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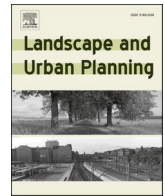
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Beyond scenic views: an integrative review of visual research on heritage landscapes—themes, methods, and typologies across scales

Yuyang Peng^a, Steffen Nijhuis^b, Zaichen Wu^{a,*}, Yingwen Yu^c

^a Department of Urbanism, Delft University of Technology, Julianalaan 134, 2628 BL, the Netherlands

^b ZWFull professor of landscape-based urbanism, Department of Urbanism, Delft University of Technology, Julianalaan 134, 2628 BL, the Netherlands

^c Department of Architectural Engineering and Technology, Delft University of Technology, Julianalaan 134, 2628 BL, the Netherlands

HIGHLIGHTS

- Systematic review of 203 publications on visual research in heritage landscapes since 1995.
- Identifies 5 research themes, 15 core methods, and 13 landscape object types.
- Reveals fragmentation across themes, scales, object types, and method pipelines.
- Synthesizes theme–object–method patterns and underexplored directions.

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ABSTRACT

Visual landscape research on heritage landscapes has expanded rapidly since 1995, yet its themes, study objects, and methods remain dispersed across disciplinary traditions. This review synthesizes 203 peer-reviewed studies published between 1995 and 2025 using a three-layered analytical framework that combines thematic coding, VOSviewer-based keyword co-occurrence analysis, and exploratory cross-dimensional Sankey mapping. Thematic coding shows that the field is concentrated around analysis/evaluation and management/conservation themes, with study objects dominated by formally recognized and spatially bounded heritage landscapes and methods centered on perception-based empirical approaches, GIS-based analysis, digital documentation, mixed methods, and multi-criteria evaluation. Keyword co-occurrence and cross-dimensional mapping further show that these distributions are organized through recurring but uneven theme–object–method associations. Three gaps are especially evident: perceptual and spatial evidence are often weakly coupled; less formalized, everyday, hybrid, and cross-scalar heritage landscapes remain underrepresented; and visual evidence is inconsistently translated into assessment, planning, and management contexts. Based on these findings, the review develops a review-derived organizing synthesis that relates research themes, heritage landscape types and scales, and methodological approaches. This synthesis clarifies the current structure of visual heritage landscape research, identifies underexplored intersections, and provides a basis for more transparent comparison and future empirical work.

1. Introduction

Heritage landscapes embody accumulated aesthetic, cultural, ecological, and historical values (McDowell, 2016). These values are articulated not only through practices, meanings, and uses but also through spatial form and visual characteristics such as patterns, visibility, and the presence of structures (Zube & Pitt, 1981). Consequently, the visual dimension is prominent: spatial patterns, aesthetics, and

visibility shape how heritage is perceived, valued, and governed, informing conservation, designation, and public engagement (Garden, 2006; Liu et al., 2022). However, research on the visual dimension of heritage landscapes remains diffuse and weakly integrated; this paper consolidates dispersed studies and maps how research themes, methods, and landscape typologies have been organized across scales.

Taken together, these considerations support examining visual landscape research on heritage landscapes as a distinct focus within

* Corresponding author.

E-mail addresses: Y.Peng@tudelft.nl (Y. Peng), S.Nijhuis@tudelft.nl (S. Nijhuis), z.wu-4@tudelft.nl (Z. Wu), christinayu@tudelft.nl (Y. Yu).

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general visual landscape research. In heritage contexts, visual evidence is often connected to designation, impact assessment, protection governance, and policy-related concerns, and is interpreted through heritage-specific attributes such as integrity, authenticity, protected views, and traceability. This gives visual heritage landscape research a problem structure and methodological emphasis that differ from general visual landscape research (Deghati Najd et al., 2015; Nijhuis et al., 2011).

1.1. Heritage landscapes: definitions and the diversity of types and scales

Heritage landscapes have been defined in multiple ways, reflecting diverse disciplinary traditions and policy frameworks. Under the World Heritage Convention (UNESCO, 1992), cultural landscapes are described as “combined works of nature and humankind,” grouped into designed, organically evolved (continuing or relict), and associative types (Rössler, 2006). The European Landscape Convention (Council of Europe, 2000) adopts a broader formulation, defining landscape as “an area, as perceived by people,” whose character results from the interaction of natural and/or human factors. In this sense, landscape is a perceivable area (Bell, 2012; Zube & Pitt, 1981). The former provides a legal and administrative basis for inscription and monitoring, whereas the latter offers a conceptual and policy foundation for understanding landscape as a culturally recognized entity. Complementary scholarship has expanded this understanding. McDowell (2016) views heritage as an accumulated record of cultural and ecological processes over time. Tengberg et al. (2012) emphasize heritage as a source of cultural ecosystem services (CES), including aesthetics, identity, and spirituality. Heras et al. (2019) focus on governance and the integration of expert and community perspectives. Approaches such as the *Historic Urban Landscape* (UNESCO, 2011) and the *Faro Convention* (Council of Europe, 2005) extend attention from formally designated sites to landscapes shaped by social practices and community values. More recently, researchers have drawn attention to “everyday,” vernacular, or ordinary heritage landscapes that may lack formal designation but are meaningful to communities through identity, memory, and belonging (Jones, 2016; Waterton & Watson, 2010).

For the purposes of this review, heritage landscapes are identified through the way they are framed in the reviewed literature: either through formal designation or through documented recognition by heritage communities. Formal designation, whether at UNESCO, national, regional, or local level, indicates institutional recognition rather than a direct hierarchy or measure of heritage value (Deacon & Smeets, 2013; Fredheim & Khalaf, 2016). Recognition by heritage communities refers here to documented collective recognition of specific landscape attributes, practices, associations, or meanings as heritage, rather than residence, use, scenic preference, or popularity alone (Arriaza et al., 2004; Deacon & Smeets, 2013). Such recognition may involve resident, descendant, religious, ethnic, Indigenous, traditional-user, or custodial groups, but current residence is neither a necessary nor a sufficient condition. Across both pathways, attributes such as integrity, authenticity, historical continuity, setting, and associative meanings remain central to how heritage significance is documented and compared (Australia ICOMOS, 2013; Stephenson, 2008).

Within this scope, natural or mixed landscapes are included only where the literature frames them through heritage-related meanings, values, designation, recognition, valuation, assessment, conservation, or visual management concerns. Because value indicators differ across cultural, natural, and mixed heritage landscapes, designation level, visitor numbers, scenic quality, and popularity are not treated as universal proxies for heritage value. This formal-designation/documentated heritage-community recognition pathway constitutes the operational basis for literature selection and coding in subsequent analyses, ensuring consistent use of the term “heritage landscape.” Given the contested nature of definitions and the stance adopted here, the corpus reviewed spans a wide range of heritage landscape types and spatial scales.

In addition, this review is explicitly situated within the heritage-landscape domain. While it borrows concepts and tools from environmental and spatial planning, its scope is heritage-specific, calibrated to attributes such as integrity, authenticity, protected views, setting, visual relationships, and traceable heritage recognition, and it does not aim to generalize to environmental planning at large. The corpus, therefore, centers on studies in which visual evidence is connected to heritage designation, recognition, valuation, assessment, conservation, or management, including cases where natural settings are part of heritage significance. This breadth also has methodological implications: methodological pathways and data choices tend to align with particular types and scales, leading to dispersed and partially siloed practices that this study seeks to synthesize (López Sánchez et al., 2020; Pintossi et al., 2021).

1.2. Visual dimensions of heritage landscapes: perception, representation, and heritage value

Although heritage landscapes vary widely, the ways in which their heritage value is recognized are closely tied to perception, representation, and interpretation. In landscape contexts, historical meaning, place identity, and cultural significance are often conveyed through visible spatial relations such as setting, views, skyline, landmark relations, and spatial composition. Heritage scholarship has long argued that heritage is not simply inherent in objects or places, but is shaped through processes of social recognition, narration, and institutionalization. The Faro Convention expresses this clearly by emphasizing that what matters is not objects and places “in themselves,” but the meanings and values people attach to them (Council of Europe, 2005). In a similar vein, values-based heritage research has framed heritage as a social construct, formed through the attribution, negotiation, and application of value (Fredheim & Khalaf, 2016; Poullos, 2010; Walter, 2014).

Seen in this light, visual dimensions are important because visual perception and representation help shape how heritage value is understood and communicated. Studies of heritage representation suggest that visibility extends beyond surface appearance, as images, ways of seeing, and narrative frames influence what is noticed, remembered, and recognized as heritage (Waterton, 2009; Waterton & Watson, 2010; Watson & Waterton, 2010). Landscape research further indicates that value should not be reduced to visible form alone, since landscape values emerge through the interaction of forms, relationships, and practices over time and may include aesthetic, identity-related, spiritual, and cultural meanings (Stephenson, 2008; Tengberg et al., 2012). Visuality, then, can be understood as an important medium through which heritage value becomes perceptible and communicable, while also foregrounding some meanings and viewpoints more readily than others (Avrami et al., 2019; Waterton & Watson, 2010).

In heritage practice, values are often expressed and managed through attributes such as form and design, location and setting, spirit and feeling, views, and wider setting. This makes it useful to consider how visual landscape research can support the identification, interpretation, and application of such information in heritage assessment, planning, and management (ICOMOS, 2011, UNESCO, 2011, UNESCO, 2025).

1.3. Visual landscape research: diversity of methods and data

To investigate the visual dimensions of heritage landscapes, it is useful to draw on the broader field of visual landscape research, which offers a mature and interdisciplinary body of methods, concepts, and data sources (Cortésão et al., 2020; Zhang et al., 2023). Visual landscape research underpins landscape planning and related practice and brings together perspectives from landscape architecture, urban planning and design, geography, environmental psychology, sociology, and environmental ethics (Gobster et al., 2019; Khan et al., 2022; Nijhuis et al., 2011). Although theories, research strategies, and applications vary

across these traditions (Fig. 1), the field provides a common basis for examining how landscapes are perceived, represented, evaluated, and managed.

Within this field, research has developed along several interrelated directions. Spatial analysis, often rooted in geographic information science, examines visibility, spatial composition, and landscape change through techniques such as viewshed modeling, landscape metrics, and geo-visualization (Liu & Nijhuis, 2020). Human-centered landscape perception research explores how people perceive, interpret, and respond to landscapes through surveys, interviews, participatory mapping, and experimental tools such as street-view imagery, eye tracking, and immersive media (Dupont et al., 2015). Planning, design, and management-oriented approaches translate visual evidence into rules, guidelines, and interventions, including view-corridor control, buffer

zoning, visual sensitivity mapping, and scenario testing (Arriaza et al., 2004; López Sánchez et al., 2020; Wu et al., 2026). These directions are often combined, for example by linking perception studies with spatial indicators or integrating participatory inputs with GIS-based evaluation (Zeng et al., 2024).

This methodological diversity is matched by a wide range of data sources. GIS-based approaches may draw on DEMs (Digital Elevation Models), satellite and aerial imagery, historical maps, and street-view imagery. Perception studies may incorporate questionnaires, interviews, participatory inputs, eye-movement data, and other physiological measures. Planning and design workflows often employ multi-criteria evaluation, risk assessment, and scenario-based methods. Data also vary considerably in source and precision, ranging from archival materials and survey responses to point clouds, photogrammetry, and

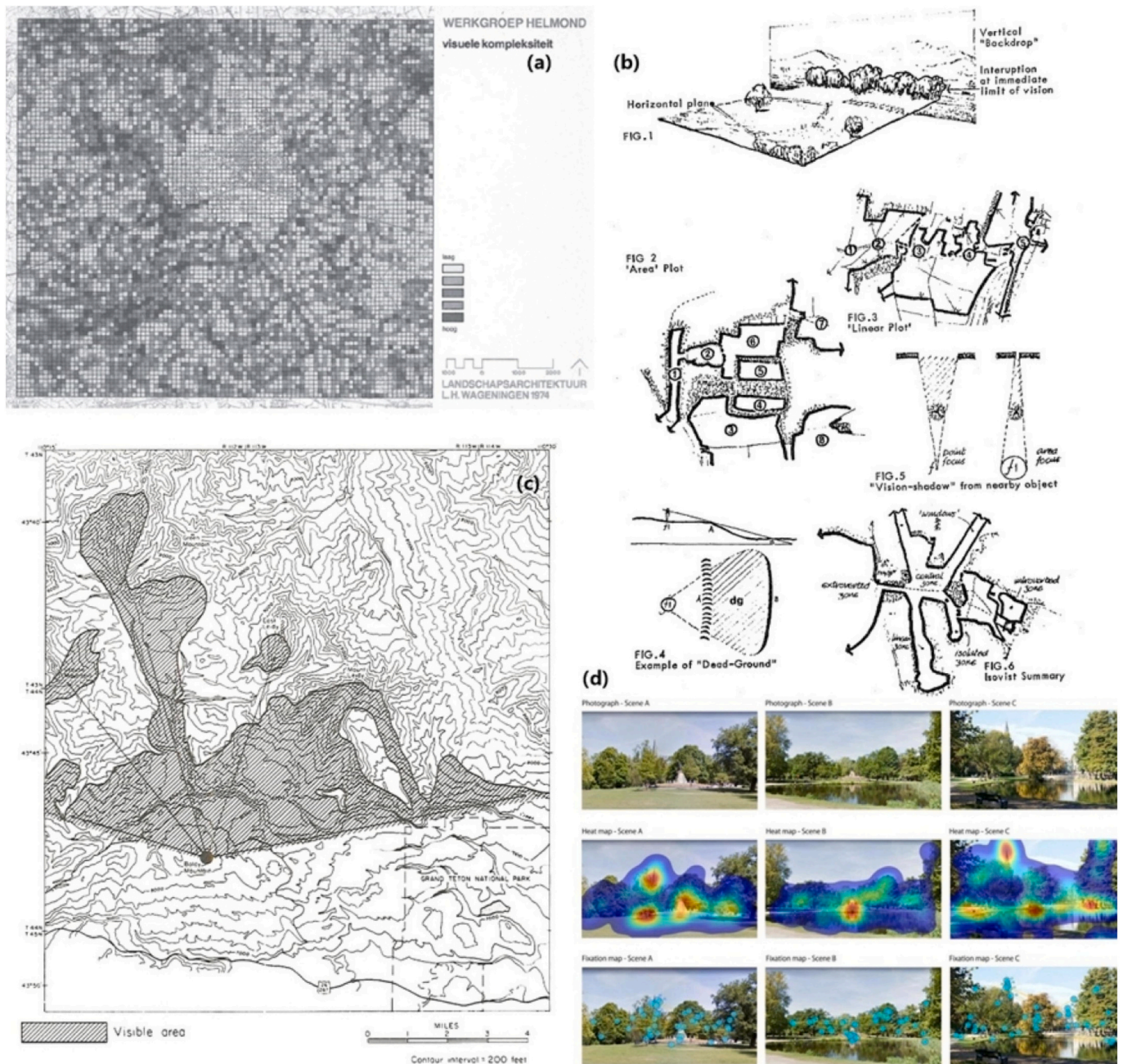


Fig. 1. The long-standing tradition and methodological diversity in visual landscape research: (a) an early example of GIS-based raster analysis in landscape characterization (Kerkstra, 1974); (b) a schematic example of spatial-visual analysis (Lynch, 1976); (c) an early isovist application for landscape visibility assessment (Tandy, 1967); (d) an example of eye-tracking technology used to capture visual perception behaviors in landscape contexts (Liu & Nijhuis, 2020).

national LiDAR repositories. This diversity expands analytical possibilities, but it also contributes to methodological heterogeneity, especially in heritage landscapes, which vary markedly in type, scale, designation status, and value emphasis (Ginzarly & Teller, 2018; Zhang & Zou, 2022). For this reason, visual landscape research merits closer discussion here, particularly in relation to how its methods have been adapted and applied in heritage landscape contexts.

1.4. Research gap and objective

Therefore, the research gap is clear: the blurred definitional boundaries of “heritage landscape,” the diversity and cross-scalar nature of research objects, and the variety and disciplinary needs or preferences of methods have produced a non-uniform and fragmented landscape of visual analysis and management in heritage landscape contexts. This heterogeneity is partly inherent to the objects of study and partly reflects broader differences in heritage meanings, value systems, legal frameworks, politics, and governance. In heritage practice, such fragmentation may make it harder to compare cases, trace how visual evidence is generated and interpreted, and translate findings across scales and institutional contexts (López Sánchez et al., 2020; Zube & Pitt, 1981). It also makes it more difficult to clarify which visual attributes are being addressed, how different forms of evidence are generated and compared, and how such evidence is translated into planning, assessment, and management decisions. In this sense, the gap is methodological and conceptual, with practical implications for evidence use in assessment, planning, and management.

Against this background, this paper systematically reviews the literature on visual landscape research in heritage landscape contexts in order to clarify the field’s main themes, objects, methods, and interrelationships, and to examine how its diversity affects evidence integration and potential application in assessment, planning, and management. The review is guided by the following research questions: (RQ1) What are the main research themes and emphases in visual

heritage landscape research? (RQ2) What heritage landscape types and spatial scales have been studied as research objects? (RQ3) What methods, tools, and data have been used? (RQ4) How are research themes, study objects, and methodological approaches associated across the reviewed literature? (RQ5) What gaps and emerging directions characterize the organization and integration of visual evidence in visual heritage landscape research?

This paper is structured as follows. The Methods section outlines the literature selection criteria and the analytical framework used in this review. The Results section addresses RQ1–RQ4 by presenting findings on research themes, study objects, methods, and their cross-dimensional associations. The Discussion section responds to RQ5 by examining gaps and emerging directions in visual heritage landscape research. Taken together, the paper makes two review-based contributions: (a) it synthesizes fragmented visual landscape research in heritage contexts by clarifying current themes, study objects, methods, and gaps; and (b) it develops an organizing synthesis that relates research themes, heritage landscape types and scales, and methodological approaches.

2. Methods

We conducted a systematic review following PRISMA (PRISMA Executive, 2020) guidelines to identify and analyze visual landscape research within heritage landscape contexts. The protocol was not pre-registered. Searches were performed in Web of Science (WoS) and Scopus for records published between 1995 and 10 April 2025. This review followed a three-stage analytical process (Fig. 2): (a) literature retrieval using keyword combinations to capture the relevant corpus across disciplines; (b) screening via the PRISMA framework to enforce consistent inclusion/exclusion rules; and (c) multi-layer analysis involving coding, bibliometric mapping, and cross-dimensional synthesis to construct a structured knowledge map, expose deep regularities and trajectories, and integrate insights across perspectives and scales.

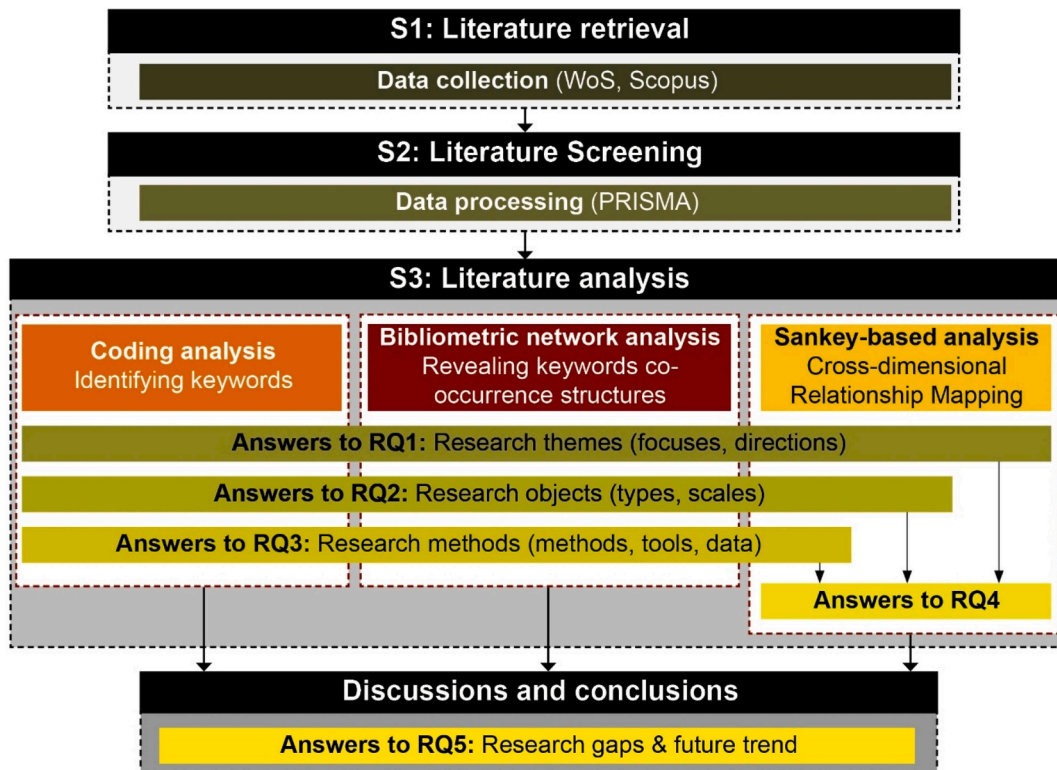


Fig. 2. Multimethod analytical framework for reviewing visual landscape research in heritage landscape contexts: Arrows indicate the analytical sequence from literature retrieval and screening to coding, bibliometric mapping, Sankey-based mapping, and synthesis.

2.1. Literature retrieval

We searched WoS Core Collection (SCI-EXPANDED, SSCI, A&HCI, ESCI) and Scopus for records published between 1995 and 10 April 2025, with the last search conducted on 9 October 2025. These databases together provide comprehensive coverage across the natural sciences, social sciences, and humanities. The search strategy targeted two core themes: “heritage landscapes” and “visual landscape research.” The latter was divided into (a) visual analysis and evaluation (including GIS-based and perception-based methods) and (b) visual management, planning, and design (Nijhuis et al., 2011). Based on these dimensions, three keyword groups were constructed and combined as follows:

- (a) **(a) Heritage landscape:** TS (TITLE-ABS-KEY) 1 = (“heritage NEAR/1 landscape*” OR “cultural landscape*” OR “historic* NEAR/1 landscape*” OR “traditional landscape*” OR “heritage site*” OR “historic site*” OR “historic environment*” OR “historic* NEAR/1 garden*” OR “historic* NEAR/1 park” OR “heritage* NEAR/1 garden*”);
- (b) **(b) Visual analysis:** TS (TITLE-ABS-KEY) 2 = (“visual analysis” OR “visual NEAR/1 spatial analysis*” OR “visual attribute*” OR “spatial attribute*” OR “visual NEAR/1 spatial characteristic*” OR “visual characteristic*” OR “perceptual analysis” OR “visibility analysis” OR “landscape perception” OR “aesthetic value” OR “visual NEAR/1 evaluation*” OR “visual NEAR/1 assessment*”);
- (c) **(c) Visual management:** TS (TITLE-ABS-KEY) 3 = (“landscape NEAR/1 design” OR “landscape” NEAR/1 “plan” OR “manag* AND visual”);
- (d) **(d) The combination:** (TS1) AND ((TS2) OR (TS3)).

Before finalizing the query, we conducted a brief search calibration

step using eight widely recognized works as validation anchors. We iteratively adjusted Boolean/proximity operators until the finalized strings automatically retrieved all eligible anchors, thereby checking sensitivity without using them as seeds. We did not systematically search grey literature (e.g., theses, technical reports, design briefs, management plans), and we excluded practice-based case files not published in peer-reviewed venues (e.g., Visual Impact Assessment, Visual Resource Management, Environmental Impact Assessment case documentation) to ensure indexing consistency and methodological comparability. In addition, this review does not cover general environmental planning and includes studies only when heritage is the central research object. In line with Section 1.1, we applied a strict heritage × method criterion (including scenic beauty evaluating methods) to ensure replicability, acknowledging that this may omit studies addressing heritage values without explicit heritage terminology; visual landscape studies outside heritage contexts were excluded.

2.2. Literature screening

Following PRISMA 2020 guidelines (Page et al., 2021), the screening involved two stages: title/abstract review and full-text assessment (Fig. 3). Two reviewers independently screened records at both stages (titles/abstracts and full texts) after a brief calibration to align criteria; disagreements were resolved by discussion. After removing 285 duplicates from the 630 records retrieved from WoS and Scopus (by EndNote), a total of 345 unique records were retained. In the first stage, titles and abstracts were reviewed to determine basic relevance. Records were excluded if they (a) were not published in English or (b) did not address either heritage landscapes or visual landscape research as a primary focus. In the second stage, full texts of the remaining records were assessed against more detailed inclusion criteria. Exclusions at this

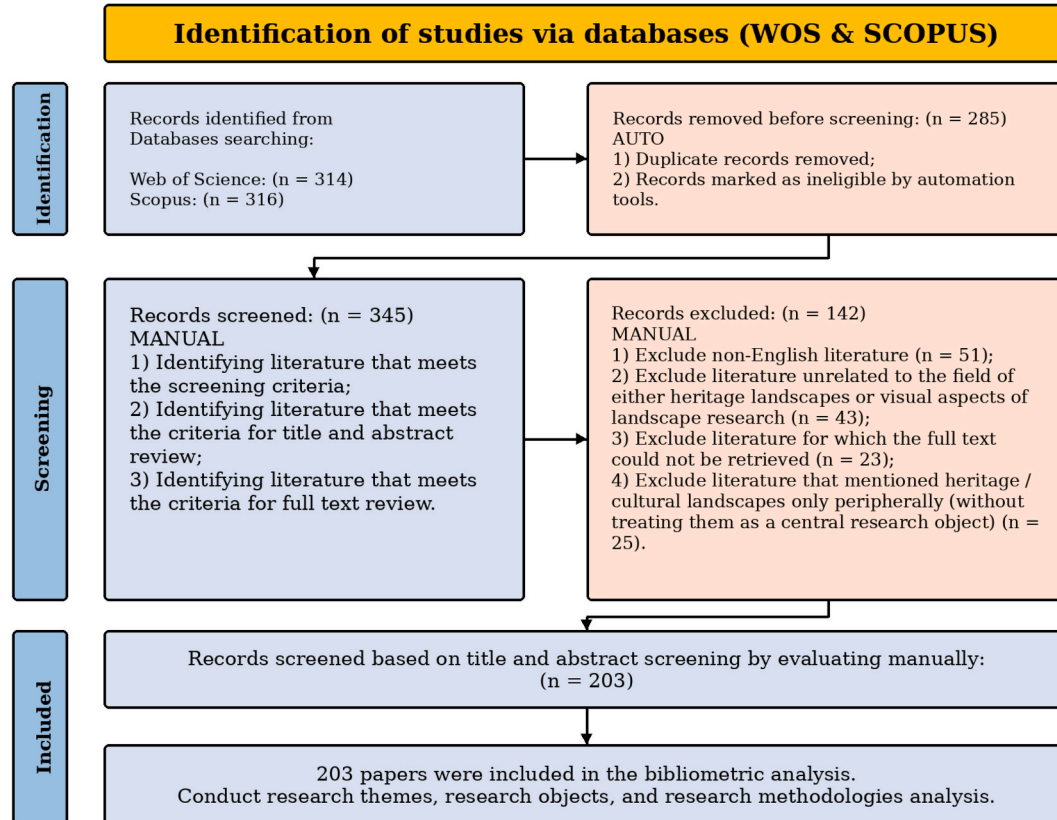


Fig. 3. The workflow of PRISMA: Selecting 203 literature from the 630 records. Blue boxes indicate retained records and screening/inclusion stages, orange boxes indicate removals or exclusions, and arrows indicate the filtering sequence. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

stage included documents that: (a) lacked full-text access (e.g., abstract-only); (b) mentioned heritage or cultural landscapes only peripherally (without treating them as a central research object); (c) did not engage with visual characteristics through methodological discussion, evaluation, or planning and design strategies; or (d) examined visual or scenic qualities of natural settings without explicitly framing them in relation to heritage designation, recognition, valuation, or management.

After applying these criteria, 203 documents were selected for further analysis. The final dataset includes peer-reviewed journal articles, conference proceedings, and academic book chapters that met both thematic and methodological relevance requirements.

2.3. Coding and reliability

We analyzed the 203 studies using a hierarchical codebook aligned with three analytical dimensions (hierarchical structures are reported in the Results): (a) research themes, (b) research objects (heritage landscape types and spatial scales), and (c) methodological approaches (methods, tools, and data). The initial codebook was drafted from a scoping review and piloted on a small subset. Two coders then independently applied it to all studies. To balance stability and openness, coders could add sub-codes under existing higher-level categories when novel terms appeared; when a potential new top-level category emerged, coding was temporarily paused for a joint decision on creation vs. merger. After independent coding, item-level discrepancies were reconciled by discussion. For frequency reporting, each publication was assigned a primary code within each analytical dimension or sub-dimension. When a study involved multiple themes, landscape types/scales, or methods, the primary code reflected the central research aim, main research object, or main source of analytical evidence, respectively. Additional relevant codes were retained as secondary or combined codes in [Appendix A](#) to preserve nuance and support cross-dimensional interpretation. For methodological coding, a publication was coded as mixed methods when two or more method families were substantively integrated and no single method was clearly ancillary. Inter-coder reliability was assessed using Cohen's κ , which ranged from 0.64 to 0.85 across dimensions; detailed values for each dimension and subcategory are provided in [Appendix A \(Tables A1–A3\)](#).

2.4. Literature analysis

To understand the evolution and structure of visual landscape research for heritage landscapes, this paper employed a three-layered analytical framework ([Fig. 2](#)):

- (a) **Thematic coding layer with systematic content analysis:** Using the hierarchical codebook described in [Section 2.3](#), we extracted three dimensions for each study. This enabled a fine-grained thematic classification ([Onwuegbuzie et al., 2012](#)), offering insight into dominant topics, typological distributions, and methodological diversity. This layer directly responds to RQ1–RQ3.
- (b) **Conceptual network layer with bibliometric mapping:** We mapped term co-occurrences with VOSviewer ([van Eck & Waltman, 2010](#)) using default parameters (association-strength normalization, resolution = 1.0, minimum cluster size = 5) and binary counting. Terms appearing fewer than three times across the corpus were excluded. Before analysis, keywords were standardized and merged to remove lexical variation (plural/singular, British–American spelling, abbreviations vs. full terms). Clusters were generated algorithmically; layouts were exported to Pajek for clearer spatial separation and label readability. This post-processing affected only visualization, not cluster membership.
- (c) **Integrative mapping layer with cross-dimensional synthesis:** The cross-dimensional relationships were visualized through

Sankey diagrams, which mapped links among research themes, research objects, and research methods. This approach complements frequency-based or cluster-based summaries by highlighting recurring linkages and underrepresented pairings across dimensions. It provides an exploratory synthesized view of how different dimensions are associated within the research “landscape.”

This multi-tiered approach supports a structured account of how the field has developed and where integration remains limited.

3. Results

3.1. Preliminary analysis results

The preliminary bibliometric analysis serves to contextualize the more detailed thematic and methodological findings that follow. [Fig. 4a](#) shows the annual publication trend from 1995 to 2025. Publications remained sparse before 2010, followed by steady growth after 2011 and a sharp rise from 2019 onward, with cumulative outputs surpassing 200 by 2025. This trajectory reflects increasing scholarly attention to visual approaches in heritage contexts. [Fig. 4b](#) identifies journals with three or more relevant publications. *Sustainability*, *Land*, and *Landscape and Urban Planning* are the most active, indicating strong interdisciplinary links across sustainability, spatial planning, and heritage studies. Other frequent contributors—such as *Journal of Cultural Heritage*, *Heritage Science*, and *ISPRS International Journal of Geo-Information*—highlight the integration of geospatial technologies and cultural theory. The diversity of journals suggests growing visibility across environmental sciences, conservation, and digital humanities, particularly within open-access platforms. [Fig. 4c](#) maps the geographic distribution and collaboration network. China, Italy, the UK, and the US lead in publication volume and international linkage. European countries like Germany, Spain, and France form a dense collaborative cluster, while the UK, the US, and Australia constitute a second, English-speaking group. Emerging contributors such as Malaysia, Poland, and Lithuania also appear, indicating expanding global relevance.

3.2. Systematic coding of research dimensions

This section presents the results of systematic manual coding and directly addresses RQ1, RQ2, and RQ3. Unless otherwise stated, frequency counts in this section are based on one primary code per publication within each analytical dimension; source allocation and secondary or combined coding details are documented in [Appendix A](#). Five major research themes were identified; 15 categories of core research methods were recognized; and 13 heritage landscape types were distinguished across seven spatial scales ([Fig. 5](#)).

3.2.1. Research themes

Through systematic coding and thematic classification of the literature, 5 categories (18 sub-categories) of research themes are identified ([Table 1](#)):

- (a) **Analysis and evaluation of heritage (106 publications, 52.22%)** is the most prevalent theme. Within this category, *visual characterization and visual quality evaluation* (48 publications, 23.65%) constitute the dominant subtheme, emphasizing aesthetic and perceptual qualities of heritage landscapes. Other notable subthemes include *visual perception and well-being* (24 publications, 11.82%), focusing on psychological and emotional responses such as place attachment and mental health, along with heritage value assessment, environmental impact assessment, and landscape transformation, which span ecological, cultural, and social dimensions.

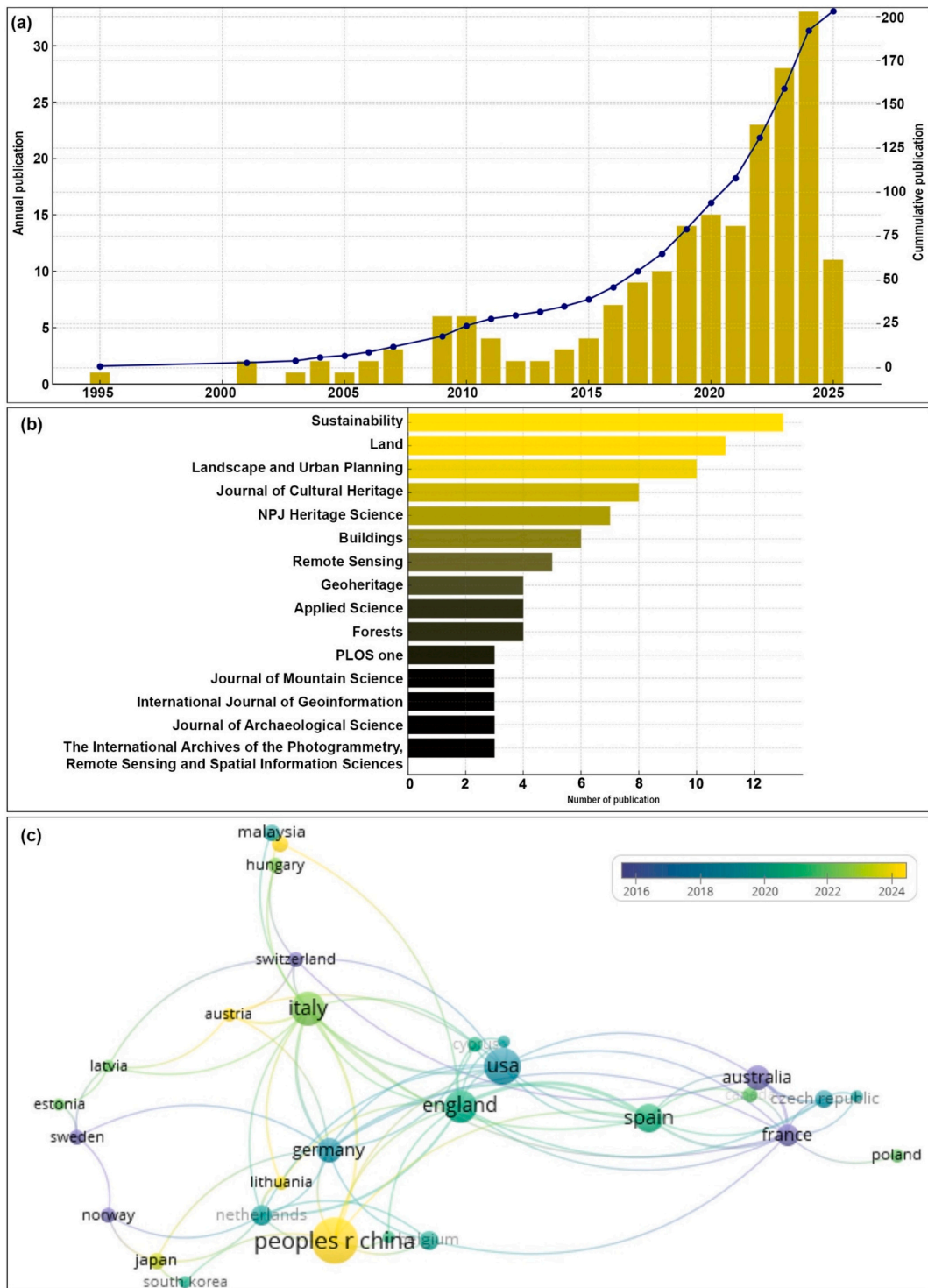


Fig. 4. Preliminary results of bibliometric analysis: (a) Temporal distribution of publications; bars indicate annual publication counts, and the line indicates cumulative publications. (b) Journals with more than three relevant articles; bar length indicates the number of publications. (c) Geographic distribution and collaboration network of contributing countries and regions; node size indicates publication volume, line thickness indicates collaboration strength, and colors indicate collaboration clusters.

(b) **Management and conservation of heritage (47 publications, 25.15%)** centers on *digital documentation and restoration* (33 publications, 16.26%). Additional subthemes include visual environment management (e.g., buffer zones, visibility control) and risk management, which address spatial regulation and vulnerability mitigation.

(c) **Development and sustainable use of heritage (24 publications, 11.82%)** explores the integration of heritage resources into contemporary societal functions, with emphases on heritage tourism, regional revitalization, and landscape planning. These studies reflect the growing interest in linking heritage with economic transition and spatial sustainability agendas.

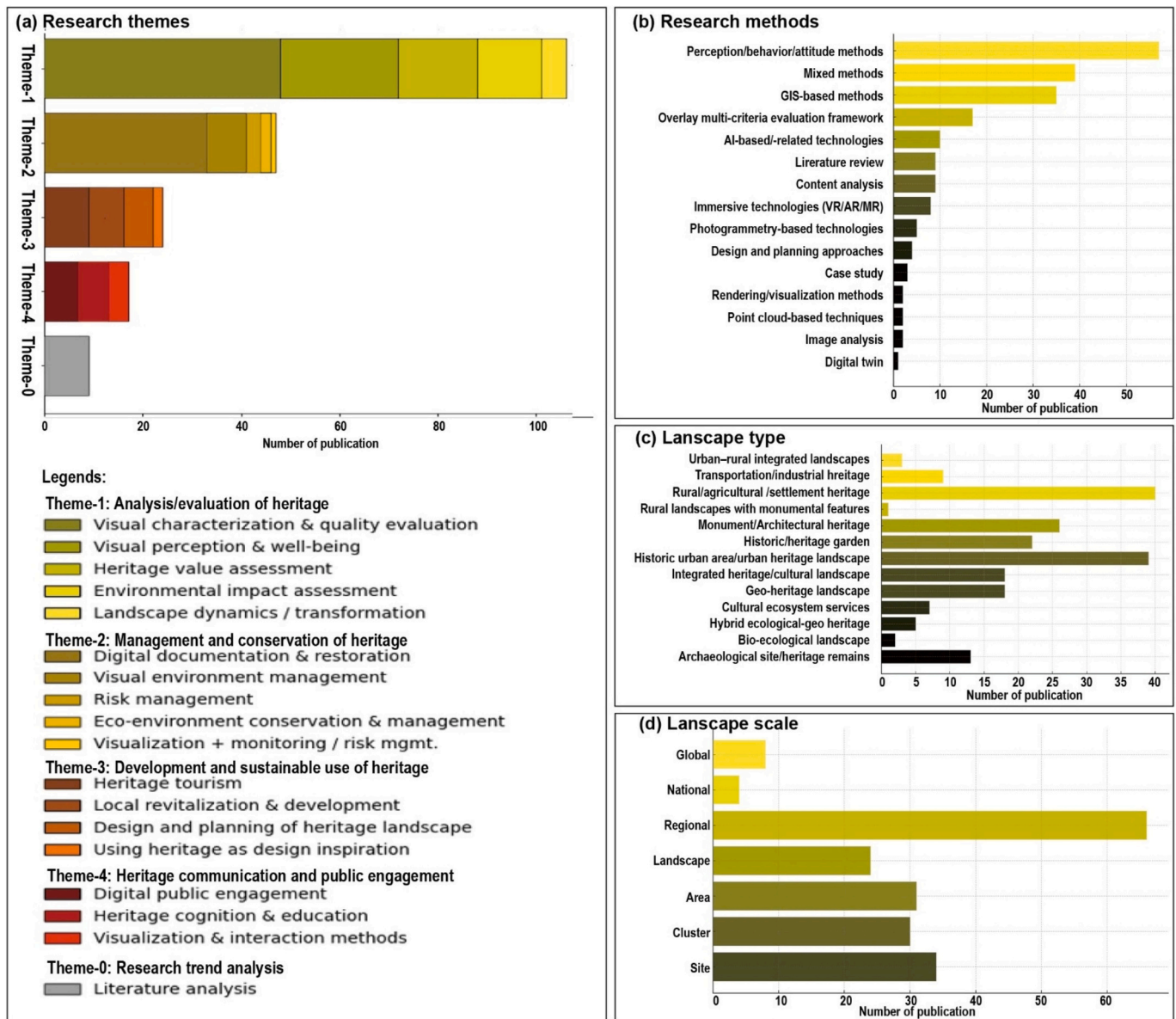


Fig. 5. Summary of bibliometric coding analysis: (a) Publication counts by research themes; (b) publication counts by research methods; (c)–(d) publication counts by research objects. Bar length indicates the number of publications. Colors distinguish coded categories or subcategories as shown in the legend.

(d) **Heritage communication and public engagement (17 publications, 8.37%)** covers themes such as digital participation, heritage education, and public engagement. Notably, *Visualization and interaction methods* (4 publications, 1.97%) represent an emerging subfield emphasizing immersive technologies.

(e) **Research trend analysis (9 publications, 4.43%)**, though useful for identifying gaps and frameworks, is relatively narrow, with most studies centered on karst geo-heritage (is dominated by contributions from China-based scholars).

3.2.2. Research objects

13 landscape types and 7 spatial scales have been identified across the reviewed literature, revealing both content preferences and spatial framing in visual heritage landscape research

(a) **Landscape types (Table 2):** The most frequently studied categories are *rural/agricultural/rural settlement landscapes* (40 publications, 19.70%) and *historic urban areas/urban heritage landscapes* (39, 19.21%), followed by *monuments/architectural*

heritage (26, 12.81%). Other common types include *historic/heritage gardens* (22, 10.84%), *geo-heritage landscapes* (18, 8.87%), and *integrated cultural landscapes* (18, 8.87%). These six types account for over two-thirds of the literature, reflecting a preference for tangible, visually prominent, and human-centered landscapes. Less represented types include *transportation/industrial heritage* (9, 4.43%), *cultural ecosystem service landscapes* (7, 3.45%), *hybrid ecological-geo heritage* (5, 2.46%), and *urban-rural integrated landscapes* (3, 1.48%). Rare categories, such as *rural landscapes with monumental features* or *bio-ecological heritage*, tend to lack clear spatial framing or fall outside the mainstream landscape types discussed in the literature.

(b) **Spatial scales (Table 3):** Seven spatial scales were identified in the reviewed literature. *Regional* scale is the most frequently applied (55 publications, 27.09%), commonly used in studies of rural, agricultural, and geo-heritage landscapes. *Cluster* (15.76%) and *site* scales (14.78%) are also prevalent, particularly in research focused on gardens, monuments, and architectural heritages. *Area* (12.32%) and *landscape* (9.85%) scales appear

Table 1
Summaries of research themes.

Categories	Examples of sub-categories	Amount	Percentage
Analysis and Evaluation of Heritage	Visual quality evaluation; visual perception and well-being; heritage value assessment; environmental impact assessment; landscape transformation	106	52.22%
Management and Conservation	(Digital) documentation and restoration; visual environment management; risk management	47	25.15%
Development and Sustainable Use	Heritage tourism; regional revitalization; design and planning of heritage landscapes; design applications	24	11.82%
Heritage communication and public engagement	Public participation; heritage education; visualization and interaction methods	17	8.37%
Research Trend Analysis	Literature analysis	9	4.43%

Note: A detailed table listing the literature sources associated with each sub-theme is provided in [Appendix A \(Table A1\)](#).

Table 2
Summaries of research objects' types.

Heritage landscape type	Amount	Percentage	Dominant scale(s) of this type
Rural/agricultural/Rural settlement landscapes	40	19.70%	Regional
Historic urban areas/urban heritage landscapes	39	19.21%	Area / Landscape
Monuments/architectural heritage	26	12.81%	Site / Cluster
Historic/heritage gardens	22	10.84%	Site / Cluster / Area
Geo-heritage landscapes	18	8.87%	Regional / Landscape
Cultural heritage landscapes (no specific type)	18	8.87%	Regional
Archaeological site/Heritage remains	13	6.40%	Site / Cluster / landscape
Transportation/industrial heritage	9	4.43%	Regional / Site / Landscape
Cultural ecosystem service	7	3.45%	Landscape / Regional
Bio-ecological and geo-heritage hybrids	5	2.46%	Cluster / Landscape / Regional
Urban-rural integrated heritage landscapes	3	1.48%	Regional
Bio-ecological heritage	2	0.99%	Regional
Rural heritage landscapes with monuments	1	0.49%	Cluster

Note: [Appendix A \(Table A2b\)](#) provides detailed definitions and references for these heritage landscape types.

with moderate frequency, reflecting intermediate spatial extents such as historic urban area. By contrast, *national* (2.46%) and *global* (1.97%) scales are rarely employed, and these instances primarily involve literature reviews or comparative *meta-analyses*, rather than site-based investigations.

In summary, current research is dominated by studies of spatially discrete, anthropocentric heritage types, particularly rural, urban and garden heritages, analyzed predominantly at site and regional scales ([Fig. 6](#)). Ecological-cultural hybrids and infrastructure-related heritage remain underexplored, suggesting potential for future diversification.

3.2.3. Research methods, tools, data

The analysis of 203 publications reveals 15 recurring method categories reported in the literature, spanning four methodological layers: (a) methodological approaches, (b) technologies and technical

Table 3
Summaries of research objects' spatial scales.

Scales	Amount	Percentage	Description
Site	34	16.75%	Single heritage elements (e.g., imperial garden, monumental building)
Cluster	31	15.27%	Grouped heritage features (e.g., architectural ensemble)
Area	30	14.78%	Urban or rural sections (e.g., historic urban core, historic community)
Landscape	25	12.32%	Visually or ecologically coherent landscape units (e.g., terraced agricultural landscape, historic town)
Regional	71	34.98%	Governance-defined zones often cover multiple landscape units (e.g., cultural heritage conservation buffer zone, large-scale traditional agricultural landscape)
National	4	1.97%	(Close to) Entire country spaces
Global	8	3.94%	Cross-country spaces

Note: [Appendix A \(Table A2\)](#) provides a detailed table listing the literature sources associated with each landscape type/scale.

workflows, (c) study designs, and (d) integration modes. [Table 4](#) summarizes the frequency of the methodological categories identified in the reviewed studies, whereas [Fig. 7](#) visualizes how these categories relate to representative tools and data types.

Among the (a) **methodological approaches**, *perception-based empirical methods* are the most frequently applied, accounting for 57 studies (28.08%). They remain foundational for examining visual perception, experiential response, and behavior in heritage landscapes. Common tools include surveys, interviews, participatory workshops, and field observations, while more recent studies also employ eye-tracking, physiological sensors, and immersive environments to capture attention and affect in greater detail. Some studies integrate geo-spatial participatory tools such as PPGIS, although PPGIS is treated here under perception-based empirical methods when it directly measures perception or behavior. *Multi-criteria evaluation frameworks*, reported in 17 studies (8.37%), link qualitative perception and quantitative spatial reasoning. Their applications include visual sensitivity mapping, heritage value assessment, risk analysis, and planning, often combining expert judgment, environmental indicators, perceptual surveys, and spatial overlays. *Content analysis*, found in 9 studies (4.43%), addresses discursive patterns, cultural narratives, and thematic structure by drawing on archival sources, user-generated content, and field documentation, increasingly with both manual and computational coding tools. *Design and planning approaches*, although less common (4 studies; 1.97%), provide applied perspectives through scenario building, co-design, and spatial prototyping.

A second layer consists of (b) **technologies and technical workflows**. *GIS-based technologies*, reported in 35 studies (17.24%), are the most prominent in this group. GIS supports spatial analysis of visibility, land use, terrain, and spatial relationships through viewshed analysis, spatial modeling, and overlay techniques, using inputs such as DEMs, satellite imagery, point clouds, and georeferenced historical maps. *AI-based technologies*, though still emerging (10 studies; 4.93%), extend analytical capacity through machine learning and deep learning for image classification, semantic segmentation, and content clustering, often within GIS or image-processing pipelines. *Immersive technologies* account for 8 studies (3.94%) and use VR, AR, and MR environments for experiential evaluation, participatory design, and interactive interpretation. *Photogrammetry-based techniques* (5 studies; 2.46%) and *point cloud-based techniques* (2 studies; 0.99%) are central to digital reconstruction, structural documentation, and high-resolution spatial analysis, and they increasingly converge in hybrid workflows for virtual preservation, building diagnostics, and interaction design. *Image analysis* (2 studies; 0.99%) focuses on visual metrics such as color measurement and segmentation, while *rendering/visualization/modeling* (2 studies; 0.99%) supports the communication and interpretation of spatial

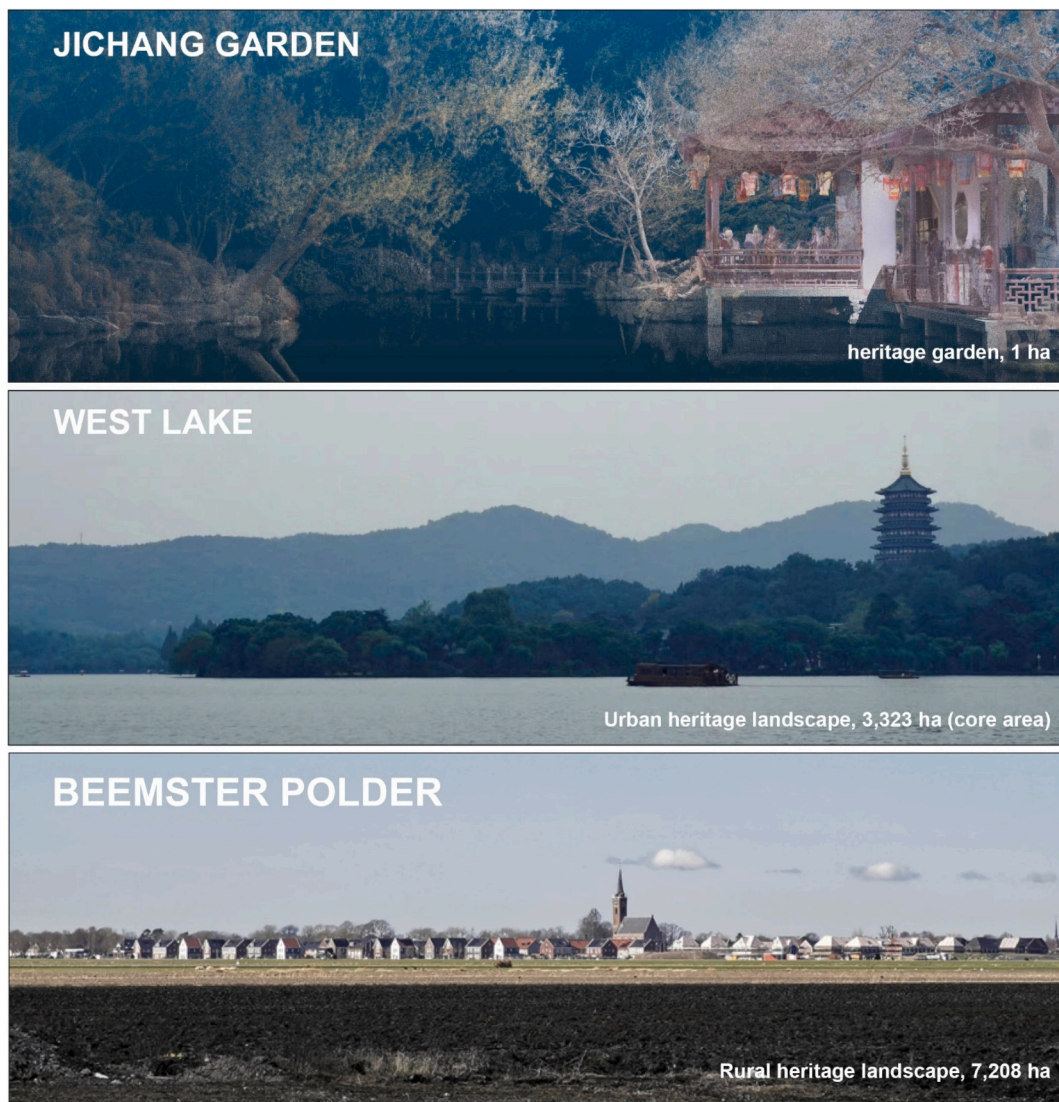


Fig. 6. Examples of diversity in heritage landscape types and spatial scales: (a) Jichang Garden, site scale, classical heritage garden; (b) West Lake, Hangzhou, landscape scale, urban heritage landscape; (c) Beemster Polder, regional scale, agricultural heritage landscape.

qualities through 3D mesh rendering, modeling platforms, and visualization pipelines. *Digital twin*, represented by 1 study (0.49%), links high-fidelity 3D models with real-time building or environmental data to support dynamic simulation, monitoring, and management.

A third layer concerns **(c) study designs**. *Literature review*, reported in 9 studies (4.43%), contributes synthetic perspectives on discursive trends, thematic evolution, and conceptual development, often using bibliographic databases, coding, and mapping tools such as CiteSpace or VOSviewer. *Case study*, reported in 3 studies (1.48%), provides grounded and context-specific inquiry, typically through field-based exploration and interview-driven analysis. Although these are not methods in the same sense as perception studies or GIS workflows, they shape how evidence is organized and interpreted within the field.

Finally, *mixed methods*, appearing in 39 publications (19.21%), represent an important **(d) integration mode** rather than a single standalone method. These studies combine methodological approaches, technologies, and datasets in different ways, including traditional + traditional (e.g., literature review and case study), digital + digital (e.g., GIS and AI), and, most commonly, traditional + digital (e.g., surveys with GIS or photogrammetry). Representative examples include perception-led workflows linking surveys or interviews with GIS viewshed or land-use overlays; documentation-to-experience pipelines

in which photogrammetry or point clouds generate 3D models later evaluated through VR or AR; and computation-to-interpretation loops connecting AI-based image or text analysis with GIS overlays and multi-criteria decision analysis.

This pattern suggests a broader move from relatively separate methodological strands toward more integrated combinations of approaches, technologies, and data sources. In this sense, traditional and emerging methods increasingly function not as isolated categories, but as interconnected components of multi-layered research designs.

3.3. Network visualization of conceptual structures

This section presents a bibliometric network analysis to complement the manual coding results by offering a macro-level view of conceptual linkages across the reviewed literature. Based on keyword co-occurrence extracted from titles, abstracts, and author-supplied terms, a network map was generated using VOSviewer (Fig. 8). Nodes represent keywords (scaled by frequency), and edges indicate co-occurrence strength. The analysis reveals how research themes, methods, and landscape types cluster, interrelate, and evolve. This section includes: **(a) cluster analysis**, **(b) interrelationships analysis**, and **(c) temporal analysis**.

Table 4

Summaries of core methods, tools, and data.

Methods	Amount	Percentage	Methodological layers
Perception-based empirical methods	57	28.08%	Methodological approaches
Multi-criteria evaluation frameworks	17	8.37%	
Content analysis	9	4.43%	
Design and planning approaches	4	1.97%	
GIS-based technologies*	35	17.24%	Technologies and technical workflows
AI-based technologies	10	4.93%	
Immersive technologies	8	3.94%	
Photogrammetry-based techniques	5	2.46%	
Point cloud-based techniques	2	0.99%	Study designs
Image analysis	2	0.99%	
Rendering/visualization/modeling	2	0.99%	
Digital twin	1	0.49%	
Literature review	9	4.43%	Integration mode
Case study	3	1.48%	
Mixed methods	39	19.21%	

Note: Counts report one primary method category per publication. [Appendix A \(Table A3\)](#) provides source allocation, supporting tool/data information, and the specific method combinations identified within mixed methods. Multi-method studies were counted as mixed methods when method families were substantively integrated. PPGIS and related participatory GIS approaches were coded according to their primary analytical role.

3.3.1. Clustering analysis

While [Section 3.2](#) summarized five concept-driven research themes derived from manual coding, this section presents data-driven clusters generated by keyword co-occurrence analysis. The two approaches operate at different analytical levels, reflecting semantic abstraction in the coded themes and lexical structure in the co-word network. They are not expected to fully coincide but rather to provide complementary perspectives: the co-word network reveals how research vocabulary is organized, whereas the coded themes capture how scholars conceptually frame their studies. The co-word network analysis identified 6 distinct keyword groups, each combining themes, methods, and landscape types, indicating thematic-methodological alignments and disciplinary boundaries ([Fig. 8a](#), [Fig. 9a](#)).

- (a) **The yellow cluster** is predominantly oriented toward the aesthetic and conservation dimensions of natural heritage. Core keywords such as *aesthetic value*, *conservation*, and *tourism development*, indicate a research focus on evaluating the visual and ecological qualities of scenic landscapes. Frequently studied types include *karst mountains*, *geo-heritage*, *natural heritage*, and *World Natural Heritage sites*. The primary methodological approach identified is Scenic Beauty Estimation ([Daniel & Boster, 1976](#)), a method rooted in forest landscape assessment and agency-supported visual management traditions, which enables structured visual assessment through standardized ratings provided by groups of observers.
- (b) **The purple cluster** emphasizes local communities and perceptual engagement with heritage landscapes. Central terms include *resident*, *local community*, *public*, *landscape perception*, and *behavior*, highlighting socio-cultural concerns in visual heritage landscape research. Perception-based empirical methods, like surveys, interviews, and participatory tools, are frequently used to examine experiential and behavioral responses, particularly in *traditional rural landscapes* and historic urban green spaces (*parks*).
- (c) **The green cluster** foregrounds the psychological and health-related benefits of heritage landscapes. Key terms include *place attachment*, *landscape preference*, *stress reduction*, *positive emotion*,

and *attention restoration*, indicating a research orientation toward the restorative function of heritage landscapes. Questionnaire-based, perception-based empirical methods dominate, with an emphasis on *urban heritage greenery* and *cultural eco-system service* that enhances well-being.

- (d) **The cyan cluster** focuses on land use dynamics and ecosystem-related functions. Frequent keywords such as *land use*, *urbanization*, and *ecosystem service* reflect concerns about environmental change and its visual-spatial impacts. Typical methods include *visual impact assessment* and *risk assessment*, often applied to *agricultural landscapes* and *geo-heritage sites* facing development pressures.
- (e) **The blue cluster** is associated with spatial pattern analysis and digital documentation. Prominent terms such as *pattern*, *documentation*, *point cloud*, *3D modeling*, and *photogrammetry* suggest a focus on high-resolution spatial data acquisition and visual structure mapping. This cluster typically addresses *historic gardens* and *architectural heritage*, where precision modeling supports documentation, conservation monitoring, and analysis of visual-spatial characteristics. These visual-spatial records become heritage-relevant when connected to historical evidence, cultural practices, community recognition, or management contexts.
- (f) **The red cluster** represents a technologically intensive strand of research that integrates advanced analytical tools with landscape planning and heritage transformation agendas. Core terms include *algorithm*, *deep learning*, *virtual reality*, *computer vision*, *landscape planning*, *urban renewal*, and *sustainable development*. This cluster reflects the growing incorporation of AI and immersive technologies into visual heritage landscape research, particularly for predictive modeling, interactive interpretation, and design support systems.

Overall, the keywords encompass a diverse range of landscape types, research methods, and thematic focuses, suggesting a seemingly balanced distribution. However, the methods employed and the types of heritage landscapes addressed vary significantly across clusters.

3.3.2. Interrelationships analysis

Beyond cluster patterns, the network analysis reveals structured relationships between research themes, methodological approaches, and heritage landscape types. Three key patterns are identified:

- (a) **Theme–method associations:** Different research themes correspond to distinct methodological tendencies. At the aggregate level, studies on aesthetic value employ multi-criteria analysis, perceptual evaluation, and empirical methods that involve expert judgment and public input ([Fig. 9b](#)), and they rarely combine these constructs with advanced documentation technologies. In contrast, photogrammetry-related studies concentrate on documentation, 3D modeling, and virtual reality, with limited attention to perceptual or experiential evidence at the aggregate level ([Fig. 9c](#)). This pattern indicates thematic differentiation in method use. Such associations should be interpreted as descriptive patterns rather than fixed methodological requirements. They may reflect research aims and data availability, but also method maturity, disciplinary training, institutional or funding traditions, and established assessment practices. The observed under-coupling is not inherently positive or negative; in some contexts, integration may reveal complementary insights, while in others, specialization remains appropriate for the research aims.
- (b) **Landscape types and method combinations:** Different heritage landscape types align with different clusters of methods, partly because their visual core characteristics are rooted in type-specific heritage attributes such as visual integrity and authenticity. In *historic gardens*, attributes like designed sightlines,

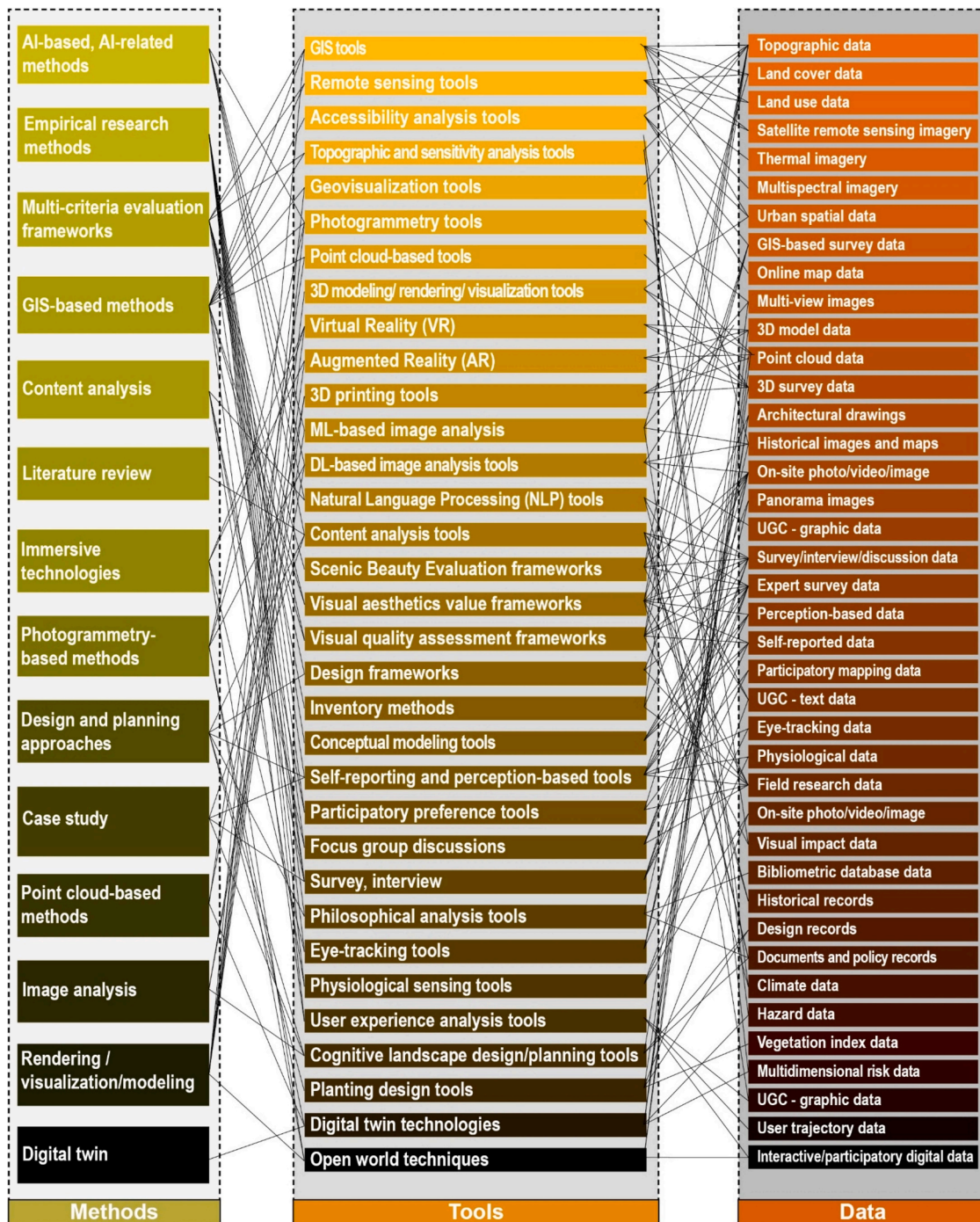


Fig. 7. Three levels of methodology: core methods–tools–data: The three columns represent method categories, associated tools, and data types. Connecting lines indicate observed method–tool–data links in the coded corpus. Colors distinguish the three levels and are used for visual grouping; line thickness does not indicate frequency. Details can be found in [Appendix A Table A3](#). An interactive online version is provided in Supplementary Material S1 to support clearer tracing of associated links.

composed vistas, and fine-grained material detail guide studies toward point-cloud documentation and 3D modeling or toward visual and behavioral assessment, with few combining the two in one workflow (Fig. 9d). In *historic districts*, attributes such as layered urban morphology, heterogeneous façades, and multiscale visibility encourage broader integrated frameworks that link perception, well-being, and place attachment with planning and sustainability (Fig. 9e). From a common-sense perspective, heritage assets are high-value by definition, which warrants using more than one method to disclose more facets of their visual-

spatial qualities. We therefore call for practice and research that systematically test this proposition, strengthening or falsifying the claim that integrated approaches deliver richer, more actionable insight.

- (c) **Bridging nodes across clusters:** Several keywords serve as conceptual bridges between otherwise distinct clusters. *Transformation* links perception studies with spatial documentation, while *visual assessment* connects psychological, ecological, and technological approaches. *Point cloud* spans traditional documentation and immersive visualization; *landscape planning*

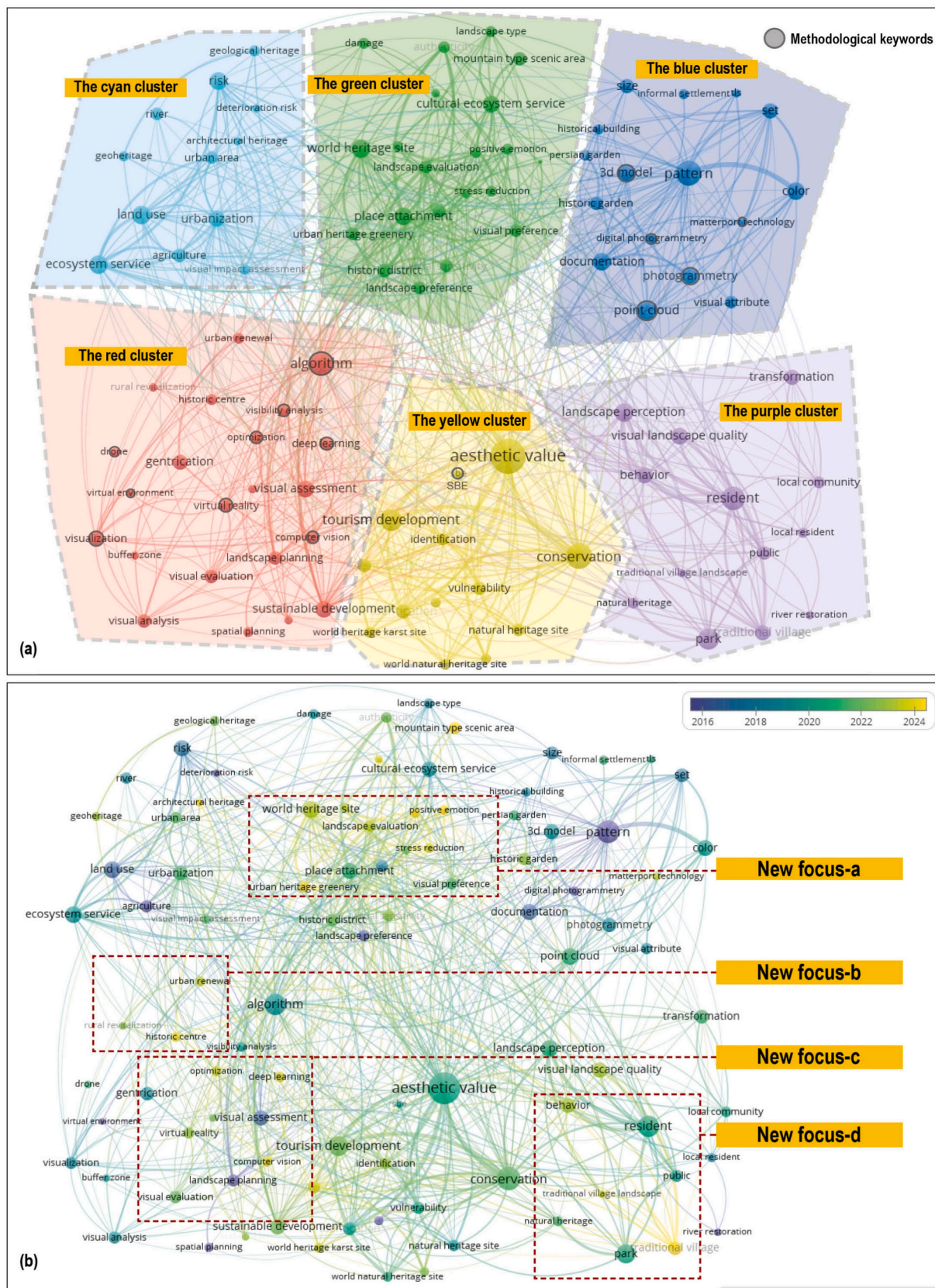


Fig. 8. Keyword co-occurrence network analysis-1: (a) Keyword clustering network. Node size indicates keyword frequency, edge thickness indicates co-occurrence strength, and colors indicate keyword clusters. Method-related keywords are highlighted with bold outlines, while other nodes refer to themes, landscape types, values, or objects. (b) Temporal overlay of keyword emergence. Node color indicates the average publication year, and dashed boxes mark emerging focus areas discussed in the text. An interactive online version is provided in Supplementary Material S2 to support clearer tracing of associated links.

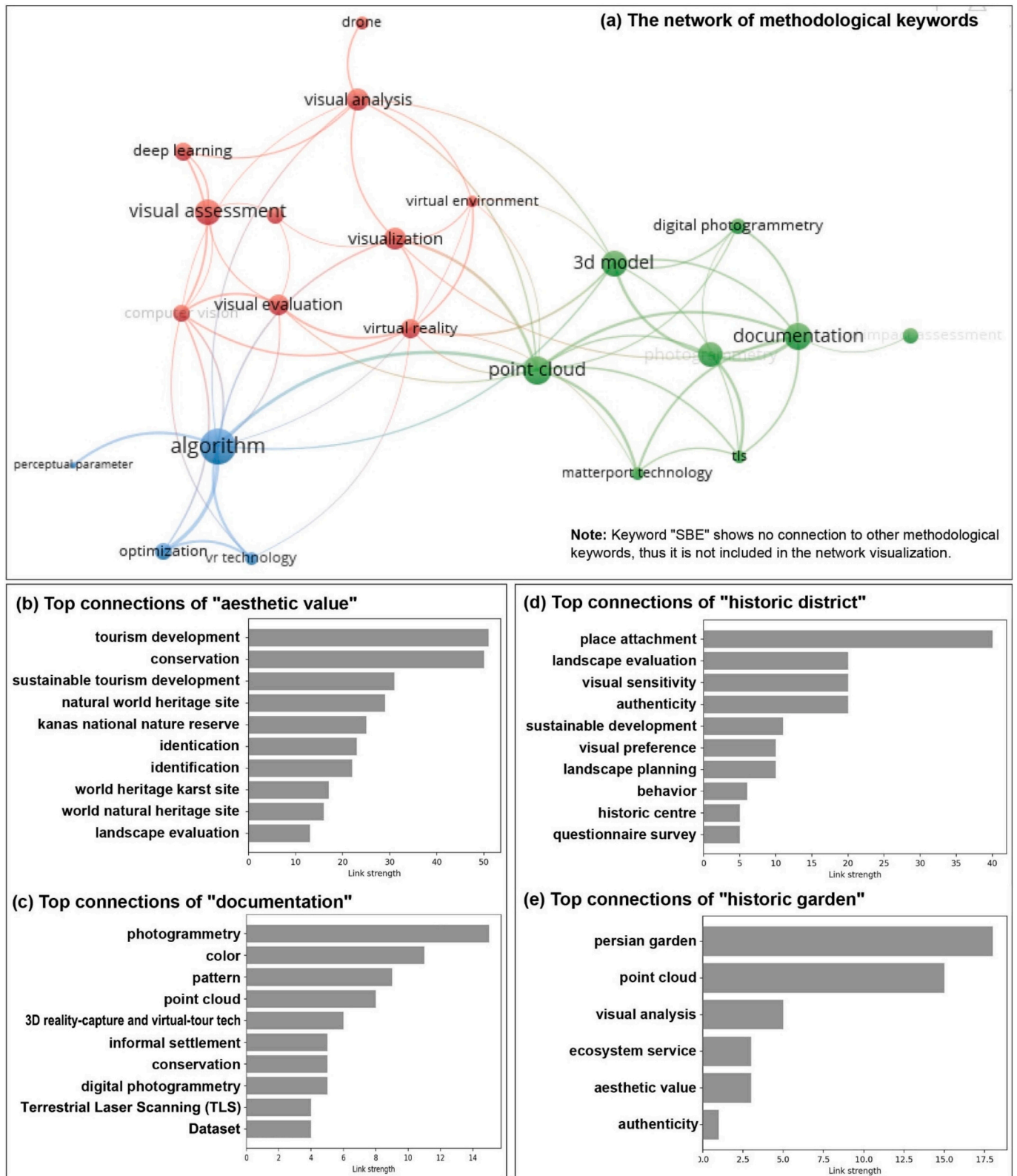


Fig. 9. Keyword co-occurrence network analysis-2: (a) Co-occurrence network of method-related keywords; node and label size indicate keyword frequency, edge thickness indicates co-occurrence strength, and colors distinguish clusters. (b)–(e) Top connections of selected keywords; bar length indicates link strength with the target keyword. TLS denotes terrestrial laser scanning.

connects participatory and spatial-analytical research. Terms like *perception* and *place attachment* cut across domains, reflecting shared concerns with emotion, identity, and renewal (Fig. 8a).

These patterns suggest that visual heritage landscape research, while showing signs of integration, remains partially fragmented. Thematic and methodological silos limit cross-domain understanding, yet bridging terms offer opportunities for hybridization. Such nodes could inform more cohesive, multidimensional frameworks linking perception, evaluation, documentation, and design.

3.3.3. Temporal analysis

The temporal keyword co-occurrence network (Fig. 8b), visualized via a color gradient from blue (earlier) to yellow (recent), reveals four emerging research focuses: **Focus-a** links *world heritage site*, *place attachment*, *urban heritage greenery*, *attention restoration*, and *positive emotion*, indicating interest in how green settings in heritage landscapes relate to well-being and attachment. **Focus-b** connects *urban renewal*, *historic center*, and *rural revitalization*, reflecting work on regeneration agendas in heritage contexts anchored in historic centers and their surrounding settlements. **Focus-c** centers on *deep learning*, *optimization*, *virtual reality*, and *computer vision*, signaling a technology-driven turn toward automated and immersive analysis pipelines for heritage landscape studies. **Focus groups** on *traditional village (landscape)*, *public (community)*, and *behavior*, foregrounding community-involved inquiry in traditional village settings and how public behavior intersects with

conservation aims.

In contrast, keywords like *pattern*, *documentation*, *land use*, *agriculture*, *visual assessment*, and *landscape planning* have maintained a stable presence, continuing to structure the core of the field. Interestingly, terms such as *digital photogrammetry* and *virtual environment* appeared relatively early but have yet to be widely adopted, despite their precision and immersive potential, indicating a gap between technological innovation and mainstream research uptake.

3.4. Mapping cross-dimensional associations

To complement the thematic (Section 3.2) and conceptual (Section 3.3) analyses, this section visualizes cross-dimensional associations among four core categories: heritage landscape types, spatial scales, research themes, and core methods. Based on the coded dataset, a Sankey diagram was constructed to show recurring pathways and underexplored pairings (Fig. 10). Rather than reflecting frequency alone, this visualization highlights the relative strength and distribution of linkages across dimensions, offering an exploratory structural perspective on how the field is composed and where integration is still limited.

(a) **Landscape types and research themes:** The flow between landscape types and research themes shows recurring emphases and structural differences (Fig. 11a). Three frequently studied landscape types, which broadly represent *regional*, *area*, and *site*

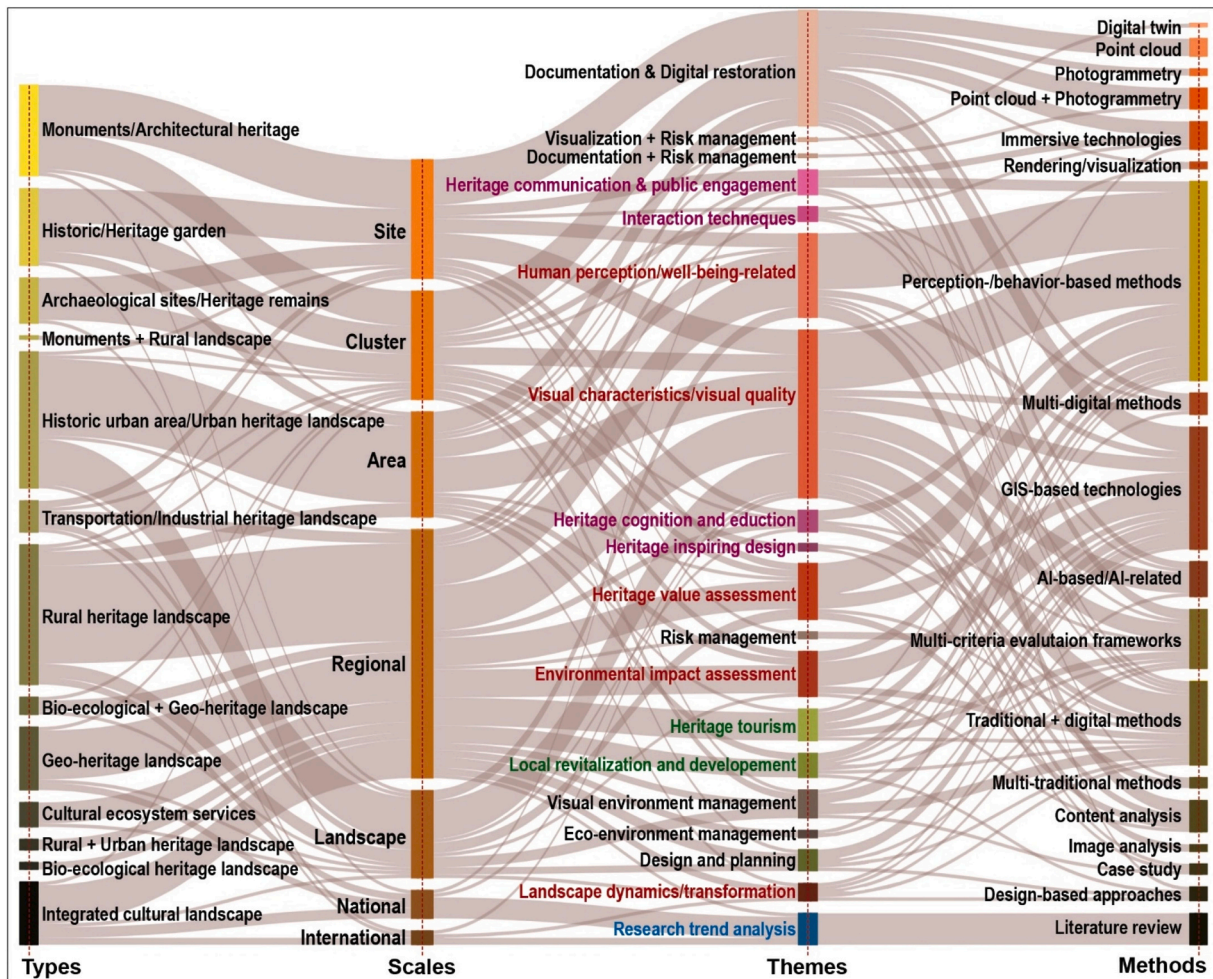


Fig. 10. Cross-dimensional associations based on Sankey mapping: Overall pathways from research objects to research themes and core methods. Node height indicates the number of coded publications in each category, and band width indicates the number of publications linking two categories. Colors distinguish analytical dimensions and category groups. An interactive online version is provided in Supplementary Material S3 to support clearer tracing of associated links.

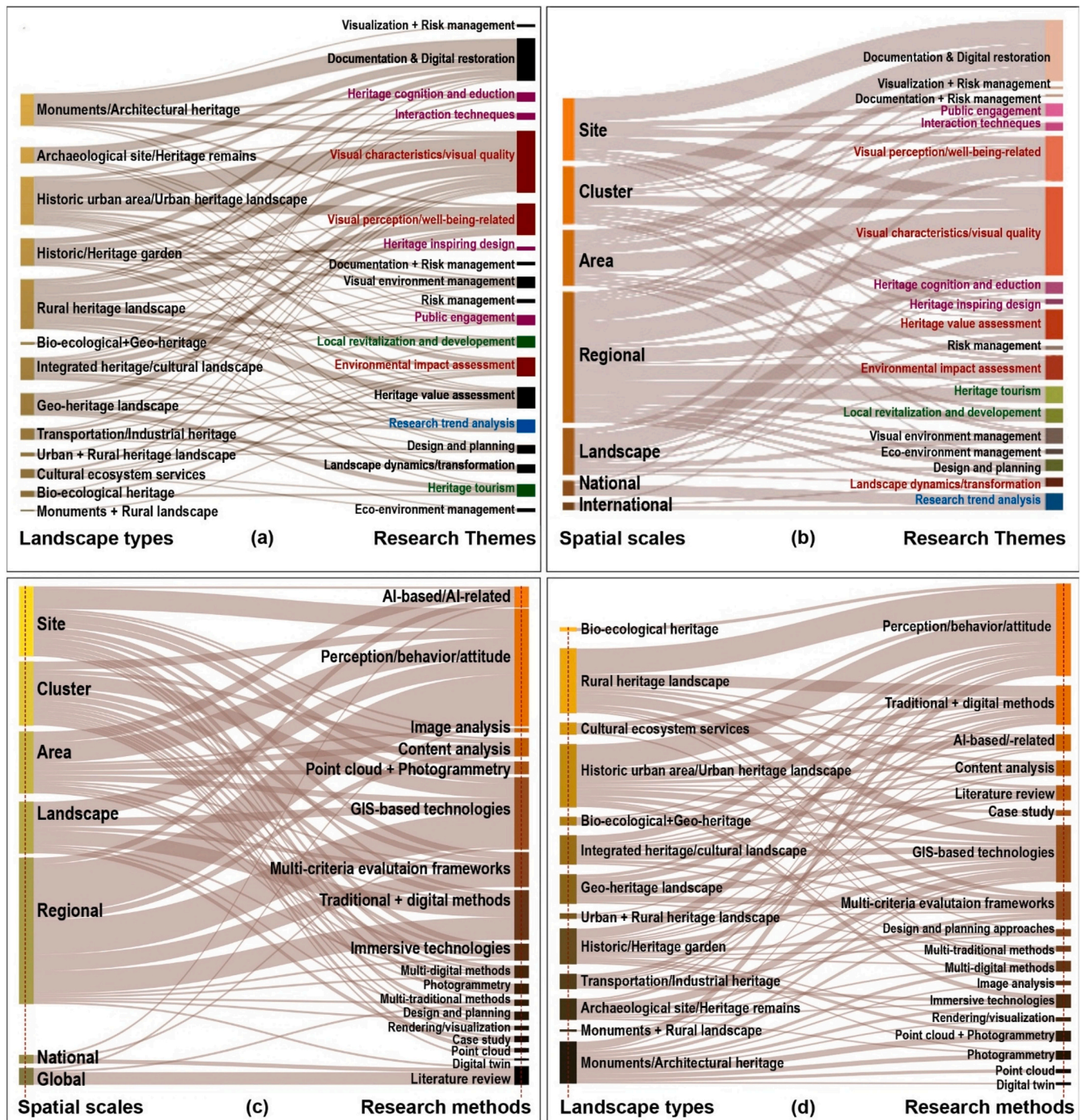


Fig. 11. Focused cross-dimensional associations based on Sankey mapping: (a) Linkages between landscape types and research themes; (b) linkages between spatial scales and research themes; (c) linkages between spatial scales and research methods; (d) linkages between landscape types and research methods. Node height indicates category frequency, and band width indicates the number of coded publications linking categories. Colors distinguish category groups.

scales, are analyzed in detail: rural/agricultural/rural settlement landscapes display the most diverse thematic profile. Dominant themes include visual characterization and quality evaluation, visual perception and well-being, and heritage value assessment (cultural, historic, ecological, and economic). Other recurrent topics, such as local revitalization, (digital) documentation and restoration, environmental impact assessment, and landscape transformation, reflect a strong planning and perceptual orientation. Historic urban areas/urban heritage landscapes show a more concentrated focus on visual characterization, with frequent attention to visual

perception, (digital) documentation, and environmental impact assessment. Themes such as public engagement and revitalization appear less often, indicating a research emphasis on visual quality, user experience, and conservation in urban built environments. Historic/heritage gardens are primarily associated with visual characterization and quality evaluation, and (digital) documentation and restoration. Other notable themes include visual environment management, heritage value assessment (especially cultural and historic), and design and planning of heritage landscapes. A distinct feature of this category is the recurring theme of

using heritage as design inspiration, rarely observed in other landscape types.

- (b) **Relationship between research themes and methods:** Each theme tends to be associated with a distinct methodological base (Fig. 10). *Analysis/evaluation* draws on a broad and balanced mix of perception-based empirical research, GIS-based analysis, and multi-criteria evaluation frameworks. Together, these three categories form a frequent methodological basis of this theme, combining perceptual inquiry, spatial modeling, and evaluation structures. *Management/conservation* is characterized by a clear technological orientation. It predominantly relies on point cloud processing, photogrammetry, and risk assessment tools, underscoring the central role of high-resolution digital data and modeling in contemporary conservation practice. *Sustainable development and use* tend to adopt planning and design approaches, often in combination with other methods, to explore the integration of heritage in evolving territorial agendas. *Communication/engagement*, meanwhile, is rooted in participatory and perception-based empirical methods, with emerging use of immersive tools such as VR/AR for enhancing interaction and interpretation.
- (c) **Relationship between spatial scales and methods:** Certain case scales are often associated with specific analytical methods (Fig. 11c). The *regional* scale is typically paired with GIS-based analysis, multi-criteria evaluation, and design and planning tools, particularly in studies addressing land-use dynamics, landscape transformation, or policy-making. *Site* scale and *cluster* scale research is often linked to point cloud technologies, photogrammetry, and perceptual assessments, reflecting a focus on detailed documentation, spatial experience, and architectural morphology. *Area* scale studies commonly adopt perception-based empirical and participatory approaches, especially in neighborhood-level urban heritage research. *National* and *global* scales are primarily addressed through literature reviews and comparative content analysis. These associations suggest that spatial scale is one factor shaping research questions and methodological choices.
- (d) **Relationship between landscape types and methods:** Heritage landscape types show recurring methodological tendencies (Fig. 11d). *Rural/agricultural/rural settlement landscapes* apply a wide mix of perception-based empirical, GIS-based, and planning methods, serving as testing grounds for perceptual and spatial analysis. *Historic urban areas/urban heritage landscapes* also show methodological diversity, combining perception studies, design strategies, and mixed methods. In contrast, *monuments/architectural heritage* and *historic/heritage gardens* rely more heavily on point clouds, photogrammetry, and risk models, emphasizing accuracy, documentation, and conservation monitoring. *Geo-heritage landscapes* are commonly examined through GIS-based visibility and accessibility tools, often within conservation or aesthetic frameworks. Less-studied types, like *cultural ecosystem service* and *urban-rural hybrids*, show fragmented patterns, indicating methodological gaps and opportunities.

The Sankey diagram highlights both structural specialization and potential integration across the field. Prominent flows are visible—for example, rural landscapes link to evaluation themes via perception-based empirical and GIS-based methods, while architectural heritage connects to conservation through digital documentation tools. Yet many cross-connections remain underexplored. For example, immersive technologies and high-resolution digital tools, such as point clouds, are rarely applied in perception or participatory studies, while perception-based empirical data and social indicators are seldom integrated into advanced visualization. These findings collectively suggest both the scarcity and potential of integrated research across themes, landscape types, spatial scales, and methodological domains, including data and

tools.

4. Discussions

Building on the coding and mapping results, this section moves beyond structural description to interpretive reflection. While the previous analyses identified key research themes, objects (in terms of landscape types and spatial scales), methods (including tools and data), and their interconnections, the focus now shifts to synthesizing these findings and exploring critical gaps and future directions.

4.1. Methodological evolution and integration trends

This section offers a synthesis of technological evolution in heritage landscape visual studies, reveals the existing research gaps, and outlines potential future directions grounded in observable trends (Fig. 12a).

4.1.1. The research evolution in the past 30 years

The development of heritage landscape visual research over the past three decades can be divided into three phases (Fig. 12b), reflecting a dual-track trajectory: one based on visual perception assessment, the other on spatial and computational tools. These periods were determined by mapping yearly method counts, tracing the first appearance and persistence of key technique keywords.

Period 1 (1995–2005): The period from 1995 to 2005 represents an early phase of consolidation in heritage landscape research, building on earlier traditions of visual management and landscape perception research, especially in the United States. Earlier work associated with the U.S. Forest Service, US Bureau of Land Management landscape, and related agencies had already developed formal visual management systems and public preference methods, including the Scenic Beauty Estimation tradition (Ribe, 1989; Tahvanainen et al., 2001), which provided an important methodological background for later heritage-oriented visual research. Against this background, heritage landscape studies during 1995–2005 became more recognizable as a distinct area of inquiry. Traditional approaches centered on visual perception, including preference studies (Chandler & Costello, 2002; Frey, 1997), place attachment (Kaltenborn & Bjerk, 2002; Uzzell, 1996), and stress reduction (Schouten, 1995), while GIS became the primary digital tool for basic spatial visualization (Summerby-Murray, 2001) and land-use analysis (Stewart, 2001; Taillefumier & Piégay, 2003). Data use was polarized: traditional studies relied on qualitative sources like interviews and archives, while digital research used coarse-resolution satellite data and early DEMs (Nijhuis et al., 2011). Although VR technologies appeared (Gaitatzes et al., 2001), technical limitations restricted their application. This period laid the groundwork for the later divergence of perception-based and computational approaches.

Period 2 (2005–2015): This decade saw the diversification of both digital and traditional methods. High-resolution techniques such as photogrammetry (McCarthy, 2014; Remondino, 2011) and point cloud scanning (White, 2013), and photogrammetry-enhanced spatial modeling. Perception-based studies evolved through the use of physiological sensing such as eye-tracking (Sang et al., 2014), while literature-based (Brown et al., 2015) and design-oriented research gained prominence (Deghati Najd et al., 2015; Ignatieva et al., 2011). GIS began to integrate perceptual data, enabling behavioral-spatial modeling (Nijhuis et al., 2011). Although UGC was not yet central, multi-data frameworks began to emerge, combining field surveys, historical documents, and high-resolution spatial data.

Period 3 (2015–2025): The recent phase marks a shift toward AI-supported, data-rich, and integrative research. Point clouds (Grilli et al., 2019; Pierdicca et al., 2020; Sánchez-Aparicio et al., 2023) and photogrammetry (Aicardi et al., 2018; Kingsland, 2020; Rahaman & Champion, 2019) became standard tools for small- to mid-scale spatial modeling. AI and deep learning support large-scale pattern recognition, semantic segmentation, and content extraction (Liu et al., 2022;

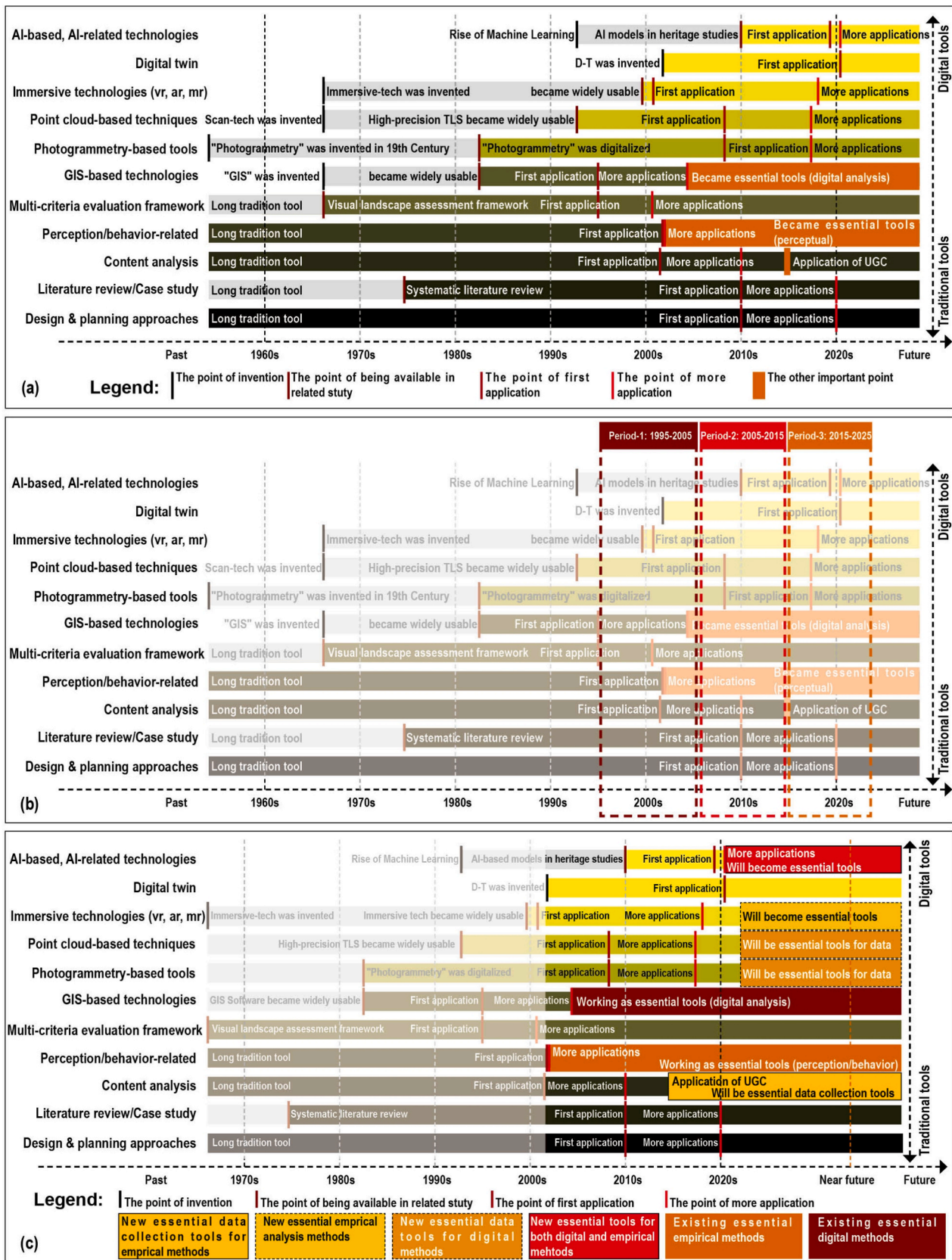


Fig. 12. Evolution and trends of research methods: (a) Key milestones in methodological development; (b) distinct periods of evolution; (c) emerging trajectories for future research. Colors and shading indicate methodological status or trajectory as defined in the in-figure legend, and dashed vertical lines mark the three review periods.

Matrone et al., 2020). Digital twins emerged as a conceptual framework for simulation and monitoring (Lucchi, 2023; Shabani et al., 2022). VR and AR re-entered the field, supported by improved 3D data quality and computational power (Debailleux et al., 2018; Gonizzi Barsanti et al., 2015). Meanwhile, rich data layers like UGC (Choo, 2023; Xu et al., 2023), panoramic imagery (Bassier et al., 2018; Koeva et al., 2017), and web-based spatial content (Nishanbaev et al., 2021) supplement traditional sources, enabling complex analyses of visual quality, transformation, and heritage perception.

4.1.2. Methodological gaps

Despite growing experimentation with mixed methods and digital tools, key methodological gaps persist.

- (a) **Epistemic and workflow disconnection between perception-based inquiry and spatial-computational analysis:** While perception-based empirical methods such as surveys and affective mapping have advanced, they are seldom integrated into spatial analysis pipelines (Bekele et al., 2018; Jones, 2016; Zhang et al., 2025). Conversely, GIS and 3D modeling often exclude user evidence, which limits the social grounding of spatial analyses (Zhang & Zou, 2022). A related issue concerns ecological validity: responses elicited by VR- or rendering-based visual stimuli may diverge from in situ experience and therefore require explicit testing and calibration (Harris et al., 2020).
- (b) **Limited reporting consistency and transferability:** Many toolsets remain project-specific, and studies often report data sources, processing steps, validation procedures, and uncertainty unevenly (Hakala et al., 2011; Su et al., 2019). This limits the accumulation of comparable and scalable knowledge (Hudson, 2011). Here, standardization refers to improving reporting consistency rather than prescribing fixed methods or method combinations.
- (c) **Uneven access to advanced hardware and platforms:** Access to high-resolution point-cloud scanners (though some smartphones can be used as mid-resolution scanners), AI platforms, and immersive systems is uneven, which can limit the breadth and reproducibility of some high-fidelity pipelines (Butcher & Pecot, 2021; Vlase & Lähdesmäki, 2023). This is an equity and scalability issue rather than a prerequisite for quality: rigorous visual heritage research can be conducted with low-cost capture and on-site protocols, provided that procedures are transparent and comparable.
- (d) **Weak cross-scale and cross-theme integration:** Eye-level perception analytics (for example, eye-tracking in virtual or field settings) are rarely linked to bird's-eye mapping, such as visibility analysis, and tools for simulation, assessment, and participatory design remain poorly interconnected. In contrast to gap (a), which concerns coupling evidence types within a pipeline, this gap concerns the translation of results across spatial scales and thematic domains once evidence exists. These silos hinder a holistic understanding of heritage landscapes as lived and layered spaces (Harvey, 2015).

Addressing these gaps requires not only technical improvement, but also clearer coordination among methods, evidence types, and validation practices. Such coordination can improve comparability while leaving room for methodological innovation and context-specific adaptation (Aimar, 2024; Liu & Nijhuis, 2020).

4.1.3. Future outlook: from tools to integrated frameworks

In addition, three key technological trajectories are reshaping the field: (a) **Immersive media** (VR/AR/MR) are evolving into perception- and response-oriented tools for studying spatial experience, preference, and simulated interaction. When combined with computer vision-based rendering (e.g., Gaussian Splatting, a rising visualization technique),

they enable real-time testing of how users perceive and respond to simulated heritage environments, although such settings cannot fully reproduce actual behavior in real world contexts (Gonizzi Barsanti et al., 2015). To ensure ecological validity, outcomes from immersive experiments should be compared with matched in situ observations at the same viewpoints and along the same routes, and the analysis should be stratified by audience groups, for example, residents, heritage community members, and visitors, in order to detect group-specific responses (Strandberg, 2023; Wynveen et al., 2012). (b) **UGC and big data** offer bottom-up insights into public sentiment and spatial behavior. Through machine learning and NLP, such content complements expert-led evaluation and supports participatory heritage mapping (Choo, 2023; Hølleland et al., 2017). (c) **Point clouds and photogrammetry** are transitioning from specialized tools to core data infrastructure. New techniques and LiDAR/UAV advances allow rapid, high-resolution 3D modeling. When scaled via national repositories (e.g., AHN, Actueel Hoogtebestand Nederland), these datasets support monitoring, planning, and multi-stakeholder engagement (Grilli et al., 2019; Khan et al., 2022; Yu, et al., 2025). Additionally, AI-based approaches can fuse perceptual data (e.g., street-view imagery or attention traces) with GIS layers to learn perception-aware spatial indicators. Such integration helps close the gap between human experience and spatial modeling in heritage landscape analysis.

These developments suggest that future progress depends not on the accumulation of individual tools but on their orchestration into interoperable and multimodal systems (Fig. 12c). Achieving methodological integration, linking digital technologies, perception-based inquiry, and heritage development practices, is essential for constructing comprehensive, adaptive frameworks for visual heritage research (Pintossi et al., 2021).

4.2. Research objects: gaps and emerging directions

In past decades, the scope of visual heritage landscape research has broadened in both types and spatial scales. While rural and urban heritage landscapes continue to dominate, newer categories, such as infrastructural, post-industrial, and hybrid ecological-cultural landscapes, are gradually emerging. Parallel to this, a shift from binary micro-macro analyses toward multi-scalar frameworks is taking shape.

4.2.1. Object-based gaps

Despite increased diversity, the current field remains typologically and spatially imbalanced. Research remains concentrated on well-bounded, visually legible types, such as traditional built environments, which align with established tools (e.g., GIS, photogrammetry) (Page et al., 2021). Complex or ambiguous heritage types, such as infrastructure corridors, ecological-cultural hybrids, or contested sites, remain underexplored, as their lack of formal recognition and clear spatial boundaries poses challenges for conventional analytical frameworks (Cortês et al., 2020). Moreover, most studies are temporally static, focusing on fixed moments rather than dynamic visual change, thus limiting engagement with processes of transformation, memory, and visual continuity. Equally important is the social dimension of temporality: changes in population composition and cultural diversity continuously reshape how heritage landscapes are perceived and valued. Few studies address how different groups or successive communities privilege particular heritage narratives over others, leaving the socio-cultural dynamics of “whose heritage” largely unexplored (Fouseki, 2022). Spatially, the dominance of micro- and regional-scale studies results in a neglect of intermediate scales and cross-scalar integration. This constrains the capacity to inform multi-level heritage governance or to link perceptual data with broader territorial strategies (Butcher & Pecot, 2021).

4.2.2. Future trends

In response to these gaps, recent studies signal a shift toward

broad, more complex understandings of heritage landscape objects (Vlase & Lähdesmäki, 2023). This transformation is unfolding along two main trajectories: **(a) Typological diversification:** There is growing scholarly attention to unconventional or previously excluded types, e.g., infrastructure corridors, *peri*-urban margins, and post-conflict landscapes (Gonçalves et al., 2021). These challenge conventional typologies and require multi-method, cross-scalar approaches to address their fragmentation, relationality, and evolving significance. Concurrently, new concepts like “everyday heritage” and “vernacular memory” reflect a growing focus on how local communities understand and value heritage in their own ways (Li et al., 2021), highlighting the need for visual research methods that can engage with informal, diverse, and sometimes unofficial heritage landscapes (Zhang et al., 2023). While the focus here is on object types and spatial scales, we note that shifts in population composition and cultural diversity can influence how those objects are perceived and valued. These socio-temporal aspects are addressed in the thematic discussion (Section 4.3). **(b) Spatial re-scaling:** Visual heritage research is advancing along two key spatial directions. At the micro-scale, it is becoming more detailed and experiential, aided by sensor-based tracking, eye movement analysis, and immersive technologies such as VR and AR (Khan et al., 2022). At the macro-scale, research increasingly draws on global visualization platforms, remote sensing technologies, and national point cloud repositories (e.g., AHN in the Netherlands), enabling large-scale comparisons and monitoring (Deghati Najd et al., 2015). Crucially, recent integrative frameworks, such as the *Historic Urban Landscape* (UNESCO, 2011) approach and *Guidance on Heritage Impact Assessments for Cultural World Heritage Properties* (ICOMOS, 2011), emphasize the need for cross-scalar analysis. These approaches recognize that the visual character of heritage is not fixed, but dynamically shaped through multi-layered spatial contexts and lived human experience.

4.3. Thematic shifts: gaps and emerging agendas

Visual heritage landscape research has traditionally focused on documentation, evaluation, and management, prioritizing visual recording, aesthetic assessment, and spatial regulation. However, shifts in technology, governance, and public values are prompting a turn toward applied, experiential, and inclusive agendas. These thematic changes also shape how heritage landscapes are defined and bounded, since inclusion or exclusion of particular visual and social attributes depends on whose perceptions and values are considered.

4.3.1. Conceptual and operational gaps

While research themes have diversified beyond documentation and visual assessment, several conceptual gaps continue to limit the scope and relevance of visual heritage studies. A major concern is the continued dominance of expert-driven evaluation, with limited integration of lay perspectives, emotional engagement, or community experience. While visual perception and well-being have gained visibility, they often remain peripheral to technical assessments (Gonçalves et al., 2021).

In many studies, the audience question is under-specified: samples are not stratified across residents, heritage community members, visitors, or cultural cohorts, and divergences among these groups are seldom reported. This gap becomes especially consequential in heritage landscapes under pressure to change, where heritage significance may be strongly held by particular communities while broader resident or stakeholder groups favor transformation. Visual research cannot determine which claim should prevail, but it can clarify which attributes are at stake, whose values are represented, and where evidence and preferences diverge. Bridging expert and public perspectives therefore requires transparent procedures that translate qualitative perceptions into comparable indicators and that document how disagreements are represented, negotiated, or carried into decisions.

A related gap concerns the visual character of authenticity and

integrity. These attributes are often treated as if their visual expression were self-evident, yet living or contested heritage landscapes may involve different judgments by experts, managing authorities, residents, heritage communities, and visitors. Visual research should therefore make explicit whose criteria are being used, which visual attributes are treated as heritage-bearing, and how everyday adaptation, management rules, or staged representation are distinguished from the conservation of heritage meaning. Bridging expert and public perspectives therefore requires transparent procedures that translate qualitative perceptions into comparable indicators and document how disagreements are represented, negotiated, or carried into decisions.

Moreover, there is insufficient dialogue between thematic research and practice-oriented application. Implementation frameworks, like the Historic Urban Landscape (HUL) approach, are frequently referenced but seldom applied in depth, with limited reporting of protocols, indicators, and feedback loops that would enable replication. Finally, ecological validity is often assumed rather than tested. Outcomes from immersive or rendering-based experiments are not consistently compared with matched in situ responses, and validations tend to focus on scenic judgments rather than meanings, memory, attachment, or short-form well-being.

4.3.2. Emerging thematic directions

Future trends in visual heritage landscape research reflect a gradual shift away from expert-centered paradigms toward more applied, practical, and socially grounded agendas. These new directions respond directly to the conceptual and operational limitations outlined above, offering a more inclusive and practice-oriented future for the field (Cortês et al., 2020). This trend points to three major shifts:

- (a) **Technology-enabled participation and interpretation:** Technologies are increasingly mobilized to support public participation, education, and heritage-related decision-making. Tools such as AI, computer vision, and immersive media are moving from experimentation to integrated, goal-oriented workflows that translate public inputs into map layers, indicators, and scenarios (Ginzarly & Teller, 2018; Khan et al., 2022; Peng et al., 2026; Yu et al., 2025). Credibility improves when sampling is stratified by audience groups, uncertainty is reported, and clear rules are provided for documenting and, where appropriate, negotiating divergent needs or preferences before indicators guide actions.
- (b) **Visuality as emotional and experiential engagement:** There is a growing emphasis on well-being, mental health, and emotional connection (Fig. 8b), particularly in relation to urban heritage green spaces (Harisanty et al., 2024). In this shift, visibility is increasingly understood not merely as a measurable attribute but as a lived and affective experience embedded in everyday interaction with the landscape. To ensure ecological validity, immersive or rendering-based results should be checked against matched in situ observations across both scenic and non-scenic outcomes, including meanings, memory, and attachment.
- (c) **Practice-oriented integration with policy and design:** Research is aligning more closely with policy and design practice. Visual-based approaches, such as scenario modeling, co-design, and visual impact regulation, are increasingly used to guide practices like urban renewal and rural revitalization in heritage contexts (Chong & Balasingam, 2018; Li et al., 2026; Peng et al., 2026). Effective applications make the path from indicators to controls and design choices explicit and report how validation and audience stratification shape criteria, assumptions, and uncertainty carried into decisions.

4.4. Toward a synthesized perspective on visual heritage research

The review suggests that visual heritage landscape research is moving toward greater integration across methods, research objects, and

thematic priorities. On this basis, Fig. 13 summarizes several emerging directions as a review-derived synthesis. Three broad axes of integration are particularly visible: methods, research objects and scales, and thematic priorities.

Methodologically, research is shifting from isolated tools to integrated, and increasingly AI-assisted, workflows that combine geospatial analysis, semantic modeling, and perception-based empirical data (Jordan-Palomar et al., 2018). Recent studies suggest that AI-assisted workflows may support tasks such as structuring complex spatial information, segmenting and classifying elements in imagery or point clouds (Zhang & Peng, 2024), detecting change, and generating Level of Detail (LoD)-aware descriptors of enclosure, skyline integrity, and corridor continuity (Biljecki et al., 2016; Wang et al., 2020). They may also help connect perceptual and spatial evidence, for example by linking eye-level imagery or attention traces with GIS layers to explore patterns of visibility and meaning (Gonizzi Barsanti et al., 2015; Hakala et al., 2011). Such developments expand the possibilities for more dynamic and multi-perspective evaluations of heritage experience, while still requiring interpretability, validation, and context-sensitive

application. As data sources diversify, there remains a need for technical interoperability and flexible mixed-method designs that allow replication and comparison across cases.

In terms of research objects, typologies are expanding to include hybrid, under-represented, and temporally dynamic landscapes, and analytical scales are moving from mono-scalar designs to multi- and cross-scalar approaches (Ashrafi et al., 2021; Zhang & Zou, 2022). This highlights the need to relate micro-level perception to broader spatial structure and to make indicator translation across scales more explicit.

Thematically, agendas are turning from expert-centered assessment toward more inclusive and value-sensitive work that addresses participation, well-being, memory, and identity, while remaining compatible with policy requirements. The reviewed literature suggests a balanced direction rather than a substitution of one perspective for another. Expert criteria related to integrity, authenticity, and technical accuracy remain important reference points, while public and user evidence can refine contextual interpretation and sensitivity ranges without reducing heritage value to preference alone. For example, in studies on West Lake (Peng et al., 2025) and Pingjiang Road (Peng et al., 2026), expert

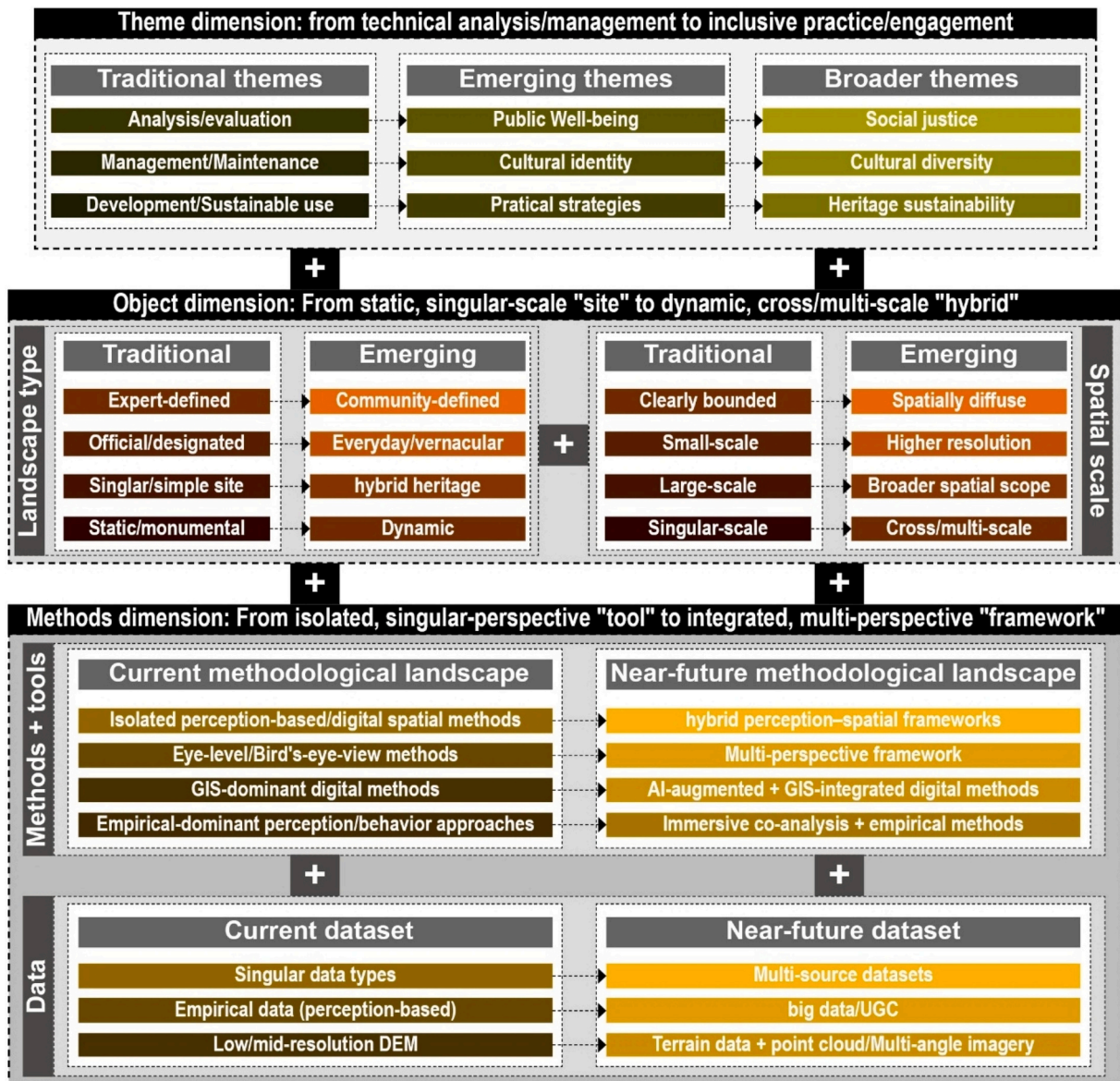


Fig. 13. A synthesized view of emerging directions in visual heritage landscape research: The figure summarizes review-derived shifts across themes, research objects, methods, and data. Arrows indicate synthesized directions observed in the reviewed literature rather than causal or predictive stages; "+" signs indicate points of integration across dimensions, where themes, object types/scales, methods, and data are increasingly combined.

assessment helps identify protected views, historically significant attributes, and acceptable change limits, while public perception evidence helps distinguish which visual changes are most noticeable or experientially sensitive to users.

Two recurring considerations in the reviewed literature concern audience differentiation and validation. First, audience stratification distinguishes residents, heritage-community members, visitors, and experts, and tests whether results generalize across groups or require group-specific handling. Second, ecological validity is assessed through matched comparisons of in situ observations and immersive or rendering-based experiments at identical viewpoints and along the same routes. Outcomes include not only scenic judgments but also meanings, memory, attachment, and short-form well-being. Where discrepancies appear, they should be addressed through recalibration, explicit reporting, and the retention of uncertainty in later scenarios and decisions. To make these directions more explicit, Table 5 distills five review-derived integration patterns observed across the literature, outlining typical uses, evidence combinations, reporting checks, and caveats relevant to assessment, planning, and management.

These patterns also clarify the limits of visual evidence. Digital documentation, reconstruction, and immersive visualization can record and communicate appearance, geometry, and spatial experience, but they should not be equated with conserving heritage meaning itself (Yu et al., 2026). Similarly, visual evidence can help identify which attributes are at stake, whose perceptions are represented, and how disagreements enter assessment or management, but it cannot by itself resolve conservation-development conflicts. Integrity, authenticity, key views, setting, and related heritage attributes remain important reference points, while uncertainty and divergence across audiences should be documented transparently.

4.5. Limitations

Some widely recognized issues, such as climate change, were not prominent in the reviewed corpus, even though they may have important implications for heritage landscapes, especially natural heritage areas. This pattern is related in part to the scope of the review and the way the corpus was defined. Studies on climate-related change,

vulnerability, or resilience may not have been included when they were framed primarily in environmental, ecological, or scenic management terms rather than in explicit heritage terms. Beyond this, the review has several additional limitations:

- (a) The review focuses exclusively on English-language publications, potentially excluding significant research published in other languages, particularly from regions with strong local research ecosystems and rich heritage traditions (e.g., China, Japan, Latin America, and parts of Europe) (Ignatieva et al., 2011; Yasumoto et al., 2011).
- (b) The search strategy also focused on peer-reviewed sources, which means that grey literature, practice reports, and policy documents were largely excluded. In addition, some studies that address visual, spatial, or cultural aspects of heritage environments may not appear in the corpus because they do not explicitly use the term “heritage/cultural landscape,” creating a degree of terminological under-coverage. This limitation is compounded by the variable definition and boundaries of “heritage landscape” across cultural and institutional contexts. The inclusion criteria used here prioritize explicit heritage framing, either through formal designation or documented heritage-community recognition, while retaining heritage-specific attributes such as integrity, authenticity, setting, and visual relationships. Accordingly, some studies on natural or mixed landscapes that address visual qualities, scenic management, or landscape perception may still fall outside the corpus unless they are explicitly framed in relation to heritage-related designation, recognition, valuation, assessment, conservation, or management. The corpus, therefore, only partially captures the wider visual management and scenic perception traditions associated with natural settings, especially earlier work outside the selected review period.
- (c) Given the breadth of the field, the synthesis prioritizes coverage and integration over fine-grained critique of individual methods. As a result, the review emphasizes cross-field patterns, interfaces, and research gaps over detailed technical comparison of individual methods. Because the corpus contains 203 publications distributed across multiple coding categories, the cross-dimensional mappings should be interpreted as exploratory associations rather than inferential tests of interaction.
- (d) The synthesis proposed here is a review-based structure derived from the literature, not a predictive or prescriptive decision model. Its practical usefulness depends on further testing through case-based application and comparison across contexts. Similarly, the integration patterns in Table 5 should not be read as universal standards, thresholds, or priority rankings, but as aids for transparent comparison and future empirical testing.

5. Conclusions

This paper provides a systematic review of visual heritage landscape research, revealing the field’s thematic concentration on evaluation, its methodological fragmentation, and its focus on a narrow range of heritage landscape types. Through systematic coding and exploratory cross-dimensional mapping, it identifies recurring patterns and associations among research themes, landscape types and scales, and methodological approaches.

Despite growing research diversity, the study identifies three persistent limitations: the disconnection between perception-based and spatial-analytical approaches; the underrepresentation of hybrid, dynamic, or contested heritage types; and the thematic divide between expert-led evaluation and socially embedded practices. These gaps suggest that visual heritage landscape research remains only partially integrated across physical, cultural, and experiential dimensions.

To clarify these patterns, this paper develops a review-derived organizing synthesis that relates research themes, heritage landscape

Table 5
Review-derived integration patterns in visual heritage landscape research.

Integration pattern	Evidence commonly combined	Main use and caution
Spatial-perceptual coupling	Visibility, viewshed, composition, field images, and perception-based empirical evidence.	Links spatial form with perceived visual quality or experience; associations require case validation.
Multi-perspective evaluation	Expert criteria, resident/visitor/heritage-community evidence, surveys, interviews, participatory mapping, and PPGIS.	Clarifies differences among expert, public, and community perspectives; public preference should not be equated with heritage value.
Cross-scale visual-spatial analysis	Site, setting, area, and regional data, including terrain, built form, vegetation, protected views, and visual corridors	Connects visual attributes across scales; scale transfer should be explicit rather than assumed.
Assessment and management translation	Spatial indicators, expert assessment, stakeholder evidence, and scenario comparison.	Supports more transparent assessment, planning, and management; visual evidence can inform but not resolve value conflicts.
Digital documentation and visualization	Photogrammetry, point clouds, 3D models, archival records, 360° imagery, street-view imagery, and on-site images.	Records and communicates visual-spatial conditions; heritage relevance depends on links to historical, cultural, community, or management context.

types and scales, and methodological approaches. This synthesis helps clarify how visual evidence is organized across different heritage contexts and how it may inform assessment, planning, and management in more transparent and context-sensitive ways. Future research may build on these synthesized directions through cross-scalar case studies, participatory methods, and computational tools to strengthen connections among perception, spatial analysis, and heritage governance.

CRediT authorship contribution statement

Yuyang Peng: Writing – review & editing, Writing – original draft, Visualization, Methodology, Conceptualization. **Steffen Nijhuis:** Writing – review & editing, Supervision, Conceptualization. **Zaichen Wu:** Writing – original draft, Methodology, Conceptualization. **Yingwen Yu:** Software.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this manuscript, the authors used ChatGPT and Grammarly to improve language clarity, readability, and grammar. After using the tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the manuscript.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.landurbplan.2026.105742>.

Data availability

No data was used for the research described in the article.

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