

Construction and Empirical Study of Quantitative Evaluation System for Cultural Inheritance in Landscape Space Creation

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ABSTRACT To address the difficulty of quantitatively evaluating cultural inheritance effects in landscape space creation, this study constructs an evaluation system for landscape practice from four dimensions: material carriers, behavioral activities, spiritual imagery, and environmental coordination. The Analytic Hierarchy Process (AHP) is used to calculate the weights of each dimension and indicator, while fuzzy comprehensive evaluation maps qualitative descriptions onto graded scales. A multi-level fuzzy synthesis model is then established to calculate comprehensive scores. Horizontal comparison among historical inheritance, modern translation, and ecological integration projects yields scores of 4.14, 3.91, and 4.03, respectively, with an inter-rater reliability coefficient of 0.85. Longitudinal verification in a historical district project further shows that the system has both discriminative capacity and practical diagnostic value. By transforming cultural features into measurable indicators, the method provides a quantitative tool for optimizing heritage-oriented design decisions. In engineering applications, the framework can be integrated with remote sensing, electromagnetic-wave imaging, and digital survey technologies to improve the acquisition and evaluation of spatial heritage information.

INDEX TERMS cultural heritage, quantitative evaluation, fuzzy comprehensive evaluation, remote sensing, landscape engineering

I. INTRODUCTION

IN the process of rapid urbanization, landscape spaces increasingly exhibit cultural homogenization and loss of distinctiveness, as traditional weaving patterns and the mechanical heritage of local industries are overshadowed by generic architectural designs. While culture is now widely recognized as essential to landscape design, and the effectiveness evaluation of culture has always been based on the qualitative and subjective experience evaluation, without a scientific and systematic quantitative standard and tool [1,2]. Therefore, it is impossible to accurately quantify heritage, hinders horizontal comparison of project outcomes, and lack data support for optimization directions. Therefore, establishing a quantifiable and operable cultural heritage evaluation system is of important theoretical and practical significance for promoting landscape design from “vague cultural intentions” to “precise cultural expression” and achieving effective protection and innovative development of cultural values [3].

Existing research mainly focuses on exploring the qualitative expression and symbolic meaning of cultural elements in the landscape. Shan and Sun proposed a land-

scape visual comprehensive evaluation method that integrates GIS spatial analysis and fuzzy hierarchical analysis, which objectively reveals the distribution characteristics and influencing factors of landscape visual resources through a multi-factor index system [4]. Zhang et al. aimed to construct a cultural heritage tourism resource evaluation system using the analytic hierarchy process, the Delphi method, and fuzzy mathematics, and to explore the optimization of tourism routes based on heritage sites in order to promote the realization of urban sustainable development goals [5]. Inspired by structural equation modeling, Li et al. constructed a landscape effectiveness theoretical model containing five latent variables, including spatial density and vegetation coverage, providing a reference for quantifying unobservable factors in the built environment [6]. Tenzer proposed a method that systematically integrates internal knowledge based on personal memory, experience, and traditional practices into the local planning and decision-making framework, while taking into account the subtlety and fluidity of this personal perspective [7]. Şenik and Uzun aimed to propose guidelines for the planning of open green space systems, including five standards, to address

the problems of fragmented green space functions, lack of unified definition, and overall analysis framework caused by rapid urbanization [8]. Xie et al. systematically analyzed the development trends, hotspots, and cutting-edge directions of rural landscape research in the fields of tourism, culture, and ecology by reviewing the research results of the past thirty years [9]. Gottwald et al. integrated the sense-of-place theory with the concept of cultural ecosystem services, aiming to deeply analyze the human-land relationship by assessing citizens' significance, attachment to, and impact on the physical and socio-economic environment of river landscapes [10]. However, existing research is still insufficient in constructing a systematic and quantifiable comprehensive evaluation method. This study aims to construct a quantitative evaluation system for cultural heritage applicable to landscape space and verify its effectiveness. First, the theoretical construction of the system is completed through the establishment of a multi-dimensional indicator system, the scientific assignment of indicator weights, and the integration of fuzzy evaluation models. Subsequently, through two empirical studies, namely, horizontal comparison of multiple cases and longitudinal diagnosis of single projects, the system's discriminative power, reliability and validity, and its diagnostic and optimization value in actual projects are tested. Finally, this study provides an operable quantitative tool and methodological support for the precise practice of cultural heritage in landscape design by translating traditional weaving structures and machinery patterns into measurable spatial elements. This empirical evidence ensures that the industrial spirit of manufacturing is accurately preserved and revitalized through modern landscape engineering.

II. ESTABLISHMENT OF EVALUATION DIMENSIONS AND INDICATOR DATABASE

In order to realize the systematic and operational evaluation of cultural heritage, the first problem to be solved is to build the evaluation index system with clear logic and hierarchical level. Taking the explicit and implicit connotation of cultural heritage in landscape space as the basis, this study establishes an evaluation system with four levels through the systematic literature review, typical case analysis and multiple rounds of expert consultation.

(1) Material Carrier Dimension: It reflects the expression of culture in the material objects of landscape. Through the literature review and case comparison, this study extracted four indicators, i.e., “reproducibility of morphological symbols”, “application rate of traditional materials and techniques”, “spatial pattern inheritance” and “cultural identity of structures”. These indicators assess the extent to which traditional forms, materials, and spatial organization are preserved and reinterpreted in new designs.

(2) Behavioral Activity Dimension: It reflects the carrying capacity of landscape space to carry and promote the occurrence of specific cultural behaviors and lifestyles. Based on the field observation and activities research, this

study established four indicators, i.e., “carrying capacity of folk festival activities”, “support for daily traditional behaviors”, “richness of participatory cultural experiences” and “cultivation of community cultural identity”. These indicators evaluate how design supports the continuation and adaptation of traditional cultural practices.

(3) Spiritual Imagery Dimension: It reflects the implicit cultural information and emotional experience conveyed by the landscape. Through the semantic analysis and research on spirit of place theory, this study selected four indicators, i.e., “intensity of place spirit perception”, “clarity of historical and cultural narrative”, “evoking degree of local identity” and “cultural fit of aesthetic conception”. These indicators attempt to analyze what extent of the culture conveying the emotional and meaning from the perspective of the visitor.

(4) Environmental Coordination Dimension: It reflects the whole relationship between cultural expression and its surrounding natural environment and human environment. Based on the sustainability theory and contextualism theory, this study established four indicators, i.e., “integration with natural landforms and ecology”, “relevance with regional historical context”, “cultural adaptability for sustainable landscape maintenance” and “cultural coordination of visual landscape”. These indicators attempt to analyze what extent of the cultural inheritance not an isolated implantation but an organic whole.

The four dimensions mentioned above and their sixteen indicators constitute the initial evaluation indicator library. These indicators considered the material and non-material aspects of culture, static display content and dynamic process, intrinsic value and contextual relationship. These indicators provide the structural basis for the subsequent assignment of weight and quantitative evaluation.

III. DETERMINATION OF INDICATOR WEIGHTS USING THE AHP METHOD

Based on the above established evaluation indicator database, this study uses the AHP method to calculate the weights of each dimension and indicator in the comprehensive evaluation of cultural heritage from the view of logical analysis, so as to fully and scientifically reflect the relative importance degree of each dimension and indicator in comprehensive evaluation. This method can decompose the complex decision making levels into ordered multi-levels and use the pairwise comparison method based on experts experience to transfer the subjective qualitative analysis into quantitative calculation, and then achieve the logical analysis of the relative importance of each level element, thus solving the problem of weight allocation in multi-criteria decisionmaking.

The specific implementation process is as follows: Firstly, import the evaluation system structure of “target layer-criteria layer (dimension)-indicator layer” into the AHP analysis framework. Secondly, design the questionnaire to compare the importance of landscape cultural heritage evaluation indicator. The questionnaire asks experts to use the

1-9 scale to compare the importance of the same level elements (such as between the four dimensions, or between specific indicators in each dimension). For example, if the “material carrier dimension” is much more important than the “behavioral activity dimension”, then value 5 will be assigned to it.

This study selected 15 experts engaged in landscape design, cultural heritage protection, urban and rural planning fields to participate in the consultation. After collecting valid questionnaires and constructing the corresponding judgment matrix for each expert, use eigenvector method to calculate the maximum eigenvalue and its corresponding normalized eigenvector of each judgment matrix; this eigenvector is the relative weight of each element. Then, do strict logical consistency check. The consistency ratio (CR) is calculated. All experts’ adopted judgment matrices satisfy the standard of $CR < 0.1$, so the logical judgments are consistent. Finally, summarize and geometrically average the calculation results of valid experts’ questionnaires for comprehensive layer by layer, and then obtain the final weight set from target layer to indicator layer. The resulting weight distribution reflects considerations specific to industrial heritage. As shown in Table 1, the “Material Carrier” dimension retains the highest weight (0.30), acknowledging the primacy of tangible elements like machinery. Notably, the “Environmental Coordination” dimension was increased to 0.25—equal to “Spiritual Imagery”—based on expert re-evaluation specific to large-scale industrial relics. For such heritage, the environment is not mere backdrop but an integral narrative component: the factory’s spatial volume and site layout are essential for contextualizing machinery and conveying industrial spirit. This higher weight ensures the framework assesses artifacts and their indispensable settings as a unified whole, preventing decontextualized evaluation. All matrices passed consistency checks ($CR < 0.1$), confirming logical coherence.

IV. FUZZY GRADING OF EVALUATION CRITERIA

This study pre-determines a five-level rating set $V = \{v_1, v_2, v_3, v_4, v_5\}$ for each indicator, corresponding to “Very High Inheritance”, “Relatively High Inheritance”, “Moderate Inheritance”, “Relatively Low Inheritance”, and “Very Low Inheritance”, respectively. The key work lies in assigning clear, observable, and judgmentable

specific connotations or thresholds to each level. For example, for the indicator “Usage Rate of Traditional Materials”, the grading standard is not a general “high” or “low”, but is defined as follows: “Very High Inheritance” (v_1) refers to the main structure and finishing materials of major buildings using traditional materials or faithfully replicated modern materials, with a proportion $>80\%$; “Relatively High Inheritance” (v_2) refers to the application proportion of traditional materials in major landscape structures being between 60% and 80% ; “Moderate Inheritance” (v_3) refers to the use of traditional materials as embellishments or in certain areas, with a proportion between 30% and 60% ; and

so on, until “Very Low Inheritance” (v_5) is defined as $<10\%$. For qualitative indicators such as “Perception of Genius Loci,” which cannot be directly measured by percentages, a multi-anchor descriptive framework is employed. Each qualitative indicator is broken down into several observable sub-dimensions identified through literature review and expert consultation. For “Perception of Genius Loci,” these include historical narrative density, visitor emotional engagement, spatial distinctiveness, and cultural consensus. Each level of the five-grade scale is then defined by a combination of these sub-dimensions: v_1 requires high density of narrative elements, consistent visitor emotional engagement, marked spatial distinctiveness, and strong cultural consensus; v_3 describes fragmented narratives, occasional engagement, moderate distinctiveness, and moderate consensus; v_5 indicates absent narratives, little emotional response, no spatial distinctiveness, and low consensus. Similar multi-anchor frameworks were developed for all qualitative indicators.

By grounding fuzzy grading in multiple tangible dimensions, the evaluation process guides raters to aggregate evidence rather than rely on intuitive impressions, enhancing inter-rater reliability and ensuring numerical vectors reflect systematic observation. The formulation of these grading standards was extensively cross-referenced against relevant design specifications, published case studies, and expert interviews. With this systematic fuzzy grading, an evaluator can precisely classify complex on-site experiences into one of five graded levels, providing a sound basis for subsequent fuzzy mathematics calculation and solving the quantitative problems arising from cultural evaluation’s inherent subjectivity.

V. INTEGRATION OF A MULTI-LEVEL FUZZY COMPREHENSIVE EVALUATION MODEL

With the completion of indicator weight assignment and fuzzy grading, a multi-level fuzzy comprehensive evaluation model is applied to quantify the cultural heritage of landscape spaces. The model aggregates fuzzy evaluations from lower-level indicators upward through the hierarchy, converting qualitative expert assessments into a quantitative composite score. The computation follows a bottom-up progressive logic. First, for a given landscape case, evaluators rate each sub-indicator according to the fuzzy grading standards. The frequency distribution of ratings across all evaluators for a specific indicator is calculated, producing a fuzzy evaluation vector that represents the indicator’s membership degree to each of the five rating levels. The vectors of all indicators within the same dimension are then combined to form that dimension’s fuzzy judgment matrix. Next, hierarchical fuzzy synthesis is performed. For each dimension, its fuzzy judgment matrix is synthesized with its corresponding indicator weight vector (determined by AHP) using a weighted average operator. This yields a new fuzzy vector representing the dimension’s membership degree to each rating level, effectively integrating multiple indicator evaluations into a dimensional performance assessment.

TABLE 1. Evaluation Index System and Weight Allocation for Landscape Cultural Heritage Inheritance.

Dimension (Weight)	Evaluation Indicator	Relative Weight	Composite Weight
Material Carrier (0.30)	1. Representation of Form & Symbol	0.4	0.12
Material Carrier (0.30)	2. Application Rate of Traditional Materials	0.35	0.105
Material Carrier (0.30)	3. Inheritance of Spatial Pattern	0.25	0.075
Behavioral Activity (0.20)	4. Capacity for Folk Activities	0.35	0.07
Behavioral Activity (0.20)	5. Richness of Participatory Experience	0.4	0.08
Behavioral Activity (0.20)	6. Cultivation of Community Identity	0.25	0.05
Spiritual Imagery (0.25)	7. Perception of Genius Loci	0.45	0.113
Spiritual Imagery (0.25)	8. Evocation of Historical Memory	0.3	0.075
Spiritual Imagery (0.25)	9. Recognition of Cultural Symbols	0.25	0.063
Environmental Coordination (0.25)	10. Integration with Natural Landscape	0.4	0.1
Environmental Coordination (0.25)	11. Continuity of Regional Context	0.35	0.0875
Environmental Coordination (0.25)	12. Environmental Sustainability	0.25	0.0625

This synthesis process is repeated at the dimension level. The four dimensional fuzzy vectors are combined into a second-level judgment matrix, which is then synthesized with the dimension weight vector. The result is the target layer's membership vector—the overall cultural heritage degree expressed as membership to the five rating levels. To obtain an intuitive quantitative score for comparison, numerical values (5 through 1) are assigned to the five rating levels. The target layer's membership vector is weighted against these values, producing a final composite score between 1 and 5 that encapsulates the landscapes cultural heritage performance.

VI. EMPIRICAL VERIFICATION OF THE QUANTITATIVE EVALUATION SYSTEM

A. SYSTEM CONSTRUCTION AND EMPIRICAL RESEARCH

To comprehensively validate the system's reliability and practical utility, this study designed the following empirical research protocol. First, establish two objectives: verifying reliability and validity of the evaluation system and reliability and validity of application value of the evaluation system in guiding project diagnosis and optimization. Several representative built landscapes in terms of cultural type and techniques were selected as experimental samples according to principles of typicality, diversity and accessibility. Second, organize an evaluation team composed of experts and representatives from communities in the cities and counties involved in the project. The evaluation manual and scoring sheet were designed to standardize experimental evaluation. In the implementation process, we controlled the subjective bias of the evaluators through unified training and “back-to-back” independent scoring. Fuzzy comprehensive evaluation model was used in key calculation, and statistical method was used to conduct reliability and validity test and sensitivity analysis of evaluation results.

B. SYSTEM RELIABILITY VERIFICATION—EXPERT EVALUATION AND HORIZONTAL COMPARISON BASED ON MULTIPLE CASES

This study selected three types of landscape spaces—historical reappearance, modern translation and innovation, and integration with nature and ecology—as empirical cases.

An evaluation team composed of experts in landscape design and cultural heritage was invited. Based on the constructed quantitative evaluation system for cultural heritage, the evaluation team conducted independent and systematic on-site evaluations of each case based on four dimensions: material carriers, behavioral activities, spiritual imagery, and environmental harmony. Multi-dimensional quantitative data were collected to verify the reliability of the evaluation system.

Figures 1 (a-c) respectively show the score comparison, weighted comprehensive score results, and multidimensional performance patterns presented by radar charts for the three landscape cases in each evaluation dimension. Case A (Historical Feature Type) scored 4.17 in overall inheritance, demonstrating outstanding performance in the dimensions of material carriers (4.2) and spiritual imagery (4.5); Case B (Modern Translation Type) scored 3.89, showing advantages in the behavioral activity dimension; Case C (Ecological Integration Type) scored 4.06, achieving a score of 4.5 in the environmental coordination dimension. Given the exploratory nature of this study, the reliability check was conducted as an initial assessment of the evaluation system's consistency and discriminative power. Although the number of cases ($n=3$) is limited—a recognized limitation that will be addressed in future research—the evaluation design incorporated multiple raters (10 experts per case) to enhance statistical robustness. The inter-evaluator reliability coefficient ($ICC = 0.85$) indicates a high level of agreement among experts, suggesting that the evaluation criteria and fuzzy grading standards are sufficiently clear and operable. Furthermore, the horizontal comparison served primarily to test discriminant validity: the system successfully produced score profiles that align with the intrinsic characteristics of each case type (e.g., high spiritual scores for historical sites, high behavioral scores for modern translation projects). This alignment with theoretical expectations provides initial evidence of the system's construct validity. While acknowledging the need for larger-scale validation, these preliminary results support the system's potential as a reliable tool for comparative cultural heritage assessment in landscape design.

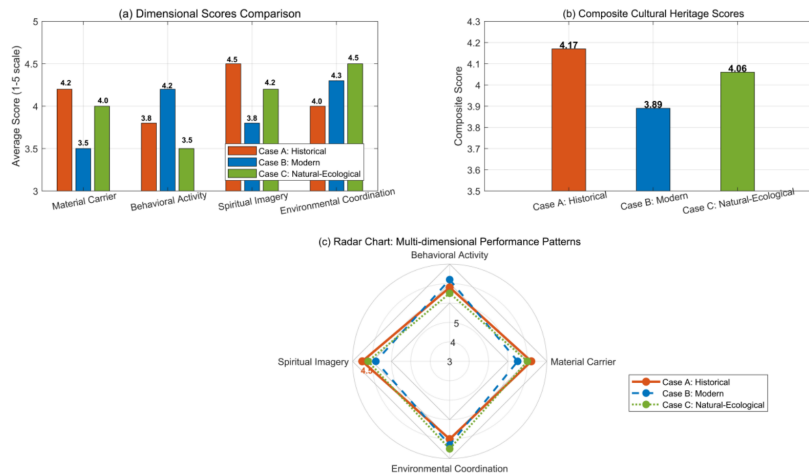


FIGURE 1. Expert Evaluation and Horizontal Comparison Based on Multiple Cases

C. VERIFICATION OF SYSTEM APPLICATION VALUE—LONGITUDINAL EVALUATION AND OPTIMIZATION DIAGNOSIS IN SPECIFIC PROJECT CYCLES

This experiment selected a micro-renewal project of public space in a historical district as the object for longitudinal tracking research. First, the established evaluation system was used to conduct a baseline evaluation of the current site (Score A). Subsequently, the initial design proposal was evaluated using the same system (Score B). By comparing Scores A and B across dimensions, weak links in inheritance were identified—most notably, a decline in the Spiritual Imagery dimension. These diagnostic results were compiled into a quantitative report and fed back to the design team, prompting targeted revisions. Finally, the optimized design proposal was evaluated (Score C) to assess the effectiveness of the system-guided adjustments.

TABLE 2. Longitudinal Assessment and Optimization Diagnosis in a Specific Project Cycle

Evaluation Dimension	Baseline Score (A)	Initial Design Score (B)	Optimized Design Score (C)	Net Change (C - A)
Material Carrier Dimension	3.2	4.1	4.3	1.1
Behavioral Activity Dimension	3.5	3.8	4	0.5
Spiritual Imagery Dimension	3.8	3.6	4.1	0.3
Environmental Coordination Dimension	3.9	4.3	4.4	0.5
Composite Heritage Degree	3.59	3.97	4.22	0.63

As shown in Table 2, the initial design proposal improved the composite score from 3.59 to 3.97 (+0.38) but revealed a critical deficiency: the Spiritual Imagery dimension decreased by 0.2 points, indicating that the design's cultural narrative and place spirit had been diluted. After receiving this diagnostic feedback, the design team revised the proposal to strengthen symbolic elements and historical narrative expression. The optimized design achieved a composite score of 4.22—a net increase of 0.63 from the baseline and 0.25 from the initial proposal—with all four dimensions showing improvement. Notably, the Spiritual Imagery dimension rebounded to 4.1 (+0.3 from baseline),

confirming that the system successfully identified the initial design's weakness and guided effective remediation. This longitudinal verification demonstrates that the quantitative evaluation system possesses not only diagnostic capability to pinpoint cultural deficiencies but also practical value in guiding targeted design optimization.

VII. CONCLUSION

This study constructed a quantitative evaluation system for landscape cultural heritage across four dimensions using an AHP-fuzzy comprehensive evaluation model. Empirical results from a preliminary multi-case assessment ($n=3$) demonstrate the system's ability to differentiate heritage levels across landscape types, with high inter-rater reliability ($ICC=0.85$) and discriminant validity consistent with theoretical expectations. In a longitudinal case study, the system successfully diagnosed a 0.2-point decline in spiritual imagery within an initial design, guiding optimization that achieved a net composite improvement of 0.60. However, the study's primary limitation is the small sample size for reliability validation; three cases are insufficient to claim broad generalizability. Future research will expand the case library to include a wider range of geographical regions, cultural contexts, and project scales. Cross-validation with alternative assessment methods and longitudinal tracking of implemented projects will further strengthen the empirical foundation of the system, ultimately enhancing its robustness and applicability in professional landscape design practice.

AUTHOR CONTRIBUTIONS

Congyi Jin designed, collected and analyzed the data, and drafted the manuscript. Congyi Jin conducted the study, critically revised the manuscript for important intellectual content, and gave final approval of the version to be published. Congyi Jin participated fully in the work, take public responsibility for appropriate portions of the content, and agreed to be accountable for all aspects of the work in

ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

CONFLICTS OF INTEREST

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REFERENCES

- [1] X. Y. Wu, "Design for the Enhancement of Urban Public Open Spaces from the Perspective of Public Health: A Case Study of Wulongtan Area in Jinan City," *Design*, vol. 09, no. 06, pp. 650-664, 2024, doi: 10.12677/design.2024.96736.
- [2] X. Pan, "The Inheritance and Innovation of "Artistic Conception" in Traditional Gardens in Modern Landscape Design," *Modern Horticulture*, vol. 48, no. 9, pp. 154-156, 2025, doi: 10.3969/j.issn.1006-4958.2025.09.047.
- [3] D. Li, "Discussion on Cultural Inheritance and Innovation in Garden Landscape Design," *Southern Horticulture*, vol. 35, no. 3, pp. 65-70, 2024, doi: 10.3969/j.issn.1674-5868.2024.03.013.
- [4] P. Shan and W. Sun, "Research on 3D urban landscape design and evaluation based on geographic information system," *Environmental Earth Sciences*, vol. 80, no. 17, pp. 597-598, 2021, doi: 10.1007/s12665-021-09886-y.
- [5] S. Zhang, J. Lin, Z. Feng, et al., "Construction of cultural heritage evaluation system and personalized cultural tourism path decision model: An international historical and cultural city," *Journal of Urban Management*, vol. 12, no. 2, pp. 96-111, 2023.
- [6] Z. Li, X. Han, X. S. Lin, et al., "Quantitative analysis of landscape efficacy based on structural equation modeling: Empirical evidence from new Chinese style commercial streets," *Alexandria Engineering Journal*, vol. 60, no. 1, pp. 261-271, 2021, doi: 10.1016/j.aej.2020.08.005.
- [7] M. Tenzer, "Social Landscape Characterization: a people-centred, place-based approach to inclusive and transparent heritage and landscape management," *International Journal of Heritage Studies*, vol. 30, no. 3, pp. 269-284, 2024, doi: 10.1080/13527258.2023.2289424.
- [8] B. Şenik and O. Uzun, "A process approach to the open green space system planning," *Landscape and Ecological Engineering*, vol. 18, no. 2, pp. 203-219, 2022, doi: 10.1007/s11355-021-00492-5.
- [9] H. Xie, Z. Zhu, Y. He, et al., "Integrated framework of rural landscape research: Based on the global perspective," *Landscape Ecology*, vol. 37, no. 4, pp. 1161-1184, 2022, doi: 10.1007/s10980-022-01401-3.
- [10] S. Gottwald, C. Albert, and N. Fagerholm, "Combining sense of place theory with the ecosystem services concept: empirical insights and reflections from a participatory mapping study," *Landscape Ecology*, vol. 37, no. 2, pp. 633-655, 2022, doi: 10.1007/s10980-021-01362-z.