Shanshui-Informed Digital Rural Planning: Modular Aesthetic-Spatial Mapping with GIS Ecological Analytics

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Abstract: Under rapid urbanization, rural planning in China is often driven by functional efficiency, contributing to ecological fragmentation and landscape homogenization. This paper proposes a modular digital planning framework coupling quantified *shanshui* (Chinese landscape aesthetics) parameters with GIS-based ecological analytics. Traditional landscape paintings are treated as visual proxies for cultural spatial cognition. Computer vision extracts spatial-organizational principles, formalized as an aesthetic-spatial mapping matrix translating compositional rules into computable ecological constraints and spatial weights. The framework guides the generation of ecological, productive, residential, and cultural modules. A case study in Wufeng Village demonstrates improved ecological performance, landscape-visual quality, and service accessibility relative to a baseline scenario, indicating a reproducible pathway for embedding cultural principles as generative rules in performance-driven planning.

Keywords: Aesthetic-spatial mapping,GIS ecological analytics, modular design, digital rural planning, shanshui

1 Introduction

1.1 Research Background and Problem

Rapid urbanization in China, driven by functional efficiency, has alienated human-land relations and fragmented landscape structures. As spatial production erodes local symbols and meanings (LEFEBVRE 1991), standardized construction leads to pervasive homogenization, reducing villages to land-use quotas rather than carriers of collective memory. Addressing this, this paper draws on *Tian-Ren-He-Yi* as a holistic worldview. We adopt a "five-in-one" model integrating ecological, economic, cultural, technological, and aesthetic dimensions (YAO et al. 2018). This perspective aligns with the nature-humanities-technology eco-design framework (WANG & LUO 2018) and *shanshui*-city symbiosis (ZHANG & WANG 2018), framing *shanshui* as a cultural-spatial paradigm to coordinate topography, water systems, and settlement forms.

1.2 Research Gaps and Objectives

Although digital technologies have become standard in contemporary landscape and rural planning, they still face methodological bottlenecks when dealing with culturally complex landscapes. On one side, prevailing digital tools prioritize quantitative modeling of biophysical processes and functional indicators, offering limited means to engage cultural semantics such as *yijing* (artistic conception); this functionalist bias can further intensify cross-regional morphological homogenization. On the other side, culturally oriented planning studies emphasize continuity of cultural context and place identity (WANG 2019, WANG 2021, WU 2024), yet often remain at the level of qualitative strategies or superficial symbol-making,

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lacking an operational pathway to couple spatial design decisions with ecological-physical processes in a systematic, quantitative manner.

Addressing this dual gap, this paper develops a modular digital planning framework jointly constrained by cultural rules and ecological indicators. By analyzing the spatial grammar embedded in Chinese painting and translating it into GIS-recognizable parameters, the framework enables the coordinated advancement of ecological restoration and cultural regeneration in rural landscape space through performance-grounded modeling and computation.

2 From Shanshui Philosophy to Computable Parameters

This study translates the holistic ecological ethic of *Tian-Ren-He-Yi* (Harmony between Man and Nature) into operational spatial language (YU 1996). We adopt *shanshui* as a spatial-organizational paradigm coordinating habitation with natural systems (QIAN 1993, WU & CAO 2022), utilizing traditional landscape paintings as "cognitive maps" that provide implicit, computable rules for 3D spatial arrangement (ZONG 1986, WU 2023).

To bridge cultural translation and digital operation, we draw on Ledderose's (2000) concept of modularization in Chinese art. Recent studies confirm this logic applies to *shanshui* paintings, where finite elements and combinatorial rules construct complex spaces. By treating pictorial elements as standard components and compositional principles as generative algorithms, we establish a structural isomorphism between *shanshui* aesthetics and parametric design. This justifies decomposing fluid cultural expressions into measurable spatial parameters for subsequent GIS quantification (Tab. 1).

Table 1: Operational Definitions of Core Aesthetic Concepts

Aesthetic Concept	Cultural/Spatial Meaning	Measurable Dimensions / Spatial Operations
Six Distances	A compositional principle for constructing multi-dimensional spatial experience (e. g., high, deep, and level distance).	GIS viewshed analysis; terrain relief/roughness; view-corridor width; building height control.
Gazing-Traveling-Wandering-Dwelling, Sequence	An experiential sequence for an ideal living environment.	Path-network connectivity; density of viewpoints; 10-minute service-area coverage; residential clustering and layout.
Liubai / Void	Rhythmic flow (qi resonance), interplay of void and solid, and spatial "breathing room."	Width of ecological buffer zones; proportion of non-development land; distance to water edges/riparian zones.
Host-Guest / Hierarchical Correspondence	Visual hierarchy and compositional order.	Elevation contrast (primary vs. secondary peaks); dominance of visual focal points.

3 A Digital Workflow Coupling Aesthetics and Ecology

3.1 Study Area and Data

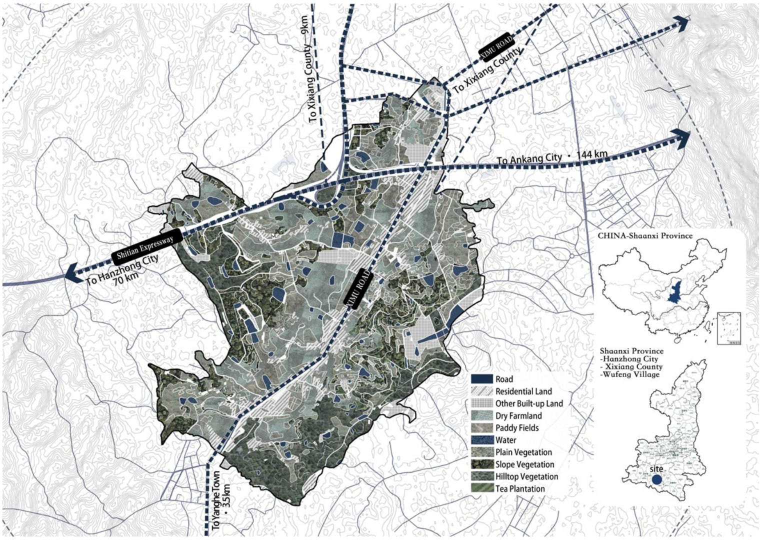

Fig. 1: Site Location and Existing Landscape Conditions

Wufeng Village (Shaanxi Province) was selected because its representative "mountain-water-field-settlement" vertical landform naturally aligns with the nested spatial logic of the "Three Distances" in traditional *shanshui* painting, offering an ideal testing ground against the threat of standardized construction (Fig. 1). Base data includes a 30m DEM, 0.5m satellite imagery, and land-use/hydrological data. The 30m DEM serves as a macro-to-meso topographical baseline. Acknowledging that 30m is too coarse for micro-scale "Six Distances" operations, we calibrated module placements and sightlines using 0.5m imagery and extensive field surveys.

3.2 GIS-Based Ecological Redline Delineation and Suitability Assessment

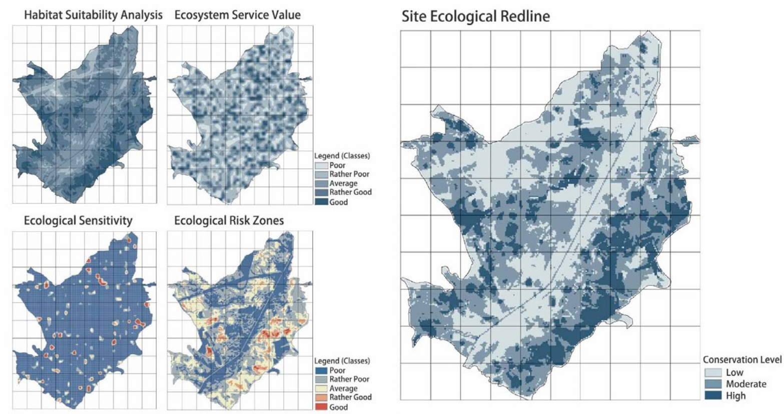

Fig. 2: Workflow and Results for Delineating the Site's Ecological Redline

Using GIS, we construct an ecological redline delineation system centered on multi-dimensional evaluation and weighted overlay. Site ecological attributes are decomposed into four core dimensions and assessed through fine-grained single-factor evaluations (Tab. 2), producing a three-tier protection scheme (low, medium, high). Areas classified as highly sensitive or high-risk are strictly designated as ecological redlines, clarifying differentiated regulatory intensities and providing a precise "*liubai*" (reserved void) base map for subsequent placement of *shanshui*-informed modules.

Table 2: Weighting Scheme for Ecological Redline Delineation

Criterion	Weight	Ecological Rationale
Ecologically Sensitive Areas	0.30	Indicates the sensitivity of the site's baseline ecological conditions
Key Ecological Function Areas	0.10	Represents core supply areas for ecosystem services
Ecological Redline (Vulnerable Zones)	0.40	Vulnerable zones exhibit low ecological stability and therefore require the highest management priority.
No-Development Zones	0.20	Strictly protected areas corresponding to zones of high habitat suitability.

3.3 Digital Extraction and Clustering of Shanshui Aesthetics

To extract *shanshui* modules, we combined machine-vision with art-historical validation (WANG 2021). From a manually compiled corpus of 112 high-resolution image patches from Song-dynasty paintings, we employed the CLIP model to automatically derive high-dimensional numerical feature vectors. This automated step converts abstract visual attributes (e. g., misty rain, steep ridges) into computable mathematical representations for similarity measurement. Following an automated HDBSCAN clustering of these patterns, human experts manually calibrated and semantically labeled the results against the site's baseline to prevent meaningless AI outputs. This hybrid process finalized six tailored pictorial archetypes: Open-Field Hamlet, Hillside Terrace, Forest-Embraced Hills, Construction Reserve, Vibrant Street-Alley, and Forest-and-Spring Ecological Zone.

3.4 The Aesthetic-Spatial Mapping Matrix

To translate abstract pictorial conceptions into implementable spatial schemes, we construct an element-based, hierarchical mapping matrix. Target *shanshui* archetypes are decomposed into specific states of five core elements – mountain, water, forest, settlement, and farmland – and mapped onto combinational GIS conditions across the site. Table 3 summarizes the generation logic for six *shanshui* character zones derived from factor scoring and weighted analysis.

Based on this matrix, GIS is used to validate the site's suitability for the six *shanshui* character zones. Areas with the highest pictorial potential are then selected for each zone to assemble the final planning scheme.

Table 3: A Factor-Scoring and Weight-Based Mapping Matrix for Shanshui Character Zoning

Target Archetype & Zone	Element Characteristics	GIS Weights & Thresholds
A: Open-Field Hamlet Zone *correspondence : Level Distance*	Buildings: scattered; farmland: dense; vegetation: scattered; views: long-range views; slope: flat (0–10°).	Weights: slope 0.30; buildings 0.25; vegetation 0.25. Threshold: slope < 10°.
B: Hillside Terrace with Scattered Dwellings *Correspondence : Deep Distance*	Buildings: moderate; farmland: moderate; vegetation: dense; views: long-range views; slope: moderate (10–25°).	Weights: vegetation 0.50 (highest); farmland 0.30; slope 0.20. Threshold: 10° < slope < 25°.
C: Forest-Embraced Hills *correspondence : High Distance*	Buildings: scattered; vegetation: dense; farmland: scattered; slope: steep (>25°, or 10–25° in some contexts).	Weights: farmland 0.40 (patch protection); vegetation 0.30; slope 0.20. Threshold: slope > 25°.
D: Construction Zone *correspondence : Production*	Buildings: dense; roads: high accessibility; vegetation: scattered; slope: flat (0–10°).	Weights: production buildings 0.40; buildings+roads 0.25; slope 0.10. Threshold: high road-network density.
E: Vibrant Street-Alley Quarter *correspondence : Vibrant Life*	Buildings+roads: dense; services: convenient; vegetation/farmland: scattered; slope: flat (0–10°).	Weights: buildings+roads 0.40; services 0.20; slope 0.20. Threshold: within service-facility catchments.
F: Forest-and-Spring Ecological Zone *correspondence : Void/Seclusion*	Vegetation: dense; water: dense; roads: sparse; ecology: sensitive/vulnerable.	Weights: ecological redline 0.45; vegetation 0.35; roads 0.20. Threshold: within ecological redlines & water-buffer zones.

4 Case Application and Results

The planning proposal is developed across three nested scales: (i) a macro-scale integration of the *shanshui* landscape pattern and functional structure, (ii) a meso-scale landscape-character zoning plan, (iii) a micro-scale design of experiential sequences.

4.1 Macro-Scale: Integration of Landscape Pattern and Functional Network

A viewshed-based framework safeguards long-distance corridors, repositioning the site within the regional urban-rural corridor (Fig. 3). Targeted road connections strengthen visual and ecological linkages to surrounding mountains and waters, establishing the village as a strategic regional ecological node.

4.2 Meso-Scale: Landscape Zoning based on Painting Suitability

We first screen *shanshui* archetypes against field-identified landscape features. Paintings are abstracted into planar diagrams to derive preliminary criteria. Finally, integrating residential, industrial, and ecological factors, we construct a comprehensive evaluation matrix for zoning.

GIS-based multi-character suitability analysis is then conducted to identify optimal locations for each pictorial archetype (Fig. 5). Guided by the spatial organizational logic of *shanshui* painting, the final plan synthesizes an "one axis-two belts-six zones" structure (Fig. 6), ensuring that pictorial conceptions such as level and deep distances are materially projected into the physical landscape (Fig. 7).

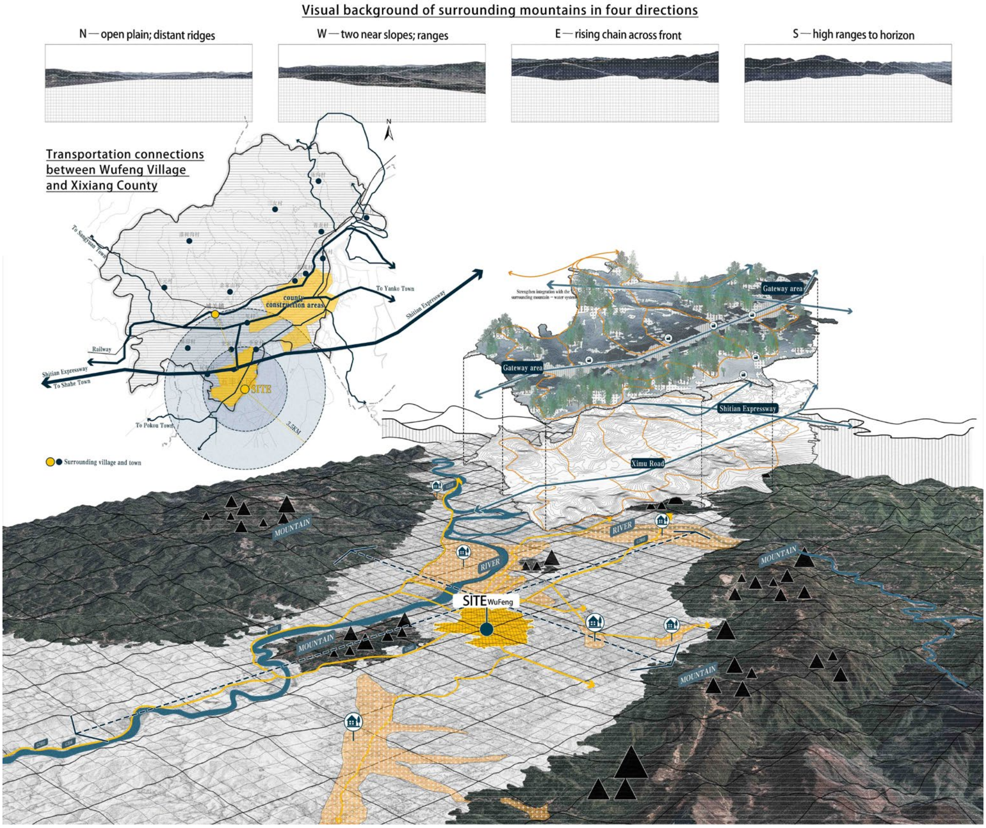

Fig. 3: Surrounding Landscape Pattern and Transportation Plan

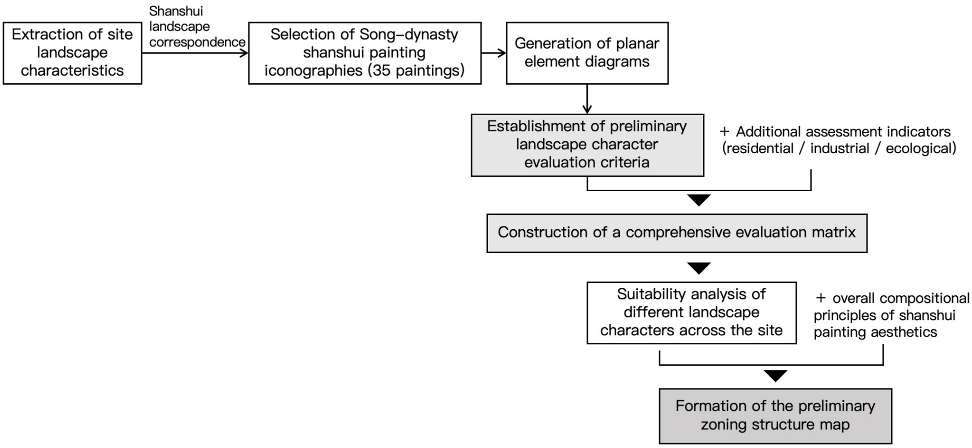

Fig. 4: Technical Workflow for Painting-Informed Zoning

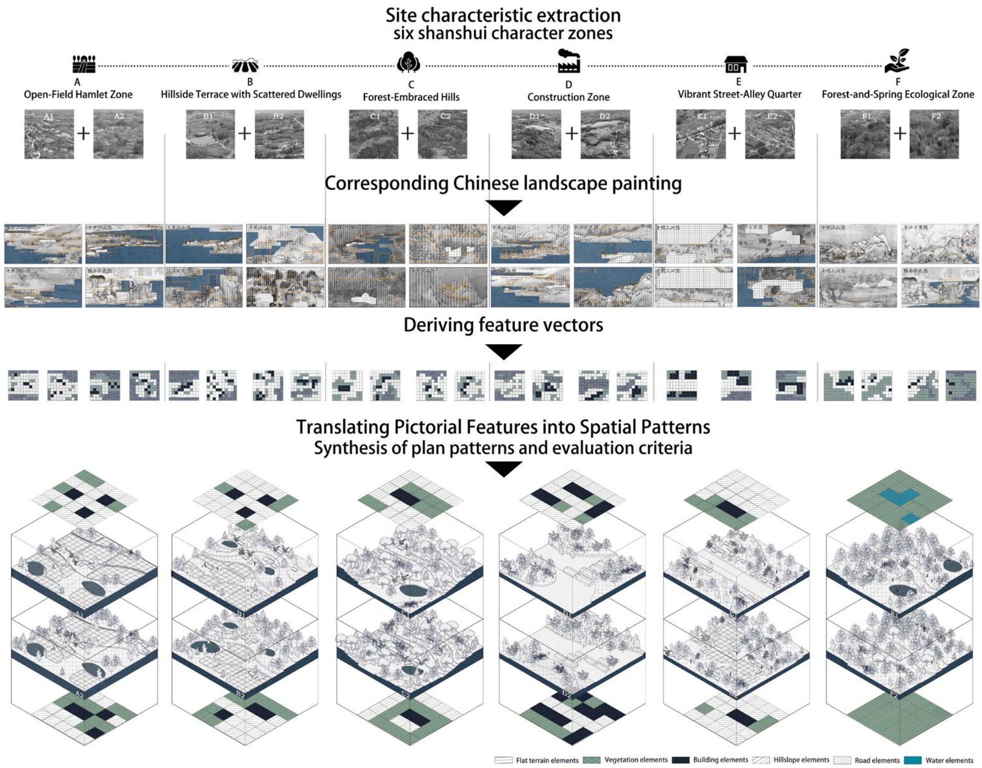

Fig. 5: Spatial Patterns Corresponding to Six *Shanshui* Pictorial Archetypes

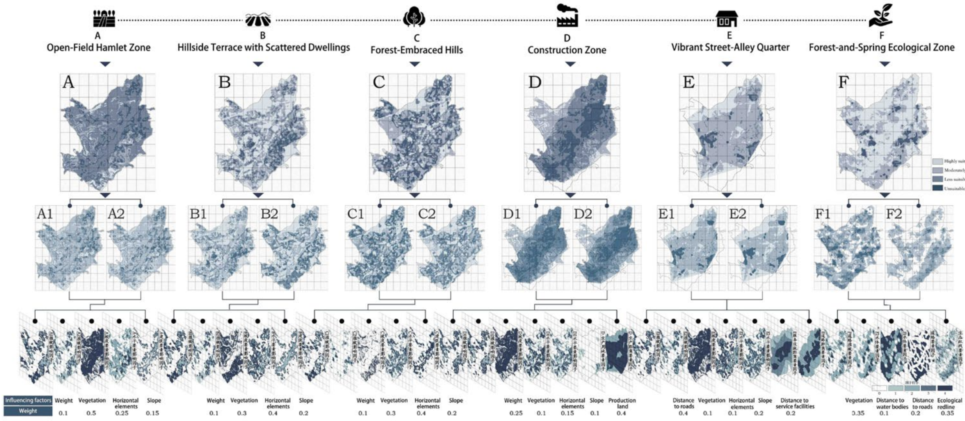

Fig. 6: Suitability Analysis for Six Pictorial Archetypes

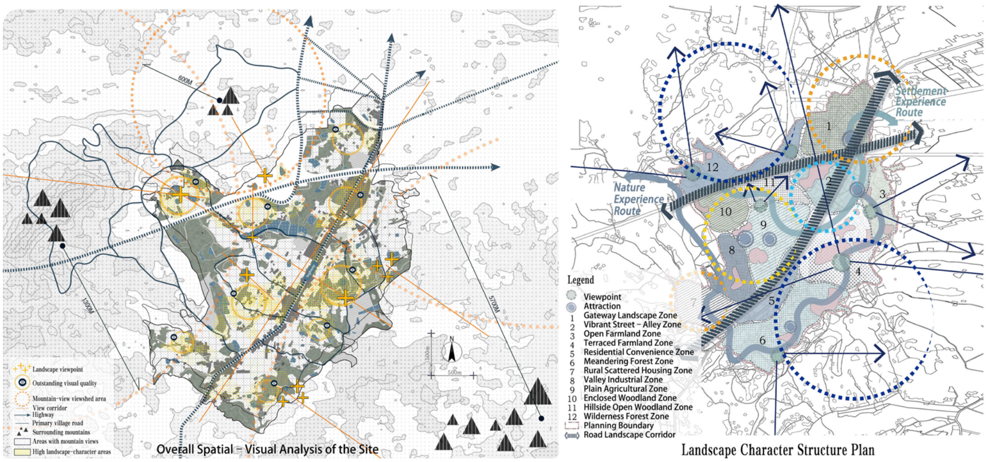

Fig. 7: Structural Diagram of the Landscape Plan：Overall Spatial-Visual Analysis of the Site

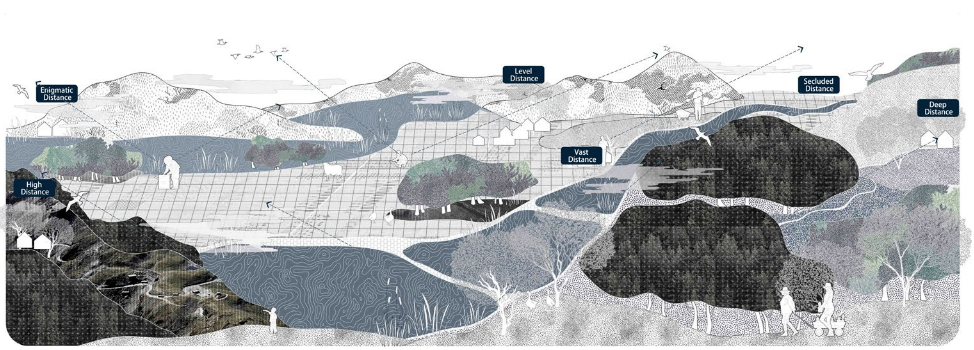

Fig. 8: Planning Illustration of the Six-Distance Scheme for the Site

Table 4: Meanings and Spatial Characteristics of the "Six Distances" in Shanshui Painting

Name	Classical Description	Spatial Characteristics
High Distance	Looking up from the foot of a mountain to its summit is called high distance.	Vertical height; sublimity.
Deep Distance	Looking from a near mountain toward a distant mountain is called level distance.	Layered depth (receding spatial strata).
Level Distance	Peering from the front of a mountain toward what lies behind it is called deep distance.	Lateral extension.
Vast Distance	Broad plains and vast rivers/lakes, where the far sky seems boundless, are called vast distance.	Expansive openness.
Enigmatic Distance	Mist and haze, where waters separate the view and what lies beyond appears indistinct, are called enigmatic distance.	Veiling; ambiguity.
Secluded Distance	When scenery reaches an extreme yet remains faint and ethereal, it is called secluded distance.	Emptiness; quietude; contemplative atmosphere.

4.3 Micro-Scale: Experiential Sequence of "Gazing, Traveling, Wandering, Dwelling"

We operationalize *shanshui* experiences through a dual "line and point" strategy. The line strategy structures routes following "Six Distances" and "walkable/viewable" principles. GIS viewshed analysis identifies high-value corridors, while route patterns extracted from paintings guide trail design and vantage point compositions. The point strategy deploys modular "habitable" units. Three painting-derived dwelling patterns are mapped onto buildable areas, with signature nodes like the "Recluse Dwelling" visualized through collage renderings articulating *shanshui* conceptions via local materials (Figs. 9-10).

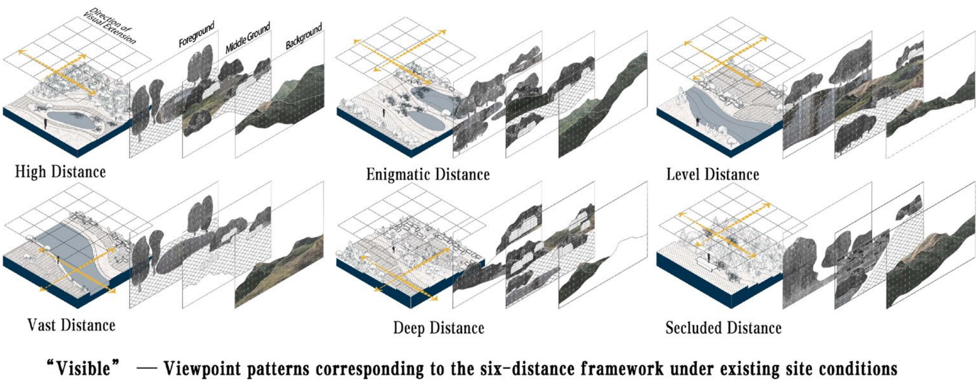

Fig. 9: Compositional patterns of Wufeng's Six-Distance scenes at specific on-site vantage points. The accompanying montage uses in-situ imagery from Wufeng to illustrate the actual scenes.

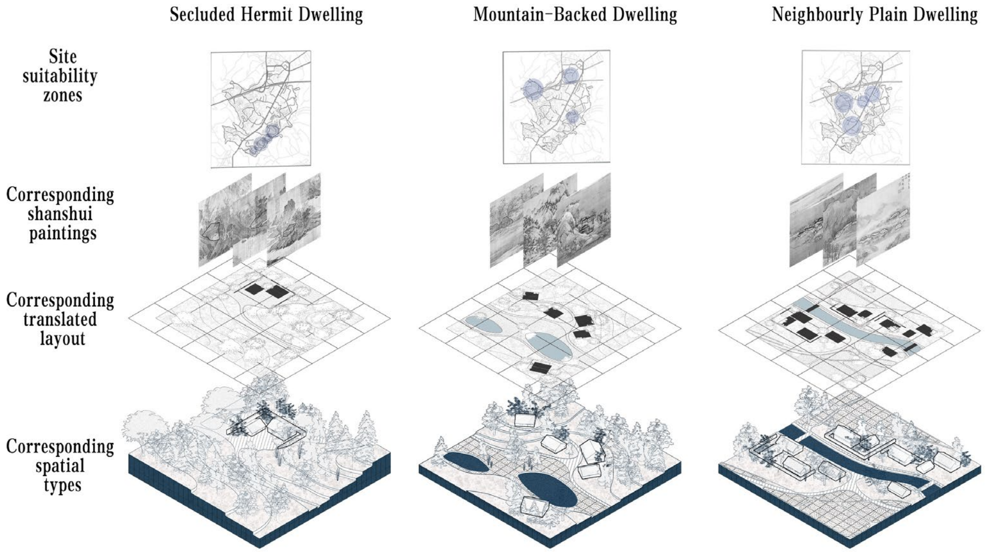

Fig. 10: Three "Habitable" Spatial Types and Their Corresponding Site Selection Areas

4.4 Quantitative Performance Evaluation

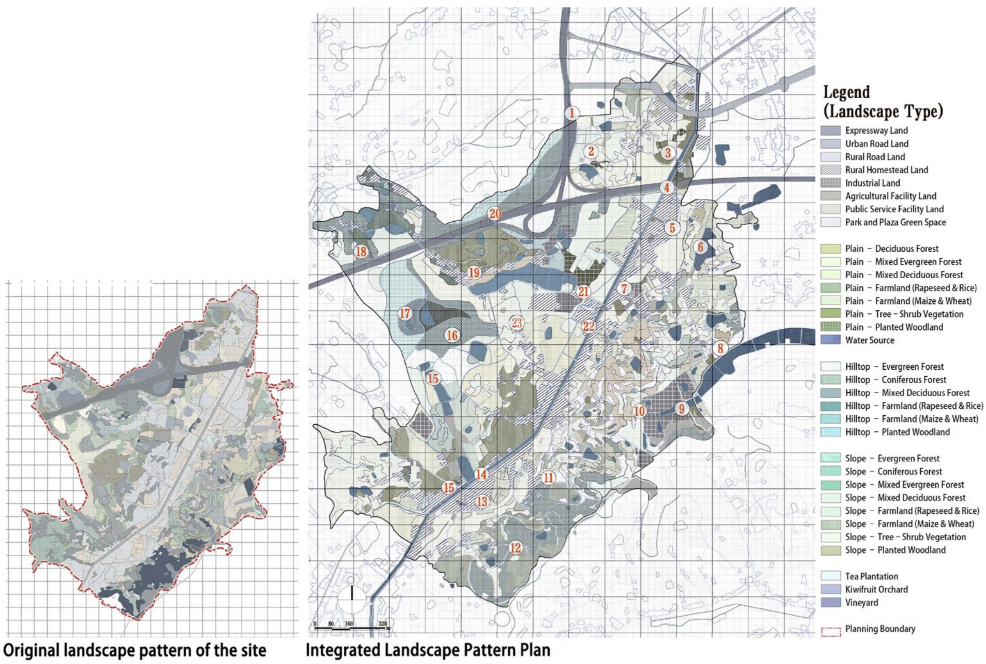

Fig. 11: Landscape Conditions Before and After Planning

Quantitative comparison against existing conditions shows the scheme improves ecological connectivity (PC index) by 18% via restored corridors. Viewshed analysis reveals a 31% increase in primary *shanshui* vistas within public spaces. Furthermore, optimized module placement reduces built land in flood-prone areas while improving 10-minute service accessibility from 63% to 82%, significantly enhancing both regional resilience and daily convenience (Fig. 11).

Discussion and Conclusion

This research formalizes *shanshui* spatial grammar into operational rules, establishing a reproducible pathway to integrate traditional culture into performance-driven planning. However, we critically acknowledge that GIS analytics evaluate the physical prerequisites and geometric armatures of *shanshui* spaces, rather than directly quantifying the ineffable *yijing* (artistic conception). Discretizing fluid cultural experiences involves reductionism; thus, fulfilling GIS metrics provides an optimized spatial "canvas" that facilitates and encourages, rather than guarantees, the intended cultural aesthetic. This framework functions as a decision-support tool to augment designer intuition. Future work will explore graph neural networks to capture deeper scene semantics for adaptive planning.

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