limited state involvement, so settlement expansion trigger pronounced fluctuations in social and cultural structures (Voudoukas et al., 2022). Endangered WHNUs concentrate even more in inland desert and grassland zones, suggesting intensifying aridification and inland isolation are turning latent vulnerability into acute heritage risks (UNESCO & Water Assessment Programme, 2020). C3 also hosts the highest proportion of endangered WHNUs (UNESCO, 2024).

C4 is shaped by long-term superposition of high-density built environments, cultural tourism dynamics and pronounced thermal conditions in mature urban systems. The Endangered C1 faces dual pressures in historic centre, where regional warming and more extreme heatwaves combine with inward-oriented infill and vertically extended construction, and constrained green-blue infrastructure amplifies heat exposure and structural stress (UNESCO, 2024; Loibl et al., 2021). C4 and C1 are both urban contexts, but C1 is influenced by outward expansion while C4 is more influenced by inward densification.

C5 is characterised by limited urban economic vitality, weak infrastructure and governance capacity, and a highly fragmented rural-urban transitional structure. Most WHNUs sit in everyday agricultural landscapes and small settlements outside major growth urban context, where patchwork farmland, local roads and dispersed villages are associated with landscape fragmentation and pressures on local ecosystem functions. C5 concentrates in inland semi-arid and seasonally dry regions, with endangered WHNUs narrowing to fully inland arid zones. Deterioration of architectural and urban coherence and volatile agricultural income trigger under maintenance and recurrent structural crises (Cissé, 2020). The resulting fragmentation of morphology, functions and territorial interfaces compounds vulnerability and reinforces their marginality in development agendas (UNESCO, 2024). C5 mainly represents transitional rural-urban and peri-urban landscapes with strong agricultural characteristics.

C6 combines cultural diversity, human capital and a tourism-oriented economy, forming a stable structure that converts cultural capital into a specialised, knowledge-intensive economy tied to local identities. These WHNUs are mostly in medium-sized cities where historic cores are not overtaken by high-rise buildings or large-scale infrastructure, sustaining local vitality and enabling a cautious balance between conservation and development through refined planning and management. They leverage their multilingual structure and international institutions to strengthen cultural heritage governance and high value-added services (Laroche & Gryszkiewicz, 2022). C6 WHNUs concentrate in temperate climates, especially warm-summer types, and show an almost balanced coastal-inland distribution. C6 has lower disaster vulnerability, and thus high heritage integrity with no endangered WHNUs.

6.4 From Cluster Characterization to Landscape Design Toolbox

6.4.1 Design toolbox of C 1: rapid urban expansion

C1 Landscape Design Toolbox must be translated directly from cluster characterization into a heritage anchor driven development grammar. Otherwise, design actions easily drift into generic urban renewal techniques and lose heritage specificity. For WHNUs, what development most readily erodes is not individual buildings, but an interdependent bundle of OUV supported attributes, including the legibility and continuity of historic morphology and fine grain, traditional materials and crafts together with a repairable supply chain, the sense of place structured by view corridors and skylines as setting, living heritage sustained by everyday rhythms and traditional livelihoods, and governance capacity that can reliably convert development gains into routine inspection and minor repair funding. In C1, nighttime light intensity, built environment density and expansion rate, and heat intensity can be treated as proxy variables for pressure on these attributes, providing auditable design and permitting bases.

Operationally, the toolbox should not be anti-development, but should fold new uses into an OUV compatible construction logic through light touch interventions and reversible insertions that safeguard spatial narratives and tectonic order, with reversibility grades, and visibility control of structural strengthening embedded as permit conditions, while institutionalizing a share of rent or operating income to flow back into a maintenance fund to close the loop between operation and upkeep (Zhang et al., 2025; Zhang & Zhang, 2023) (Fig 6.5A). Functionally and economically, to prevent tourism consumption from replacing living heritage with a single staged economy, traditional trades and everyday community livelihoods should be treated as the heritage skeleton, supported through micro renewal and small scale spatial patching, and safeguarded via tools such as livelihood diversity indicators, accessibility of community services, and rent escalation buffering mechanisms, while night lighting and signage should shift from image making to a light load budget using zoned luminance caps, buffers around sensitive points for light spill, and dynamic flicker limits to protect nocturnal ambience and material authenticity (Geletič et al., 2026) (Fig 6.5B). Spatially, its core is not simple down zoning, but a density reconfiguration that protects the grain under spatial compression, enforcing grain conservation by limiting large parcel amalgamation and wholesale clearance, allowing new build to grow along the traditional plot

logic through small volume accretion and reversible infill, and codifying auditable thresholds such as maximum frontage segment length, minimum ground floor permeability, minimum alley dimensions, and retention rates of spatial sequences (Chen et al., 2025; Coimbra et al., 2025) (Fig 6.5C). Given the heat accumulation trigger indicated by the C1 danger subset, shading should be elevated to preventive conservation infrastructure rather than an accessory, linking arcades, semi outdoor grey spaces, and tree canopy into a continuous shade network, with quantified targets such as shading coverage along primary walking routes, improvements in thermal comfort, and reductions in peak surface temperatures of historic materials directly entering the approval and audit chain (Shen et al., 2025; Yin et al., 2022) (Fig 6.5D). Environmentally, cooling must be framed as a system project for safeguarding authenticity and integrity. A cooling landscape is not decorative greening but a continuous coolth network organized along daily movement lines, using canopy, evapotranspiration, permeable paving, and micro topography to lower surface temperature and shorten exposure time, thereby reducing material decay and out migration risks driven by heat stress (Barau et al., 2025; Kousis & Pisello, 2023) (Fig 6.6E). At the level of setting and perception, view corridors and negative space should be treated as heritage attributes rather than residual land. Setbacks, chamfered corners, and deliberate voids should lock key sightlines and ventilation paths into a structural urban skeleton, with landmark visibility thresholds, corridor obstruction ratios, and segmented skyline control serving as permit and audit criteria (Peng et al., 2025; Sukwai et al., 2022) (Fig 6.5F).

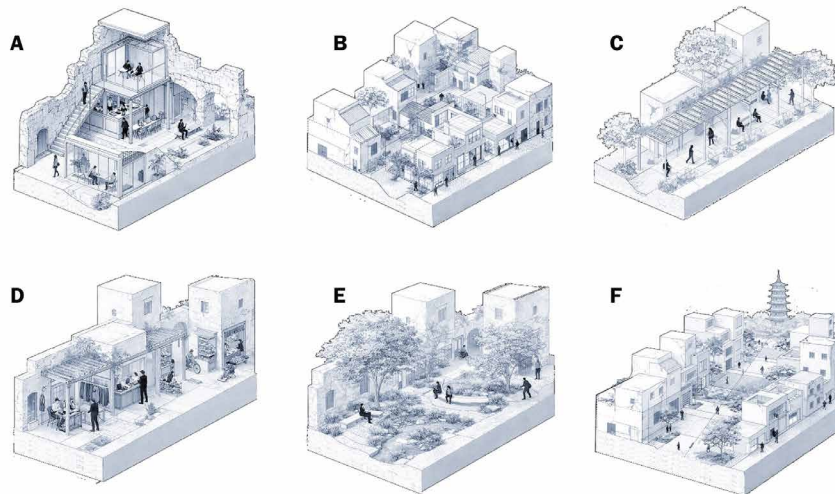


FIG. 6.5 Six landscape design toolbox for C1 WHNUs.

Finally, all heat adaptation and material strategies must be conditional on compatibility and repairability, avoiding irreversible coatings or incompatible substitutes that generate long term pathologies. Compatibility review grades, repairability scores, and supply chain availability requirements should encode the principle of repairable, replaceable, and sustainable into development conditions. This is how C1 cluster characterization can be fully translated into a heritage oriented design toolbox: every intervention corresponds to a specific heritage attribute and risk pathway, enters the permitting chain through auditable thresholds, and stabilizes long term maintenance capacity by converting gains from protective use and adaptive reuse into routine upkeep.

6.4.2 **Design toolbox of C 2: hazard and ecological sensitivity**

C2 World Heritage natural units are typically situated along an environmental gradient where multiple hazards overlap and ecological sensitivity is high, with degradation already accumulating to varying degrees. The core tension lies in the co-presence of biodiversity hotspots and landscape fragmentation. Hotspot areas carry critical ecological value and restoration potential yet are highly disturbance sensitive, while fragmentation weakens connectivity and constrains system recovery capacity. As a result, hazard exposure no longer functions as an occasional background condition but becomes a structural driver that persistently erodes ecosystem integrity and undermines heritage maintainability. The danger subset further converges toward hot arid and coastal settings, implying that under compounded pressures from water resource variability, coastal erosion, and more frequent extreme rainfall, risk is more readily amplified and more quickly translated into irreversible loss. The Fortifications on the Caribbean Side of Panama and Peru's Chan Chan Archaeological Zone exemplify this extreme configuration. Therefore, the C2 landscape design toolbox must anchor development in the environmental processes that sustain OUV and in the requirements of authenticity and integrity, redefining development as a mechanism of risk shaping that can be designed, constrained, and audited rather than an external disturbance variable.

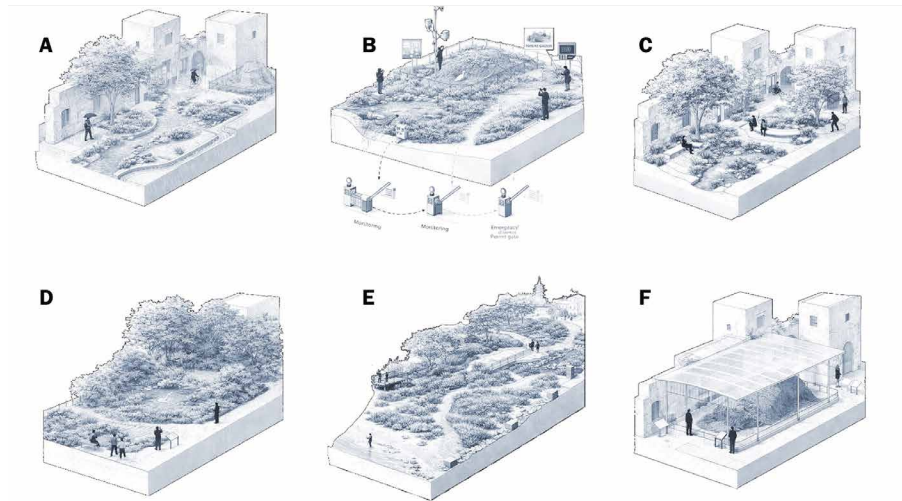


FIG. 6.6 Six landscape design toolbox for C2 WHNUs.

At the spatial and infrastructure level, the toolbox first embeds stormwater management into historic streets and surface systems, translating roads and alleys into a hydrological sequence for guidance and energy dissipation. Permeable paving, shallow swales, rain gardens, and micro topography are used to slow, spread, and infiltrate runoff, while flow paths are deliberately routed away from sensitive archaeological layers (Pour et al., 2020) (Fig 6.6A). It then treats monitoring as a designed system rather than an add on technology, establishing coupled remote sensing and in situ sensor points and embedding thresholds into permit gates and emergency response so that exceedances trigger visitor restriction, closure, maintenance, and rollback actions (Chen et al., 2026; Chrysoulakis et al., 2021) (Fig. 6.6B). In parallel, low disturbance pocket parks and micro renewal nodes are deployed to absorb stopping and dispersal, using reversible elements, light touch foundations, and light and noise budgets to prevent tourism driven upgrades from eroding living rhythms and the sense of place (Han et al., 2022; Zhou, 2025) (Fig 6.6C). Across ecologically sensitive zones and coastal edges, the toolbox uses a quiet core and soft edge micro zoning to define non-negotiable conservation cores and controllable transitional use areas, reducing disturbance in hotspot contexts through fencing, wayfinding, designated paths, and time based control (Jia et al., 2025; Sisneros-Kidd et al., 2021) (Fig 6.6D). It also upgrades the buffer from a static boundary to a thickened absorption field, organizing wetland, dune, saltmarsh, or mangrove restoration and expansion along coastal and catchment sections, while stitching corridors and stepping stone habitats to rebuild connectivity, delivering verifiable net gains in buffering and connectivity (Bridges et al., 2022; Inácio et

al., 2020)(Fig 6.6E). For earthen heritage and other fragile material systems, a rain shield light intervention is adopted, using reversible, lightweight, and breathable sheltering and drainage elements to reduce rainfall impact while maintaining visibility and ventilation, thereby avoiding short term cosmetic improvement achieved through irreversible cladding or incompatible materials (Cassar, 2025; Peng et al., 2026) (Fig 6.6F). To ensure these design moves genuinely operate through development and remain implementable, the toolbox must be embedded in the permit pathway and governed through a closed loop: a risk budget logic positions multi hazard exposure as a permit gate requiring bundled alternatives, mitigation commitments, and monitoring packages, while protective use and adaptive reuse are tied to a use pays for care financing and operations mechanism, establishing ring fenced maintenance returns, routine inspection and minor repair services, and heritage first aid protocols so that new construction and operations are consistently translated into concurrent risk reduction, ecological restoration, and long term maintenance capacity building.

6.4.3 Design toolbox of C 3: socially vulnerable settlement

C3 reveals vulnerabilities that do not primarily originate from the physical environment but are embedded in social systems. Where cultural and educational foundations are weak, human capital is limited, and institutional support is thin, external shocks can rapidly escalate into deeper social disturbance. In WHNUS such as the *M'Zab Valley and Koutammakou*, heritage continuity relies heavily on intergenerational transmission of knowledge and community structures, yet constrained education and employment options force younger groups to choose between staying with limited prospects and leaving with weakened cultural ties, producing craft gaps, weakened routine maintenance, and a gradual thinning of heritage meaning.

In response, the toolbox first establishes a minimum viable maintenance system that shifts conservation from episodic projects to a service infrastructure of routine inspection and minor repairs, spatialized through maintenance routes, repair points, tool caches, and material depots to sustain baseline protection even under governance volatility (Della Torre, 2021; Wu & van Laar, 2021) (Fig 6.7 A). It then anchors Local Craft and Materials Supply Chains as heritage infrastructure by organizing sourcing, processing, storage, training, and repair spaces into a legible production chain, preventing incompatible substitutions and mitigating the risk of craft discontinuity that undermines authenticity(Evans et al., 2025; Shih & Agrafiotis, 2026) (Fig 6.7B). Meanwhile, these WHNUS are often situated in arid or

semi-arid inland regions marked by persistent water scarcity, unstable livelihoods, inadequate infrastructure, and limited state involvement, where out migration and settlement change readily trigger sharp fluctuations in social structure and cohesion. To address this structural condition, the toolbox reframes development as social reproduction. It deploys Adaptive Reuse as Intergenerational Transmission Space by layering reversible, light touch programs that embed apprenticeship workshops, shared repair yards, and community collaboration spaces within heritage compatible buildings, creating durable pathways for skills transfer and local livelihoods that stabilize living practices and heritage meaning (Gravagnuolo et al., 2024; Vafaie et al., 2023) (Fig. Fig 6.7C). In parallel, it treats Water Security and Micro Infrastructure as a Heritage Section by choreographing low tech, maintainable systems for collection, storage, distribution, shading, and drainage along everyday routes and key communal nodes, recognizing that basic water reliability and thermal comfort are preconditions for habitation continuity and thus for integrity (Aklan et al., 2025; Sharma & Ji, 2024; Zhou et al., 2024) (Fig 6.7D). It further manages growth through Soft Edge Expansion and Buffer Patchwork, using phased, fine grained edge conditions and infrastructure first sequencing to make settlement change gradual and reversible, avoiding road cutting and large scale outward growth that would abruptly fragment community structure (Guo et al., 2023) (Fig 6.7E).

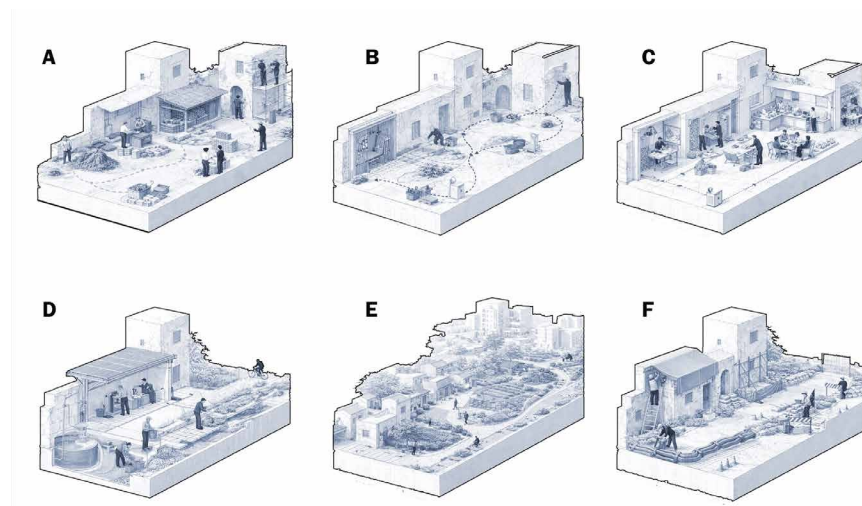


FIG. 6.7 Six landscape design toolbox for C3 WHNUs.

The danger subset converges toward inland desert and steppe contexts, indicating that intensifying aridification and interior isolation are converting latent social vulnerability into acute heritage risk. Samarra Archaeological City and the Old City of Sana'a illustrate how conflict, governance failure, and limited maintenance capacity become tightly coupled with conservation outcomes. To keep these design moves genuinely operating through development, the toolbox must be embedded in the permit pathway and governed through a closed loop. Approvals should bind investment to ring fenced maintenance returns, defined inspection frequencies, and minor repair response times so that new construction and operations do not hollow out local capacity. Finally, Heritage First Aid and a Minimum Conservation Threshold pre designs worst case action choreography through portable first aid kits, rapid temporary stabilization and waterproof covering, zoned access control, and emergency routes, supported by trigger rules and drill cycles so that basic protection can be maintained during governance disruption and irreversible losses are avoided ([Romao & Bertolin, 2022](#)) ([Fig 6.7F](#)).

6.4.4 **Design toolbox of C4: compact historic urban core**

C4 represents a typical risk configuration of compact historic urban cores within mature urban systems, where pressures are driven not by outward expansion but by the long term superposition of high density built environments, cultural tourism and creative industry agglomeration, and pronounced thermal intensification. Functions are highly mixed while space is extremely constrained, and narrow street canyons, continuous street walls, and limited ventilation corridors create complex microclimates that amplify heat island effects during summer heatwaves and reduce thermal comfort, which in turn erodes living heritage through resident loss and use replacement. The danger subset further converges toward temperate inland contexts, indicating that under regional warming and intensifying extreme heat events, inward oriented infill and vertical extension, combined with constrained green blue infrastructure, more readily accumulate heat exposure and structural stress. Therefore, the C4 landscape design toolbox must anchor development in heritage attributes such as historic street scale, skyline and view corridors, microclimatic setting, and sense of place, and translate development into protective use and adaptive reuse mechanisms that render thermal and use loads auditable rather than treating densification and functional layering as default trajectories.

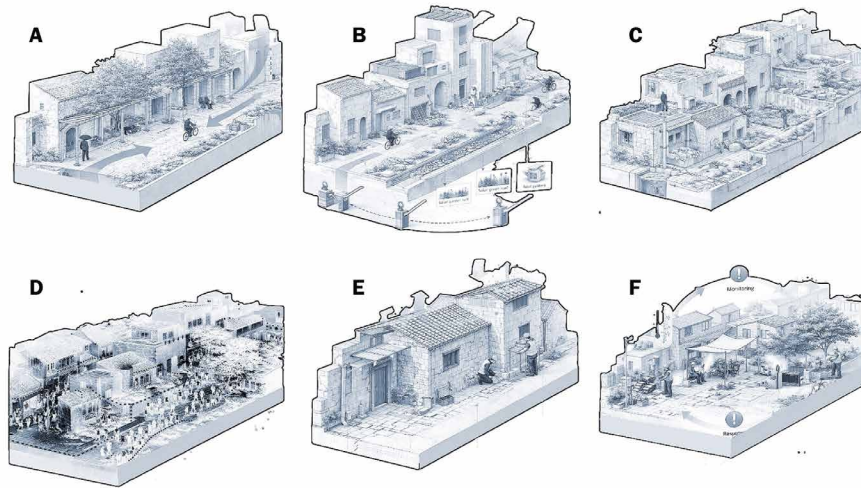


FIG. 6.8 Six landscape design toolbox for C4 WHNUs.

At the spatial and morphological level, the toolbox rebuilds a breathable microclimatic skeleton through a street canyon coolth section approach, using sectional micro adjustments, nodal apertures, continuous shading, and micro wind inlets to organize coolth corridors and ensure that ventilation continuity is not further compressed by infill development (Orejon-Sanchez et al., 2022)(Fig 6.8A). In parallel, inward densification is governed through a thermal budget permit gate, requiring each infill or vertical extension proposal to submit a quantified heat load offset package so that net thermal load is neutral or negative at the project scale, with compliance verified through indicators such as heatwave hot spot area, duration of thermal stress exposure, and nocturnal heat retention (Wang et al., 2025) (Fig 6.8B). Given the scarcity of open space in compact cores, roofs and inner courtyards are treated as the fifth facade and primary coolth interfaces, where reversible and maintainable green blue patchworks deliver detention and evapotranspirative cooling while strictly protecting key skylines, view corridors, and the legibility of historic materiality, monitored through runoff peak reduction, post rainfall drawdown time, and surface temperature and humidity response (Busker et al., 2022) (Fig 6.8C).

At the operational and maintenance level, the toolbox shifts tourism and night time economies from growth logic to load governance by establishing light, noise, and crowding budgets, applying zoned luminance and frequency controls, spill reduction, and porous flow redistribution so that principal streets do not become conduits for heat and congestion. Enforcement relies on auditable thresholds for

night time light intensity, peak pedestrian density, and nocturnal heatwave exposure duration (Fewella, 2024) (Fig 6.8D). It further addresses the accumulation of material pathologies under high heat through a heat stress compatible maintenance system that sets compatibility, reversibility, and repairability as entry conditions for interventions, supported by a standardized detail library and work order based maintenance rhythm, and tracked through condition metrics such as crack growth, moisture content, and salt related deterioration (C. Wang et al., 2023) (Fig 6.8E). Finally, a slow risk closed loop makes governance part of design by defining heatwave trigger levels and zoned responses, pre positioning rapidly deployable shading and cooling elements, and binding monitoring thresholds, trigger action lists, and circle fenced funding returns into the permit pathway, thereby translating inward growth into concurrent thermal risk reduction, controllable use loads, and strengthened long term maintainability (Busker et al., 2022) (Fig 6.8F).

6.4.5 Design toolbox of C5: rural-urban transitional fragmentation

C5 describes WHNUs embedded in rural urban transitional mosaics where low economic intensity, limited human capital, weak infrastructure, and constrained governance capacity combine with a distinctly high landscape fragmentation pattern. Heritage value is carried less by monumental cores than by living agricultural systems, small settlements, and continuous land use logics that depend on routine maintenance. In this setting, dispersed roads, scattered construction, and incremental plot conversions operate as a cumulative driver, gradually weakening ecosystem services and eroding communities' ability to sustain everyday repair. The danger subset converges toward fully inland arid and seasonally dry contexts, where chronic water scarcity, soil degradation, and livelihood volatility amplify the risk of intermittent under maintenance that can escalate into periodic structural crises.

To translate this cluster characterization into a development oriented, heritage anchored landscape design toolbox, the first move is to arrest fragmentation before it becomes irreversible through a Fragmentation Stop Line and patchwork control regime that treats new linear cuts as the primary threat to landscape continuity and legibility. Development is permitted only when it consolidates access and construction into existing corridors and nodes, with auditable constraints on road penetration and dispersed siting, and with monitoring tied to fragmentation change rates and road network density (Hou et al., 2025; Wu & Li, 2022) (Fig 6.9A). The second move frames agriculture as the conservation mechanism through Productive Conservation with Maintenance Return, binding any tourism or industry intervention to work orders, compatible materials and labor budgets, irrigation,

earthen structures, and routine upkeep, monitored through terrace failure, irrigation functionality, and annual maintenance hours (Zhou et al., 2023) (Fig 6.9B). The third move addresses the arid inland trigger by deploying Micro Resilience Infrastructure that choreographs low tech, community maintainable water and soil measures into a continuous system of retention, infiltration, slope protection, and shading, with permits requiring a water and soil plan that does not increase downstream risk and monitoring based on soil moisture, erosion proxies, and dry season supply stability (Y.-W. Wang et al., 2023)(Fig 6.9C).

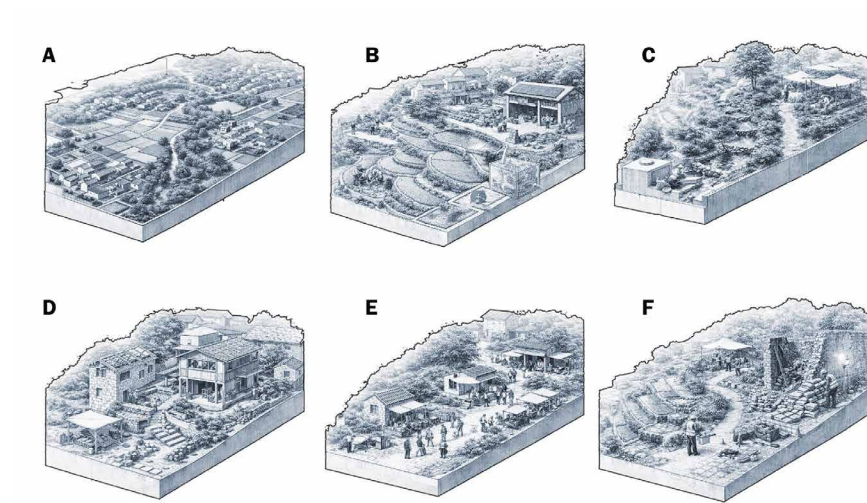


FIG. 6.9 Six landscape design toolbox for C5 WHNUs.

At the settlement and governance scale, C5 requires development to be slow, reversible, and compatible rather than transformative. Progressive Renewal with Reversible Construction limits massing, enforces phased approvals, and requires material compatibility review so that edge settlements can be reinforced and repaired without one time modernization replacement, monitored through the share of non traditional construction and the disturbance intensity to plot grain and street patterns (Letzter, 2023) (Fig 6.9D). Because tourism dependency is low and volatile, Low Intensity Tourism with Distributed Service Nodes avoids single point commodification and instead builds small, capacity limited nodes and slow mobility links whose revenues are contractually routed back into maintenance, monitored through revenue volatility and maintenance coverage ratios (Cai et al., 2021) (Fig 6.9E). Finally, the toolbox is closed by a Minimum Viable Governance System and Emergency Maintenance Line that makes routine inspection frequency,

trigger thresholds, rapid repair kits, and responsibility chains a precondition for any external investment, with monitoring focused on inspection coverage, response time, defect accumulation, and crisis recurrence, ensuring that development consistently translates into risk reduction, maintenance continuity, and long term heritage viability (Torres-González et al., 2021) (Fig 6.9F).

6.4.6 Design toolbox of C6: stable cultural diversity

C6 represents WHNUs with high cultural diversity, strong human capital, and a culture and tourism-oriented economy that converts cultural capital into a specialised, knowledge intensive development pathway closely tied to local identity. These sites are typically located in medium sized cities where the historic core has not been overwhelmed by high rise redevelopment or major infrastructure, which helps preserve high heritage integrity and explains why no endangered WHNUs emerge in this cluster. The broader context is also comparatively favourable, with low hazard pressure on average, a positive vegetation trend, low landscape fragmentation, and only moderate heat stress with occasional peaks. The design task in C6 is therefore not crisis response but integrity management, preventing incremental loss by keeping development within a clearly governed capacity envelope.

The C6 landscape design toolbox begins by translating OUV attributes into a Heritage Integrity Envelope that sets auditable spatial rules for skyline segmentation, view corridor protection, plot grain continuity, and street section proportions so new projects align with historic morphology rather than erasing it (Sukwai et al., 2022; Zhang et al., 2024) (Fig 6.10A). It then governs success itself through a Tourism Load Budget that stabilises seasonality and protects everyday life using capacity thresholds, timed entry, porous routing, and service node sizing, complemented by enforceable light and noise limits and residential continuity safeguards (Pásková et al., 2021) (Fig 6.10B). Within this managed envelope, Adaptive Reuse functions as knowledge economy infrastructure, prioritising reversible program layering that houses cultural production, education, and creative industries in heritage compatible buildings, while requiring compatibility checks for materials, structure, and MEP routes to avoid short term fit out convenience eroding authenticity (Vafaie et al., 2023) (Fig 6.10C).

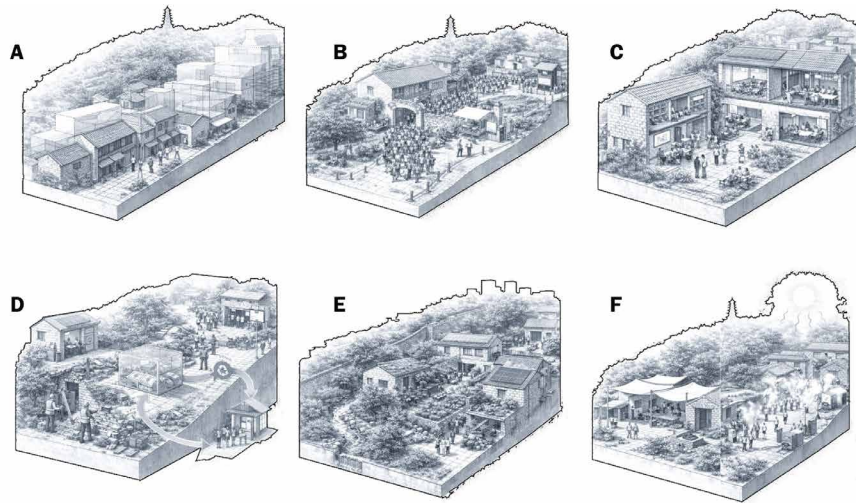


FIG. 6.10 Six landscape design toolbox for C6 WHNUs.

To keep the system self-reinforcing, the toolbox closes the loop through governance, ecology, and climate operations. A governance and revenue circle ring fences a share of tourism and cultural economy income into routine inspection, minor repairs, and public realm stewardship, with transparent responsibilities and audit mechanisms so prosperity is consistently converted into preventive conservation capacity (Rosselló-Nadal & Sard, 2026) (Fig 6.10D). Blue Green Continuity and NDVI Uplift protects the positive vegetation trajectory and cohesive landscape matrix via courtyard, roof, river edge, and pocket scale greening that delivers net ecological gain without compromising historic setting, supported by monitoring of NDVI trends, canopy coverage, and connectivity (Soltanifard & Amani-Beni, 2025) (Fig 6.10E). Finally, a Heat Comfort and Event Protocol treats occasional heat spikes as a manageable operational risk by delivering continuous shade networks, visually compatible cool surface upgrades, and heatwave triggers that adjust use and maintenance practices, with performance tracked through thermal stress exposure, surface temperature peaks, and public space usability (Kousis & Pisello, 2023) (Fig 6.10F).

6.5 The Application of Landscape Design Toolbox to CMR

6.5.1 From design toolbox to spatial demonstration and measurable difference

The cluster-based landscape design toolboxes developed above do not function as abstract conceptual recommendations or as general policy principles. In this dissertation, design grammar is defined as a rule based spatial translation system that converts cluster characterization into concrete spatial operations, measurable performance changes, and directly applicable design procedures. Its purpose is to ensure that the transition from characterization to design does not stop at the level of interpretation, but proceeds into visible transformation on the ground, auditable design effects, and operational guidance for future interventions.

First, each design grammar implies a set of explicit spatial changes on the ground. These changes are not limited to broad strategic intentions, but are expressed through concrete transformations in spatial structure, section, surface, edge condition, and maintenance infrastructure. Depending on the cluster, such transformations may include plot subdivision control, reversible infill, shaded pedestrian continuity, courtyard retrofitting, roofscape adaptation, hydrological guidance through streets and alleys, ecological corridor stitching, buffer thickening, service node redistribution, repair point placement, and compatible material replacement. In this sense, the design grammar is intended to be legible in drawings and in-built form. It changes how streets are sectioned, how voids are retained, how edges are treated, how water is routed, how shade is connected, and how maintenance capacity is spatially organized.

Second, these spatial transformations are intended to produce measurable differences rather than merely qualitative improvement. Although the exact indicators vary across clusters, the proposed grammars are designed to be assessed through auditable before and after comparisons. For morphology-oriented clusters, this may include frontage retention, alley continuity, plot grain preservation, skyline obstruction ratio, and view corridor protection. For heat related clusters, measurable differences may include shading coverage, peak surface temperature reduction, nocturnal heat retention, and duration of thermal stress exposure. For hydrological and ecological clusters, indicators may include runoff peak reduction, infiltration

increase, ecological connectivity improvement, hotspot disturbance reduction, and buffer width gain. For socially vulnerable clusters, measurable outcomes may include inspection frequency, repair response time, local craft participation, maintenance coverage, and access to water or service infrastructure. The key point is that the proposed design of grammar is not only form giving devices, but performance oriented and monitorable intervention systems.

Third, the design grammar is intended to support immediate application by designers and heritage managers. To make this possible, the toolboxes can be used through a four-step workflow. Step one is to identify the dominant coupling between heritage attributes and risk pathways in the target site, such as heat accumulation and grain loss, ecological fragmentation and hazard exposure, or social vulnerability and maintenance discontinuity. Step two is to select the corresponding intervention family from the relevant cluster toolbox, such as shade network, buffer patchwork, reversible infill, rain shield, maintenance route, or fragmentation stop line. Step three is to translate this family into scale specific spatial operations at the levels of plot and building, street and public space, and district or buffer. Step four is to check the design against the proposed auditable thresholds and operational requirements, so that approval, monitoring, and maintenance can be linked from the beginning of the design process. In this way, the grammar is not a stylistic language, but a structured protocol for action.

TABLE 6.1 Translational logic of the design grammar from cluster characterization to implementation

Dimension	Core question	Design translation content	Example indicators
Spatial demonstration	What changes on the ground?	plot, street, buffer, shade, water, edge, maintenance nodes	frontage retention, shading continuity, buffer width
Measurable difference	What is the measurable difference?	thermal, hydrological, ecological, social, morphological performance	temperature reduction, runoff peak, connectivity, response time
Design application	How does a designer apply this tomorrow?	diagnosis, toolbox selection, scale translation, threshold check	permit thresholds, monitoring packages, maintenance requirements

Accordingly, the value of the six cluster toolboxes lies not only in showing different development orientations, but in providing a transferable bridge from diagnosis to intervention. They specify what should change spatially, how that change can be evaluated, and how a designer can apply it in practice. This also means that the contribution of the chapter is not limited to proposing design principles for WHNUs but extends to establishing a replicable design translation logic through which cluster characterization can be operationalized in future heritage contexts.

To clarify this translation, the toolbox of each cluster can be read through three parallel questions: what changes on the ground, what measurable difference is expected, and how can the intervention be applied tomorrow. This framing makes the design grammar both spatially demonstrable and operationally testable, and strengthens its usefulness for heritage-based development, planning control, and design implementation.

6.5.2 CMR as a case for landscape design translation

In the typological framework established in Section 6.2, CMR is classified as C6, a stability-oriented profile characterized by high cultural industry and tourism dependence, relatively stable education and multicultural conditions, low density and limited spatial expansion, a positive NDVI trend, low fragmentation, and moderate heat stress. Positioning CMR within this cluster does not imply an absence of risk. Rather, it clarifies that the central planning task differs from crisis-oriented recovery. For C6 cases, the primary design challenge is not post-event repair, but the long-term management of integrity, carrying capacity, and routine maintenance. In this sense, the significance of treating CMR as a C6 case lies in translating relative stability and prosperity into preventive conservation capability and institutionalized maintenance capacity.

At the same time, C6 does not mean pressure-free. Compared with clusters marked by structural breakdown or rapid decline, pressures in C6 more often take the form of localized accumulation that intensifies at specific nodes or during particular time windows. In CMR, such pressures typically include route and node congestion, microclimatic heat stress, increased sensitivity of shoreline and slope soil–water processes under extreme rainfall, and the gradual dilution of landscape experience through commercial spillover. These are not signs of typological transition, but monitorable pressure pathways emerging within a stability-oriented baseline.

For this reason, cross-cluster borrowing is methodologically justified. The purpose is not to claim that CMR should be reclassified by importing problems from other clusters. Rather, what is borrowed are transferable mechanisms, namely risk pathways and design levers that can be activated when localized thresholds are exceeded, while the baseline objectives of C6 remain unchanged. In other words, typological identity is held constant, but the design response is allowed to draw on modular grammars associated with other cluster conditions.

To make this process reproducible rather than ad hoc, this section adopts a Pressure–Tool Matching rule. Since the main typology remains C6, the baseline toolkit is organized around an integrity envelope and capacity budgeting. This includes spatial integrity constraints, a tourism load budget and allocation logic, a revenue loop for maintenance reinvestment, blue–green continuity as a process-based substrate, and a heat response protocol. On this basis, localized pressures can trigger modular calls to other cluster grammars once monitoring or point-cloud indicators exceed predefined thresholds.

For example, congestion, commercial spillover, and rising nighttime light load may activate C1-related modules, including auditable permitting thresholds and shade networks as preventive conservation infrastructure. Heat accumulation in narrow corridors or core nodes may activate C4-related modules, such as heat-budget permitting gates and a breathable microclimatic skeleton. Slope runoff concentration, shoreline erosion, or extreme rainfall sensitivity may activate C2-related modules, such as stormwater path design and soft boundaries with thick buffers. Peripheral fragmentation or the outward expansion of parking and service facilities may activate C5-related modules linked to landscape fragmentation control and maintenance reinvestment logic. Within this framework, point-cloud data play a key operational role by translating spatial experience and morphological constraints into computable parameters for pressure diagnosis, threshold identification, and module selection. In this way, design translation becomes monitorable, geometrically grounded, and auditable.

Taken together, CMR as a C6 case demonstrates how a stability-oriented heritage landscape can move from typological diagnosis to design translation through a modular and threshold-based logic. The emphasis is therefore not on dramatic intervention, but on a reproducible framework that protects integrity, manages capacity, and selectively introduces targeted tools where local pressures accumulate.

6.5.3 Experimental unit selection and overall design framework

This study does not treat a single scenic spot as the experimental unit. Instead, it adopts scene combinations as transferable spatial prototypes for design testing. The reason is that the main pressures observed in CMR rarely operate as isolated point conditions. They are usually produced through chained interactions across routes, thresholds, shoreline segments, terraces, and slope systems. A single scenic node may register congestion, heat, runoff, or perceptual overload at a given moment, but it cannot adequately represent how these pressures accumulate, propagate, and spill over into adjacent spaces.

Crowd congestion, for instance, is shaped not only by the capacity of one courtyard or gate, but also by upstream arrival rates, downstream clearance, and lateral staying behavior. Heat stress is similarly conditioned not only by the existence of a hotspot, but also by canopy continuity, radiant exposure, airflow obstruction, and the distribution of stopping opportunities along a route. Runoff, erosion, and shoreline degradation are likewise process-based phenomena, emerging through terrain convergence, flow concentration, and the interaction between hydrological movement and fragile edge conditions. For this reason, a single point is too narrow to serve as the analytical and design unit for heritage-oriented intervention.

Methodologically, point-cloud data are used to classify the site into reproducible spatial groups according to five dimensions that jointly shape experience and environmental performance: openness, canopy cover, slope and flow accumulation potential, route accessibility, and dwelling capacity. These dimensions are selected because together they capture the principal morphological and operational conditions through which localized pressure becomes spatially legible and measurable. On this basis, representative combinations are selected and organized through a three-part structure of node, transition, and background. The node records the most concentrated form of occupation, stopping, or ecological sensitivity. The transition captures how pressure is transmitted through movement, sequence, or material continuity. The background describes the wider spatial field that conditions visibility, thermal moderation, hydrological behavior, and perceptual coherence. In this way, each combination represents not only localized impact, but also the process-based mechanisms through which pressure intensifies or dissipates.

The purpose of constructing these combinations is not merely classificatory. It is to establish experimental units that are both representative and transferable. Each unit must reflect the constraint structure of a recurring spatial type, while also allowing the corresponding design grammar to be tested in a form that can later be migrated to similar scenes elsewhere in the Mountain Resort. This is especially important in a heritage property such as CMR, where conservation action cannot be organized as a series of one-off responses to visually prominent spots alone. What is required instead is a reproducible method for linking measurable pressure pathways to modular intervention logics under conditions of authenticity, reversibility, and operational auditability.

When the classified combinations are compared across the site, they converge into three broader landscape systems that structure the main conservation and management challenges of CMR: the Palace Area, the Lake Area, and the Mountain Area. These are not arbitrary scenic categories, but the three dominant spatial regimes through which pressure is organized and expressed. The Palace Area is

governed primarily by ceremonial routes, enclosed courtyards, axial thresholds, and dense visitor occupation, making it the key domain for testing interactions among congestion, stopping behavior, microclimatic heat load, and operational control. The Lake Area is defined by shoreline interfaces, boating routes, wet ecological edges, bridges, and pavilions, making it the principal domain for examining hydrodynamic risk, ecological degradation, protective use, and the coordination of scenic and habitat processes. The Mountain Area is shaped by topographic gradients, runoff pathways, terraces, hillside paths, and slope instability, making it the most appropriate domain for investigating erosion, landslide susceptibility, terrain-sensitive circulation, and invisible stabilization strategies.

On this basis, the following three experiments are introduced as representative applications of the pressure–tool matching logic established above. Rather than testing three isolated scenic spots, they examine three transferable landscape prototypes corresponding to the major process-based pressure regimes of CMR. Importantly, these experiments were not developed as abstract design speculations in isolation, but through close collaboration with the Cultural Heritage Bureau of the Chengde Mountain Resort and a wider group of interdisciplinary stakeholders, including heritage managers, conservation practitioners, environmental specialists, ecological experts, hydrological and microclimatic simulation researchers, digital survey teams, and site-based operational staff. This collaborative structure ensured that the experiments responded simultaneously to conservation priorities, management realities, scientific rigor, and implementation feasibility.

The experiments were also supported by the coordinated use of multiple hardware and software systems, forming an integrated technical pathway from field measurement to simulation, diagnosis, and design translation. Across the three landscape systems, the workflow incorporated UAV oblique photogrammetry, RTK ground control, infrared beam counters, mmWave radar, compact weather stations, spatial logger arrays, globe thermometers, and thermal cameras, together with digital platforms including point-cloud modelling environments, hydrodynamic and hydrological simulation tools, ENVI-met, MassMotion, and OpenFOAM. These tools made it possible to transform spatial form, environmental process, and visitor behavior into measurable and comparable parameters, so that intervention strategies could be grounded in monitored evidence rather than intuitive judgment alone.

Together, these three experiments provide the operational bridge from typological diagnosis to design implementation. The Palace experiment addresses density and heat under conditions of ceremonial order and spatial legibility. The Lake experiment addresses hydrological and ecological pressures under conditions of scenic continuity and protective use. The Mountain experiment addresses runoff and slope risk under

conditions of terrain authenticity and restrained stabilization. Taken together, they demonstrate how a typology-led framework can move from abstract cluster logic to scene-based, monitorable, technically supported, and transferable conservation action.

6.6 Three Experiments of Landscape Design in CMR

6.6.1 Experiments in Palace Area: entrance circulation and thermal capacity

In heritage environments, design interventions are not about visual beautification but about managing readability, circulation and environmental capacity. Architecture, courtyards and paths carry cognitive and ceremonial functions while also accommodating density, viewing and thermal load. Congestion, photographing pauses and heat accumulation frequently overlap during high visitation periods, which means that intervention must be read together with operational logic. The task is to improve legibility, stay and evacuation without compromising integrity, visual coherence or material authenticity. Reversibility and auditability are essential conditions so that interventions do not become permanent intrusions or opaque policies (Fig 6.11).

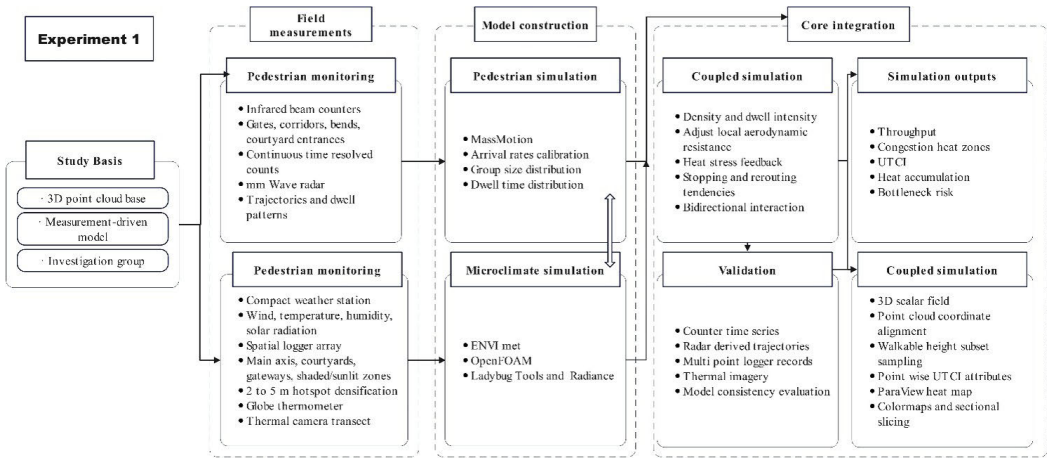


FIG. 6.11 Framework of Experiment 1: Measurement Driven Coupled Pedestrian Flow and Microclimate Simulation.

This workflow was developed in close collaboration with the Cultural Heritage Bureau of the Chengde Mountain Resort and a wider group of interdisciplinary stakeholders, including heritage managers, environmental specialists, simulation experts, and site-based practitioners. Building on an existing 3D point cloud base, the study established a measurement driven framework to simulate summer pedestrian dynamics and microclimatic heat accumulation in the Palace Area. Field investigations combined pedestrian monitoring and microclimate monitoring. Pedestrian data were collected through infrared beam counters and mm Wave radar to capture counts, trajectories, and dwell behavior at key gates, corridors, bends, and courtyard entrances. Microclimate data were recorded through a compact weather station, spatial logger arrays, globe thermometer measurements, and thermal camera transects, with denser sampling at hotspots and bottlenecks. These observations informed pedestrian simulation in MassMotion and microclimate simulation in ENVI met, supported by local wind refinement in OpenFOAM and radiation analysis in Ladybug Tools with Radiance. The two systems were then coupled by linking pedestrian density and dwell intensity with local thermal and airflow conditions, allowing heat stress to influence stopping and rerouting tendencies. Model consistency was evaluated against multiple empirical datasets, including counters, radar trajectories, logger records, and thermal imagery. Final outputs, such as throughput, congestion heat zones, and UTCI, were integrated into the 3D point cloud environment and visualized in ParaView as spatially explicit heat maps.

At the main entrance the recurrent issue is not insufficient width but conflicts between transit and stay intentions near the gate opening. Point cloud models can identify passable width, local minima, reverse trajectories and stay patches, which allows transit, buffering and short-stay behaviors to be spatially separated (Fig 6.12A). Short photography pockets should be positioned where they do not obstruct the main sightline or axial alignment, and their coordinates can be selected through field-of-view analysis and assessment of backlight (Fig 6.12B). Seating and leaning elements should be low, reversible and visually permeable, while guidance is carried by material differentiation and low-contrast paving cues rather than by an accumulation of signage (Fig 6.12C). The objective is to reduce critical pauses at the center of the gate opening and make evacuation within a given time unit more predictable while keeping the entrance axis legible.

At the scene EK.07 density and heat interact, which makes limiting measures insufficient if they are treated as blocking. In an integrated operational and design approach, two triggers can be established. The first trigger is based on instantaneous density and the clearance time of the buffering zone, which activates one-way transit and short-stay clearance. The second trigger is a heat budget that combines land surface temperature, humidity index and radiant exposure time.

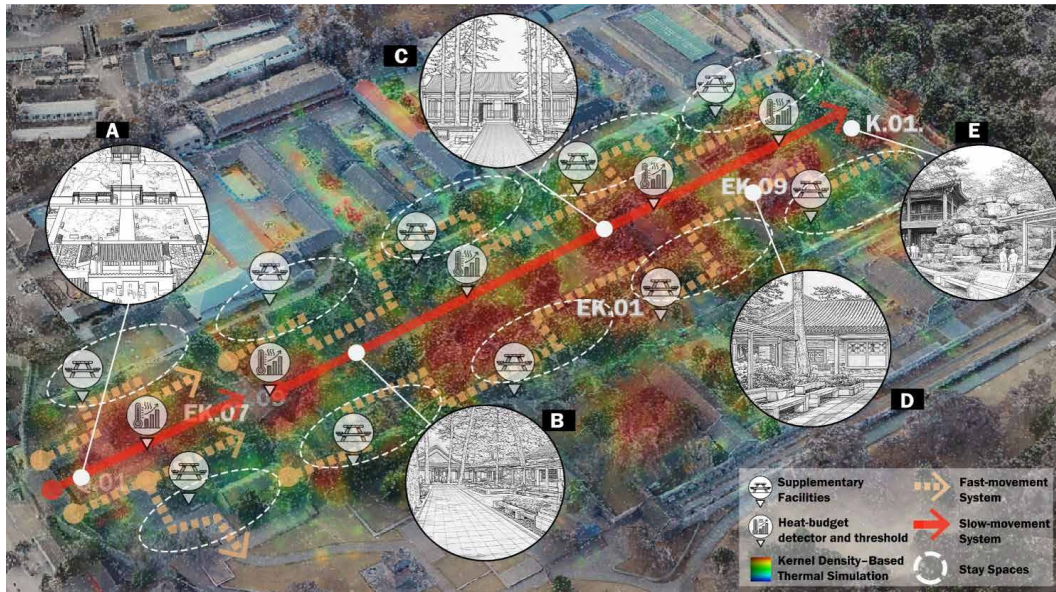


FIG. 6.12 Experiments on representative scenes in the palace area: integrated visitor flow, stay-zoning and heat-budget intervention map.

When the heat budget reaches its threshold, visitors are redirected toward shaded galleries, secondary displays and cool spots without the need for verbal instructions. Vegetation, lightweight galleries and displays form the physical interface of permission, signage forms the audit interface, and sensors form the trigger interface (Fig 6.12C-D). All components should be reversible and low-intrusive. Performance can be evaluated through peak reduction of heat exposure in the core courtyard, predictability of clearance time and transparency of thermal budgeting. Permission to enter the core courtyard becomes a governed condition rather than an ad hoc restriction.

In front of the central axis carries sightlines, ceremonial and transit functions, therefore stay activities are better shifted toward the lateral edges of the courtyard (Fig 6.12C). Continuous seating and leaning elements along the sides enable photography, observation and resting without obstructing the axial view (Fig 6.12D). Surface materials can employ tactile and friction differentiation with minimal color contrast to define stay areas without introducing disruptive visual markers. Fastening points for furniture should be reversible and non-invasive to the substrate. The central axis remains open for transit and reading, and the photographic and interpretive activities become more structured and less accumulative. The density of stays moves laterally rather than pooling in the center.

For the later part, the issue is not insufficient landscape quality but discontinuities in microclimate created by canopy gaps, heat retention surfaces and blocked wind corridors. Point cloud and thermal imaging can detect these discontinuities and guide a three-layer response. The first layer is canopy restoration with species that are locally adapted and tolerant of pruning in order to restore continuous shade. The second layer is temporary lightweight galleries that bridge local gaps without becoming the visual focus (Fig 6.12E). The third layer is high-albedo and permeable paving that reduces heat storage and reintroduces evapotranspiration. Drinking and short-stay pockets are positioned at the edges of shade so that they do not accumulate in front of key viewing points. Wind corridors and hydration points work as compensatory instruments within the thermal budget. Performance can be assessed through reductions of surface temperature, smoother dwell-time profiles, smaller speed differentials and shorter clearance times.

For heritage environments to benefit from such interventions, design and operations must be jointly audited. Materials and components are constrained by reversibility, operations are constrained by measurable indicators of density and heat, and heritage is constrained by legibility and integrity. If these three conditions coexist, interventions can enhance visitor experience and environmental performance without compromising the artifact or the spatial narrative.

6.6.2 Experiments in Lake Area: shoreline ecology and adaptive intervention

This study adopts an integrated approach developed specifically in collaboration with the Cultural Heritage Bureau and multidisciplinary stakeholders of the Chengde Mountain Resort, combining real-scene three-dimensional basemaps, hydrodynamic simulation, and ecological shoreline index extraction to scientifically simulate hydrological confluence risks and shoreline ecological degradation. The analytical framework was carried out through close cooperation with heritage managers, site administrators, technical survey teams, and environmental and ecological experts associated with the Chengde Mountain Resort, so that data acquisition, model construction, and risk interpretation could respond to both scientific requirements and practical conservation needs. High-resolution three-dimensional models are first generated through multicopter oblique photogrammetry and corrected with RTK ground control points to produce DSMs and high-precision orthophotos as the spatial basemap. Next, based on terrain slope, water boundaries, and inflow pathways, a two-dimensional hydrodynamic model is constructed to simulate water level fluctuations, flow velocity distributions, and shear stress, enabling

the extraction of high-risk erosion zones and seasonal low-water exposure areas. Multi-temporal remote sensing data are then used to compute NDVI, NDWI, and wetland indices, which are combined with shoreline evolution and vegetation time-series to identify ecologically sensitive belts characterized by wetland degradation, macrophyte decline, and weakened bank systems. Finally, hydrodynamic outputs and ecological indices are rasterized and reclassified, and risk intensity is visualized through kernel density estimation and hot-spot rendering to represent spatial gradients of degradation and disturbance (Fig 6.13).

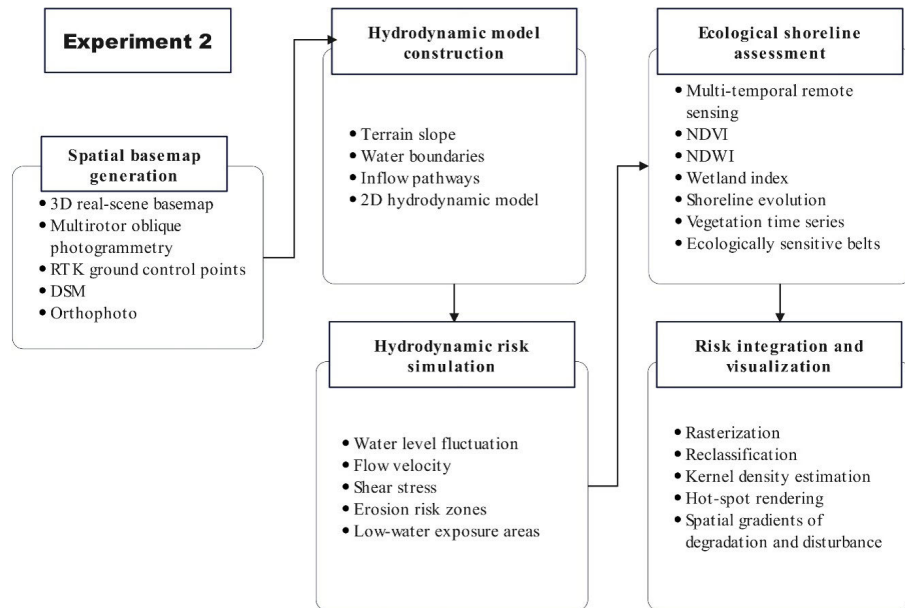


FIG. 6.13 Framework of Experiment 2: Spatial Basemap Generation, Hydrodynamic Modelling, and Ecological Shoreline Risk Integration.

The heritage-oriented landscape design of the lake district at the Mountain Resort focuses on integrating the existing stone embankments, pavilions and bridges, boating routes and wet shoreline systems into a composite framework that is ecological, experiential, operable and maintainable. Along the Ruyi Lake and Mirror Lake segments, gentle shoreline grading and additional emergent plantings create ecological buffers and shallow water gradients that enhance self-purification and ecological continuity across the land water transition zone. Portions of the stone beaches can be reworked with seating steps, leaning steps and micro topographies to enlarge the resting surface and organize a walk pause sit sequence for slow

experiences and waterside viewing. Minimal seating elements, cushion like stone blocks and low wooden pieces can be applied as protective furnishings to improve comfort and durability. Materials should rely on stone and wood with low visual prominence and easy reparability (Fig 6.14A).

Along Cheng Lake and Mirror Lake, the wet shoreline can support seasonal aquatic assemblages of sweet flag, sedges, lotus leaves and water shield to provide low disturbance habitats for aquatic insects and fish while reducing bank erosion and thermal stress. These measures require no imported materials or new landscape structures and do not alter the established mountain water pictorial composition (Fig 6.14B). Protective use near water side heritage structures requires a monitoring system to sustain ecological processes, cultural scenes and user behaviors over time. Monitoring targets include hydrological and ecological indicators such as water level, water quality and transparency, habitat indicators such as shoreline stability and vegetation dynamics, heritage maintenance indicators such as structural humidity and material aging, and operational indicators such as resting density and boating frequency.

Nodes of bridges and pavilions can function as structural and ecological connectors (Fig 6.14 C and G). Shaded and humid micro habitats under bridge piles and pavilion floors can support mosses, liverworts, small ferns and sedges, improve node legibility while retaining structural integrity. Shallow water retention and reduced hydrodynamics can be achieved through localized micro topographic adjustments without introducing new built structures or hard facilities. These nodes can accommodate low intensity protective use and may selectively reconstruct historically attested minimalist boarding platforms, detachable sitting platforms, bamboo and timber handrails and lightweight signage systems to support slow boating, interpretation and low density resting. Materials should remain primarily wood and stone with reversible joints to reduce interference with the pavilion bridge structural and visual system (Fig 6.14D).

Along the shaded western shores of Mirror Lake and Cheng Lake, parallel circulation and resting paths can guide visitors and improve resting efficiency. Circulation and resting facilities can adopt low component paving, seating stones, leaning stones and micro wooden elements while dismantling and prohibiting modern sunshades and bulky furniture (Fig E). Minor canopy openings can optimize sightlines and reflective surfaces and reinforce borrowed scenery, thereby improving slow use and viewing quality without increasing facility density (Fig 6.14F).

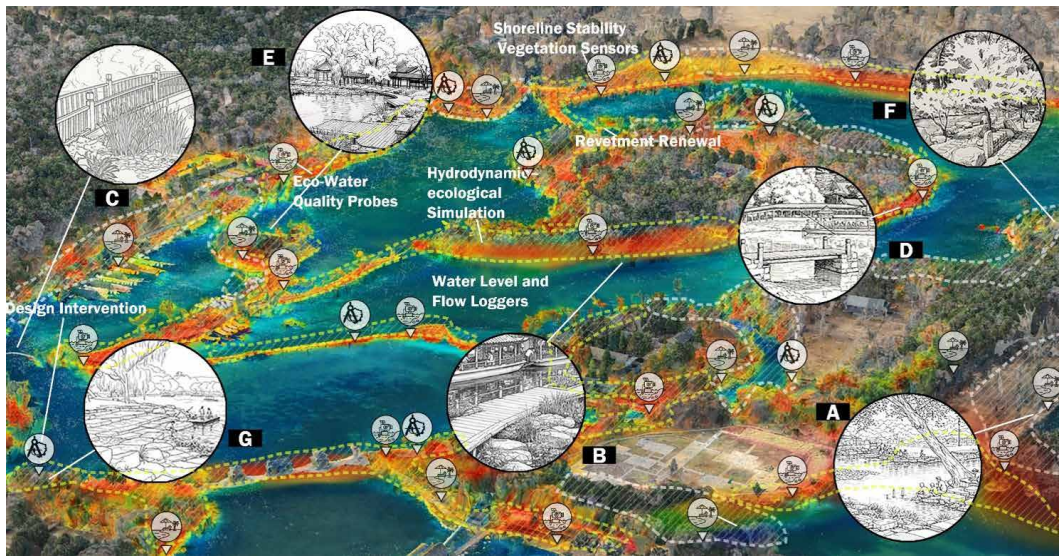


FIG. 6.14 Experiments on representative scenes in the lake area: integrated hydrodynamic–ecological risk landscape design framework.

The boating system around the central islands can adopt slow navigation, segmentation and small scale docking to create a low impact recreation system. Boat materials and structures should allow repair and replacement and can incorporate bamboo and timber components with reversible fixings to extend operational lifespan and ease maintenance. At selected nodes, low prominence cues and compact interpretive elements can support combined ecological and cultural appreciation without landscape embellishment or large scale signage. The overall approach follows the principles of small scale, multi point distribution, low prominence, reversibility, maintainability and cultural compatibility, treating infrastructure, ecological patches and heritage grammar as an integrated system rather than replacing ecology with engineering, replacing use with landscape or replacing culture with facilities. The result is a comprehensive framework that is ecological through shallow water gradients and seasonal assemblages, experiential through resting, observing and boating, operable through low load operations and moderate interpretation, maintainable through repairable stone, timber and wet vegetation, and heritage compatible through material legitimacy, semantic consistency and authenticity. This system applies to nodes such as Ruyi Islet, Misty Rain Tower, Willow Bridge, Lake Pavilion, Cheng Lake and Mirror Lake.

As a cultural landscape inscribed as a World Cultural Heritage property, interventions in the Mountain Resort must respond to the heritage substrate and establish coherence between science and art and between ecology and culture. The scientific dimension involves hydrological processes, ecological habitats, material performance, maintenance lifecycles and dynamic patterns of use. The artistic dimension involves landscape composition, path and sightline sequences, boating perspectives, pavilion bridge relations, reflective surfaces and seasonal expression. Ecological measures should be grounded in plant community structure, hydrodynamic conditions and habitat connectivity while maintaining the historical visual density and aesthetic presentation of the lake district. Cultural expression should not rely on new symbols or designed spectacles but should be sustained through viewing, resting, borrowed scenery and boating. The outcome is a co construction of ecological and cultural processes in which the site operates as both ecological and cultural carrier. Protective use remains compatible with heritage values without substituting ecology for culture, culture for ecology or facilities for the heritage substrate.

6.6.3 Experiments in Mountain Area: terrain management and tourism planning

The mountain cultural landscape of the Chengde Mountain Resort is a royal hillside system structured by mountains as the skeleton, water as the veins, architecture as focal points, and movement as sequence. Its value does not lie in the accumulation of designed scenes, but in its obedience to real terrain and inherited spatial order. Historic buildings follow the slopes, terraces are clearly articulated, and courtyards and open clearings emerge naturally, forming a legible progression from low to high and from outer to inner. Confronting the typical tensions of mountain heritage, including large elevation differences, concentrated runoff, fragile slopes, and compounded visitor disturbance, this proposal adopts four guiding principles, minimal intervention, authenticity, invisible protection, and a restrained landscape aesthetic. We do not alter the landform silhouette, add visually dominant structures, or amplify landmark imagery. Instead, we establish a transferable set of measures, vegetation structure, micro topographic drainage, path scale calibration, and a subdued material palette. With these measures in place, most heritage spots and their surroundings can be precisely restored, reconstructed, and repaired. Visually, interventions should be nearly imperceptible. Structurally, the underlying mechanisms, including slope stability, soil retention, runoff management, and disturbance control, become more robust and maintainable, reducing long term risk and maintenance burden while safeguarding heritage value.

Developed in close collaboration with the official management and conservation authorities of the Chengde Mountain Resort, this workflow links technical analysis with practical heritage protection needs. It begins with a high precision spatial basemap generated from UAV oblique photogrammetry and RTK ground control, which captures mountain terrain, historic structures, paths, terraces, and surrounding landscape conditions in three dimensions. Based on this foundation, key terrain and environmental factors such as slope, runoff pathways, vegetation cover, and exposed surfaces are extracted to assess the drivers of soil erosion and slope instability. Hydrological and hydrodynamic modelling is then used to simulate water movement and concentration across the site, identifying areas of stronger runoff, higher erosion pressure, and greater landslide susceptibility. These results are further combined with the distribution of historic buildings, terrace edges, key circulation routes, and visitor use patterns, so that risk is evaluated not only as a natural hazard but also in relation to heritage vulnerability and management priorities. The final outputs are integrated into a composite risk map and visualized through a clear graphic system of hotspots, gradients, and sensitive belts, supporting more targeted conservation, maintenance, stabilization, and visitor management strategies across this highly sensitive mountain heritage landscape.

At the site wide level, protection must be translated into an operational spatial order. The core approach is clear zoning and control. Historic buildings and immediately adjacent terraces form the core protection area, prioritizing maintenance, micro repair, and only necessary safety reinforcement. Existing open spaces between buildings and terrace edges form buffer and transition areas, accommodating small scale pause points and ecological regulation through reversible, low intervention actions. The continuous steep slope and switchback path zone on the right is designated as the ecological stabilization and risk control area, where access and trampling are restricted and invisible protective measures take priority. Existing main paths and a limited number of viewpoints serve as visitor bearing areas, where capacity management and experiential refinement replace physical expansion. Meanwhile, key visual corridors must be safeguarded. The open axis from principal buildings toward the mountain backdrop and sky should remain unobstructed, allowing the architecture to breathe within the terrain and remain legible and dignified (Fig 6.15).

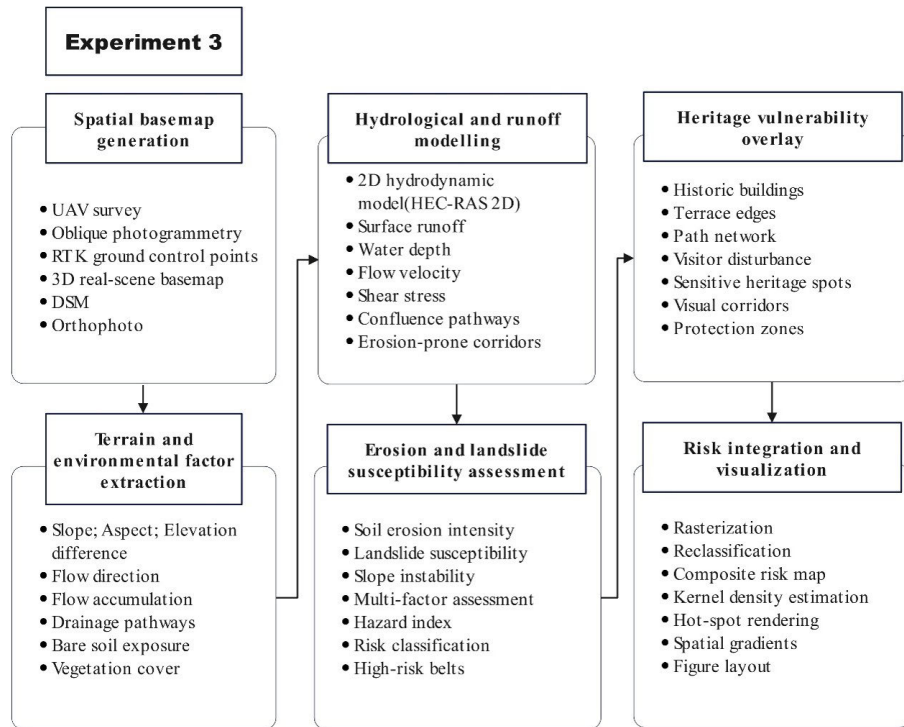


FIG. 6.15 Framework of Experiment 3: mountainous hydrological modelling, hazard assessment, and heritage vulnerability overlay.

At the spot level, the scene EQ.34. emphasizes a place character of ravine, water, and quietness (Fig 6.16A). Such locations are most vulnerable to becoming too new through hard engineering, or to being flattened into convenient plazas along the water edge. The strategy here is to focus on hydrological logic and discreet slope stability. Maintain the natural streamside boundary through terrain following micro drainage and in situ material patching, keeping the atmosphere clear and tranquil, while risk control remains embedded beneath the surface and within vegetation structure, never competing with the heritage ambience. The scene EQ.26 (scene number in Appendix B) is defined by elevation organization and terrace connectivity (Fig 6.16B). In this typology, critical risks concentrate at terrace edges and slope path junctions. Once runoff begins to cut along edges, or trampling exposes soil, erosion, edge collapse, and path base instability follow. The corresponding strategy treats the terrace edge as a carefully managed line. Use low, deep-rooted stabilizing vegetation and repairable edging materials to form a soft boundary, then combine this with small scale energy dissipation at the slope toe and dispersed drainage to prevent concentrated flow from rushing downslope. Overall, terrace relief and

layered landform should remain intact, and complex terrain should not be leveled for convenience. The scene EQ.17. is best positioned to support pause and turning moments within a slow, processional route (Fig 6.16C). It does not need to be intensified into a busy attraction node, it needs calmer rhythm and better crowd behavior. Without rerouting or widening paths, we refine experience by locally easing steps, subtly calibrating turning walking scale, and using existing open clearings as small buffer stops. This allows visitors to pause naturally during continuous ascent, while gently shifting foot traffic away from high-risk edges and fragile slopes, reducing cumulative disturbance over time. The scene K.14. is fundamentally about atmosphere control, quiet, clarity, and poetic restraint (Fig 6.16D). Such spaces are easily compromised by excessive interpretation signage and over equipped facilities, which erode their quiet value. The strategy therefore leans toward management and restraint. Minimize visible signage and hard installations, control visual and acoustic interference, preserve deliberate emptiness, and guide movement subtly so that moon viewing and lingering can occur naturally. In maintenance, priorities are modest but crucial. Keep micro drainage functional and ground cover continuous to prevent localized ponding, muddiness, and trampling scars that would undermine the overall mood.

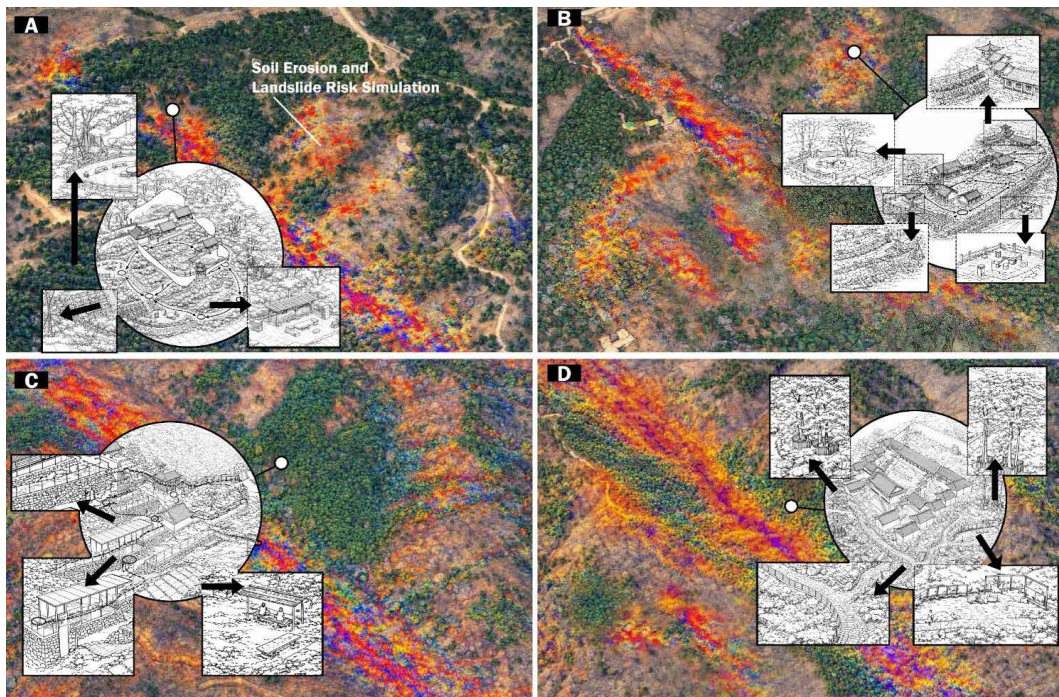


FIG. 6.16 Representative Scene Experiments in Mountain Cultural Landscape: Risk Fields and Low-Intervention Spatial Responses.

Vegetation and ecological design function as the site's underlying technical system. The goal is not ornamental shaping, but natural in appearance and reliability in structure. Given the strong elevation changes, clear runoff pathways, and fragile mountain ecology, planting must actively contribute to slope stability, soil retention, and runoff deceleration. Trees are used sparingly for framing and background stabilization while avoiding foundations and key view corridors. Shrubs form the structural backbone on steep slopes and along path edges. Ground cover emphasizes continuous protection, prioritizing bare soil control, erosion reduction, and mud prevention. The aesthetic remains non gardenized, with no topiary spheres and no hedge like pruning, so the landscape reads as if it belongs to the mountain rather than as a designed overlay.

Infrastructure and material choices follow a strict rule, install only what is necessary, keep it minimal, and keep it visually recessive. Paving favors stone, rough stone, and rammed earth like textures that match the mountain's subdued tones. Slight irregularity in scale and edges is acceptable and desirable, so additions recede into the background. Drainage follows an infiltrate, detain, disperse, and convey logic, prioritizing concealed infiltration bands, shallow vegetated swales, and micro topographic guidance to split and slow water, avoiding conspicuous channels and rigid ditches that would disrupt authenticity. Safety elements rely first on landform and planting to create soft boundaries. Only where necessary are low profile, low reflective components introduced, ensuring they never compete with the heritage setting.

Finally, every intervention is controlled by the same restrained quality checklist. Through this discipline, the mountain cultural landscape remains clear but not loud. The landform skeleton is preserved, landmark making is avoided, invisible protection reduces erosion and landslide risk, minimal intervention sustains authenticity, and slow, processional movement with strategic emptiness preserves the site's spirit, so the scenery can appear to have grown naturally from the mountain itself.



Synthesis and Outlook

This dissertation develops and demonstrates a landscape approach to the conservation and development of cultural landscapes, using Chengde Mountain Resort as a case study. It starts from the recognition that cultural landscapes are living heritage systems shaped by land, water, ecology, settlement, governance, and everyday use. Under climate change, ecological degradation, and the combined pressures of urbanization and tourism, these systems face compounded risks that threaten material integrity, ecological function, and cultural legibility. In response, the dissertation argues that conservation should be development oriented and design based, so that change can be guided rather than only resisted, through workflows that connect evidence to spatial decisions.

The core outcome is an integrated approach that links three components into a coherent chain from diagnosis to implementable action. First, landscape mapping is used for characterization. Second, landscape planning is used for conservation. Third, landscape design is used for development. This integration addresses a central gap identified in both research and practice, namely that assessment often remains descriptive and does not consistently translate into spatial interventions that are operational, auditable, and scalable.

7 Conclusions

7.1 Summary of Main Outcomes

7.1.1 Landscape mapping outcome: characterization through reconstruction of evolution

The dissertation develops a scene based mapping pathway to reconstruct long term evolution and to operationalize cultural landscape dynamics as comparable indicators. Using Chengde Mountain Resort as the anchor case, it reconstructs multiple historical phases and organizes the site as a scene system, enabling clustering and typological interpretation. This produces a characterization that makes persistence and change legible, connects evolution to present day functions, and supports management through an explicit structure rather than narrative description alone ([Manolaki et al., 2019](#); [Sahle & Saito, 2021](#); [Schulp et al., 2019](#)). In doing so, it demonstrates how “digitalization of evolution” can serve conservation as an evidence base that remains interpretable and governance usable.

7.1.2 Landscape planning outcome: conservation through HEPLP and PSLPM

First, the Hazard Ecology Perception Landscape Planning framework (HEPLP) integrates hazards, ecological sensitivity, and heritage value perception from both expert assessment and public perception mapping. It produces cluster targeted zoning and governance strategies that explicitly manage trade-offs between ecological limits, perceived value, and risk exposure. A key planning insight is that perception and ecological sensitivity can diverge, and that conservation guidance becomes more implementable when such divergences are surfaced and spatially specified rather than treated as a general dilemma. Second, the Perceptual Spatial Landscape Planning Model (PSLPM) treats route planning as a conservation

instrument for managing tourism pressure and interpretive quality. It quantifies public perception from large scale text data using a large language model, couples perception with spatial networks, and optimize routes to reduce hotspot pressure while improving diversity and interpretive coherence. This reframes visitor routing from an operational adjustment into a value informed planning intervention that can simultaneously support protection, experience, and interpretation.

Taken together, the two frameworks form a coherent planning sequence. HEPLP establishes the diagnostic and governance structure by identifying where pressures, values, and ecological constraints intersect, whereas PSLPM translates these findings into a spatial intervention strategy through route design and visitor redistribution. Their logical relationship is therefore hierarchical and complementary: the first framework explains what should be managed and why, and the second demonstrates how one major category of pressure can be addressed through implementable planning action.

7.1.3 **Landscape design outcome: development through a design based global toolbox**

To make conservation development oriented, the dissertation translates comparative diagnosis into design action. It constructs a global resilience index and clustering for World Heritage neighborhood contexts, and then translates the cluster logic into an operational design grammar and development toolboxes. These toolboxes do not prescribe a single solution, but define cluster specific design levers and rules that can guide change while respecting integrity and legibility. The site scale experiments in Chengde Mountain Resort then demonstrate how representation and prototyping can make design rules enforceable and transferable, grounding development choices in computable parameters and explicit thresholds rather than ad hoc judgement.

7.2 Revisiting Research Questions

This dissertation is structured around three interconnected problems that align with the three steps of the integrated landscape approach. The thesis builds an integrated landscape approach including landscape mapping for characterization, landscape planning for conservation, and landscape design for development. Revisited through this structure, the research questions are not independent inquiries, but a progressive sequence that moves from making cultural landscapes legible, to making conservation decisions implementable, and finally to making development-oriented conservation operational and defensible.

7.2.1 The characterization problem and the role of landscape mapping

The first research question addresses a characterization problem ([Manolaki et al., 2019](#); [Sahle & Saito, 2021](#); [Schulp et al., 2019](#)). Cultural landscapes are often described through isolated heritage attributes or single scale descriptions, while their value and vulnerability emerge from long term evolution and cross scale interdependencies ([Funsten et al., 2020](#); [Kümmerling & Müller, 2012](#)). In complex cases where designed scenes, land use dynamics, and associative meanings interact, existing approaches struggle to produce an integrative characterization that is comparable, interpretable, and useful for management ([Jones, 2003](#); [Scazzosi, 2004](#)). As a result, key questions remain unresolved, including which persistent structures organize the landscape, how change accumulates through time, and where vulnerability concentrates within the landscape system.

This dissertation answers first question by demonstrating how landscape mapping can be organized as characterization through reconstruction and the digitalization of evolution in Part B. Using Chengde Mountain Resort as the case study, it builds a scene-based representation that reconstructs long term evolution and derives comparable indicators that support clustering and typological interpretation. This makes persistence, transformation, and accumulation processes legible within a single evidence structure in Part C and D. The outcome is a characterization that is simultaneously integrative and management usable, because it enables explicit identification of organizing structures, spatial differentiation of vulnerability, and a clearer linkage between historical evolution and present day function.

7.2.2 The conservation planning problem and the role of landscape planning

The second research question addresses a conservation planning problem. Cultural landscapes face compounded pressures from hazards, ecological degradation, and imbalanced expert and public value perceptions under climate change and urbanization (Cook et al., 2021; Coombes & Viles, 2021; Sesana et al., 2020), yet planning frameworks rarely integrate these dimensions, leading to fragmented and insufficient responses (Jun, 2020; Pan et al., 2024; Shi et al., 2025). The dissertation revisits this problem by asking how conservation planning can integrate risk, ecology, and perception within one workflow, and how such integration can be translated into spatial strategies that are implementable at the scale of zones, routes, and governance actions.

The thesis addresses this gap through two complementary planning models developed in Chengde Mountain Resort. The Hazard Ecology Perception Landscape Planning framework produces cluster based zoning and governance strategies that distinguish areas requiring complete conservation from areas where careful trade offs are necessary, particularly where ecological limits and perceived cultural value diverge. The Perceptual Spatial Landscape Planning Model addresses perception space mismatch by coupling perception scores derived from social media comments with a scene network and optimizing routes to reduce hotspot overconcentration while improving diversity and interpretive coherence. Together, these contributions answer second question by showing that conservation planning becomes more effective when hazards, ecology, and perception are treated as coupled drivers and are translated into spatially explicit zoning logic and visitor flow interventions rather than handled as separate managerial domains.

7.2.3 The development translation problem and the role of landscape design

The third research question addresses a development and design translation problem. Even when diagnosis and clustering results are available, they often remain analytical outputs rather than actionable design knowledge (Von Haaren, 2014). The missing link is a design based mechanism that converts assessment into operational spatial rules, capacity thresholds, and reversible intervention principles. Without this translation, development-oriented conservation cannot be executed in a defensible way, and resilience remains a general ambition rather than a spatially specific governance system that guides minimal intervention while safeguarding heritage integrity and landscape legibility (Fekete & Kollanyi, 2019; Motloch, 2000; Liu & Nijhuis, 2020).

This dissertation answers question 3 by demonstrating how landscape design can operationalize development oriented conservation through toolboxes and design grammars that are derived from diagnostic typologies. It translates comparative clustering outcomes into design levers, spatial rules, and threshold logics that specify how and where change can be guided while maintaining integrity and legibility. The case study experiments further illustrate how representation and prototyping can support enforceable and traceable design decisions, providing a defensible mechanism for minimal and reversible interventions under continuous climate and tourism pressures. In this way, the dissertation revisits the development question as a governance question, and it shows how design can function as an operational layer that turns resilience from a general aim into a spatially specific system of rules and capacity management.

7.3 Reflection on the Research

This dissertation proposes and tests an integrated landscape approach to the conservation and development of cultural landscapes, with Chengde Mountain Resort as the empirical and methodological anchor. It frames cultural landscapes as living heritage systems whose integrity emerge from long term evolution and cross scale interdependence among land, water, ecology, settlement, governance, and everyday use. Under climate change, ecological degradation, and urban and tourism pressure, the thesis argues that conservation must be development oriented and design based, so that change can be guided through traceable workflows that connect evidence to spatial decisions.

7.3.1 Scientific contribution

This dissertation advances cultural landscape research by moving from fragmented assessment toward an integrated, operational framework that connects characterization, conservation, and development within a single, reproducible workflow. Rather than treating landscape mapping, planning, and design as separate domains, the research positions them as interdependent steps within a coherent reasoning chain that links evidence to spatial decision-making.

The scientific contribution of this dissertation is structured in relation to the three research questions, corresponding to landscape mapping, landscape planning, and landscape design, and can be summarized in four key innovations:

1 Landscape mapping as characterization

The dissertation establishes an integrated mapping–planning–design workflow in which landscape mapping reconstructs long-term evolution and identifies persistent spatial structures as a basis for decision-making recommendation ([Gkoltsiou & Paraskevopoulou, 2021](#); [Fairclough et al., 2018](#); [Swanwick, 2002](#)). By developing scene-based characterization, clustering methods, and reconstruction techniques, the research demonstrates how cultural landscapes can be represented as dynamic and relational systems. This contribution provides a reproducible bridge between descriptive analysis and actionable knowledge, addressing a persistent gap in landscape characterization.

2 Landscape planning as conservation

The dissertation introduces a multi-dimensional landscape planning model integrating hazard, ecology, and perception through the Hazard–Ecology–Perception Landscape Planning (HEPLP) framework. This model combines environmental risk, ecological sensitivity, and both expert and public heritage value perception within a unified analytical system, enabling explicit evaluation of conservation trade-offs and supporting cluster-based zoning and governance strategies.

In addition, the dissertation develops a perception–spatial coupling method using large-scale data and machine learning through the Perceptual–Spatial Landscape Planning Model (PSLPM). By linking spatial landscape characteristics with public heritage value perception derived from large-scale textual data and combining large language model–based scoring with graph-based spatial analysis, the research demonstrates how perception can be operationalized as a planning variable and used to inform route-based conservation and visitor management strategies

3 Landscape design as development

The dissertation introduces a design-based resilience translation from analysis to spatial intervention, in which comparative landscape diagnosis is translated into operational design grammar. This includes spatial rules, capacity thresholds, and reversible intervention principles that guide development-oriented conservation.

By structuring design as a rule-based and evidence-informed process, this contribution bridges the gap between analytical outputs and implementable spatial strategies, enabling conservation and development to be addressed simultaneously in a spatially explicit and auditable manner.

4 An integrated framework linking mapping, planning, and design

Beyond these individual components, the dissertation's overarching innovation lies in the integration of mapping, planning, and design into a single operational framework. This framework connects historical reconstruction, environmental analysis, perception data, and design translation into a continuous workflow that is both reproducible and transferable across contexts.

Taken together, these contributions reposition cultural landscape conservation as an evidence-based, design-oriented practice in which analytical insight, planning intelligence, and spatial intervention are systematically connected. The novelty of the research lies not in a single model, but in the integration of multiple methods into a coherent framework that is both operational and adaptable to different cultural landscape contexts.

7.3.2 Societal contribution

Cultural landscapes are increasingly exposed to hazards, ecological stress, and intensified use, while management is often constrained by fragmented responsibilities and competing objectives ([Cook et al., 2021](#); [Coombes & Viles, 2021](#); [Sesana et al., 2020](#)). The integrated approach in this dissertation supports risk informed governance by clarifying where strict conservation is necessary and where carefully guided development is feasible, making tradeoffs explicit rather than implicit. This helps shift practice from reactive repair toward preventive conservation and capacity management. By linking diagnosis to action through explicit variables, clusters, rules, and threshold logics, the dissertation supports more transparent communication among planners, conservation authorities, tourism managers, and the public. It offers a defensible way to justify why certain zones are constrained, why other areas can host adaptive reuse, and how interventions can remain minimal and reversible while still improving resilience and maintaining legibility.

Many heritage sites face tension between ecological limits and public demand. The perception integrated planning components provide a structured way to surface these tensions spatially, rather than treating them as abstract disagreements (Bosher et al., 2020; Hu et al., 2021; Ferreira et al., 2023; Rey-Pérez & Roders, 2020). Route based planning strategies can redistribute visitor pressure away from hotspots, bring marginal yet meaningful scenes into interpretive sequences, and support more equitable access to heritage experiences while reducing ecological and spatial overload. Although the case study provides depth, the global resilience index and clustering provide a comparative horizon that can inform broader policy and practice for cultural landscapes managed under the World Heritage system. The value is not in exporting a single solution, but in offering a structured method for differentiating contexts and selecting intervention logics that match dominant risk pathways and governance capacity.

The research has also shown practical relevance through its engagement with collaborators and heritage managers in the Chengde Mountain Resort. In discussion and collaboration with the Cultural Heritage Bureau of the Chengde Mountain Resort, parts of the framework were recognized as useful for clarifying management priorities, supporting more structured communication across conservation and development concerns, and translating analytical results into possible planning and design actions. At the same time, the reception has also confirmed that implementation is necessarily gradual and selective. Some elements can inform ongoing practice, whereas others remain closer to a strategic vision whose full realization will depend on future funding, institutional coordination, and long-term governance commitment. This response from practice is itself significant, as it suggests that the dissertation's value lies not only in methodological innovation, but also in its capacity to function as a realistic bridge between research, management discussion, and potential phased implementation.

7.3.3 Case specificity, generalizability, transferability, and contextual adaptation

A central issue in evaluating this dissertation is the extent to which its findings are specific to Chengde Mountain Resort and the extent to which they can inform other cultural landscape contexts. This distinction needs to be made explicit. The empirical outputs of the dissertation are case-specific. These include the reconstructed scene system of Chengde Mountain Resort, the interpretation of its long-term historical evolution, the identified hazard and ecological sensitivity patterns, the perception distributions derived from its own textual corpus, the zoning boundaries generated through HEPLP, the optimized routes produced through PSLPM, and the design

experiments developed in relation to its imperial mountain-water garden morphology and local governance setting. These results should therefore not be treated as directly replicable solutions for other sites.

What is generalizable is not the substantive outcome, but the conceptual and methodological logic. At a general level, the dissertation argues that cultural landscape conservation becomes more operational when characterization, planning, and design are connected as a continuous chain from diagnosis to intervention. It also proposes a more general planning proposition, namely that hazard exposure, ecological sensitivity, and heritage value perception should be treated as interacting rather than separate dimensions, and that visitor routing can function not only as a management adjustment but also as a conservation instrument.

What is transferable is the analytical structure and workflow. This includes the scene-based reconstruction pathway for landscape characterization, the HEPLP framework for integrating hazards, ecology, and perception, the PSLPM framework for coupling perception with spatial networks and route optimization, and the translation of comparative diagnosis into design grammars, thresholds, and toolboxes. These components can be transferred to other cultural landscape contexts as methodological modules. However, their application is not automatic. Contextual adaptation is required in the definition of spatial units, indicator selection, weighting methods, perception data sources, language model prompting strategies, hazard categories, ecological variables, zoning thresholds, governance arrangements, and intervention rules. In this sense, the dissertation does not propose a universal model with fixed outputs, but an adaptable methodological framework whose operational content must be recalibrated in relation to local landscape structure, data conditions, management capacity, and heritage values.

7.3.4 **Restating the major limitation**

The integrated approach is demonstrated in depth through a single complex case study, which strengthens internal coherence but limits direct generalizability. While transferability is supported through the methodological structure, the comparative typologies, and the modular principles proposed in mapping, planning, and design, further case replications are still needed to test robustness across different cultural landscape types, governance regimes, and data environments, and to clarify which components remain stable and which require local recalibration.

A second set of limitations concerns uncertainty, scale, and implementation. Public perception is inferred from social media texts and mediated through large language model supported scoring, which can introduce bias in who contributes data, what is expressed, and how language is interpreted. In addition, LLM based interpretation is inherently sensitive to prompt design, category definition, and contextual framing. Even under a standardized prompting structure, relatively small changes in wording, model configuration, or input formulation may influence the scoring outcome. The model is also not a neutral interpreter of public discourse, as its outputs may reflect biases embedded in training data, dominant linguistic patterns, uneven platform representation, and culturally selective modes of expression. As a result, certain values, voices, or interpretive nuances may be amplified, while others remain less visible. Reproducibility also remains conditional rather than absolute, particularly when commercial models are updated over time or when the same task is processed under slightly different technical settings. For these reasons, the resulting indicators are best treated as situated and comparative signals for planning exploration rather than direct or definitive measures of societal value. Their role in this dissertation is therefore interpretive and relational, capturing relative differences in public discourse across scenes rather than providing exact measurements of heritage value perception. Although the scoring procedure is structured and documented, and the outputs are evaluated in relation to expert judgment and baseline comparisons, they cannot be assumed to be fully equivalent to direct human interpretation. Continued validation through stakeholder engagement and complementary data sources therefore remains necessary.

Hazard and ecological sensitivity assessments similarly depend on available spatial datasets and modelling choices with varying resolution and update frequency, meaning the outputs represent a snapshot under current data conditions and should be strengthened through longitudinal monitoring and post implementation feedback as climate extremes and land use dynamics evolve. Finally, the proposed design translation into operational grammars, rules, and thresholds remains contingent on institutional capacity, permitting systems, budgets, and enforcement, and although threshold setting and module triggering are methodologically grounded, they inevitably include normative choices that must be negotiated in practice. Evaluating long term institutional adoption, compliance, and outcomes lies beyond the scope of this dissertation.

7.4 Recommendation for Future Research

Future research can strengthen and extend the integrated landscape approach by moving from a single deep case toward systematic replication, comparative testing, and implementation evaluation. First, the framework should be applied to a portfolio of cultural landscapes that vary by typology and governance context, including different garden forms, climate zones, hazard regimes, and tourism intensity. Such replication would allow researchers to test which characterization indicators and clustering structures remain stable, how sensitive the results are to data availability and scale, and whether the mapping to planning and design steps can be standardized into a reusable protocol. A related direction is benchmarking the approach against alternative heritage assessment and planning methods, using shared evaluation criteria such as interpretability, decision usefulness, and the ability to produce implementable zoning and intervention guidance.

Second, methodological development is needed for uncertainty handling, perception validity, and long-term feedback loops. For perception-based components, future work should triangulate social media signals with participatory methods, surveys, visitor tracking, and expert elicitation, and should test cross language consistency, demographic representativeness, and model stability under different large language models and prompting strategies. For hazard and ecology integration, research should introduce temporal updating and scenario-based stress testing, linking climate projections and land use trajectories to dynamic zoning logic and adaptive thresholds. Finally, the design translation step would benefit from implementation science approaches, including piloting operational grammar within real governance processes, evaluating institutional adoption and compliance, and tracking outcomes over time through monitoring systems that connect interventions to measurable changes in integrity, ecological function, visitor distribution, and cultural legibility.

Appendices

Literature List for Review

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Characterization of CMR

Rectification of Historical Maps

For ancient construction phases, such as P1 to P3, there are many archaeological survey maps and historical maps available can be used through the approach of historical cartography. This process involves rectifying the geographic information of historical maps and orthophotos, combining extensive textual records, archival materials, and old photographs as descriptive reference materials to identify and deduce the past historical appearance. Although there may be some deviations in accuracy, the potential and gaps for further research and exploration can be indicated through certainty classification of space.

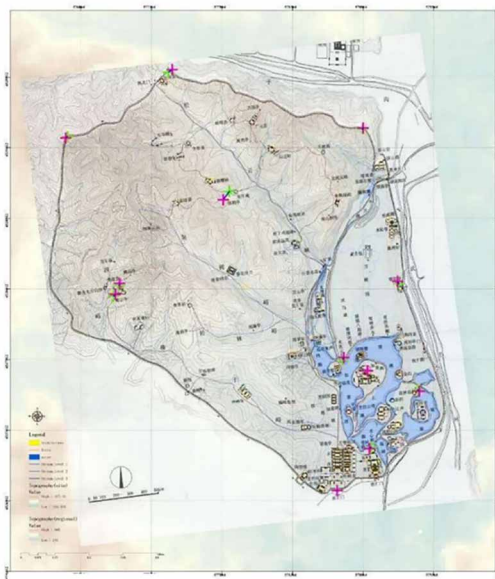


FIG. APP. B.1 Geo-rectification of source historical map (Qian Long era) to orthophoto

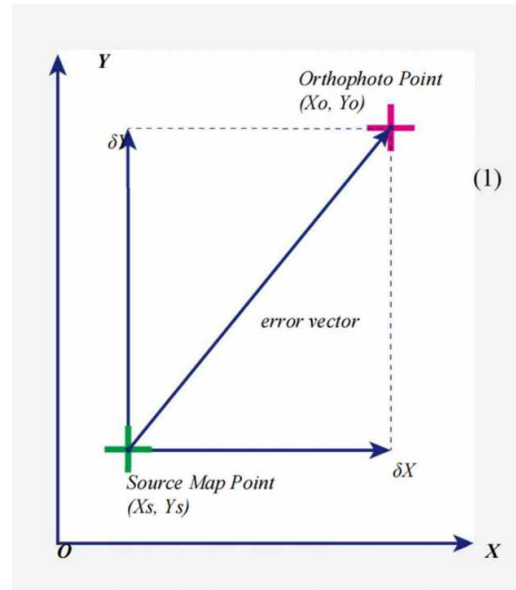


FIG. APP. B.2 Vector representation of the RMSE between source historical map (Qian Long era) to orthophoto

Here we used the Phase 3 (1740-1798) as an example to showcase how to rectify the ancient maps with the current data, and other historical maps of different periods will also follow this scheme. We selected archaeological survey maps from the Qianlong period as our ancient maps. At least 20 control points were chosen from both the source historical map and the orthophoto to synchronize the geographic information between them. These control points were required to be plotted on prominent geographical features for more effective matching. Furthermore, by calculating the root mean square error (RMSE) of the coordinate pairs, including the X and Y coordinates, the spatial two-dimensional error (vector) can be determined, providing insights into the accuracy and reliability of the ancient map (Fig.. APP. B.1, APP. B.2).

$$\delta \bar{x} = \frac{1}{n} \sum_{i=1}^n \delta x_i \quad (\text{APP. B.1})$$

Similar to the calculation of the variance and standard deviation of a statistical sample, the root mean square error (RMSE) m_x and m_y of a set of coordinate measurements is determined by taking the square root of the mean of the squared deviations. This calculation helps to assess the overall dispersion and accuracy of the coordinate data. By examining the RMSE values, we can gain insight into the level of accuracy and reliability associated with the measurements.

$$m_x = \sqrt{\frac{1}{n} \sum_{i=1}^n \delta x_i^2} \quad \text{and} \quad m_y = \sqrt{\frac{1}{n} \sum_{i=1}^n \delta y_i^2} \quad (\text{APP. B.2})$$

The total root mean square error (RMSE) is calculated using a formula that applies the Pythagorean rule. It is determined as the length of the average vector obtained by taking the square root of the sum of squared deviations.

$$\left[m_{\text{total}} = \sqrt{m_x^2 + m_y^2} \right] \quad (\text{APP. B.3})$$

The coordinates on the source historical map and the orthophoto coordinates as well as the residuals were derived from GIS separately (Table. Appx B1), and after the above cartometric analysis, the mean squared deviation was obtained. However, according to the Federal Geographic Data Committee, the map has a scale of 1:5000 and the RMSE must be less than or equal to 1.25m for the accuracy of the map. The final RMSE of this map is 0.865, which is acceptable as reference for other study. To visually represent the variations in planimetric accuracy found in the original maps, MapAnalyst was employed to create a grid of distortions, as well as vectors and circles (Fig. APP. B.3).

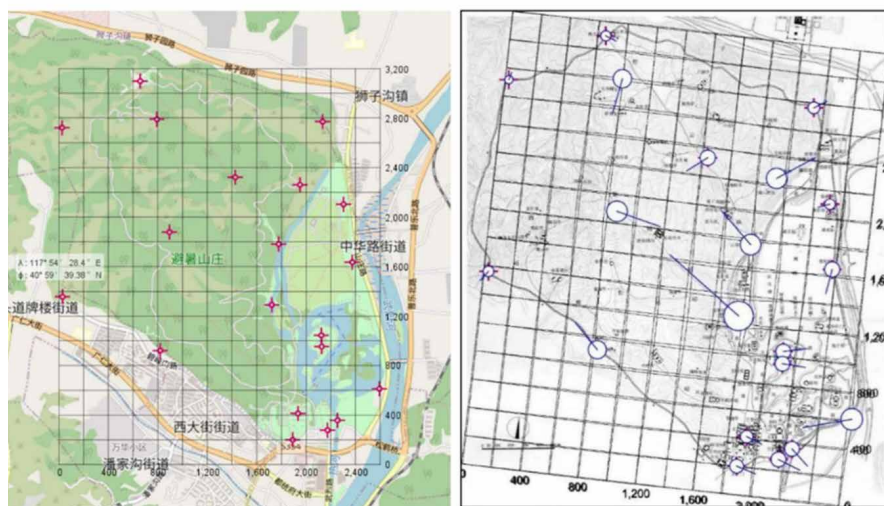


FIG. APP. B.3 Fig. Appx B 3 Geo-rectification of source historical map (Qian Long era) to satellite map in *MapAnalyst*. **A:** Visual representation of the source map georectification; **B:** Satellite image georectification; **C:** The accuracy of this map is higher, but the accuracy of the mountainous area is lower than that of the lake area. The vectors show the direction of distortion and the circles indicate the amount of distortion.

TABLE APP. B.1 Coordinates georectification between historical maps (Source Map Point) and orthophoto

Point No.	Xs	Ys	Xo	Yo	Residuals
01	577490.798	4539948.536	577517.4189	4539964.315	17.4641
02	576774.7965	4539489.487	576757.9524	4539480.868	25.0725
03	577774.2321	4539154.03	577773.5829	4539167.208	8.42283
04	577135.987	4538436.747	577140.643	4538440.912	5.78007
05	577096.7439	4538360.954	577099.594	4538372.443	11.304
06	578692.1211	4536997.254	578689.0674	4536992.645	5.73195
07	578933.7193	4537293.148	578923.0888	4537284.556	18.3986
08	579235.4154	4537700.858	579240.4058	4537696.066	11.6731
09	578886.5616	4537822.112	578896.067	4537832.312	5.37766
10	578728.2082	4537912.461	578735.0074	4537924.937	6.98024
11	579117.5367	4538448.429	579109.675	4538465.044	19.8801
12	579002.3997	4539250.077	579011.9295	4539271.784	7.76367
13	578862.3449	4539546.219	578867.1579	4539553.111	14.7214
14	578006.132	4537684.661	578007.3592	4537671.036	14.2361
15	578367.2728	4538728.841	578413.692	4538756.459	42.3417
16	577546.1809	4539006.257	577540.596	4539031.083	20.3011
17	578058.1471	4539587.14	578070.049	4539576.387	24.3011
18	578558.2503	4538336.391	578566.967	4538350.11	6.27581
19	578969.5267	4537487.319	578981.856	4537484.699	9.4293
20	579104.7525	4538033.743	579130.055	4538054.883	20.8702

A brief interpretation of different types of textual and graphic research materials

A Traditional paintings graphic research

Traditional painting can be categorized into panoramic and singular compositions. Through the lens of traditional artistic techniques, we conduct a thorough analysis and study of these paintings, focusing on elements such as composition, coloring methods, focal points, as well as perspectives and rules of visual representation (Lacina & Halas, 2015; Zhang & Zo, 2020). These analyses reveal the characteristics of CMR landscapes as perceived by historical graphs, shedding light on their structural composition, geographical space, proportional area distribution, and degrees of convergence and dispersion (Fig. APP. B.4). Finally, these paintings contribute significantly to the reconstruction of missing chronological information when integrated with the rectification of historical maps.

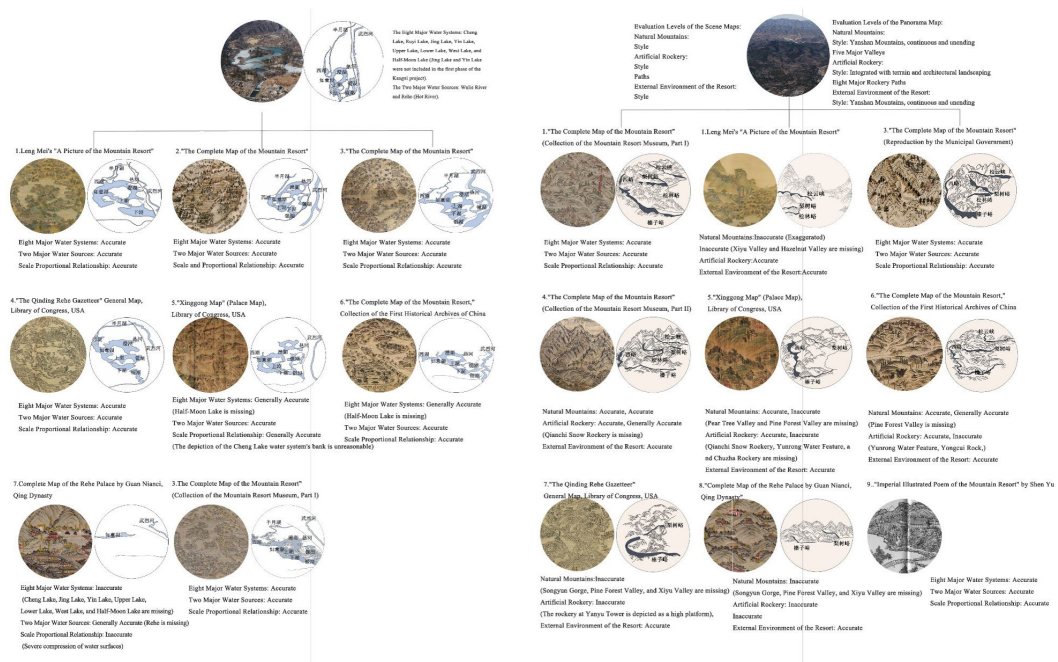


FIG. APP. B.4 Traditional paintings graphic research

B Reprocess the engineering drawings

The engineering drawings primarily include the master plan, floor plans, elevation drawings, and sectional drawings. Some of these drawings are hand-drawn ink sketches from the 20th century, mainly sourced from historical references and ancient texts. Since they are not editable, we opted to use the Raster Design toolset included with AutoCAD 2025 to convert the original raster images into vector drawings. These are then manually calibrated to create editable versions that will aid in the restoration of collapsed or vanished structures (Fig. APP. B.5).

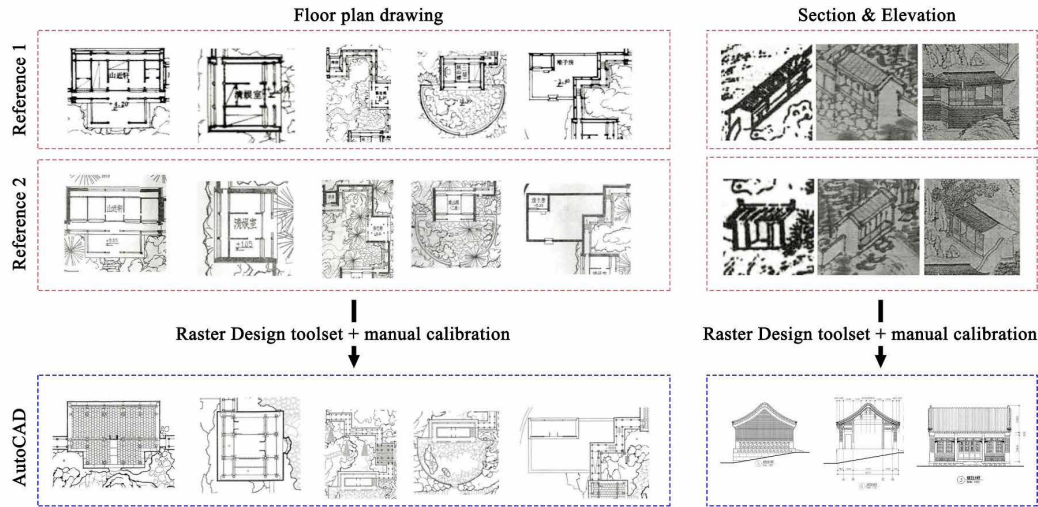


FIG. APP. B.5 The process of the engineering drawings

C Segmentation analysis of old photography

Segmentation analysis of old photography include AI coloring, depth mapping, openness mapping, and element mapping (Fig. APP. B.6) These mappings were achieved through computer deep learning technology. 1) Depth mapping: We used the pre-trained model developed by Ranftl (2020) for monocular depth estimation to obtain depth mapping. This mapping estimates the relative depth of different elements in the scenery archetype, providing a basis for understanding the composition and configuration of foreground, middle ground, and background. 2) Openness mapping: Based on element mapping, we performed binary label coloring according to whether elements obstruct the observer's line of sight to obtain openness mapping. 3) Element

mapping: The selected photo data was preliminarily processed through a pre-trained model developed by Zhou et al. (2017) based on the ADE20K dataset. To improve the accuracy of the results, we further used the Segment Anything model developed by Kirillov et al. (2023). This model can automatically recognize and segment elements in photo data through user-selected point and surface samples, without additional training. This allows for flexible and efficient manual correction of element mapping.

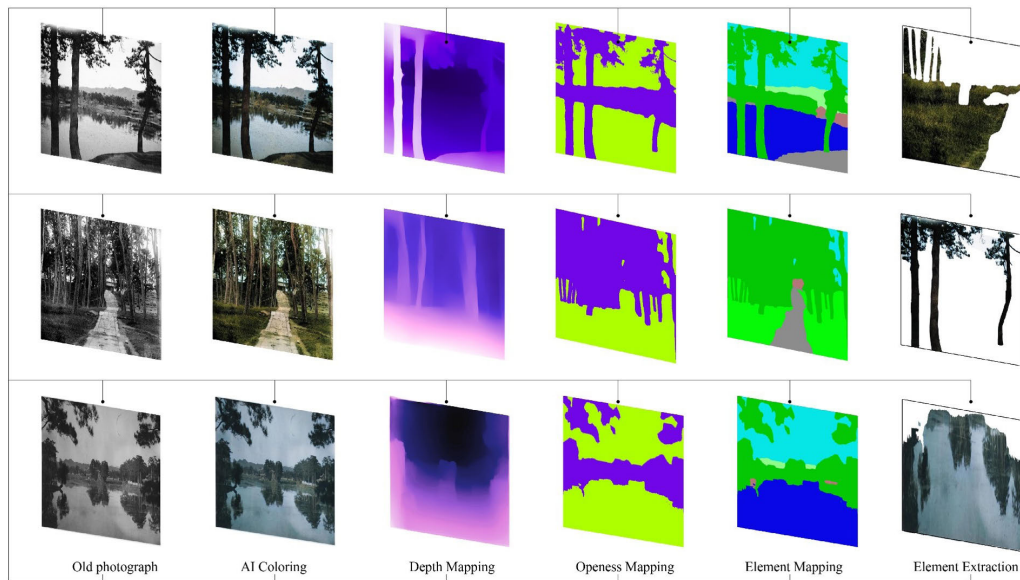


FIG. APP. B.6 The process of the semantic segmentation

D Poems' textual and geospatial links

To develop a Web GIS project that integrates ancient poetry with spatial coordinates, the primary objective is to visualize and interact with historical texts in a geographic context (Davis, 2012). Initially, the project requires the collection and digitization of poetry data, ensuring that each poem is linked with precise spatial coordinates. In the implementation phase, a Web GIS platform such as Leaflet.js or Open Layers is utilized to render interactive maps. Each poem's location is represented as a geographic marker on the map. Clicking on these markers triggers a pop-up window displaying the associated poetry, providing users with immediate access to the textual content. To enhance usability, the system incorporates search and filter functionalities, allowing users to query poetry by title, author, or keywords.

E Academic papers textual and geospatial links

We have organized and collected relevant papers based on academic data indexing platforms (Web of Science, Baidu Research). Using Python programming, we conducted keyword analysis, thematic analysis, content analysis, and text mining to classify the papers. Then, based on the extracted scene names, we matched them with spatial coordinates and established connections. In this way, users can quickly find the target papers and research through filtering and searching for points of interest in the interactive interface.

References of Appendix B.1

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APP. B.2 Measurement Formulas of Various Indicators

- STWA (scene-to -water accessibility) formula:

$$A_i = \min_j \{C(P_i, W_j)\} \quad (\text{APP. B.4})$$

P_i is the i -th point; W_j is the j -th water body point; $C(P_i, W_j)$ is the cost distance from point P_i to water shore point W_j ; A_i is the accessibility of point P_i , equal to the minimum cost distance to any water point

— **STSA (scene-to -scene accessibility) formula:**

$$A_{ij} = \frac{1}{n(n-1)} \sum_{i=1}^n \sum_{\substack{j=1 \\ j \neq i}}^n C_{ij} \quad (\text{APP. B.5})$$

n is the number of scenes; C_{ij} is the travel distance cost from scene i to j , calculated based on the actual road network data; A_{ij} is the average accessibility

— **ESV (scene's exterior visibility) formula:**

$$E_{cv} = \sum_{i=1}^n V_i \quad (\text{APP. B.6})$$

E_{cv} is the cumulative viewshed value of a scene as an observation point;
 V_i is the visibility value (1 or 0) of each raster cell i ; n is the total number of raster cells

— **OSV (observed scene visibility) formula:**

$$\left[\frac{1}{N} \sum_{i=1}^N \left(\frac{\sum_{j \in A} V_{ij}}{A} \right) \right] \times 100\% \quad (\text{APP. B.7})$$

P_i is an observation point on the route (10m apart); N is the total number of observation points on the route; V_{ij} is the visibility value (1 or 0) of raster cell j for observation point P_i ; A is the total number of raster cells in the area of the scene; Z_i is the sum of visibility values (zonal statistics) for the geometric area of the building for observation point P_i

To assess grouping quality, we applied the Calinski–Harabasz Index (CH Index), which evaluates inter-group separation and intra-group compactness.

$$CH = \frac{\sum_{i=1}^k N_i (\bar{x}_i - \bar{x})(\bar{x}_i - \bar{x})^T}{\sum_{i=1}^k \sum_{x \in C_i} (x - \bar{x}_i)(x - \bar{x}_i)^T} \times \frac{N - k}{k - 1} \quad (\text{APP. B.8})$$

Where: N is the total number of data points; k is the number of clusters; N_i is the number of points in the i -th cluster; $\bar{x}_i$ is the centroid of the i -th cluster, $\bar{x}$ is the overall mean of the data; C_i represents the i -th cluster, and x denotes the individual data points in the clusters.

As shown in the [Fig. APP. B.7](#), Dataset 02 achieved the highest Calinski–Harabasz value (31.04), followed by Dataset 03 (29.20) and Dataset 04 (27.57), all of which fall within the “good clustering” range, indicating relatively strong inter-group separation and intra-group compactness. By contrast, Dataset 01 obtained a CH value of 23.22, which falls within the “moderate clustering” range, suggesting that although the grouping structure is still acceptable, some overlap between groups may remain. Overall, the results suggest that Datasets 02–04 provide more robust and discriminative clustering performance than Dataset 01. These differences are also consistent with the data construction logic discussed in **Section 3.1.3**, where variations in indicator composition and dataset structure are expected to influence the separability and compactness of clustering outcomes.

The left panel shows the cumulative pixel-based visibility result, where observation points spaced at 10 m intervals along the route are used to calculate visibility toward the target scene, and warmer raster cells indicate areas visible from more route positions while cooler cells indicate weaker or intermittent visibility. The right panel presents the scene level OSV extracted from these raster outputs using zonal statistics, aggregating pixel level patterns into comparable average values that reveal which buildings or scene units are more consistently perceived along the route and which remain visually recessive ([Fig. APP. B.8](#)).

Boxplots [Fig. APP. B.9](#) summarize the p-value distributions of the Levene test, Shapiro–Wilk test, and Kruskal–Wallis test for parameters P1 to P4. Overall, most parameters show very low p-values, indicating widespread departures from homogeneity of variance, normality, and equal group distributions, with the Kruskal–Wallis results further confirming significant differences among parameter groups.

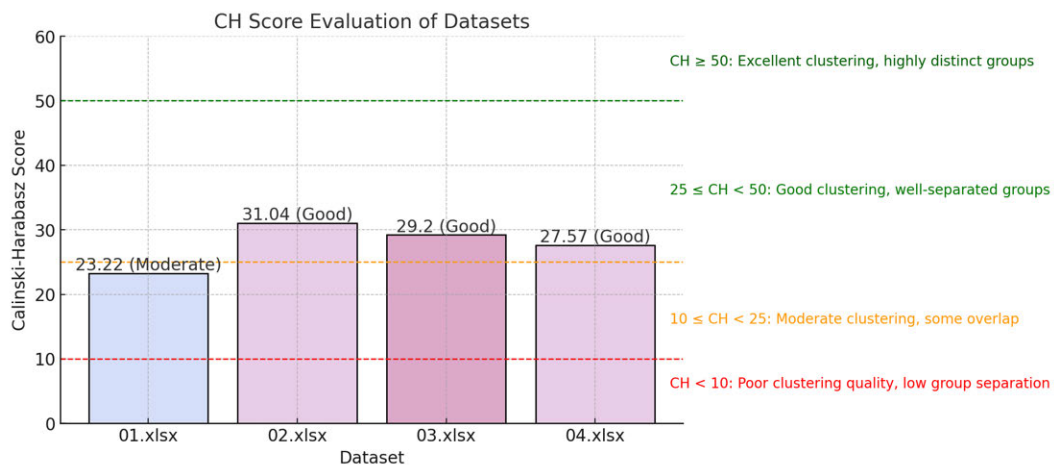


FIG. APP. B.7 Comparison of Calinski–Harabasz Scores across Datasets

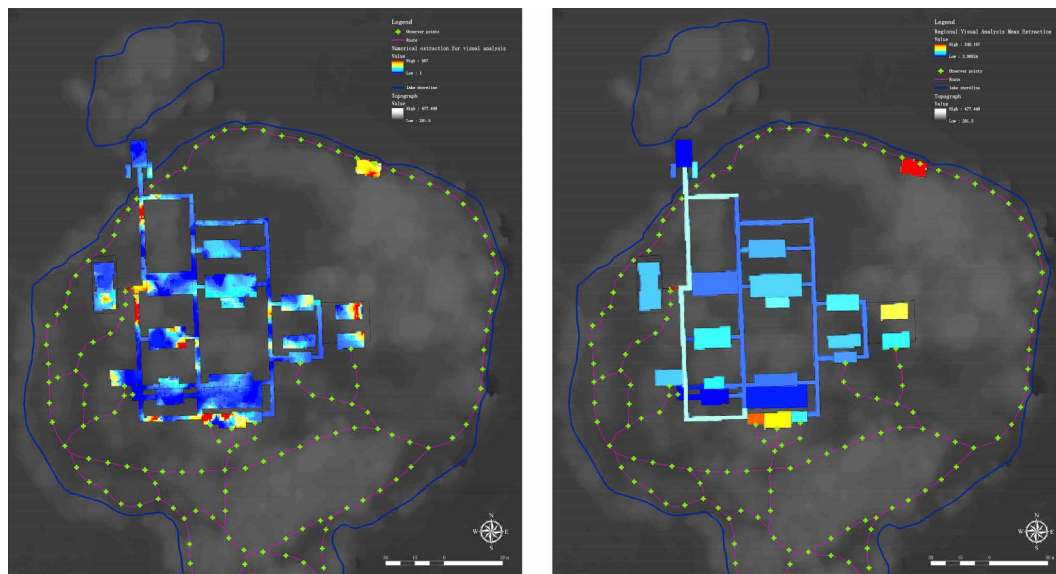


FIG. APP. B.8 Graphical representation of OSV mean calculation and extraction

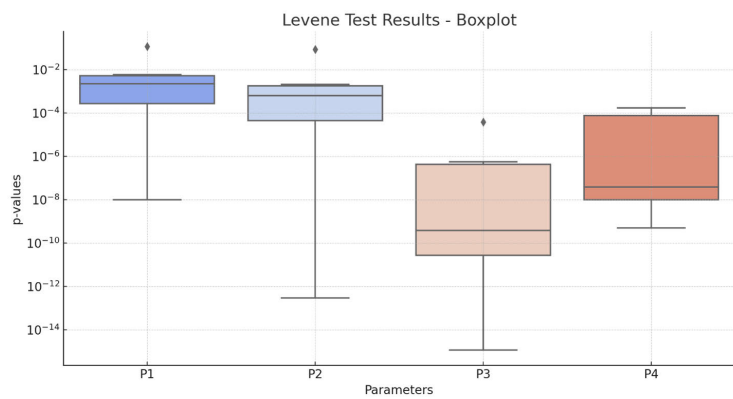


FIG. APP. B.9 Distribution of Kruskal–Wallis Test Results across Parameters

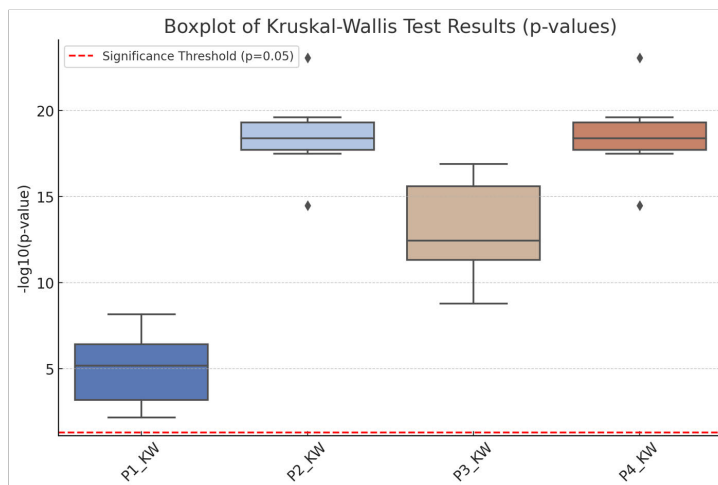
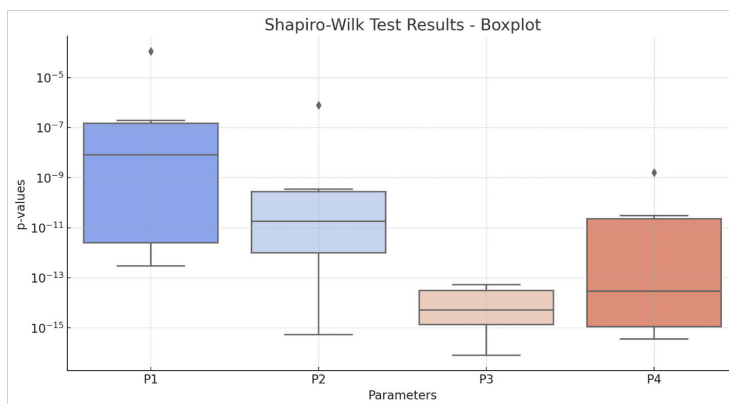


TABLE APP. B.2 Results of Levene, Shapiro–Wilk, and Kruskal–Wallis Tests for Landscape Parameters across Four Datasets

Variable	Phase	Levene	Shapiro-Wilk	Kruskal-Wallis
Elevation	P1	5.81E-03	7.37E-12	0.001957
	P2	2.06E-03	1.86E-13	3.84E-19
	P3	6.72E-10	4.93E-15	6.98E-12
	P4	4.96E-10	2.28E-15	3.84E-19
Slope	P1	5.31E-08	9.29E-13	0.006764
	P2	1.78E-04	5.37E-16	2.58E-20
	P3	5.68E-07	8.00E-17	1.59E-12
	P4	1.72E-04	3.60E-16	2.58E-20
STW	P1	9.97E-09	2.96E-13	2.24E-07
	P2	1.00E-06	3.40E-12	8.66E-24
	P3	1.16E-15	1.46E-16	1.33E-17
	P4	9.59E-09	7.11E-16	8.66E-24
STSA	P1	1.16E-01	1.12E-04	2.51E-05
	P2	8.57E-02	7.81E-07	3.30E-15
	P3	1.07E-10	5.51E-15	1.64E-09
	P4	6.50E-08	5.63E-14	3.30E-15
ESV	P1	3.43E-03	1.63E-08	1.84E-06
	P2	1.08E-03	3.28E-11	3.20E-18
	P3	3.81E-05	4.04E-14	8.93E-14
	P4	1.04E-04	3.06E-11	3.20E-18
OSV	P1	1.08E-03	1.93E-07	6.79E-09
	P2	2.97E-13	3.53E-10	4.71E-19
	P3	2.85E-14	5.39E-14	3.52E-17
	P4	1.17E-08	1.61E-09	4.71E-19

Table APP. B.1 reports the p-values of the Levene test, Shapiro–Wilk normality test, and Kruskal–Wallis test for six parameters across P1 to P4. The results show that most variables significantly violate variance homogeneity and normality assumptions, while the Kruskal–Wallis test indicates statistically significant differences among groups for all parameters.

TABLE APP. B.3 The number of scenes

Scene Number	Name of Scenes (Chinese Pin Yin)	Scene Number	Name of Scenes (Chinese Pin Yin)
K.01.	Yan Bo Zhi Shuang	Q.04.	Ru Yi Hu
K.02.	Zhi Jing Yun Di	Q.05.	Qing Que Fang
K.03.	Wu Shu Qing Liang	Q.06.	Yi Wang Lou
K.04.	Yan Xun Shan Guan	Q.07.	Xun Lu Po
K.05.	Shui Fang Yan Xiu	Q.08.	Shui Xin Xie
K.06.	Wan He Song Feng	Q.09.	Yi Zhi Tang
K.07.	Song He Qing Yue	Q.10.	Chang Yuan Tai
K.08.	Yun Shan Sheng Di	Q.11.	Jing Hao Tang
K.09.	Si Mian Yun Shan	Q.12.	Leng Xiang Ting
K.10.	Bei Zheng Shuang Feng	Q.13.	Cai Ling Du
K.11.	Xi Ling Chen Xia	Q.14.	Guan Lian Suo
K.12.	Chui Feng Luo Zhao	Q.15.	Qing Hui Ting
K.13.	Nan Shan Ji Xue	Q.16.	Bo Re Xiang
K.14.	Li Hua Ban Yue	Q.17.	Cang Lang Yu
K.15.	Qv Shui He Xiang	Q.18.	Yi Pian Yun
K.16.	Feng Quan Qing Ting	Q.19.	Ping Xiang Pan
K.17.	Hao Pu Jian Xiang	Q.20.	Wan Shu Yuan
K.18.	Tian Yu Xian Chang	Q.21.	Shi Ma Dai
K.19.	Nuan Liu Xuan Bo	Q.25.	Cheng Guan Zhai
K.20.	Quan Yuan Shi Bi	Q.26.	Cui Yun Yan
K.21.	Qing Feng Lv Yu	Q.27.	Yan Hua Chuang
K.22.	Ying Zhuan Qiao Mu	Q.28.	Ling Tai Xv
K.23.	Xiang Yuan Yi Qing	Q.32.	Lin Fang Shu
K.24.	Jin Lian Ying Ri	Q.34.	Yong Cui Yan
K.25.	Yuan Jin Quan Sheng	Q.35.	Su Shang Zhai
K.26.	Yun Fan Yue Fang	Q.36.	Yong Tian Jv
K.27.	Fang Zhu Lin Liu	Q.33.	Zhi Yu Ji
K.28.	Yun Rong Shui Tai	Q.01.	Li Zheng Men
K.29.	Cheng Quan Rao Shi	Q.02.	Qin Zheng Dian
K.30.	Cheng Bo Die Cui	Q.03.	Song He Zhai
K.31.	Shi Ji Guan Yu	Q.22.	Jia Shu Xuan
K.32.	Jing Shui Yun Cen	Q.23.	Le Cheng Ge
K.33.	Shuang Hu Jia Jing	Q.24.	Su Yun Yan
K.34.	Chang Hong Yin Lian	Q.29.	Qian Chi Xue
K.35.	Pu Tian Cong Yue	Q.30.	Ning Jing Zhai
K.36.	Shui Liu Yun Zai	Q.31.	Yu Qin Xuan
EK.01	Dan Bo Jing Cheng	EQ.01.	Chang Yuan Lou
EK.02	Tan Tan Dang Dang	EQ.02.	Ji De Tang

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TABLE APP. B.3 The number of scenes

Scene Number	Name of Scenes (Chinese Pin Yin)	Scene Number	Name of Scenes (Chinese Pin Yin)
EK.03	Yue Se Jiang Sheng	EQ.03.	Qing Yin Ge
EK.04	Qing Shu Shan Guan	EQ.04.	Fu Shou Yuan
EK.05	Si Zhi Shu Wu	EQ.05.	Wen Yuan Shi Zi Lin
EK.06	Juan Er Sheng Jing	EQ.06.	Jie De Tang
EK.07	Yue She Men	EQ.07.	Hui Wan Zong Chun Zhi Miao
EK.08	Yue Ting	EQ.08.	Yan Yu Lou
EK.09	Wan Sui Zhao Fang	EQ.09.	Wen Jin Ge
EK.10	Xi Suo	EQ.10.	Chun Hao Xuan
EK.11	Xiu Yun Men	EQ.2.	Yong You Si
EK.12	Jian Shi Zhai	EQ.12.	Xie Xin Jing She
EK.13	Qing Bi Ting	EQ.13.	Tong Fu Si
EK.14	Jing Ji Shan Fang	EQ.14.	Bi Feng Si
EK.15	Ying Xin Tang	EQ.15.	You Zhen Yi Xuan
EK.16	Xia Qin Xuan	EQ.16.	Jiu Yun Si
EK.17	Hu Shan An Hua	EQ.17.	Xiu Qi Tang
EK.18	Huan Bi	EQ.18.	Jing Han Tai Gu Fang
EK.19	Cheng Guang Shi	EQ.19.	Zhu Yuan Si
EK.20	Fang Yuan Jv	EQ.20.	Lv Yun Lou
EK.21	Fu Pian Yu	EQ.21.	Pu Yuan Ting
EK.22	Han Run Ting	EQ.22.	Li Yun Ting
EK.23	Shang Di Ge	EQ.23.	Shi Zhe Jv
EK.24	Re He Quan	EQ.24.	Chuang De Zhai
EK.25	Guan Pu Ting	EQ.25.	Qing Xi Yuan Liu
EK.26	Jia Qiang Wei Jian	EQ.26.	Shan Jin Xuan
EK.27	Wang Yuan Ting	EQ.27.	Guang Yuan Gong
EK.28	Zhu Zhao Xia	EQ.28.	Gu Jv Ting
EK.29	Ji Xia Ting	EQ.29.	Chang Qing Zhai
EK.30	Ling Ze Long Wang Miao	EQ.30.	Shui Yue An
EK.31	Kuang Guan	EQ.31.	Fang He Ting
EK.32	Han Cui Zhai	EQ.32.	Zhan Tan Lin
EK.33	Xian Yuan Zhao Ling	EQ.33.	Han Qing Zhai
EK.34	Dou Lao Ge	EQ.34.	Bi Jing Tang
EK.35	Yin Hong Xie	EQ.35.	Yu Cen Jing She
EK.36	Xia Biao	EQ.36.	Yi Zhao Zhai

Table APP. B.3 presents the scene numbers and corresponding Chinese pinyin names for all 144 scenes, covering the K, Q, EK, and EQ groups. It provides the complete coded inventory used for scene identification and subsequent spatial analysis.

Supporting Indicator Frameworks

APP. C.1 Geographical Hazard Indicator Scoring and Weighting

TABLE APP. C.1 Geographical hazard indicators based on expert's scoring through AHP

Indicators	Segmentation standards	Score	Indicators	Segmentation standards	Score
Lithology -LI	Bedrock	1	Vegetation Coverage- VC (%)	>70%	1
	Sedimentary Rock	2		40–70%	2
	Loess	3		<40%	3
Groundwater Level- GL(m)	< -1m	1	Terrain Slope-TS (°)	<5	1
	0 ~ -1m	2		5–30	2
	0m (Surface)	3		>30	3
Gully Development- GD	Shallow Gully	1	Distance to the faults - DF(m)	>5000 m	1
	Moderate Gully	2		5000–5500m	2
	Deep Gully	3		4500–5000m	3
Water Erosion- WE	Low Erosion	1		4000–4500m	4
	Moderate Erosion	2		3500–4000m	5
	Frequent Erosion	3		3000–3500m	6
Geomorphic Unit - GU	Plain	1		2500–3000m	7
	Valley	2	Landslide & Rockfall Occurrence (LR)	Low Occurrence	1
	Slope	3		Moderate Occurrence	2
				High Occurrence	3

The table summarizes the hazard related indicators, their segmentation standards, and corresponding scores used in the AHP based expert assessment. Higher scores represent less favorable geoenvironmental conditions and greater potential hazard sensitivity across lithology, groundwater, gully development, erosion, terrain, vegetation, fault distance, geomorphic unit, and landslide or rockfall occurrence ([Table APP. C.1](#)).

TABLE APP. C.2 AHP weight matrix of each geographical hazard indicators

Indicators	LR	TS	GD	WE	DF	LI	VC	GU	GL	Weight
LR	1	3	3	5	5	7	7	9	9	0.035
TS	1/3	1	3	5	5	7	7	7	9	0.024
GD	1/3	1/5	1	3	5	5	7	7	7	0.164
WE	1/5	1/7	1/3	1	3	3	5	7	7	0.110
DF	1/5	1/7	1/5	1/3	1	3	5	5	5	0.070
LI	1/7	1/7	1/5	1/3	1/3	1	3	5	5	0.050
VC	1/7	1/9	1/7	1/5	1/5	1/3	1	3	3	0.020
GU	1/9	1/9	1/7	1/5	1/5	1/3	1/3	1	3	0.024
GL	1/9	1/9	1/7	1/5	1/5	1/3	1/3	1/3	1	0.014

The table presents the pairwise comparison matrix and derived weights for each geographical hazard indicator in the AHP analysis, showing their relative importance in hazard assessment. The consistency ratio is 0.0765, which is below the threshold of 0.1, indicating that the judgment matrix has acceptable consistency and the weighting results are reliable ([Table APP. C.2](#)).

Ecological Indicator Classification and Weighting

TABLE APP. C.3 The Positive / Negative Indicators with explanation

Indicators	Positive / Negative	Explanation
Construction Land	Negative	Construction Land is considered a negative factor because it typically involves the removal of vegetation, soil compaction, and surface sealing. These activities disrupt natural habitats, increase surface runoff, reduce groundwater recharge, and fragment ecosystems. Additionally, roads introduce noise, pollution, and human disturbances, which can negatively impact biodiversity and ecological stability. Therefore, areas with higher proportions of Construction Land are deemed more ecologically sensitive and less suitable for conservation.
Grassland	Positive	Grasslands are viewed as positive factors in ecological sensitivity because they often serve as important habitats for various species, contribute to carbon sequestration, and support soil stability. They can regulate microclimates and maintain hydrological balance. In ecological terms, a higher percentage of grassland cover usually indicates better vegetation health, greater ecosystem resilience, and lower human disturbance, which are all favorable for ecological sustainability.
Water Body	Positive	Water bodies are essential components of an ecosystem, offering numerous ecological functions such as regulating temperature, supporting aquatic biodiversity, maintaining local humidity, and enabling nutrient cycling. Their presence often enhances the environmental quality of a landscape. In ecological sensitivity analysis, areas near or containing natural water bodies are generally considered ecologically valuable and less disturbed, which is why this factor is treated as positive.
Mixed Forest (Coniferous and Broadleaf)	Positive	Mixed forests, which include both coniferous and broadleaf trees, provide diverse habitats and high biodiversity value. They support a wider range of species, enhance ecological resilience, and offer better ecosystem services such as soil protection, carbon storage, and climate regulation. Their structural diversity helps them adapt to environmental changes, making them valuable in maintaining ecological balance. Therefore, they are considered a positive indicator.
Coniferous Forest	Positive	Coniferous forests are often seen as ecologically beneficial due to their ability to grow in harsh environments, prevent soil erosion, and maintain year-round green coverage. They provide shelter and resources for specific wildlife and contribute to carbon fixation. Though sometimes lower in species diversity than mixed forests, their ecological functions still contribute positively to environmental quality.
Broadleaf Forest	Positive	Broadleaf forests are considered highly positive due to their high productivity, rich biodiversity, and strong contribution to nutrient cycling and habitat provision. They typically grow in more fertile soils and support diverse flora and fauna. These forests enhance ecological connectivity and stability, and their canopy structure helps regulate temperature and moisture levels. Thus, they are key indicators of ecological health.

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TABLE APP. C.3 The Positive / Negative Indicators with explanation

Indicators	Positive / Negative	Explanation
Distance from Roads	Negative	This factor is considered negative because shorter distances to roads usually imply greater exposure to human disturbances, including pollution, noise, habitat fragmentation, and increased accessibility for exploitation or development. Areas closer to roads are often more degraded ecologically. Therefore, a shorter distance from roads reduces ecological quality, making it a negative indicator.
Distance Between scenes	Negative	In the context of ecological sensitivity, a shorter distance between scenes often suggests concentrated human activity, which can lead to habitat disturbance, waste generation, and increased infrastructure pressure. While tourism may be economically beneficial, closely spaced scenic areas can intensify ecological stress in fragile environments. Hence, this is regarded as a negative factor.
Elevation	Positive	Higher elevations are often associated with lower human activity due to accessibility challenges, which can reduce ecological pressure. These areas can host unique species and microclimates, contributing to biodiversity conservation. Elevation can also influence temperature and precipitation patterns, indirectly affecting ecological conditions. As such, higher elevation is considered a positive factor in ecological sensitivity evaluations.
Slope	Positive	Steeper slopes typically discourage urban development and agriculture, which helps preserve natural vegetation and reduce human interference. These areas are less likely to be altered, maintaining natural land cover and supporting ecological functions such as water retention and erosion control. Because of their relative inaccessibility and ecological integrity, steeper slopes are treated as positive factors in sensitivity analysis.
Slope Direction	Positive	South-facing slopes are sunny, dry, with high evaporation and sparse vegetation, scoring 8. Southwest-facing slopes are also sunny and relatively dry, scoring 7. West-facing slopes have moderate sunlight, slightly dry, scoring 6. Southeast-facing slopes get moderate sun with moisture variation, scoring 5. East-facing slopes receive morning light, scoring 4. Northwest-facing slopes are less sunny, moist, and support plant growth, scoring 3. North-facing slopes have the least sun, high humidity, and stable ecology, scoring 2. Northeast-facing slopes are shaded, moist, with good vegetation, scoring 1.

The table classifies each indicator as positive or negative according to its ecological implications and explains how different land cover, topographic, and accessibility factors influence ecological quality and sensitivity. Overall, positive indicators reflect conditions that support ecosystem stability and biodiversity, whereas negative indicators represent stronger human disturbance or environmental pressure (Table APP. C.3).

TABLE APP. C.4 The weight matrices of the different indicators based on EWM

Indicator	Entropy	Weight
Water Body	0.995	0.129
Broadleaf Forest	0.994	0.188
Mixed Forest (Coniferous and Broadleaf)	0.989	0.089
Coniferous Forest	0.902	0.142
Slope	0.885	0.185
Grassland	0.837	0.13
Elevation	0.836	0.083
Distance from Roads	0.829	0.002
Slope Direction	0.806	0.035
Distance Between Scenes	0.768	0.008

The table presents the entropy and corresponding weights of each indicator, showing their relative contribution to the ecological sensitivity assessment; broadleaf forest, slope, and coniferous forest receive the highest weights, whereas distance from roads and distance between scenes contribute relatively little to the final weighting scheme (The table classifies each indicator as positive or negative according to its ecological implications and explains how different land cover, topographic, and accessibility factors influence ecological quality and sensitivity. Overall, positive indicators reflect conditions that support ecosystem stability and biodiversity, whereas negative indicators represent stronger human disturbance or environmental pressure (Table APP. C.4).

TABLE APP. C.5 The weight matrices of the different indicators based on AHP

Indicators	WB	MF	BF	CF	DR	GL	SL	EL	DS	SD	CL	Weight
WB	1	3	3	5	5	5	7	7	9	9	9	0.283
MF	1/3	1	3	3	3	5	5	7	7	9	9	0.184
BF	1/3	1/3	1	3	3	3	5	5	7	9	9	0.15
CF	1/5	1/3	1/3	1	3	3	3	5	5	7	9	0.108
DR	1/5	1/3	1/3	1/3	1	3	3	3	5	7	9	0.083
GL	1/5	1/5	1/3	1/3	1/3	1	3	3	5	5	7	0.064
SL	1/7	1/5	1/5	1/3	1/3	1/3	1	3	3	5	7	0.045
EL	1/7	1/7	1/5	1/5	1/3	1/3	1/3	1	3	5	5	0.036
DS	1/9	1/7	1/7	1/5	1/5	1/5	1/3	1/3	1	3	5	0.023
SD	1/9	1/9	1/9	1/7	1/7	1/5	1/5	1/5	1/3	1	3	0.014
CL	1/9	1/9	1/9	1/9	1/9	1/7	1/7	1/5	1/5	1/3		0.01

*WB: Water Body, MF: Mixed Forest, BF: Broadleaf Forest, CF: Coniferous Forest, DR: Distance to Road, GL: Grassland, SL: Slope, EL: Elevation, DS: Distance Between scenes, SD: Slope Direction, CL: Construction Land

The table presents the pairwise comparison matrix and derived weights for the ecological sensitivity indicators in the AHP analysis. The consistency ratio is 0.0298, which is below the threshold of 0.1, confirming that the judgment matrix has acceptable consistency and that the weighting results are reliable (Table APP. C.5).

APP. C.3 Heritage Value Dimensions and Retrieval Keywords

TABLE APP. C.6 Heritage Value Assessment Matrix

Heritage Value	Value description
Historical Value	– The Mountain Resort serves as historical evidence of the formation and consolidation of China as a unified multi-ethnic nation. They also bear witness to the ethnic and religious policies of the Qing Dynasty and provide factual records of significant historical events during that era. – The Mountain Resort, as the second political center of the Qing Dynasty and a historical site of ethnic integration, are a significant national heritage site. – The Mountain Resort is the largest surviving classical imperial garden in China. – The surrounding temples form the largest extant group of imperial temples in China. – These temples provide important physical evidence of the development of Tibetan Buddhism. – The Mountain Resort and its surrounding temples were constructed based on a unified plan. The temples are distributed along the northern and eastern foothills of the Mountain Resort, forming a layout with the resort at the center and the temples arranged like stars around the moon. This design successfully integrates architecture with nature, reflecting the ancient Chinese concept of a unified state. – The Mountain Resort and its surrounding temples are a concentrated representation of the cultures of multiple ethnic groups, including Han, Manchu, Mongolian, and Tibetan.
Artistic Value	– The Mountain Resort inherits the traditions of ancient Chinese imperial gardens, blending the gardening styles of both northern and southern China. Its skillful adaptation to natural features creates a harmonious, natural aesthetic, reflecting the Qing emperors' vision of recreating the world in miniature. This masterpiece of classical Chinese garden and architectural art stands as a shining example, not only possessing exceptional value in art history but also serving as a direct inspiration for contemporary design. – The architectural forms of the surrounding temples integrate the styles of Han, Mongolian, and Tibetan ethnic groups, showcasing remarkable artistic value. – The site selection for the Mountain Resort and its surrounding temples reflects the influence of traditional Chinese Feng Shui principles, demonstrating exceptional landscape value.

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TABLE APP. C.6 Heritage Value Assessment Matrix

Heritage Value	Value description
Scientific Value	– The planning and design of the Mountain Resort and its surrounding temples fully account for natural elements such as topography and water systems. By adapting to the terrain and following the contours of the mountains, the site selection and layout reflect a high degree of scientific precision. – The diversity of architectural types within the Mountain Resort and its surrounding temples represents a comprehensive Chinese architectural system. – The tall wooden structures and masonry buildings within the Mountain Resort and temples showcase the advanced technological achievements of their time. – The water system of the Mountain Resort is designed with scientific rigor, seamlessly combining engineering techniques with the art of garden design. – The surrounding temples feature a variety of structural types, including Han-style, Tibetan-style, and hybrid Han-Tibetan structures, demonstrating the integration of traditional Chinese architectural forms with religious functions, which embodies significant scientific value.
Social Value	– The Mountain Resort and its surrounding temples serve as a base for patriotic education, promoting national unity, and celebrating the excellent traditional culture of the Chinese nation. – They are among the top destinations for visitors to explore, offering opportunities for sightseeing, summer leisure, cultural enrichment, and experiencing classical gardens and religious culture. – As one of the centers of Tibetan Buddhism in northern China, the surrounding temples are important places for devotees to practice their faith. – The Mountain Resort and its surrounding temples, as extensive green recreational areas, play a vital role in the modern urban landscape of Chengde. – They are cherished by Chengde residents as a symbol of their love for and commitment to their hometown and serve as an important connection for overseas Chinese. – With profound cultural significance, the Mountain Resort embodies essential values in ethnic interaction, the integration of religion with society, the preservation and transmission of traditional culture, and the harmonious coexistence of humans and nature. Protecting, passing on, and utilizing these heritage sites effectively while exploring their rich heritage will help strengthen cultural confidence and unite the national spirit.
Cultural Value	– The planning and design of the Mountain Resort and its surrounding temples reflect profound cultural connotations, such as China's ancient ideals of unity and ethnic integration, serving as tangible carriers of the nation's outstanding cultural heritage. – Both the garden and architectural designs of the Mountain Resort and temples integrate elements of classical Chinese philosophy, aesthetics, and literature, making them representative masterpieces of traditional Chinese culture. – The construction of the Mountain Resort leveraged natural topography, blending the elegance of southern landscapes with the grandeur of northern terrains. It combines palace garden culture, mountain and river culture, Jiangnan water town culture, central plains agrarian culture, and steppe nomadic culture. Its historical landscapes, epitomized by the "72 Scenic Spots of the Kangxi and Qianlong Eras," intertwine cultural and natural elements, showcasing profound cultural significance. – The Mountain Resort and surrounding temples house a wealth of ancillary artifacts, including couplets, plaques, stone carvings, and murals. These items vividly reflect achievements in literature, calligraphy, and painting, showcasing the richness and diversity of China's exceptional traditional culture.

The table summarizes the five heritage value dimensions, namely historical, artistic, scientific, social, and cultural value, together with their detailed descriptions, highlighting the site's significance in national history, landscape and architectural art, technical achievement, social function, and cultural integration (Table APP. C.6).

TABLE APP. C.7 Keywords Used for Public Perception Data Retrieval of the CMR

Category	Chinese	English and Pin Yin
general case-related names	承德避暑山庄, 避暑山庄, 避暑山庄景区, 避暑山庄公园, 避暑山庄园林, 承德山庄, 承德园林, 承德古建, 承德皇家园林, 清代避暑山庄, 清避暑山庄, 皇家避暑山庄, 清朝避暑山庄, 清帝行宫, 热河行宫, 热河避暑山庄, 承德热河行宫, 承德行宫, 山庄景区, 山庄公园, 山庄园林, 世界文化遗产承德避暑山庄, 避暑山庄世界遗产, 承德世界遗产, 承德世界文化遗产, UNESCO承德避暑山庄, 承德文化景观, 避暑山庄文化景观, 避暑山庄历史景观, 避暑山庄古迹, 避暑山庄风景区, 避暑山庄5A级景区, 避暑山庄著名景点, 避暑山庄游览区, 承德著名景点, 承德必去景点, 承德旅游景点, 承德地标建筑, 承德热门景区, 承德历史文化景区, 承德传统园林, 皇家园林避暑山庄, 中国皇家园林承德避暑山庄, 中国古典园林避暑山庄, 清代皇家园林避暑山庄, 避暑山庄皇家建筑群, 承德宫殿区, 承德园林建筑, 避暑山庄自然景观, 避暑山庄历史景观区, 避暑山庄建筑群, 避暑山庄山谷景观, 避暑山庄湖泊景观, 避暑山庄博物馆, 避暑山庄导览, 避暑山庄游览体验, 避暑山庄旅游攻略, 避暑山庄旅行分享, 避暑山庄游记, 避暑山庄旅游评价, 避暑山庄点评, 避暑山庄打卡, 避暑山庄游客体验, 避暑山庄旅游推荐, 避暑山庄热门景点合集, 避暑山庄门票评论, 避暑山庄游玩体验, 避暑山庄旅游照片, 避暑山庄旅拍, 避暑山庄旅行笔记, 避暑山庄景点合集, 避暑山庄观光, 避暑山庄攻略分享, 避暑山庄到此一游, 避暑山庄旅游日志。	Chengde Mountain Resort, Mountain Resort in Chengde, Chengde Imperial Summer Resort, Imperial Summer Resort of Chengde, Chengde Summer Palace, Chengde Royal Garden, Chengde Imperial Garden, Mountain Resort and Its Outlying Temples, Chengde World Heritage Site, Chengde UNESCO Site, UNESCO Chengde Mountain Resort, Imperial Summer Resort China, Qing Imperial Summer Resort, Mountain Resort Scenic Area Chengde, Chengde Heritage Site, Chengde Cultural Landscape, Chengde Historic Landscape, Chengde Garden Heritage, Chengde Royal Park, Chengde Classic Garden, Chinese Imperial Garden Chengde, Chengde Scenic Resort, Chengde Tourist Attraction, Chengde Travel Review, Visit Chengde Mountain Resort, Chengde Mountain Resort Tourism, Chengde Mountain Resort Trip Guide, Chengde Mountain Resort Travel Note, Chengde Mountain Resort Visitor Experience, Chengde Mountain Resort Reviews, Chengde Mountain Resort Photos, Chengde Mountain Resort Travel Blog

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TABLE APP. C.7 Keywords Used for Public Perception Data Retrieval of the CMR

Category	Chinese	English and Pin Yin
specific names of each scene	般若相, 北枕双峰, 碧峰寺, 碧静堂, 采菱渡, 沧浪屿, 敞晴斋, 畅远楼, 畅远台, 澄波叠翠, 澄观斋, 澄光室, 澄泉绕石, 创得斋, 锤峰落照, 春好轩, 翠云岩, 淡泊敬诚, 斗姥阁, 芳园居, 芳渚临流, 放鹤亭, 凤泉清听, 浮片玉, 福寿园, 莆田丛樾, 古俱亭, 观莲所, 观瀑亭, 广元宫, 含粹斋, 含青斋, 含润亭, 濠濮间想, 湖山画卷, 环碧, 汇万总春之庙, 积霞亭, 嘉树轩, 稼穡维艰, 鉴始斋, 戒得堂, 戒德堂, 金莲映日, 静舍太古山房, 静好堂, 静寄山房, 镜水云岑, 鹭云寺, 卷阿胜境, 旷观, 乐成阁, 乐亭, 冷香亭, 梨花伴月, 丽正门, 笠云亭, 临芳墅, 凌太虚, 龙王庙, 绿云楼, 南山积雪, 宁静斋, 暖流暄波, 萍香泮, 瀑源亭, 千尺雪, 勤政殿, 青枫绿屿, 青雀舫, 清晖亭, 清舒山馆, 清溪远流, 清音阁, 晴碧亭, 曲水荷香, 泉源石壁, 热河泉, 如意湖, 山近轩, 上帝阁, 石矶观鱼, 食蔗居, 试马埭, 双湖夹镜, 水芳岩秀, 水流云在, 水心榭, 水月庵, 四面云山, 四知书屋, 松鹤清樾, 松鹤斋, 素尚斋, 宿云檐, 坦坦荡荡, 天宇咸畅, 同福寺, 万壑松风, 万树园, 万岁照房, 望源亭, 文津阁, 文园狮子林, 无暑清凉, 西岭晨霞, 西所, 峡琴轩, 霞标, 仙苑昭灵, 香远益清, 写心精舍, 秀起堂, 岫云门, 驯鹿坡, 烟波致爽, 烟雨楼, 延薰山馆, 霁画窗, 一片云, 宜照斋, 颐志堂, 倚望楼, 吟红榭, 莺啭乔木, 莹心堂, 永恬居, 永佑寺, 涌翠岩, 有真意轩, 玉岑精舍, 玉琴轩, 远近泉声, 月色江声, 阅射门, 云帆月舫, 云容水态, 云山胜地, 施檀林, 长虹饮练, 芝径云堤, 知鱼矶, 珠源寺, 曦朝霞。	Ban Ruo Xiang, Beizhen Shuangfeng, Bifeng Si, Bijing Tang, Cailing Du, Canglang Yu, Changqing Zhai, Changyuan Lou, Changyuan Tai, Chengbo Diecui, Chengguan Zhai, Chengguang Shi, Chengquan Raoshi, Chuangde Zhai, Chuifeng Luo Zhao, Chunhao Xuan, Cuiyun Yan, Danbo Jingcheng, Doumou Ge, Fangyuan Ju, Fangzhu Linliu, Fanghe Ting, Fengquan Qingting, Fupian Yu, Fushou Yuan, Futian Congyue, Guju Ting, Guanlian Suo, Guanpu Ting, Guangyuan Gong, Hancui Zhai, Hanqing Zhai, Hanrun Ting, Haoqujian Xiang, Hushan Yanhua, Huanbi, Hui Wan Zongchun Zhi Miao, Jixia Ting, Jiashu Xuan, Jiase Weijian, Jianshi Zhai, Jiede Tang, Jede Tang, Jinlian Yingri, Jinghan Taigu Shanfang, Jinghao Tang, Jingji Shanfang, Jingshui Yuncen, Jiuyun Si, Juan'a Shengjing, Kuangguan, Lecheng Ge, Le Ting, Lengxiang Ting, Lihua Banyue, Lizheng Men, Liyun Ting, Linfang Shu, Ling Taixu, Longwang Miao, Luyun Lou, Nanshan Jixue, Ningjing Zhai, Nuanliu Xuanbo, Pingxiang Pan, Puyuan Ting, Qianchi Xue, Qinzhen Dian, Qingfeng Luyu, Qingque Fang, Qinghui Ting, Qingshu Shanguan, Qingxi Yuanliu, Qingyin Ge, Qingbi Ting, Qushui Hexiang, Quanyuan Shibi, Rehe Quan, Ruyi Hu, Shanjin Xuan, Shangdi Ge, Shiji Guanyu, Shizhe Ju, Shima Dai, Shuanghu Jiajing, Shuifang Yanxiu, Shuiliu Yunzai, Shuixin Xie, Shuiyue An, Simian Yunshan, Sizhi Shuwu, Songhe Qingyue, Songhe Zhai, Sushang Zhai, Suyun Yan, Tantan Dangdang, Tianyu Xianchang, Tongfu Si, Wanheng Songfeng, Wanshu Yuan, Wansui Zhaofang, Wangyuan Ting, Wenjin Ge, Wenyuan Shizilin, Wushu Qingliang, Xiling Chenxia, Xisuo, Xiaqin Xuan, Xiabiao, Xianyuan Zhaoling, Xiangyuan Yiqing, Xiexin Jingshe, Xiuqi Tang, Xiuyun Men, Xunlu Po, Yanbo Zhishuang, Yanyu Lou, Yanxun Shanguan, Yanhua Chuang, Yipian Yun, Yizhao Zhai, Yizhi Tang, Yiwang Lou, Yin Hong Xie, Yingzhuan Qiaomu, Yingxin Tang, Yongtian Ju, Yongyou Si, Yongcui Yan, You Zhenyi Xuan, Yucen Jingshe, Yuqin Xuan, Yuanjin Quansheng, Yuese Jiangsheng, Yueshe Men, Yunfan Yuefang, Yunrong Shuitai, Yunshan Shengdi, Zhantan Lin, Changhong Yinlian, Zhijing Yundi, Zhiyu Ji, Zhuyuan Si, Zhuchao Xia.

The table lists the bilingual keyword sets used for text retrieval and classification, including general case related names for the Chengde Mountain Resort and specific names of individual scenes in both Chinese and English or pinyin. These terms provide the lexical basis for identifying case relevant content and matching references to scenic units in the dataset (Table APP. C.7).

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Curriculum Vitae

An Undefined Curriculum Vitae

I hope this CV will allow its readers to discover an engaging story about me, rather than encounter another tedious template.

A curriculum vitae is more than a record of dates, places, positions, and achievements. A person is often formed in the spaces between these categories: through a journey far from home, an unexpected conversation, or a curiosity that quietly refuses to disappear.

1 A Story of Origins

I was born in Shandong, China, in 1997. From an early age, I was drawn to both art and nature. My given name happens to contain the Chinese characters *jing* and *sen*, meaning landscape and forest. Even now, I do not know whether this was merely a coincidence or a subtle kind of prophecy, as though landscape architecture had already been quietly written into my name before I truly understood what the discipline was.

2 A Story of Art

In 2014, I began my studies at the Central Academy of Fine Arts. There, I encountered not only landscape design, but also sculpture, traditional photography, experimental art, furniture, graphic design, visual language, and art history. The different forms of art seemed to have no fixed boundaries. To me, they were not separate rooms, but windows opening onto the world from different directions.

In 2018, I travelled to Italy for a period of study and exchange in Florence. In a city that seems almost to have been built by history itself, I returned to the study of general art theory and participated in renovation and research related to the works of Brunelleschi. This allowed me to experience directly that cultural heritage is a vessel through which ideas, techniques, beliefs, and ways of life are preserved.

At the same time, I became even more clearly aware of my attraction to Eastern aesthetics. Through comparison, I saw how different civilisations often resonate when confronting similar questions, while preserving irreplaceable qualities in their own forms of expression. I later participated in projects including the restoration of the Qianlong Garden at the Palace Museum and the conservation and renewal of modern gardens on Gulangyu. Chinese historical gardens and Western historical gardens often echo one another in their spatial order, conceptions of nature, and symbolic systems, yet approach time, boundaries, human intervention, and nature in entirely different ways.

I attempted to develop these observations from different perspectives in six academic papers. The process was fascinating. Questions began on the page and entered the site, then returned to the page after practice as new concepts and arguments. It was as though a work had been given two lives.

3 A Story of Science

It was only after arriving at TU Delft that I realised how science could give art a more precise and powerful language.

What truly influenced me was not only coursework and research, but also friends from many different disciplines. A friend in aerospace engineering described turbulence as an order approaching the Dao. It appears chaotic, yet contains hidden structures. A friend in civil engineering showed me that even an ordinary piece of wood contains mechanical relationships far more complex than its appearance suggests. A friend studying theoretical physics spoke of how, when formulas are pursued deeply enough, complexity can sometimes return to a simplicity suggestive of Zen. A friend in biochemistry helped me see how life continually maintains an elusive balance between systems and individual units, control and self organisation.

These conversations profoundly changed the way I think.

For this reason, I did not want my doctoral research to be shaped solely by vertical accumulation and technical iteration. I also wanted it to expand horizontally and accommodate a broader structure of knowledge. I gradually entered fields including historical archaeology, sociology, geography, ecology, art authentication, computer science, museology, urban physics, and econometrics. These disciplines were not simply assembled side by side. They corrected and supported one another through specific questions.

What pleases me is that the six papers I completed during my doctorate move in different directions: historical gardens, cultural heritage, environmental risk, public perception, spatial computing, artificial intelligence, and urban planning. They may appear dispersed, yet they ultimately return to the same question:

How might we live better on this planet, where human civilisation and nature are so closely intertwined?

4 The Story Continues

Today, my research continues to unfold between artistic intuition and scientific method. I use GIS, remote sensing, spatial statistics, machine learning, graph neural networks, and large language models to study cultural heritage, urban environments, landscape change, and climate adaptation. Yet technology, to me, has never been the final destination of research. What truly matters is whether it can help us see relationships previously overlooked, understand the causes behind complex change, and transform knowledge into actions that are more considered, more inclusive, and more imaginative.

I remain reluctant to define myself through a single fixed label, whether artist, designer, planner, researcher, or practitioner of computational science. Each of these identities is accurate, yet none is complete.

Perhaps what this CV truly seeks to record is not what I have already become, but how I continue to learn and how I seek to understand the same world in different ways.

A Landscape Approach to the Conservation and Development of Cultural Landscapes

Chengde Mountain Resort as a Case Study

Jingsen Lian

How can cultural landscapes be conserved and developed through the landscape approach?

This thesis argues that cultural landscapes can be conserved and developed through an integrated landscape approach that treats them as living systems. Heritage value emerges not only from monuments or scenic elements, but from the interaction of physical structures, ecological processes, historical layers, and social experience. In response to climate change and urban transformation, conservation must move beyond static object protection toward system evolution, long-term resilience and adaptive capacity.

The proposed landscape approach connects three components: landscape mapping, landscape planning, and landscape design. Landscape mapping characterizes long-term evolution, persistent spatial structures, and scene-level attributes through literature synthesis, digital reconstruction, clustering, and land-use analysis, using Chengde Mountain Resort as the case. Landscape planning integrates hazards, ecological sensitivity, expert knowledge, public perception, spatial relationships, and visitor movement. The Hazard–Ecology–Perception Landscape Planning (HEPLP) framework supports targeted zoning and governance, while the Perceptual–Spatial Landscape Planning Model (PSLPM) uses large language models, graph neural networks, and route optimization to reduce visitor pressure, improve perceptual coherence, and expand access to meaningful but overlooked scenes. Landscape design translates diagnosis and planning into operational actions. Design-based and cluster-specific toolkits support reversible construction, compatible material selection, stronger ecological connections, improved water retention, and more effective visitor allocation. The overall contribution is a coherent framework that connects historical understanding and resilience with implementable strategies for conservation and development.

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