Exploring Spatial Evolution of Traditional Settlement Landscapes in the Southern Taihang Region of China: A Study on Cultural Ecosystem Dynamics and Reconstructive Strategies

Jianren Zhi [1,2,*], Qun Zhang [1]
[1] School of Architecture, Xi'an University of Architecture and Technology, Xi'an 710055, China
[2] School of Civil Engineering and Transportation Engineering, Anyang Institute of Technology, Anyang 455000, China
* Correspondence: zhiren@xauat.edu.cn J. Zhi

Abstract
As spatial manifestations of human–environment relationships, traditional village landscapes are increasingly challenged by industrialization, urbanization, and globalization. This study focuses on the southern Taihang Mountains in China and applies a cultural ecology approach to construct a process-oriented model of settlement evolution. It systematically analyzes how agrarian culture shapes spatial forms across technological, institutional, cognitive, and practical dimensions, and reveals the transformation of settlements from ecological adaptation to spatial reconstruction under external disturbances. Integrating Holling's adaptive cycle theory, the research delineates four evolutionary stages of traditional settlements and employs network analysis to build a cultural ecosystem network, highlighting mechanisms of multi-scalar spatial restructuring. Based on this, a holistic protection strategy is proposed—from node activation and cluster coordination to regional network optimization. The study offers theoretical support for the dynamic reintegration and systemic revitalization of traditional settlements in the southern Taihang region, while providing a reference framework for adaptive protection of cultural landscapes globally.

Keywords Traditional Settlement Landscapes; Cultural Ecology; Evolutionary Mechanisms; Southern Taihang; China

Introduction

As a fundamental material basis of human civilisation, villages serve an irreplaceable function in preserving historical memory and transmitting cultural heritage-Barrientos et al.,2021-. Nevertheless, the rapid advancement of industrialisation and urbanisation, alongside profound socio-economic transformations, has posed significant challenges to rural settlements globally, manifesting in depopulation, functional decline, and even the complete disappearance of some villages-Mu and Aimar, 2022; Li, Westlund and Liu, 2019-. In the context of China's rural revitalisation strategy, traditional villages constitute a critical spatial unit. They not only facilitate the modernisation of rural areas and enhance the living standards of local populations but also play a pivotal role in sustaining regional cultural identity and ensuring social cohesion.Since the initiation of systematic protection efforts in 2012, China has implemented a six-phase listing programme (2012–2023), encompassing 8,155 traditional villages and thereby establishing the most comprehensive agricultural heritage conservation framework globally -Cheng et al., 2024-. Furthermore, starting in 2020, the Ministry of Finance and the Ministry of Housing and Urban-Rural Development have successively promulgated the Model Work Programme for the Intensive and Continuous Conservation and Utilisation of Traditional Villages. This initiative targets persistent issues such as spatial homogenisation and limited revitalisation pathways in traditional village development -Zhao et al., 2024-.Against this backdrop, an in-depth exploration of the spatial characteristics and generative mechanisms of regional traditional villages has become essential. Such inquiry is vital for addressing the fragmentation in current conservation practices, unlocking cultural and ecological potentials, and advancing both theoretical understanding and practical implementation of holistic settlement preservation and cultural system reconstruction.

Research on the spatial morphology of traditional settlements has undergone a progressive evolution of theoretical paradigms, gradually forming a composite explanatory system that integrates natural, social, and cultural dimensions. In its early stages, the dominant perspective was functionalism, which highlighted the interdependence between settlements and natural geographical conditions, yet largely overlooked cultural and institutional dynamics -Li and Zhang, 2012-. Later, central place theory introduced a hierarchical logic of settlement distribution and functions, advancing the modelling of spatial systems -Hill, 2003; Pacione, 1984-. Concurrently, cultural landscape theory underscored the notion that spatial forms are shaped by cultural choices, thereby integrating cultural behaviours into spatial analysis-Sauer, 2008-.Within the structuralist tradition, Rossi's theory of architectural typology interpreted settlements as material representations of collective social cognition -Rossi, 1984-, while Hillel's spatial syntax elucidated the organisational logic of space and human behaviour through topological structures-Yamu, Van Nes and Garau, 2021-. In recent years, interdisciplinary approaches have gained

prominence, fostering closer integration between theoretical inquiry and practical application. However, most existing studies still lack a systematic framework capable of explaining the dynamic generative mechanisms behind settlement morphology, particularly those shaped by long-term interactions among ecological, cultural, and institutional forces.To address these limitations, this paper introduces the theoretical perspective of the cultural ecosystem and proposes a four-dimensional analytical framework encompassing: technology–ecology, cognition–concept, organisation–institution, and practice–strategy. This approach aims to overcome the current fragmentation and unidirectional interpretations in traditional settlement research, offering a more holistic understanding of their spatial evolution.

As scholarly inquiry deepens, empirical research on the spatial morphology of traditional settlements has gradually matured across several dimensions, including research subjects, scale frameworks, analytical methods, and variable construction. A foundational analytical pathway has emerged, characterised by the sequence of "pattern identification – typological classification – factor analysis." Most existing studies concentrate on nationally recognised villages or prominent regional cases -Liu et al., 2022-, such as Guizhou Province -Yan et al., 2021- and ethnic minority areas-Chen, Xiao and Liu, 2024-. While such research has elucidated macro-level distribution patterns, it tends to overlook marginal regions and atypical cases, thereby constraining the generalisability and applicability of findings.In terms of scale, a widely adopted three-tier analytical framework—macro, meso, and micro—is typically employed, corresponding to spatial distribution evolution, typological differentiation, and intra-settlement structural analysis, respectively-Lin, Liang and Liu, 2024-. Common methods include kernel density estimation-Bi et al., 2024-, cluster analysis, and space syntax modelling-Qin et al., 2023-. With regard to variable construction, most indicators are derived from natural, social, cultural, and institutional dimensions. However, the analytical techniques employed are predominantly linear, such as regression analysis and structural equation modelling-Yuan et al., 2024-, which often fail to capture the complex nonlinear interactions and coupling mechanisms among variables.Despite notable progress, current research continues to exhibit limitations, including inadequate identification of spatial phenomena and insufficient integration of cultural-ecological dimensions. Moving forward, it is essential to optimise indicator systems and refine analytical approaches under robust theoretical guidance, in order to achieve a more systematic and comprehensive understanding of the evolutionary mechanisms underpinning the spatial morphology of traditional settlements.

Situated within the transitional geographic zone between the Central Plains and North China, the South Taihang region represents a typical mountainous and hilly terrain bridging the eastern edge of the Loess Plateau and the North China Plain. Characterised by its fragmented topography and ecological diversity, the region has nurtured a wide spectrum of traditional settlement forms. Embedded within this landscape is a convergence of diverse cultural lineages, including agrarian traditions, mountain-based defence systems, and nomadic frontier influences. These have collectively shaped distinctive village morphologies—such as fortress-type, trade route-based, and mountain-adapted settlements—rendering the region highly representative and of considerable academic interest.In recent years, however, the acceleration of urbanisation and the deepening reconstruction of rural spatial structures have triggered profound transformations in these traditional settlements. Their embedded cultural and ecological frameworks are experiencing significant disruption, thereby necessitating timely institutional responses to safeguard their evolutionary continuity and guide appropriate conservation strategies.

Accordingly, this study pursues two primary research objectives: (1) to elucidate the historical trajectories and spatial evolution patterns of traditional settlements in the South Taihang region; and (2) to develop a protection and reconstruction pathway grounded in the cultural ecosystem perspective. Through this, the study seeks to offer a theoretical foundation and strategic guidance for the systematic conservation of traditional settlements in complex mountainous landscapes.

Research Methods

Overview of the Study Area

The Taihang Mountains extend through central North China, with the South Taihang section located in Henan Province, spanning approximately 150 kilometres from north to south. This region is predominantly mountainous and hilly, and it hosts a rich array of traditional villages whose residential and architectural forms exhibit pronounced mountainous settlement characteristics-Duan et al., 2023-. However, the rapid pace of urbanisation and tourism development has resulted in the hollowing out and commodification of many villages. Concurrently,

land use transformations and ecological degradation have posed severe threats to their sustainable development. Existing conservation efforts tend to concentrate on individual villages, often overlooking broader regional dynamics, including inter-village interactions, resource flows, and spatial functions.To address this gap, the present study selects 43 representative traditional villages—each recognised at or above the provincial level—located in the South Taihang mountainous region as the research sample (Fig. 1). These villages are characterised by long-standing histories, relatively intact preservation, and high cultural landscape value.

Fig. 1 Map of the study area of South Taihang in northern Henan Province

Data Sources

The data utilised in this study were derived from multiple authoritative sources to ensure comprehensiveness and reliability. Geographic information, including 30×30 m resolution digital elevation model (DEM) data, was obtained from the China Geospatial Data Cloud Platform (http://www.gscloud.cn/). Administrative boundary data at the provincial, municipal, county, and village levels were sourced from the Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences (http://www.igsnrr.ac.cn/). Official lists of traditional villages were acquired from the Ministry of Housing and Urban-Rural Development of China and the Henan Provincial Department of Housing and Urban-Rural Development. GDP and population statistics were also retrieved from the Institute of Geographic Sciences and Natural Resources Research. Cultural heritage data were collected from the Ministry of Culture and Tourism of the People's Republic of China (https://www.mct.gov.cn/) and the Henan Provincial Cultural Relics Bureau (http://wwj.henan.gov.cn/). Additionally, Point of Interest (POI) data, along with information on the shortest travel time and distance between locations, were obtained from the Gaode Open Platform (https://lbs.amap.com/). To complement these secondary sources, field investigations were conducted to collect primary data on village profiles, infrastructure, architectural characteristics, as well as population and economic conditions.

Analysis Framework and Research Ideas

Evolutionary Mechanism Model of the Cultural Ecosystem in Traditional Villages

Traditional settlements are not merely historical accumulations of material space; they also represent the evolving outcomes of cultural ecosystems shaped by the dynamic interplay between natural, social, and cultural forces. Drawing on the principles of cultural ecology, human societies have developed a "culture-driven core" under resource constraints and institutional regulation, from which three major cultural dimensions—material, institutional, and spiritual—have emerged-Chen, Xie and Li, 2020; Shao, Cui and Zhang, 2024-(Fig. 2). These dimensions are systematically translated into spatial expressions through four structural levels: technology–ecology, organisation–institution, cognition–concept, and practice–strategy, forming the intrinsic mechanism underlying the spatial evolution of settlements.

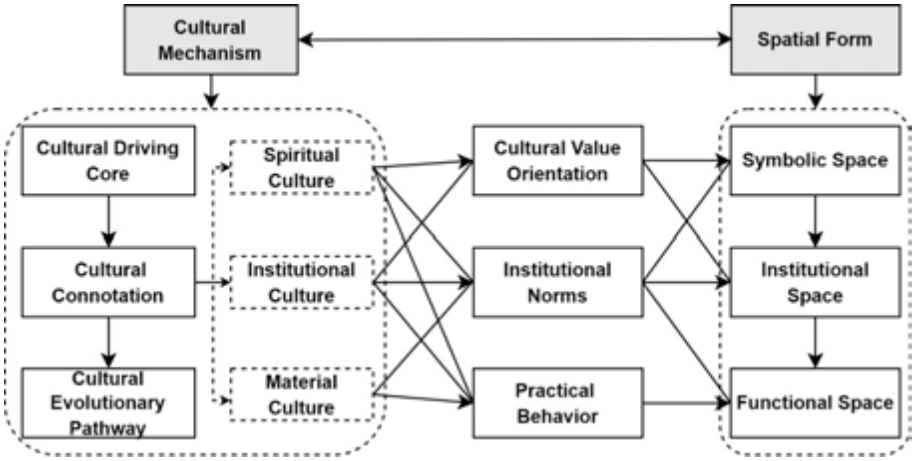

Fig. 2 Conceptual Framework of Cultural Mechanisms Driving the Formation of Spatial Forms in Traditional Settlements

To capture the temporal dynamics of this evolution, this study adopts Holling's adaptive cycle theory-Holling, 2001-, which conceptualises evolution in four phases: exploration, conservation, release, and reorganisation. This framework reveals how the culture-driven core undergoes phases of stabilisation, disintegration, and restructuring. Spatially, this process is embodied in a nested path of "culture-driven core—cultural connotation—spatial representation", leading to the construction of a three-tiered spatial network comprising nodes, clusters, and regions. This tripartite structure spans macro-regional scales, meso-level agglomerations, and micro-level settlement nodes. Overall, the proposed mechanism model demonstrates that cultural ecological spaces evolve through a dynamic process of variation–adaptation–integration, driven by self-organisation and network coupling under multiple external disturbances.

Construction of the Cultural Ecological Network of Traditional Villages

To uncover the patterns of cultural-spatial interaction among traditional villages in the South Tai hang region of northern Henan, this study constructs a cultural ecological network system. This system integrates cultural development indicators, applies the gravity model as its analytical logic, and employs social network analysis (SNA) as its methodological tool. First, a set of 16 specific indicators was developed across five criteria: historical and locational background, tangible and intangible cultural heritage, infrastructure, industrial activity, and economic status-Wang et al., 2023-, aiming to comprehensively assess the cultural development level of each village. These indicators were standardised using the extreme deviation method, and weighted through the entropy method-Chen, Zhong and Li, 2023-, yielding a composite cultural development score ranging from 0 to 1. This score serves as a proxy for the village's cultural attractiveness. Next, the traditional gravity model-Wang et al., 2025- was modified to incorporate both the composite cultural development scores and the shortest travel time between villages, thereby quantifying the intensity of cultural-spatial linkages. Based on this, a spatial cultural ecological network was established. Finally, SNA was employed to analyse the centrality of network nodes, the overall network topology, and to explore patterns of core–periphery differentiation, cohesive subgroups, and mechanisms of spatial interaction -Liu, Hao and Xia, 2024-.

Results

Stages in the Evolution of the Cultural Ecosystem of Traditional Villages

Agricultural Inception: The 'Livelihood–Adaptation' Phase of the Cultural Ecosystem

During the Ming and Qing Dynasties, traditional villages in northern Henan began to emerge and gradually coalesced into stable settlement systems. This period marked the initial formation of a cultural ecosystem grounded in agriculture as the primary mode of subsistence and ecological adaptation as the core dynamic. Although the spatial scale of these villages remained limited and their internal structures relatively loose, the foundational coupling of people–land–culture began to take shape. In response to challenges such as frequent Yellow River flooding, cold and arid climatic conditions, and scarcity of arable land, early settlers gradually constructed a preliminary yet stable cultural ecosystem. This was achieved through livelihood-based adaptation, conceptual reconstruction, organisational experimentation, and practical accumulation, laying a critical foundation for the

institutionalisation and networked evolution of traditional settlements.

Deconstructing the Intrinsic Mechanism: Origin and Adaptive Logic of the Cultural Ecosystem

In the formative stage of cultural ecosystem development, traditional agrarian settlements in northern Henan demonstrated a spatial logic rooted in livelihood adaptation.At the technology–ecology level, villages were typically situated along the seasonal water belts at the margins of the Yellow River alluvial fan. These locations enabled the construction of ridge-and-border farming systems well-suited to dryland agriculture. Productivity was enhanced through the use of agricultural tools such as waterwheels and ploughs, and small-scale settlements were spatially distributed according to topographic features.At the cognition–concept level, cultural consciousness was shaped by reverence for natural forces and adherence to agricultural seasonality. Symbolic spaces—such as land shrines and communal temples—emerged as centres of collective belief and practice, embodying the villagers' perceptual and spatial responses to ecological rhythms.

At the organisation–institution level, early village life was governed primarily by neighbourly cooperation and customary norms, with formal clan systems still in embryonic form. Nonetheless, the emergence of ancestral halls and sacrificial fields signalled the nascent development of institutional frameworks for communal organisation.At the practice–strategy level, villagers adopted a diversified risk-coping strategy involving small-scale mixed farming, crop rotation, and household-based handicrafts. They enhanced settlement resilience through cooperative practices such as ditch construction, flood control, and collective labour mobilisation. Simultaneously, early forms of interaction with local administrative structures were established, initiating the villages' gradual integration into broader regional governance networks.

Together, these four structural mechanisms—technological, cognitive, institutional, and strategic—constituted the spatial and functional basis of the early cultural ecosystem, establishing the point of departure for the sustained evolution of traditional settlements in northern Henan.

Spatial Representation: Prototypical Construction of Agricultural Settlements and Ecological Dependency Structures

In the early stages of development, agrarian settlements in northern Henan were predominantly situated along natural water systems—rivers, canals, shallow floodplains, and wells—forming a distinct ecological dependency structure that integrated agricultural production and daily living within a unified spatial context. These villages were generally small in scale, with vague or fluid boundaries, and the layout of dwellings reflected a terrain-responsive logic: houses were scattered based on topographical conditions, forming a proto-structural pattern centred around nuclear families, with miniature plots of farmland encircling the residential core.At this stage, internal functional zoning remained rudimentary, and the spatial structure was largely defined by a few critical nodes. Elements such as land shrines and wells served multifunctional roles, acting as centres for communal gathering, ritual worship, and local trade. The residential form was characterised by compact courtyard-style housing, where living and productive activities were highly integrated (Fig. 3), reflecting the underlying spatial principle of "life as livelihood."

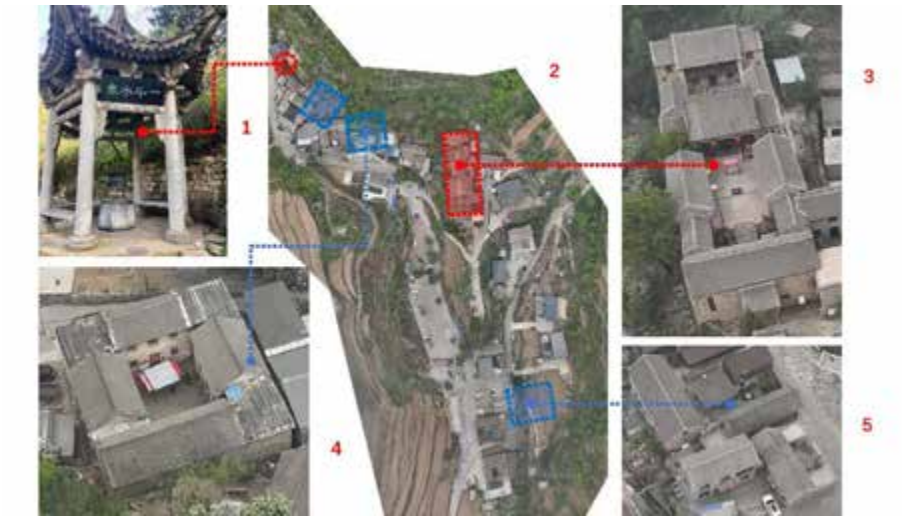

Fig. 3 Spatial features of Yidoushui Village in the 'Livelihood–Adaptation' phase of the cultural ecosystem: (1) the ancient spring well that served as the origin of settlement; (2) aerial view of the current village layout; (3) Guandi Temple, a spiritual and institutional cultural core; (4) courtyard dwellings providing commercial services during the early stage of development; (5) representative enclosed courtyards adapted for early trade and residence.

With the gradual stabilisation of agricultural cycles and the emergence of rudimentary institutional interventions, certain villages began to exhibit axial symmetry and defined residential base boundaries, marking a shift towards more organised spatial order. Simultaneously, the path system evolved into a functional network that linked residences, farmlands, and water sources—a configuration here referred to as the "house–field–water" network. This spatial transformation signified a critical transition from settlements based purely on ecological adaptation to those shaped by cultural organisation, thereby laying the structural groundwork for the subsequent institutionalisation and networked evolution of the traditional settlement system.

Agricultural Heyday: The 'Stabilisation–Adaptation' Phase of the Cultural Ecosystem

During the agricultural heyday, the advancement of agricultural technologies in northern Henan significantly enhanced human–land relations, ushering traditional villages into a phase of stabilisation-oriented evolution within the cultural ecosystem. In this stage, ecological constraints were no longer the primary limiting factors. Instead, cultural, institutional, and social dynamics emerged as the dominant shaping forces, steering the evolution of village spatial structures toward systematic organisation, functional differentiation, and networked synergy.

Deconstruction of Intrinsic Mechanism: Multi-Layered Homeostatic Synergy in Agrarian Cultural Ecosystems

At the technology–ecology level, northern Henan's geographic position—spanning both plains and hills—provided a favourable foundation for dry farming. From the Ming and Qing Dynasties onward, the widespread adoption of agricultural tools such as ploughs and waterwheels, coupled with improvements in water conservancy infrastructure, led to the development of an integrated "field–village–road" system. This structure linked irrigation networks with tributary channels, effectively boosting agricultural productivity and enhancing the external connectivity of settlements.At the cognition–concept level, ancestral halls and family temples became the spiritual and spatial axes of the village. The Confucian ideology of ritual-based governance) became deeply embedded in land allocation, residential spatial arrangements, and settlement planning. Ethical values centred on filial piety and ancestor reverence reinforced spatial hierarchies within the settlement and fostered the stable evolution of axial and enclosed spatial layouts.

At the organisation–institution level, village covenants, ancestral codes, and clan regulations—driven by lineage-based governance—effectively maintained collective order. Systems of centralised land management and collaborative farming strengthened the endogenous governance capacity of the village. Moreover, the nested interaction between formal administrative institutions (e.g., the bailiwick system) and informal clan

self-organisation provided a high degree of institutional resilience and governance flexibility.At the practice–strategy level, daily activities remained highly synchronised with agricultural seasonal cycles. Interactions across seasons, the establishment of market trading hubs, and the development of regional road networks promoted functional connectivity between villages. Additionally, Qing Dynasty rural policies—such as the establishment of marketplaces, patrolling mechanisms, and inspection systems—contributed to the institutionalisation of spatial nodes and facilitated the construction of inter-village cooperative networks.

Spatial Representation: Network Structure of Farming Villages under Institutional Embeddedness and Functional Synergy

The synergy of multi-level cultural ecosystem mechanisms during the agricultural heyday is spatially manifested in farming settlements characterised by systematic organisation, functional clarity, and enhanced network connectivity. Village layouts were typically centred around arable land and water resources, forming a spatially cohesive "cultivation–residence–ancestral shrine" structure. Within these settlements, the ancestral hall functioned as the spiritual and symbolic core, around which residential zones were organised—reflecting a spatial logic founded on the trinity of land, kinship, and faith (land–family–belief).Beyond the settlement core, roads, canals, and market access routes facilitated the construction of a rural spatial network linking adjacent villages. The implementation of market-day systems introduced a regular rhythm to local socio-economic life, transforming marketplaces into intermediary nodes for both economic exchange and cultural interaction. This system encouraged the evolution of villages from isolated spatial units into a networked and coordinated rural system, defined by multi-layered interactions and cooperative functions.

Overall, the spatial morphology of farming villages in this phase reflects the organic integration of natural, institutional, and cultural elements within a stabilisation-dominated cultural ecosystem. This period is marked by the typical features of institutional embeddedness, functional complementarity, and spatial hierarchy (Fig. 4). The resulting spatial network not only enhanced the resilience and adaptability of the settlement system but also laid a robust foundation for the future development of regional collaboration and cultural integration.

Fig. 4 Spatial Characteristics of Beizhu Village in the 'Stabilisation–Adaptation' Phase of the Cultural Ecosystem: (1) Village master plan with old village boundary (blue dashed line); (2) Bird's-eye view of fortress-like courtyard houses; (3) Clan ancestral hall as the core of spiritual and institutional culture; (4) Enclosed traditional courtyard with defensive spatial layout; (5) Main entrance and façade of a preserved residential courtyard.

Agricultural Decline: The 'Disturbance–Imbalance' Stage of the Cultural Ecosystem

Since the 20th century, driven by rapid industrialisation, urbanisation, and population mobility, the cultural ecosystem of traditional farming villages in northern Henan has entered a phase of "disturbance–imbalance". The core of cultural motivation has been severely disrupted, institutional mechanisms have disintegrated, spiritual order has collapsed, and the once-stable system has undergone fragmentation. This stage is marked by

structural dispersion and a marked weakening of spatial functionality.

Deconstruction of the Internal Mechanism: Systemic Imbalance in Traditional Cultural Ecosystems

At the technology–ecology level, the traditional agricultural system—once aligned with natural seasonal rhythms—has been supplanted by modern agricultural practices. While mechanisation and the use of chemical fertilisers and pesticides have increased productivity, they have also contributed to the degradation of soil and water resources, destabilising the ecological foundation. A significant portion of farmland has been abandoned, converted to non-agricultural uses, or left fallow, resulting in its redefinition as an inefficient and fragmented resource field.At the cognition–concept level, the societal shift toward urban employment has rendered the farming profession increasingly unattractive. Traditional cultural values such as "honour through cultivation and scholarship" and "ancestral reverence and filial piety" have weakened, leading to the erosion of cultural identity structures. The once-vibrant practices of faith-based rituals, seasonal festivals, and ancestral worship have faded, plunging village spiritual life into a state of low identification and low participation.

At the organisation–institution level, the introduction of the household contract responsibility system has restructured land-use relations, diminishing intra-village cooperation and weakening clan-based collaborative networks. Ancestral codes, clan regulations, and other traditional governance frameworks have largely become symbolic or obsolete. Grassroots village administration often persists in form but lacks substance, with governance systems existing without cultural legitimacy or communal recognition—a condition encapsulated in the notion of "the system is present, but the identity is absent."At the practice–strategy level, the collapse of seasonal agricultural rhythms and collective living practices has led to the decline of community rituals, such as temple fairs, neighbourly assistance, and village markets. The simultaneous outmigration of younger populations and aging-in-place of the elderly has critically undermined local organisational capacity. As a result, traditional settlements are increasingly reduced to spatial containers of low-frequency use, wherein everyday life becomes decoupled from spatial form, and the functional meaning of space deteriorates into obsolescence.

Spatial Characterisation: Decoupled Variation and Dysfunction of Settlement Structure

The collapse of cultural and ecological mechanisms is spatially reflected through significant distortions at three interrelated levels:First, the failure of ecological adaptation systems has led to the de-agriculturalisation of village peripheries. Farmland surrounding settlements has been increasingly abandoned, built upon, or repurposed for rental uses. These processes have disrupted the traditional "cultivation–residence–irrigation" spatial configuration, resulting in the blurring of settlement boundaries and fragmentation of functional zoning. Second, the degradation of symbolic cultural spaces has accelerated. Traditional spiritual landmarks—such as ancestral halls, temples, and sacrificial platforms—have lost their communal functions, becoming abandoned, repurposed, or neglected. These symbolic spatial nodes, once central to collective identity, have become cultural voids. Ancestral residences and study halls have been converted into storage sheds and barns, while public spaces have lost their ritualistic and integrative functions, transforming from centres of cultural life into static physical remnants.Third, the institutional spatial order has undergone disintegration. Unregulated housing expansion, ambiguous residential boundaries, and the juxtaposition of old and new structures have disrupted previously coherent axial or enclosed layouts. Former institutional nodes—such as council halls, well platforms, and clan assembly spaces—have lost their governance and symbolic roles. The result is a transformation from an orderly and synergistic spatial system to one marked by de-nucleation, decentralisation, and spatial disintegration.

Additionally, the collapse of communal living practices has further hollowed out the spatial vitality of traditional settlements. Streets and alleys lie deserted, public spaces remain unused, and the overall frequency of spatial engagement is extremely low. The proliferation of roadside construction, oriented with houses "facing away" from communal space, has produced a "back-to-the-road" layout, emblematic of spatial disengagement. Consequently, traditional settlements have fallen into functional silence, with a complete rupture in the cultural life network.In summary, the spatial pattern of settlements at this stage is characterised by structural fragmentation, functional dislocation, and cultural degradation (Fig. 5). These patterns reveal the disintegration logic of the cultural ecosystem in conditions of systemic imbalance, offering critical insights into the spatial evolution trajectory and mechanisms underlying rural decline.

Fig. 5 Spatial characteristics of traditional villages during the 'Disturbance–Imbalance' stage of the cultural ecosystem:(1) Overall spatial layout of Hankou Village: the core traditional settlement area (red dashed boundary) shows a dense and organically grown morphology with curved paths and compact buildings, contrasting sharply with the surrounding grid-like new development zones;(2) Aerial view of the core traditional zone in Hankou, showing decaying buildings and landscape disintegration;(3) Overall spatial pattern of Huanghou Village: buildings with dark roofs indicate preserved traditional houses, while blue roofs mark updated or reconstructed structures;(4) Aerial view of the inner central courtyard cluster in Huanghou, illustrating enclosed residential morphology;(5) Aerial view of edge-zone dwellings in Huanghou, representing transitional spaces undergoing functional and morphological fragmentation.

Eco-Capital Transformation: The 'Integration–Regeneration' Stage of Cultural Ecosystems

Following prolonged phases of institutional disintegration, population outflow, and functional decay, certain traditional villages in northern Henan have begun to explore new mechanisms for reconstructing their cultural ecosystems through the lens of eco-capital transformation. Distinct from earlier phases that relied primarily on endogenous resilience and passive recovery, this stage is driven by an integrated dynamic of ecological value recognition, institutional reshaping, cognitive renewal, and behavioural reactivation. Together, these four dimensions enable the simultaneous regeneration of both cultural systems and spatial structures.

Reconstruction of Intrinsic Mechanism: Pluralistic Activation of the Cultural System under the Logic of Ecological Capital

At the technology–ecology level, village ecological assets—including arable land, forests, mountains, water bodies, and courtyards—have been systematically evaluated and incorporated into a "resource–asset–capital–product" transformation chain. This is realised through digital mapping and suitability assessments, which facilitate the spatial integration of these assets into new development platforms such as "pastoral complex zones" and "eco-cultural tourism districts", enabling a shift from traditional agricultural spaces to composite ecological production landscapes.At the cognition–concept level, ecological resources have been reinterpreted as both "green wealth" and "cultural imagery." Through strategic mechanisms such as "nostalgia narratives" and "rural aesthetics", villages construct renewed cultural identities grounded in ecological memory and cultural symbolism. Spatially, this shift is embodied in the emergence of new cultural nodes, including agricultural heritage schools, festival plazas, and eco-exhibition halls, which enhance cultural attractiveness and reinforce a localized sense of place.

At the organisation–institution level, the implementation of land and resource rights confirmation reforms has clarified the ownership and usage boundaries of key ecological resources, such as mountains, forests, and waterways. This has laid the foundation for multi-party collaborative governance mechanisms, involving villages, communities, governmental entities, and private capital. Spatial governance has evolved from traditional self-organising models to platform-based, networked coordination, with newly delineated functional zones for culture, education, habitation, and ecological industry.At the practice–strategy level, villagers are no longer solely cultivators, but have transformed into "ecological stewards." Their daily practices now include eco-agriculture,

cultural tourism, community festivals, and participatory initiatives, forming an integrated "ecology + culture + participation" model of community life. In this transition, the village is redefined from a static residential unit into a dynamic cultural production and experiential space, simultaneously supporting ecological sustainability and cultural regeneration.

Reorganisation of Spatial Structure: A Mechanism for the Re-Scenarioisation of Settlements Driven by Ecological Value

Driven by the logic of ecological capital, the spatial structure of traditional villages has undergone a significant transformation, shifting from a single-function agricultural landscape to a multifunctional and synergistic spatial system. Former agricultural spaces have been reorganised into diversified zones, including ecological corridors, cultural districts, and shared public nodes, promoting the evolution of settlements towards forms characterised by block-based synergy and structural clarity. Cultural imagery and institutional networks are deeply embedded within these reorganised spaces, while everyday practices such as ecological farming, cultural tourism, and communal events revitalise spatial functions. This transformation generates a new spatial logic comprising three interrelated dimensions: platform-based governance operations, cultural expression as a symbolic axis, and scenario-based participation as a mechanism for community engagement. Overall, this phase reflects the trajectory of the cultural ecosystem through a process of system imbalance, structural reorganisation, and mechanism regeneration. It marks a critical shift from elemental dispersion to functional integration, achieving the dual transformation of spatial functionality and cultural revitalization (Fig. 6). By embedding ecological values into both material and symbolic space, this stage offers a practical paradigm for the holistic protection, adaptive reuse, and sustainable regeneration of traditional settlements.

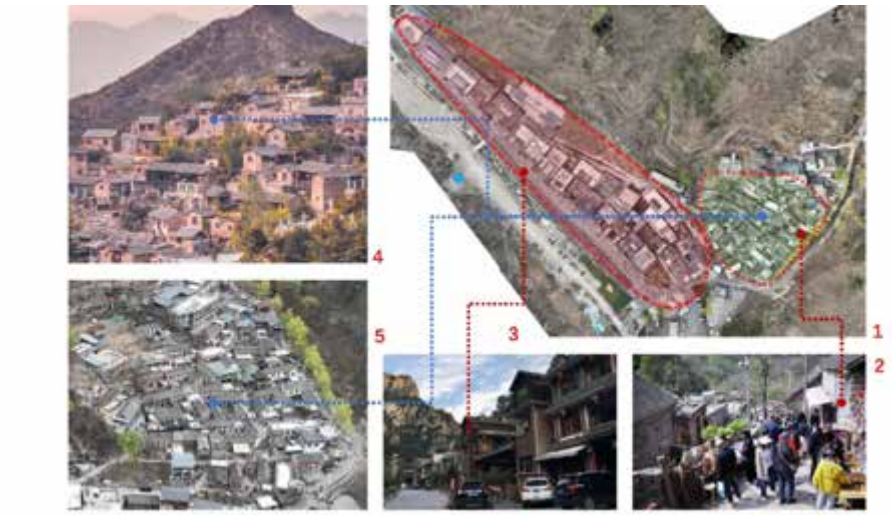

Fig. 6 Spatial reconstruction of Guoliang Village under the logic of cultural ecological capital activation: (1) current spatial layout, with the red strip representing newly developed areas and the green zone indicating the historical village core; (2) commercial landscape and streetscape in the traditional area; (3) newly constructed commercial street zone; (4) historical architectural form during the mature stage of village development; (5) current internal spatial transformation within the traditional village.

Characteristic analysis of traditional village cultural and ecological network structure

Characteristics of Network Individual Levels

Analysis of the cultural and ecological network structure of traditional villages reveals distinct patterns at the individual node level. Degree centrality results indicate that villages such as Xixiangping, Shijiagou, Wangjiatan, and Shuangmiao occupy central positions within the network (Fig. 7), with degree values significantly above the mean. These nodes demonstrate strong capacities for regional coordination and resource diffusion, functioning as key hubs. In contrast, villages such as Judeo and Lihe exhibit low degree centrality, signifying weak spatial connectivity and marginal positions within the network—factors that impede the overall network's cohesion and integrative potential.In terms of closeness centrality, villages like Xideng, Hankou, and Shijiagou possess high levels of accessibility, allowing them to quickly interact with other nodes. Their strategic spatial locations position

them as critical service hubs and network actors within the broader regional structure. Conversely, villages such as Xianmagou and Wenpo are characterised by low closeness centrality, reflecting their relative spatial isolation and reduced influence.

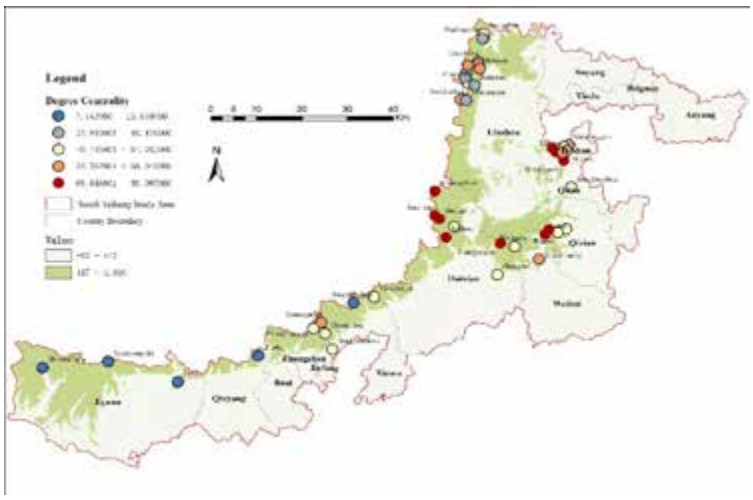

Fig. 7 Spatial Distribution of Degree Centrality of Traditional Villages in the Southern Taihang Region

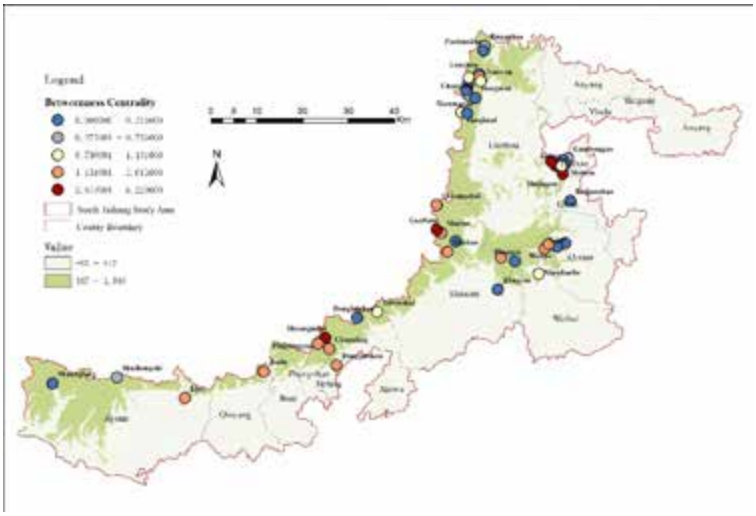

Fig. 8 Spatial Distribution of Betweenness Centrality of Traditional Villages in the Southern Taihang Region

Further, betweenness centrality analysis reveals that approximately 39.5% of villages function as bridges or intermediaries within the network, predominantly located in the central and southern subregions. These nodes exhibit strong capabilities in pathway control and resource intermediation, facilitating inter-cluster flow of information and functions. However, a subset of villages exhibits zero betweenness centrality, indicating a lack of transit or brokerage function, which restricts their role in fostering collaborative development and undermines network efficiency.Collectively, the traditional village network in the South Taihang region displays a multi-core spatial structure, characterised by core–periphery differentiation and centralised dominance. These structural features provide a critical foundation for subsequent network optimisation and the formulation of targeted conservation and revitalisation strategies.

Characteristics of Network Clusters

The spatial association network of traditional villages in the study area reveals distinct clustering patterns based on cohesive subgroup analysis, resulting in the identification of four primary network clusters. Subgroup I consists of eight villages, including Xiding and Wangjiatan, primarily concentrated in the northern area of Hebi City within the central part of the region. Subgroup II includes twelve villages, such as Xixiangping and Chefogou, encompassing all surveyed villages within Anyang City in the northernmost area. Subgroup III comprises thirteen villages, including Guoliang and Liyu, spanning ten villages in Xinxiang City and three in the southern part of Hebi City, thereby forming a central-southern transitional cluster. Subgroup IV includes ten villages, such as Donglinghou and Yidoushui, distributed across seven villages in Jiaozuo and three in Jiyuan, representing the southern part of the study area.

To further examine the relational dynamics among these subgroups, a network density matrix was constructed. Using the overall network density value of 0.531 as a threshold, intra- and inter-group densities above this value were assigned a value of 1 to represent strong linkages, while those below were assigned a value of 0, indicating weak or absent connections. This binarisation yielded a transmission relationship matrix that illustrates the potential paths of interaction and influence between clusters. The resulting structural pattern not only reflects the territorial proximity and administrative boundaries of the villages but also highlights the spatial logic of cultural exchange, ecological cooperation, and functional interdependence. These findings provide an empirical basis for promoting regionally adaptive conservation strategies and enhancing cross-cluster synergy in the holistic governance of traditional villages.

Discussion

Spatial Mechanisms Driven by the Evolution of Cultural Ecosystems

Current scholarly approaches to traditional settlement spatial studies generally follow two predominant theoretical trajectories. The first is the "taxonomy of cultural landscapes", which focuses on the classification and generalisation of settlement forms and cultural traits. While this path has yielded rich typological insights, it often remains confined to static descriptive analysis, lacking explanatory depth regarding the dynamic cultural mechanisms underlying spatial transformation-Duan et al., 2025-. The second trajectory draws on Lefebvre's theory of spatial production, which underscores the formative role of power relations and institutional structures in the production of space-Hu et al., 2019-. Although Lefebvre's "spatial triad" framework offers strong explanatory power in urban and abstract spatial contexts, its adaptability is limited when applied to ecologically, culturally, and historically intertwined traditional villages, where spatial form emerges from the long-term interplay of environment, culture, and collective practice.

To address these limitations, this study proposes an alternative analytical mechanism: the "culture-driven core – cultural connotation – spatial representation" chain-Qiao et al., 2022-. This framework integrates the logic of cultural and ecological evolution with the structural dimensions of spatial practice-Steward, 1972-, and further introduces a four-layer analytical model encompassing technology–ecology, cognition–concept, organisation–institution, and practice–strategy. This model not only clarifies the intrinsic logic of settlement spatial evolution, but also establishes a systematic framework amenable to quantitative methods such as geographic modelling and network analysis.The theoretical contributions of this study are threefold: first, it advances cultural landscape research by shifting from typological description to mechanistic interpretation; second, it offers a theoretically grounded and empirically operable paradigm for understanding the evolution of regional settlement systems, through the integration of cultural ecosystem theory and spatial network analysis; third, it promotes the deeper integration of cultural geography and rural spatial studies, enriching interdisciplinary dialogue and providing robust tools for analysing and guiding the sustainable transformation of traditional village landscapes.

Holistic Protection Path of the Regional Cultural Ecological Network

To achieve the holistic protection of traditional village cultural ecosystems, a hierarchical activation strategy should be established across the node–cluster–region scale. At the node level, functional typologies can be identified using network centrality indicators. Villages exhibiting high degree centrality (e.g., Xideng, Shijiagou) should be designated as cultural engines, serving as pilot areas for the integration of cultural heritage and tourism development. Villages with high closeness centrality may be developed as cultural dissemination hubs, facilitating regional cultural transmission. Those with high betweenness centrality can function as cultural corridors, enhancing inter-village connectivity and information flow. In contrast, peripheral nodes should focus

on revitalising endogenous cultural potential through resource re-evaluation and the reconstruction of local traditions and folklore practices.

At the cluster level, the cultural ecological network exhibits differentiated cohesion strengths among its four subgroups. Subgroups I to III, characterised by dense internal connections, should prioritise co-construction of shared resources, institutional collaboration, and the formation of integrated cultural ecological zones. In contrast, Subgroup IV, which demonstrates relatively weak connectivity, requires the cultivation of organisational systems and the construction of a "cultural bridge" to enhance its interaction with core clusters. The identity and linkage among subgroups can be further strengthened through initiatives such as "itinerant exhibitions of intangible cultural heritage", which foster inter-regional cultural recognition and cohesion.

At the regional level, a "core–linkage–periphery" spatial framework should be implemented to optimise the synergistic integration of cultural and ecological systems. This includes delineating a cultural protection red line in coordination with the existing landscape ecological patterns, thereby reinforcing the spatial co-evolution of culture, ecology, and landscape. Furthermore, the establishment of a multi-level co-governance mechanism—led by government coordination, supported by village self-governance, and enhanced through multi-stakeholder participation—can facilitate the transition of the cultural ecosystem from mechanism integration to systemic regeneration, ultimately contributing to the sustainable and dynamic revitalisation of traditional rural spaces.

Conclusion

This study focuses on the traditional villages in the South Taihang region of northern Henan Province, integrating cultural ecology theory with Holling's adaptive cycle model to construct a systematic analytical framework for understanding the evolutionary mechanisms of spatial morphology and the structure of the cultural ecological network in traditional settlements. The main conclusions are as follows:

(1) The spatial form of traditional villages represents the material expression of the long-term evolution of cultural ecosystems. Elements such as material culture, institutional arrangements, and spiritual beliefs, guided by the culture-driven core, are deeply embedded within settlement space, forming an interlinked chain of "culture–mechanism–space."

(2) Based on Holling's adaptive cycle theory, the evolution of settlement systems can be categorised into four stages: exploration, conservation, release, and reorganisation. Each stage reflects a shifting cultural core—ranging from agricultural subsistence to clan-based governance, defensive adaptation, and commercial transformation—alongside corresponding spatial characteristics that evolve from centralised to fragmented, and ultimately to composite and restructured forms. This progression reveals the non-linear, multi-causal interaction mechanisms that drive the spatial transformation of traditional villages.

(3) In terms of cultural network construction, the study introduces a multi-dimensional cultural development index system, and employs a modified gravity model combined with social network analysis (SNA) to uncover a "centre–periphery–bridge" network structure. This structure is anchored by villages of high cultural value, exhibiting spatial synergy and functional differentiation, and offering a new perspective for understanding rural cultural connectivity.

Theoretically, this study transcends the limitations of static typologies and isolated case analysis by proposing a "culture-driven → four-dimensional mechanism → evolutionary stage" model. By incorporating network analysis, the research achieves a paradigm shift from fragmented conservation to systematic spatial governance, thereby enriching the interdisciplinary dialogue between cultural geography, ecology, and human geography. Practically, the findings offer a solid basis for the classification, spatial optimisation, and policy-making of traditional villages. Stage-based typology enables the precise identification of settlement evolutionary phases, while network-based analysis facilitates the construction of cross-village collaborative mechanisms, supporting the transition from "point-based conservation" to "network-oriented governance" -Yuan et al., 2025-. Future research may extend this framework through cross-regional comparative studies and further develop dynamic modelling and mechanism validation for the evolution of cultural ecosystems.

References

Barrientos, F., Martin, J., De Luca, C., et al. (2021). Computational methods and rural cultural & natural heritage: A review. Journal of Cultural Heritage, 49, pp.250–259.

Bi, S., Du, J., Tian, Z. and Zhang, Y. (2024). Investigating the spatial distribution mechanisms of traditional villages from the human geography region: A case study of Jiangnan, China. Ecological Informatics, 81, p.102649.

Chen, H., Xiao, D. and Liu, Y. (2024). Spatial morphology and influencing factors of tunpu traditional villages in Anshun: A comprehensive study. Journal of Asian Architecture and Building Engineering, pp.1–14.

Chen, L., Zhong, Q. and Li, Z. (2023). Analysis of spatial characteristics and influence mechanism of human settlement suitability in traditional villages based on multi-scale geographically weighted regression model: A case study of Hunan province. Ecological Indicators, 154, p.110828.

Chen, X., Xie, W. and Li, H. (2020). The spatial evolution process, characteristics and driving factors of traditional villages from the perspective of the cultural ecosystem: A case study of Chengkan Village. Habitat International, 104, p.102250.

Cheng, Y., Hu, S., Yang, R., et al. (2024). Protection and utilization of the traditional villages of China in the context of rural revitalization: Challenges and prospects. Journal of Natural Resources, 39(8), pp.1735–1759.

Duan, W., Yang, X., Zhang, T. and Cai, H. (2023). From home to inn: The evolution of rural dwellings in the Taihang area of Northern Henan. Sustainability, 15(3), p.2293.

Duan, Y., Chen, M., Liu, Y., Wang, Y. and Zhang, L. (2025). Research on the cultural landscape features and regional variations of traditional villages and dwellings in multicultural blending areas: A case study of the Jiangxi-Anhui junction region. Applied Sciences, 15(4), p.2185.

Hill, M. (2003) Rural settlement and the urban impact on the countryside.

Holling, C.S. (2001). Understanding the complexity of economic, ecological, and social systems. Ecosystems, 4, pp.390–405.

Hu, X., Li, H., Zhang, X., Chen, X. and Yuan, Y. (2019). Multi-dimensionality and the totality of rural spatial restructuring from the perspective of the rural space system: A case study of traditional villages in the ancient Huizhou region, China. Habitat International, 94, p.102062.

Li, H. and Zhang, X. (2012). A review and trend on rural settlement geography abroad. Human Geography, 27(4), pp.103–108.

Li, Y., Westlund, H. and Liu, Y. (2019). Why some rural areas decline while some others not: An overview of rural evolution in the world. Journal of Rural Studies, 68, pp.135–143.

Lin, Z., Liang, Y. and Liu, X. (2024). Study on spatial form evolution of traditional villages in Jiuguan under the influence of historic transportation network. Heritage Science, 12(1), p.29.

Liu, Q., Hao, W. and Xia, M. (2024). Spatial association of coastal towns and villages in Funing District, Qinhuangdao: A study using social network analysis. Journal of Rural Studies, 107, p.103261.

Liu, S., Ge, J., Bai, M., Yao, M., He, L. and Chen, M. (2022). Toward classification-based sustainable revitalization: Assessing the vitality of traditional villages. Land Use Policy, 116, p.106060.

Mu, Q. and Aimar, F. (2022). How are historical villages changed? A systematic literature review on European and Chinese cultural heritage preservation practices in rural areas. Land, 11(7), p.982.

Pacione, M. (1984). Rural geography. [Book] London: Longman.

Qiao, J., Geng, H., Li, Y. and Li, Y. (2022). Internal logic and realization path of rural revitalization after poverty alleviation from the perspective of cultural ecology: A case study on ethnic villages with cross-stage development in southwestern Yunnan. City Planning Review, 46(11), pp.106–114.

Qin, X., Du, X., Wang, Y. and Liu, L. (2023). Spatial evolution analysis and spatial optimization strategy of rural tourism based on spatial syntax model—A case study of Matao Village in Shandong Province, China. Land, 12(2), p.317.

Rossi, A. (1984) The architecture of the city. Cambridge, MA: MIT Press.

Sauer, C. (2008) The morphology of landscape. In Duncan, J., Johnson, L. and Schein, R. (eds.) The cultural geography reader. London: Routledge, pp.108–116.

Shao, Y., Cui, J. and Zhang, X. (2024). Evolution mechanism and reconstruction strategy of the cultural-ecological system of traditional settlement clusters: A case of the salt industry traditional settlement cluster in Yunlong area. Urban Planning Forum, (S1), pp. 185–194.

Steward, J.H. (1972). Theory of culture change: The methodology of multilinear evolution. Urbana: University of Illinois Press.

Wang, J., Zhang, Y., Yang, G., Wang, Y., Cheng, X. and Xu, B. (2023). Spatial reconstruction of traditional villages towards synergistic development in the Fuchun River Basin based on the gravity model. Land, 12(5), p.1037.

Wang, Y., Wu, C., Wu, B., Zhao, J. and Wang, H. (2025). Evaluation of spatial structure resilience in coastal traditional villages using complex network analysis: Case study of Rongcheng City, Shandong Province. Land, 14(3), p.505.

Yamu, C., Van Nes, A. and Garau, C. (2021) Bill Hillier's legacy: Space syntax—A synopsis of basic concepts, measures, and empirical application. Sustainability, 13 (6), p.3394.

Yan, Y., Jing, H., Dajun, L. and Yaoyan, J.I.A. (2021). Spatial structure identification and influence mechanism of Miao traditional villages in Guizhou Province. Economic Geography, 41(2), pp.232–240.

Yuan, L., Xu, L., Zhang, Z. and Xu, Y. (2025). Traditional village clustered protection and utilization methods based on network science. npj Heritage Science, 13(1), pp.1–19.

Yuan, X., Li, Y., Song, Y., Lu, H., Wang, Y., Ge, B. and Wang, J. (2024). Spatial distribution characteristics and driving factors of 777 traditional villages in Yunnan Province: A study based on GWR model and Geodetector. Land, 13(12), p.2004.

Zhao, X., Xue, P., Wang, F., et al. (2024). How to become one? The modern bond of traditional villages in centralized contiguous protection and utilization areas in China. Habitat International, 145, p.103018.