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Translation Pathways and Public Perception Evaluation of Regional Culture in Landscape Architectural Spaces

Lihan Wang*

Renmin University of China, Beijing 100872, China

**Corresponding author: Lihan Wang, 1636515196@qq.com*

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Abstract: Against the background of urban renewal, improvements in public-space quality, and the integration of culture and tourism, regional culture remains an important resource for local vitality, urban memory, and public identity in landscape architecture. In practice, however, cultural symbols are often collected unsystematically, spatial experiences remain superficial, public participation is limited, and assessment mechanisms are absent. Taking local culture as the main research thread, this study draws on recent research on public perceptions of urban parks, cultural landscape assessment, historic-district perception, and place identity. It evaluates translated content in terms of the natural environment, history, folk customs, architectural form, materials and colors, and behavioral scenes, and proposes a “cultural identification-element extraction-spatial transformation-experience creation-public evaluation-feedback optimization” pathway. The framework is further assessed through six dimensions: cultural recognition, spatial experience, aesthetic satisfaction, functional applicability, emotional identification, and management sustainability. The study argues that regional culture should move beyond symbolic replication toward integrated expression through spatial structure, material texture, behavioral settings, and multi-sensory experience. Public perception evaluation can verify the effectiveness of cultural expression and provide a basis for continuous renewal in landscape architecture.

Keywords: Regional culture; Landscape architecture; Spatial translation; Public perception; Place identity; Evaluation system

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1. Introduction

As urban development shifts from incremental expansion to the renewal of existing urban stock, landscape architectural spaces increasingly support cultural display, public interaction, urban image-making, and the preservation of local memory. In historic districts, urban parks, waterfront parks, culture-and-tourism scenic areas, and community public spaces, local cultural expression is increasingly used to improve spatial quality and strengthen place identity. Studies of cultural ecosystem services in urban parks show that public

perceptions of leisure, culture, education, and cultural values are important for assessing the overall value of public landscape sites ^[1]. Therefore, the expression of local culture is not only a design choice; it should also be tested through public perception and user experience. In recent years, research on public-space perception has shifted from single questionnaires to multi-source evidence, including questionnaires, interviews, behavioral observations, and user-generated content. Research on the cultural ecosystem services of urban park visitors shows that social media texts and images can reflect public feedback on landscapes, culture, and services ^[2]. Studies of urban park perception based on user data further show that public evaluation of landscapes involves not only aesthetics but also paths, facilities, activities, and emotions ^[3]. These insights inform the evaluation system developed in this study.

In practice, regional culture often remains too abstract. Some projects reduce local culture to traditional patterns, sculptural miniatures, antiqued elements, or isolated local symbols, without conveying cultural meaning, spatial atmosphere, or public experience. Other designs rely heavily on designers' aesthetic judgment while overlooking public perception of cultural meaning, comfort, and emotion, resulting in a mismatch between "design expression" and "public perception". In response, this study examines the spatial translation of regional culture and the public perception evaluation of public spaces, culture-and-tourism areas, historic-district renewal, and community landscapes.

2. Translation pathways of regional culture in landscape architectural space

Cultural translation is the transformation of cultural resources into landscape architectural expression. This article discusses the process of cultural resource sorting, or cultural identification, element extraction, spatial transformation, experience creation, public evaluation, and feedback optimization, as well as their logical relationships, as shown in **Figure 1** ^[4].

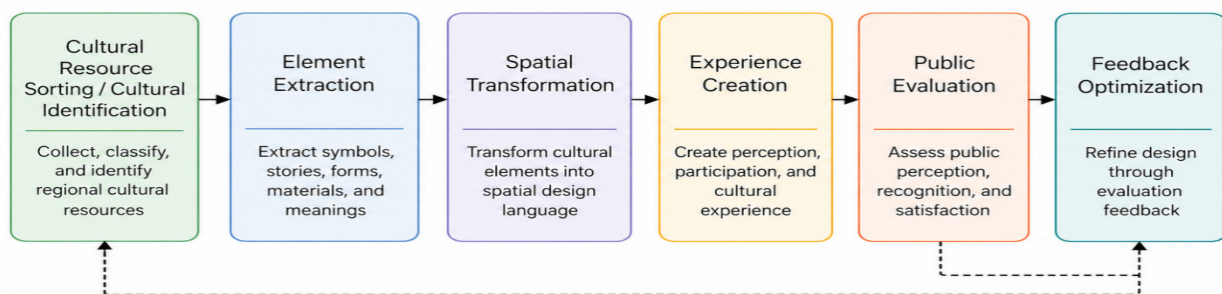


Figure 1. Translation pathway of regional culture in landscape architectural space.

2.1. Cultural identification: Establishing a list of regional cultural resources

Cultural identification is the starting point of cultural translation. In early design stages, designers should analyze the site's environment, history, style, folk culture, site evolution, and user needs in order to build a cultural resource list that includes both explicit symbols and residents' lifestyles, usage habits, and local

emotional memories. Cultural identification should follow the principles of representativeness, perceptibility, and transformability, so that cultural content can be translated into spaces, materials, structures, activities, and wayfinding languages.

2.2. Element extraction: Extracting spatial language from cultural content

After cultural identification, designers need to extract design elements that can be expressed in landscape architectural space. Element extraction is not limited to patterns or symbols; it also includes cultural structure, spatial morphology, behavioral patterns, and aesthetic concepts. Traditional street-and-alley culture, for example, can be extracted as a spatial sequence of “narrow alley-corner-node-courtyard”. Water culture can be translated through a behavioral sequence of “approaching the water-viewing the water-connecting with the water-using the water.” Traditional architectural culture can be extracted through roof outlines, eaves, courtyard enclosure, and transitional gray space.

2.3. Spatial transformation: Embedding cultural elements into landscape architecture organization

Spatial transformation is the core of regional cultural translation. Cultural elements should be embedded in spatial nodes, landscape boundaries, interfaces, material textures, and activities rather than being used merely as decoration. Spatial nodes can encode cultural logic through axes, paths, courtyards, squares, interfaces, entry points, corners, viewing platforms, pergolas, pavilions, and rest facilities. At the material level, local stone, brick, tile, wood, and plants can be used to create a recognizable local texture.

2.4. Experience creation: From visual symbols to multi-sensory perception

The representation of regional culture should not be limited to making a place “look cultural”; it should also enable people to experience and participate in it. People perceive and interact with their surroundings through visual, auditory, tactile, olfactory, and behavioral stimuli. Studies of the visual landscapes and soundscapes of World Heritage sites show that visual and auditory experiences influence visitors and nearby users ^[5]. Landscape structures should therefore enrich multi-sensory experience and behavior through local plants, water and wind sounds, local music, stone and wood textures, exhibition markets, and interactive facilities.

2.5. Public evaluation and feedback optimization: Examining the effectiveness of cultural translation

Public perception is a critical factor in assessing the effectiveness of regional cultural translation. Designers may believe that a space contains culture, but the public may not necessarily understand or identify it. Public participation in green cultural heritage conservation is influenced by attitudes, subjective norms, and perceived behavioral control ^[6]. This suggests that culturally oriented landscape spaces should remain legible, shareable, and open to co-use. Spatial nodes, cultural displays, wayfinding systems, activity organization, and facility configuration should be adjusted according to public feedback.

3. Key problems in the translation of regional culture

3.1. Symbolic cultural expression

At present, many landscape architectural spaces translate regional culture into traditional patterns, sculptural

miniatures, antique-style gate towers, or cultural walls, but fail to deepen cultural meaning or spatial relationships. Although such designs are recognizable, the public often sees only surface symbols and can hardly understand their historical background or relevance to everyday life.

3.2. Superficial spatial experience

Some projects focus on visual appearance without considering real users. Cultural nodes may be suitable for taking photos but not for staying; landscape structures may lack shade, seating, and opportunities for communication; and visitor routes may be overly busy, leaving spaces visible but not truly usable.

3.3. Insufficient public participation

Local culture comes from local life, but some projects fail to involve local users. Designers often make decisions based on materials or professional knowledge, while the opinions of residents, tourists, and everyday users are not fully included in the design process. This can easily create a gap between cultural translation and public perception.

3.4. Insufficient integration of traditional form and modern function

The translation of regional culture must negotiate the relationship between tradition and modernity. Some projects overemphasize antique forms and produce outdated spatial images with insufficient functions, while others are excessively modernized and lack specific local character. How to represent traditional culture through modern landscape structures remains an important issue in local cultural translation.

3.5. Lack of post-operation and evaluation mechanisms

If a regional cultural landscape loses its cultural value after construction, its significance will gradually decline, especially when operation, facility maintenance, or public feedback is insufficient. Studies of cultural and heritage sites show that the strengths and weaknesses of heritage experiences can be identified through importance-performance analysis, which is also relevant to the later operation of landscape architectural spaces^[7].

4. Optimization strategies for regional cultural landscape architectural spaces

4.1. Establish a systematic mechanism for sorting regional cultural resources

Designers should first sort local cultural resources systematically. Through literature review, historical maps, site surveys, resident interviews, and image or video records, they can organize information on the natural environment, history, architecture, folk life, and public memory. They should then determine which resources are representative, which can be translated into spatial language, and which are more suitable for exhibitions or events.

4.2. Promote a shift from symbolic reproduction to spatial translation

Regional culture should be expressed through space rather than by simply copying local patterns or historical symbols onto walls and pavements. Cultural content should be translated through spatial organization, behavior, materials, and experience. For example, courtyard culture can be expressed through enclosure and transitional spaces, water culture through waterfront interfaces, and folk culture through activity plazas and

market spaces.

4.3. Strengthen public participation and co-design

Public participation should be strengthened throughout the design process. In the early stage, questionnaires, interviews, and community discussions can be conducted; during design, suggestions can be collected through scheme presentations and opinion polls; and after completion, the space can be optimized through satisfaction surveys and behavioral observations. For community public spaces and historic districts, resident co-creation, local memories, and cultural activities can also be incorporated.

4.4. Emphasize multi-sensory experience and emotional identification

Regional cultural landscapes should not be only visual; they should also be multi-sensory. At the visual level, they should express local characteristics; at the tactile level, they should convey the texture of local materials; at the auditory level, they can integrate water sounds, wind sounds, local music, and performances; and at the behavioral level, they should support participation in cultural experiences. Studies of restorative perception in rural landscapes show that environmental properties, perceptual experience, and psychological restoration are linked, suggesting that cultural expression should also attend to public psychological feelings and emotions ^[8].

4.5. Improve evaluation, feedback, and continuous operation mechanisms

Regional cultural landscape architectural spaces should be evaluated not only as finished products but also through their ongoing use and operation. Managers should conduct regular satisfaction surveys on cultural identification, user experience, facility use, and activity participation. Festivals, cultural markets, public art, intangible cultural heritage events, and community activities can then be used to maintain vitality and improve the space over time.

5. Conclusion

Regional culture supports local identity and public recognition in landscape architecture. This study suggests that the translation from cultural resources to spatial experience should follow a pathway of cultural identification, element extraction, spatial transformation, experience creation, public evaluation, and feedback optimization. This pathway is an important approach to strengthening local identity in public landscapes. The content translated from local culture usually includes the natural environment, historical context, folk customs, architectural forms, materials and colors, and behavioral scenes. Different types of content require different translation methods: the natural environment reflects ecology and site conditions; historical context emphasizes spatial continuity and memory; folk customs highlight public participation; and architectural forms, materials, and colors require abstraction, refinement, and functional integration. Public perception evaluation can be used to assess the performance of cultural translation. Dimensions such as cultural recognition, spatial experience, aesthetic satisfaction, functional fit, emotional identification, and management sustainability can show whether cultural expressions are recognized, understood, and accepted by the public. Future landscape architecture and spatial design should emphasize deep translation and public participation, avoid superficial, homogenized, and static cultural expression, and integrate local culture into spatial structure, behavioral experience, and emotional identification.

Disclosure statement

The author declares no conflict of interest.

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Analysis of the Impact of Key Points in Quality Inspection and Control of Incoming Raw Materials on the Molding Quality of Cement Concrete Pavement Construction

Shili Zhang, Jianzhi Li*, Yingying Ye, Guixiang Rao, Yanyan Li, Shengzhong Xiang

China Merchants Chongqing Testing Center for Highway Engineering Co., Ltd., Chongqing 400067, China

**Author to whom correspondence should be addressed.*

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Abstract: Based on the fundamental background of a cement concrete pavement construction project for a highway engineering endeavor, this paper delves into the impact of key points in quality control for incoming raw materials on the molding quality of the pavement during construction. It encompasses the effects of incoming inspections on cement, aggregates, admixtures, and mineral admixtures on the subsequent molding quality of the pavement. Additionally, targeted optimization suggestions are proposed based on various impacts. The aim is to provide valuable references for controlling the quality of raw materials and the molding effects of pavements in similar future projects.

Keywords: Cement concrete pavement; Raw materials; Incoming quality inspection; Molding quality

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1. Preface

Cement concrete pavements offer numerous advantages, including high strength, durability, and long service life, and have been widely applied in modern highway and municipal road construction. Their molding quality directly influences road service life and traffic safety. As the most fundamental material in cement concrete pavement construction, the quality control of raw materials is crucial for ensuring molding quality. Therefore, engineering units must place sufficient emphasis on the quality inspection of incoming raw materials, clarify the primary impacts of key control points on the subsequent molding quality of pavement construction, and thereby reasonably control pavement molding quality through incoming quality sampling inspection and control methods.

2. Project background

A municipal road mainline renovation project spans 8.6 km with a pavement width of 24 m and a designed speed of 60 km/h. The construction requires the application of a cement concrete rigid pavement structure, with a concrete strength design of C35, requiring a flexural strength of no less than 4.5 MPa, and a designed service life of 15 years. Since the project section passes through farmland areas, industrial parks, and residential areas, it experiences heavy traffic flow and is significantly affected by the rainy season. Therefore, high requirements are placed on the pavement's strength, smoothness, impermeability, and wear resistance during construction. A large amount of cement, aggregates, admixtures, and mineral admixtures will be used during construction, with various raw materials sourced from a wide range of suppliers, resulting in significant differences in product quality. Additionally, some raw materials may be contaminated or dampened during transportation. Given the tight project schedule, large batches and high frequencies of incoming raw materials, higher demands are placed on quality inspection and control. To ensure the molding quality of pavement construction, engineering units need to analyze the key points of quality control for incoming raw materials and their impact on the molding quality of pavement construction.

3. Key points in quality control for incoming raw materials

3.1. Inspection and control of incoming cement

In cement concrete mixtures, cement serves as the core binding material, and its quality directly determines the strength and durability of the concrete. According to engineering design standards, ordinary Portland cement should be used for this project. Upon arrival, engineering units should first strictly verify relevant documents such as supplier qualifications, factory inspection reports, and product certificates to ensure that the cement variety, production batch, and strength grade meet design requirements, promptly returning any cement materials that do not comply with design standards. During inspection, engineering units should strictly follow design requirements to conduct batch sampling and send for inspection, focusing on checking indicators such as cement fineness, mortar strength, soundness, and initial and final setting times to ensure that they meet design standards. Unqualified materials should be strictly prohibited from entering the site. Meanwhile, cement from different manufacturers and batches should be stored separately, with storage time controlled at three months or less, and rain and moisture protection measures should be taken to ensure cement stability^[1]. **Table 1** outlines the key indicator control requirements for cement incoming inspection for this project.

Table 1. Key indicator control requirements for cement incoming inspection for this project

No.	Indicator	Control requirement
1	Fineness (Specific Surface Area) (m ² /kg)	300-350
2	3d flexural strength (MPa)	≥ 3.5
3	28d flexural strength (MPa)	≥ 4.5
4	Initial setting time (min)	≥ 45
5	Final setting time (h)	≤ 10

3.2. Inspection and control of aggregate mobilization

Cement concrete aggregate mainly consists of coarse aggregate and fine aggregate, whose quality plays a

decisive role in the strength, compactness, and workability of the mixture. The coarse aggregate selected for this project is continuous graded crushed stone ranging from 5–31.5 mm. Upon mobilization, strict quality inspections must be conducted in accordance with design requirements to ensure that the crushing index does not exceed 15%, the mud content does not surpass 1.0%, the content of flaky and elongated particles is controlled at 15% or below, the compressive strength of the parent rock reaches 80 MPa or above, and there are no impurities or weathering. Natural medium sand is chosen as the fine aggregate, requiring a fineness modulus of 2.3–3.0, a mud content not exceeding 3.0%, a clay lump content not exceeding 0.5%, a mica content controlled at 2.0% or below, and the colorimetric test for organic matter content must meet design standards. According to the engineering design requirements, all materials arriving on site should undergo batch sampling inspections, and unqualified aggregate should be promptly removed from the site. Additionally, the mobilized aggregate should be stacked separately to prevent contamination or mixed stacking ^[2].

3.3. Inspection and control of admixture and mineral admixture mobilization

Admixtures are crucial materials that ensure the strength, workability, and durability of cement concrete. In this project, the selected admixture is a polycarboxylate-based high-efficiency water reducer. Upon mobilization, strict verification of its factory inspection report and product qualification certificate should be conducted in accordance with engineering design requirements to ensure that key indicators such as setting time and water reduction rate comply with design specifications and that it exhibits good compatibility with cement. Simultaneously, batch sampling tests should be conducted to inspect key indicators such as bleeding rate, air content, and water reduction rate. Only after confirmation of qualification can mobilization be permitted; otherwise, its use is strictly prohibited. The selected mineral admixture is Class I fly ash, which should undergo strict batch sampling inspections in accordance with design standards upon mobilization, with the water ratio controlled at 95% or below and the ignition loss controlled at 8% or below. Unqualified materials are strictly prohibited from entering the site for use ^[3]. Both the mobilized admixtures and mineral admixtures should be properly labeled and stored separately.

4. The main impacts of quality control over incoming raw materials on the forming quality of cement concrete pavement construction

4.1. The impact of cement testing and control on construction forming quality

In the construction of cement concrete pavements, the strength and crack resistance are directly influenced by the quality of the cement. If strict testing and control measures are not implemented upon arrival, allowing substandard cement to be used in construction, a series of quality issues may arise. If the fineness of the cement exceeds standards, the rate of hydration reaction in the cement concrete mixture will accelerate, further shortening the initial setting time of the concrete. This can easily lead to rapid slump loss or poor vibration compactness during construction, resulting in quality issues such as honeycombing and pitting on the pavement surface. If the soundness of the cement does not meet design standards, uneven volume shrinkage is likely to occur during the concrete hardening process, leading to the formation of through-cracks on the pavement at any time, which seriously affects the integrity and service life of the pavement. If the strength grade of the cement is insufficient, the compressive and flexural strengths of the pavement will not meet design requirements, leading to issues such as spalling, sanding, or slab breakage during use,

significantly reducing the pavement's load-bearing capacity. During the incoming inspection of raw materials for this project, the engineering unit discovered a batch of damp cement. After testing, it was found that the 3-day flexural strength of the damp cement mortar was only 3.2 MPa, failing to meet engineering design requirements. Upon discovery, the engineering unit promptly returned this batch of cement raw materials and prevented their use, effectively avoiding issues of insufficient strength in the formed pavement.

4.2. The impact of aggregate testing and control on construction forming quality

As the framework of the cement concrete mixture for highway pavements, key indicators of aggregates such as particle size distribution, silt content, and crushing value must undergo strict testing before arrival. The effectiveness of control over these incoming inspection indicators will directly impact the subsequent compactness, strength, and workability of the concrete mixture. If the particle size distribution of coarse aggregates does not meet design requirements and exhibits excessive void content, the amount of cement used will increase further, thereby increasing the risk of pavement cracking under the action of hydration heat. Moreover, achieving good control over compactness after vibration becomes difficult, easily leading to the formation of pores within the pavement, reducing its wear resistance and impermeability, and making it more prone to quality issues such as sanding and water seepage during subsequent practical use ^[4]. If the silt content of coarse aggregates exceeds engineering design standards, the soil will envelop the aggregate surface, weakening the bond between cement paste and aggregates. This will further reduce the strength of the concrete mixture and increase its shrinkage, making the pavement more prone to cracking. Similarly, if the quality of fine aggregate incoming inspections is not effectively controlled, it can also significantly adversely affect the forming quality of pavement construction. If the fineness modulus of fine aggregates is too low and contains excessive fine sand, the amount of cement and water used in the concrete will increase further, leading to increased concrete shrinkage and easily triggering pavement cracking issues ^[5]. If the fineness modulus is too high and contains excessive coarse sand, the workability of the concrete will decrease, and vibration will become more difficult, ultimately resulting in quality defects such as pitting and honeycombing on the pavement surface. **Table 2** compares the basic impact parameters of silt content in coarse aggregates for cement concrete in this project on pavement strength and smoothness.

Table 2. Comparison of basic impact parameters of silt content in coarse aggregates for cement concrete in this project on pavement strength and smoothness

No.	Indicator	Clay content in coarse aggregate (%)		
		≤ 1	1.5–2.0	> 2.0
1	28d compressive strength of concrete (MPa)	38.6	34.2	29.8
2	28d flexural strength of concrete (MPa)	4.9	4.2	3.7
3	Pavement smoothness pass rate (%)	98.5	82.3	65.7

4.3. Impact of inspection and control of admixtures and mineral admixtures on construction molding quality

During the pavement construction process using cement concrete mixtures, proper control over the incoming inspection of admixtures and mineral admixtures can further improve the performance of the concrete, thereby ensuring that the pavement molding quality meets standards. Conversely, improper inspection and control of incoming admixtures and mineral admixtures can severely affect the final construction molding quality of the pavement ^[6]. If the water-reducing rate of the admixture is insufficient, it will increase the

water consumption during the mixing process of the concrete mixture, further increasing the water-to-binder ratio of the mixture, reducing the concrete strength, and causing greater shrinkage of the concrete, which can easily lead to pavement cracking. If the admixture and cement do not have good compatibility, it will result in rapid loss of concrete slump, further increasing the difficulty of mixture paving and vibration, adversely affecting pavement smoothness, and making it prone to quality defects such as honeycombing and pitting. For mineral admixtures, if the incoming inspection control is unreasonable, resulting in excessive loss on ignition of fly ash and high residual carbon content, it will reduce the bond strength between cement paste and aggregates, thereby decreasing concrete strength. At the same time, it will further adsorb admixture molecules, causing abnormal loss of slump. If the fly ash has excessive moisture content, the actual water consumption during concrete mixing will further increase, exacerbating concrete shrinkage and easily leading to pavement cracking problems ^[7]. During the inspection of this project, a problem of poor compatibility between an admixture and cement was once discovered, resulting in a loss of more than 50% of the concrete slump within half an hour. By promptly replacing the admixture, the engineering unit effectively ensured the pavement molding quality.

5. Optimization suggestions for incoming inspection and control of raw materials based on ensuring the construction molding quality of cement concrete pavements

Based on the analysis of the impact of raw material selection and on-site quality inspection on pavement molding quality during cement concrete pavement construction in this project, to further ensure the construction molding quality of cement concrete pavements in actual construction, engineering units need to take the following measures to optimize the incoming inspection and control of raw materials ^[8]. Firstly, establish a stricter admission mechanism for raw material suppliers, strictly review their production qualifications, quality management systems, and historical cooperation performance, and prioritize suppliers with good reputation and stable quality. Additionally, comprehensively specify raw material quality standards and inspection requirements when signing supply contracts to control raw material quality from the source effectively. At the same time, regularly assess supplier qualifications to promptly identify and eliminate suppliers with unstable material quality, providing better guarantees for the supply quality of raw materials. Secondly, optimize the incoming inspection process for raw materials, arrange professional inspectors for inspection, and equip them with complete inspection equipment. Clearly define the inspection methods, frequency indicators, and acceptance criteria for various raw materials, and require inspectors to strictly implement sampling inspection according to regulations to ensure the authenticity and accuracy of on-site inspection results. At the same time, establish a comprehensive raw material inspection ledger to record detailed information such as incoming batches and inspection results of raw materials, ensuring full traceability of raw materials ^[9]. Thirdly, strictly inspect and manage the storage quality of raw materials, regularly review their actual storage conditions and quality and performance to control the stability of raw materials effectively. Fourthly, strengthen professional training for on-site inspectors and management personnel, comprehensively popularize quality inspection and control points for various raw materials, further improve the responsibility awareness and technical level of inspectors, and make inspection work more standardized and efficient. At the same time, establish a comprehensive raw material quality responsibility mechanism to clarify the relevant responsibilities of personnel in each position, avoiding situations such as dereliction of duty or misconduct by personnel during incoming inspection of raw materials, thereby ensuring good control over inspection work ^[10].

6. Conclusion

In summary, during the construction process of modern cement concrete pavements, scientific, reasonable, and strict incoming inspection and control of raw materials are key measures to ensure the quality and performance of raw materials, while also directly affecting the construction molding effect of pavements. Therefore, engineering units need first to clarify the key points of quality inspection and control and their impact on the subsequent construction molding quality of pavements, and then take reasonable measures to optimize the incoming inspection and control work of raw materials based on actual engineering conditions. This will further improve the incoming inspection quality of cement concrete raw materials, ensure the construction molding effect of cement concrete pavements, improve pavement performance, and extend pavement service life.

Disclosure statement

The authors declare no conflict of interest.

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Clan-Cultural Influences on Spatial Organization in Lingnan Traditional Villages: A Case Study of Chengyanggang, Chaoshan

Ziyue Jiang, Yuan Xiong*

Faculty of Innovation and Design, City University of Macau, Macau 999078, China

**Author to whom correspondence should be addressed.*

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Abstract: In traditional Lingnan villages, ancestral halls commonly serve as spatial centers, with residences and streets organized around clan relationships. However, the mechanisms underlying this spatial configuration remain insufficiently explained. Taking Chengyanggang Village as a case study, this paper investigates the relationship between clan culture and village space through literature review, field investigation, semi-structured interviews, and spatial hierarchy analysis. The study examines ancestral halls, street networks, residential clusters, and domestic spaces at multiple scales. The findings indicate that the village's spatial structure was shaped not only by environmental conditions and construction techniques but also by the long-term influence of the clan system. Specifically, clan hierarchy and kinship ties informed residential distribution; ancestral halls functioned as centers of public activity; and the proliferation of clan branches drove village expansion along existing street networks. This paper demonstrates how clan relationships and everyday practices jointly shaped the spatial organization of Lingnan traditional villages, contributing a culturally grounded perspective to the understanding of settlement morphology in the region.

Keywords: Clan culture; Traditional villages; Spatial organization; Chengyanggang village; Ancestral halls

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1. Introduction

The natural environment and the building technology of the traditional villages are not only factors that influence the spatial shape of the village but also the social interaction between people, culture, and life as well. Particularly in the Lingnan and Chaoshan areas, there is a tendency to have an established spatial structure with the ancestral halls being at the center, where houses are arranged according to the relations of the clans, streets running through the various branches of the families, and clusters of homes. This pattern of space implies that the space occupied by the villages is not necessarily architecturally related; it is also associated with the clan-based organization.

Most of the past research on traditional villages has been devoted to architectural typologies, climatic adaptation and spatial morphology. As an example, some studies have investigated ventilation, moisture control, and courtyard designs in conventional Chaoshan houses, and others have studied common residential types like Si Dian Jin (Four-Point Golden) and Xia Shan Hu (Mountain-Descent Tiger) typologies. Such works have successfully explained the local features of Lingnan vernacular architecture, but they are more inclined towards explaining what the spatial form is, rather than why such spatial organizations come into existence.

From the sociological and rural studies point of view, more focus has been placed on the clan culture *per se*. Fei Xiaotong (2008), in his book *From the Soil*, suggested that traditional Chinese rural society is defined by kinship-based relationships and a differential mode of association, where the intimacy of social relations determines social order and daily life. In the Chaoshan region too, these clan relations affect the spatial distribution^[1]. As an illustration, members of the same lineage branch tend to live in proximity; the ancestral halls are usually located in the central residential area, and the later branching families slowly extend to the outskirts. This spatial form is not the product of one planning action, but it has been stabilizing over long periods of time due to settlement and development of clans.

Over the past few years, certain researchers, such as Zhao Shule (2022), have started to pay attention to the connection between ancestral hall spaces and public activities. It has been noted that Chaoshan ancestral halls are not only used in rituals but also as significant places of decision-making, festivals, and gatherings^[2]. Since clan activities have long been centered on ancestral halls, these areas have slowly evolved into the common center of villages. In the meantime, the street system is not a transportation network alone; main streets, secondary lanes, and residential clusters form a clear spatial hierarchy which, in some ways, represents the organizational structure of the clan.

International studies by Knapp, R. G.(1999) also indicate that the settlement space is closely associated with social relations and cultural practices, providing useful insights for understanding the spatial organization of traditional villages^[3].

Currently, the studies of traditional Chaoshan villages have been conducted on clan culture, residential typologies, and settlement spatial structure in various aspects. Nevertheless, there is little systematic analysis of how clan structures specifically affect village spatial organization. While most scholars agree that clan culture is significant, very few scholars have combined ancestral halls, street systems, residential distribution, and clan relations into a single analytical framework.

This paper uses the example of Chengyanggang Village. In the light of clan culture, it examines the interrelationships between ancestral halls, street networks, residential spaces, and the general structure of the village in an attempt to elucidate how clan relations are involved in forming the spatial organization of traditional villages.

2. Research methods

There were four methods used. The theoretical framework was established through a literature review. Field research in the village offered primary spatial data based on observation, photography, and measurement. Qualitative information on ancestral hall activities, residential patterns and street use was obtained by conducting semi-structured interviews with elderly residents and long-term inhabitants; their answers were thematically coded. The morphological gradation of main streets to alleys and the center-periphery distribution of residential clusters was analyzed using the spatial hierarchy analysis. Triangulation of these

techniques will guarantee that there is a strong interpretation of the connection between clan culture and spatial organization.

3. Analysis of the clan structure of Chengyanggang Village

3.1. Clan branches, spatial clustering, and the hierarchical village pattern

The clan relations in the traditional Lingnan villages are mostly based on blood relations and their identity as ancestors, with the ancestral halls, rituals, and lineages splitting out of the family tree. The Chaoshan ancestral halls have not only a ritualistic role but also contribute to the local culture and people's involvement in village life (Lin Yuancheng, 2020) ^[4]. Chengyanggang Village demonstrates this. It has been observed that one or two major surnames dominate the population of the village, and it is constantly being divided into sublineages, which over time lead to the formation of several lines. Such branches tend to be concentrated spatially and are at the same time connected through the common origin of their ancestors. In turn, this means that there is an evident settlement pattern of the co-settlement of the lineage. The layout of the space is not random but rather related to the underlying structure of the clans. The various branches of the lineages occupy quite compact spaces, and yet they are associated with each other via the ancestral halls and communal areas, hence creating a hierarchical yet cohesive spatial organization (**Figure 1**).



Figure 1. Chengyanggang village's rural texture.

3.2. From center to periphery: kinship and spatial hierarchy in village layout

Clan organization is not only expressed in terms of the continuity of kinship relations, but also implies a very clear hierarchical order. In traditional clan systems, concepts of seniority and generation distinction are among the most important social principles, and such relations are also expressed in space. Clan identity derived from the clan system means not only the sense of belonging to the lineage group felt by its members, but also self-awareness rooted in the overall clan structure.

The ancestral hall in Chengyanggang Village is usually located at the center of the settlement, and it is surrounded by a relatively high density of primary residential units, whereas peripheral areas were mostly

developed in the later stages of expansion. Generally, the central area houses about 30–40% of all residential units, which is a distribution pattern that is highly associated with internal kinship proximity **Figure 2**.

Spatially, the members of closer kinship relations tend to occupy the areas that are nearer to the ancestral hall, and later emerging branches occupy the more distant ones. This outward expansion of the center forms a spatial gradient between public space and private space, and it is also an indication of the internal hierarchical order of the clan.



Figure 2. Distribution map of ancestral halls in Chengyanggang village.

3.3. The role of ancestral halls in shaping clan activities and public space

The clan activities directly control the use of the village space. It has been reported that in modern rural life, the ancestral halls are still used as places of meeting, as well as a place of cultural gathering and even as part of the rural administration Liu Meixin, 2023) ^[5]. The ceremonies and meetings of clans have to be held in definite areas, and this is why the ancestral houses are located in the middle of the village.

The space around the ancestral hall often creates an open space of a certain dimension for daily casual activities and festive gatherings. In fact, it can be observed that the ancestral hall not only satisfies the ritual functions, but also determines the organizational logic of the surrounding space.

4. Interview data and verification of spatial relationships

To supplement the spatial observation, semi-structured interviews with elderly villagers and long-term residents were carried out, concentrating on the functions of ancestral halls, residential distribution, street uses and village expansion.

After the interviews were conducted, the data gathered were arranged in a systematic manner, and the themes that emerged repeatedly were reduced to key analytical concepts such as the public nature of ancestral halls, concentration of clan activities, kinship-based settlement patterns, clan-based housing clusters, alley-driven expansion and hierarchical street-alley networks. These results were cross-referenced with field observations on the location of ancestral halls, distribution of houses, and alley arrangement to determine whether the clan culture has affected the spatial organization of the village. The table below is a detailed summary of the findings. See **Table 1**.

Table 1. Interview outline and data organization

Number	Participant profile	Focus point	Typical answer	Key summary	Conclusion
A1	A resident, aged 78	Venues for discussing key village affairs.	The ancestral hall is the most important place; in the past, all village matters were discussed there.	The ancestral hall serves as the central public space.	An ancestral hall possesses both a central role and a public nature.
A2	A member of the clan, aged 72	The main venue for ancestral worship, festivals, or public events.	Ancestral worship ceremonies, meetings, and wedding celebrations are typically held near the ancestral hall.	Clan activities are concentrated in certain areas.	Clan activities reinforce the central role of the ancestral hall.
A3	A resident, aged 68	The relationship between kinship ties and residential distance	The closer relatives all lived nearby; only as the branches multiplied did they gradually expand outward.	Blood-related settlements.	Residential distribution is influenced by clan relationships.
A4	An elderly resident of the village, aged 75	Whether established site selection guidance existed during past house construction.	In the past, building a house also required considering family lineage; the location wasn't chosen arbitrarily.	The hierarchical order influences site selection.	The spatial hierarchy corresponds to the clan hierarchy.
A5	A resident, aged 70	The future development direction for new housing projects.	As more people gathered behind, construction gradually expanded outward along the alley.	Expand along the alley.	The village expands along the existing structure.
A6	A senior member of the clan, aged 82	Space utilization during festivals such as Qingming and the Winter Solstice.	During the Qingming Festival and Winter Solstice, the ancestral hall is particularly bustling with a large crowd.	Festival activities.	The event cycle enhances the utilization of public spaces.
A7	A resident, aged 65	Whether different apartment complexes share relatively concentrated residential areas.	Each household typically lives together, with their own designated area.	The branches form residential clusters.	The space exhibits a branched aggregation structure.
A8	A resident, aged 74	The Differences in the Use of Main Streets and Alleys.	The narrow alleys connect every household, while the main roads are used by everyone.	The streets and alleys are clearly graded.	The streets and alleys have a hierarchical structure.

The interview results broadly support the spatial analysis. The ancestral hall functions as the public center of the village, residential distribution reflects kinship ties, and the street network exhibits a clear hierarchy. Taken together, these findings suggest that clan culture continues to shape the spatial organization of the village.

5. Analysis of the spatial organization of residential houses and villages: A case study of Chengyanggang Village

5.1. The basic spatial composition of residential buildings

The chapter provides a detailed description of the traditional houses and spatial layout of Chengyanggang Village based on field research, analysis of spatial hierarchy, and interview information. The conventional houses in Lingnan and Chaoshan areas developed slowly with the impact of the long-term local living

conditions and environmental factors, which led to relatively stable space arrangements. Chengyanggang village has retained most of its original Chaoshan traditional settlement pattern, and there is a distinct similarity between the spatial structure of the village and the clan relations within it.

The interior spatial design of the traditional houses in the village of Chengyanggang is mostly made up of three elements, which are the hall, courtyard, and living rooms. They are arranged around a central line that creates a clear structure of space. The center of the house is the hall, where the family members will be able to conduct most of their social activities and also conduct rituals and other ceremonies. It is located between various functional spaces, and the courtyard provides sufficient light and air as well as movement between the areas. Rooms like the bedroom can be found on one side or at the rear of the hall with more privacy. The plan of the entire place shows a gradual process of turning the public into the private. In the Chaoshan area, there is a rather constant relationship of space in the main hall, the courtyard, and the living quarters Lin Jiena, 2024) ^[6]. Not only does the basic front hall-courtyard-back hall scheme allow the adaptation of the Lingnan region to its humid weather conditions, but it is also the basis of the future layers of the space, and therefore this scheme becomes an important prototype of the organization of the residential space in the Lingnan tradition.

5.2. Spatial hierarchy and usage relationships

It is also worth noting that the hierarchy of space in the old house does not only depend on the functions, but it also has a connection to the way of life and social interaction among families. Rapoport (1969) believed that there are other factors, besides climate, materials, technology, etc ^[7]. The buildings of the Chengyanggang Village have an open front and street side with a very large entrance, and this part is used for everyday living and going out; the hall is the place where the family members spend their time; the interior of the house is composed of rooms, which can be accessed by the residents of the house only. The courtyard acts as a buffer zone between the various areas so that no one area is connected with the other one.

The living rooms are the ones that start to change in the outside and inside of a home, so there is a hierarchy of openness and privacy as well, which can be compared to the real-life usage of homes. The houses of the families were also built in such a way that they spread out on the horizontal or vertical axis when the family was large enough, and the clan had branches. In most cases, the houses were added to the current houses with the addition of space but without any break in space. Houses tend to have a hall-centered plan where it is followed by a succession of enlarging and deepening parts, and this is not only because of natural conditions and construction methods but also because of the clans and the need to perform the functions practically.

Regarding the general spatial organization of the village, Chengyanggang Village has a layout that is based on the ancestral hall, and the street and alley hierarchies and residential clusters are arranged in this way. The village still maintains a comparatively intact comb-like layout as well as traditional Chaoshan residential designs like Four-Point Golden and Mountain-Descent Tiger designs. Being the most significant public structure of the village, the ancestral hall is usually placed at the center or at some important points, not only as a symbol of the clan but also as a place where rituals, deliberations, and other activities take place. A system of ancestral halls has been developed by Chengyanggang Village: the main ancestral hall is situated in the village centre, with the surrounding spaces devoted to worship and gatherings; branch ancestral halls of different branches of clans are located in various residential clusters and are spatially linked to their respective housing areas, creating a distinct stratified spatial structure. The ancestral halls are the

spatial center of the village, which not only represents the organization of the clan relationships within the spatial framework.

5.3. Spatial configuration of the street-alley system and residential aggregations

The street-alley network is the most important part of the system of the ancestral hall, home, and public place. The hierarchy of streets and alleys in the village of Chengyanggang has a well-defined level of differentiation between the main street and the branches of the alleys. The primary avenue connects the ancestral halls with the large space of the people, where the size of the space is bigger, and the purpose of it is to serve as a transport and social activity center. Other branch alleyways are much narrower than other types of residential buildings, as they are built into the houses of separate families and family lines. The pattern of streets and alleys is also associated with the residential patterns of the clan branches. The various branches make relatively small settlements on the basis of particular alleys, so that the entire village can be considered as having a certain degree of zoning. It is the street order that shows the spatial arrangement of the relations between clans, and the distribution of the population according to the village's spatial structure.

In Chengyanggang Village, the residential units of different clan branches show a significant clustered pattern. Families with close kinship relations mainly live in the vicinity of the ancestral hall and central area, and descendant branches gradually spread outwards. In total, more than 70% of the residential units are concentrated into different clusters, thus forming clear residential boundaries. This pattern not only reinforces internal clan relations, but also maintains inter-cluster relations via the street and alley network.

With the increase in population and the creation of new branches of clans, more residential units are being constructed along streets or at the periphery. However, they all still fit into the current spatial structure with continuity between the old and the new areas. Chengyanggang Village has therefore created a model of spatial organization based on the ancestral hall, which is connected by streets and alleys and where the distribution of residential buildings is clustered: an obvious indication of the long-term impact of clan relations on the spatial organization of the village.

5.4. Residential distribution and clan groupings

The layout of the village, Chengyanggang, is based on the ancestral house and has a definite hierarchy of streets and lanes with houses built in such a way that they are arranged around the ancestral hall, and the settlement was progressively added to the existing one. These are also interdependent features: the location of the ancestral house will affect the distribution of residential units as well as the structure of the street-alley; the structure of the street-alley will ensure that there is a connection between the clusters of residential buildings. Therefore, the spatial arrangement of the village is determined by the natural and practical factors, but also by the fact that the relations among clans have been part of the organization of space.

6. The impact of clan culture on the spatial organization of Chengyanggang Village

6.1. Clan relationships and the spatial morphology of the village

The analysis of the clan, spatial arrangement, and village structure in Chengyanggang Village has been done in the previous chapters. The chapter continues to explain how the clan relationship is also involved in the formation of the villages as well as the distribution of residential space, public activities, and expansion of the village. Put differently, it is not a matter of the culture of clans in an abstract sense but that of their actual

embodiment in the ancestral halls, streets, and organization of residences. The way the natural environment, building processes, family relations, and everyday life were connected did not result in the emergence of the spatial design of the Chengyanggang Village; this was a long-term process. Another research on traditional villages suggests that when we preserve the traditional village, we must not only preserve the buildings but also the shape of the village, lifestyle, and social connections of the villagers Cheng Yeqing, (2024) ^[8]. It is therefore the blood relationships which form the basis of the village space in terms of the clans. As the main physical point of the clan identity, ancestral halls have an impact on the design of the village: they are located in the center where most of the houses are concentrated, and then new homes are built around the existing ones with the growth of the branches of the clans, and the entire area grows towards the periphery. This system is a representation of the living relations between people, and at the same time there is order and continuity in the evolution of the village.

6.2. Clan hierarchy and its spatial correspondences

The spatial arrangements clearly reflect the hierarchical organization of the clan. The ancestral hall is a high-level spatial node with strong public and symbolic importance Lin Jiena, 2024) ^[6]; therefore, its immediate environment tends to be a core residential area, whereas peripheral regions tend to become more private. This pattern of spatial distribution that decreases as one moves away from the center fits well with the internal kinship dynamics and hierarchy of the clan. Likewise, in single-family houses, the spatial hierarchy of the main hall, courtyard and living quarters is mirrored by the functional relations within the household. Therefore, not only does the spatial hierarchy emerge due to the functional differentiation, but it also demonstrates the significance of social relationships in the spatial structure.

6.3. The role of clan activities in shaping spatial functions and organization

The spatial functions are directly affected by clan activities. There is a need for a specific space where ritual ceremonies and deliberations can be performed; hence, ancestral halls and their surroundings are the main public areas in villages. In the meantime, streets and alleys act as connectors and transitional components of everyday life, connecting various spatial units and preserving overall spatial continuity. One can see that the emergence of spatial functions is not only conditioned by daily needs but also has much to do with organizational patterns of clan activities.

The streets were then gradually occupied by new houses as the clan branches spread and the spatial arrangement was preserved. The social relations are organized in the form of the clan system, which organizes the human settlement patterns and the needs of the space to be a unique spatial organization over time Chen Zhaojia, (2025) ^[9]. More specifically, the clans determine the residential units, the clan activities determine the spatial functions, the development of the branch of the clan determines the spatial growth, and the formation of structural elements such as centers of ancestral halls, spatial hierarchy, and street networks. Therefore, the village space is not created by one aspect but through a process of social interaction. Moreover, it has been observed that there are high correlations between the number of ancestral halls, the number of streets, and the number of houses, which is why the role of the clan structure in the spatial distribution of the villages is very important.

7. Conclusion

The study takes Chengyanggang Village as a representative Lingnan traditional settlement to examine how its spatial organization was formed. The findings indicate that village space cannot be explained solely by environmental conditions or construction techniques, but is the result of interactions among natural factors, building practices, and clan culture. In Chengyanggang Village, the ancestral hall gradually became the spatial and social center through repeated communal activities, while kinship ties encouraged residential clustering and shaped the hierarchical street network. These spatial characteristics demonstrate that the village developed through the long-term continuity of clan relationships rather than formal planning. At the same time, the humid subtropical climate, local topography, land resources, and population growth also influenced the physical form and expansion of the settlement. This study treats clan culture as an analytical factor rather than merely a cultural background and proposes a framework linking clan organization, social relations, spatial needs, and spatial structure. The framework not only explains the spatial formation of Chengyanggang Village but also provides a reference for analyzing other lineage-based settlements in the Lingnan region. Although the research is limited by its single-case focus and relatively simple quantitative analysis, it offers a useful basis for future comparative studies, the application of advanced spatial analysis methods, and the conservation and sustainable renewal of traditional villages.

Disclosure statement

The authors declare no conflict of interest.

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Integration Practice of BIM and AI-Guided Learning in Mountain Architecture Teaching under the Background of Intelligent Construction

Yajuan Liu*

Chongqing Energy College, Chongqing 402260, China

**Author to whom correspondence should be addressed.*

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Abstract: To further enhance the quality of mountain architecture teaching, strengthen talent cultivation, and precisely meet the demand for new architectural talents driven by the development of intelligent construction, this paper explores the integration of BIM and AI-guided learning in mountain architecture teaching. It first analyzes and interprets the value of integrating BIM and AI-guided learning in mountain architecture teaching, then examines the supporting system for their integration in mountain teaching, and finally proposes practical strategies to address current issues in integrated teaching. These strategies include optimizing teaching platform functionalities, innovating teaching resource provision, improving teaching evaluation systems, and deepening school-enterprise collaboration, thereby effectively promoting deep integration of BIM and AI-guided learning in mountain architecture teaching and providing solid support for talent cultivation in mountain architecture under the context of intelligent construction.

Keywords: Intelligent construction; BIM; AI-guided learning; Mountain architecture teaching; Integration practice

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1. Preface

With the rapid popularization of intelligent construction technologies, the construction industry has embraced new development opportunities, and the demand for compound talents with both digital capabilities and mountain engineering literacy has become increasingly urgent. Mountain architecture, characterized by complex terrain, challenging construction, and unique scenarios, imposes stricter requirements on talent cultivation. Traditional teaching models fail to achieve a deep connection between theory and engineering practice^[1]. Therefore, in the current context of intelligent construction, it is necessary to deeply integrate BIM and AI-guided learning into mountain teaching to drive teaching innovation, create a three-dimensional

teaching model that combines visualization, personalization, and practicality, and enable students to deeply master digital design, construction, and management skills in mountain architecture, thereby enhancing talent cultivation levels and effectiveness and continuously supplying high-quality talents to the mountain architecture field.

2. Core value of integrating BIM and AI-guided learning in mountain architecture teaching

2.1. Meeting the special needs of mountain architecture teaching

Mountain architecture teaching presents special characteristics such as complex terrain, abstract scenarios, and significant practical challenges, which traditional teaching models cannot intuitively present, resulting in insufficient teaching adaptability ^[2]. The integration of BIM and AI-guided learning in teaching can precisely meet the special needs of mountain architecture teaching, effectively visualizing terrain relationships and construction challenges in mountain architecture construction. This not only helps students more accurately understand theoretical knowledge regarding mountain architecture site selection and terrain adaptability but also precisely addresses challenges in teaching practice, thereby improving teaching quality and effectiveness.

2.2. Aligning with intelligent construction talent cultivation goals

The integration of BIM and AI-guided learning in mountain architecture teaching deeply aligns with the goals of intelligent construction talent cultivation. In the current era of intelligent construction, the demand for compound talents with digital capabilities and mountain engineering literacy in the mountain architecture field is becoming increasingly urgent. The integration of BIM and AI-guided learning in education can effectively promote the connection between digital technologies and the entire teaching process, enabling students to master skills such as BIM visual modeling and AI-guided learning during their studies, and cultivating their digital thinking and engineering practice abilities. This not only drives precise alignment between teaching and industry needs but also highly aligns with the core goals of intelligent construction talent cultivation, continuously supplying high-quality talents to industry development ^[3].

3. Supporting system for integrating BIM and AI-guided learning in mountain architecture teaching

3.1. Establishing a digital teaching technology support framework for mountain architecture

The integration of BIM and AI-guided learning in mountain architecture teaching requires establishing a digital teaching technology support framework for mountain architecture to ensure that education and teaching deeply meet the special needs of mountain teaching. In practice, it is necessary to closely revolve around the entire process of mountain architecture teaching and establish a technology application logic that adapts to mountain architecture teaching scenarios, such as integrating BIM and AI-guided learning into various aspects of mountain architecture theory teaching, practical guidance, Q&A sessions, and outcome feedback. This not only achieves deep integration of BIM and AI-guided learning in mountain architecture teaching but also enables innovation and transformation of various teaching links under technology

adaptation, meeting students' professional learning needs and promoting quality and efficiency improvements in integrated teaching ^[4].

3.2. Constructing a “BIM + AI” teaching content adaptation mechanism

Constructing a “BIM + AI” adaptation mechanism helps improve the effectiveness of integrated teaching and ensures deep integration of mountain teaching with BIM and AI-guided learning. In teaching practice, the primary task is to sort out the core content of current mountain architecture teaching and strive to embed BIM and AI throughout the entire teaching process, such as using BIM technology for contour line processing teaching in terrain modeling links and utilizing AI-guided learning for precise knowledge point delivery in Q&A sessions to ensure the adaptability of teaching content to students' learning needs. Additionally, in teaching practice, it is necessary to accurately observe students' learning progress, ability foundations, and professional levels to ensure precise alignment between BIM and AI-guided learning during the integration stage and students' growth needs, thereby improving teaching quality ^[5].

4. Existing problems in the integration of BIM and AI-guided learning in mountain architecture teaching

4.1. Insufficient adaptability of BIM and AI technology applications to mountain architecture teaching

The integration of BIM and AI-guided learning in mountain architecture teaching faces challenges related to insufficient adaptability, resulting in suboptimal teaching outcomes and hindering teaching innovation. Mountain architecture teaching is characterized by complex terrain and unique construction challenges, yet the application of BIM and AI technologies often falls short in addressing these specific needs. BIM technology is predominantly utilized for conventional architectural simulations, with limited optimization for special scenarios in mountain architecture, such as contour line processing, slope adaptation, and slope protection. Similarly, AI technology lacks deep integration with teaching content, lacking tailored guidance modules specifically designed for mountain architecture teaching, thereby limiting the full potential of BIM and AI technologies ^[6].

4.2. Need for improvement in the personalized teaching adaptability of AI-guided learning

The personalized teaching adaptability of AI-guided learning requires enhancement, posing a significant challenge in mountain architecture teaching. This limitation hinders the precise alignment of teaching content with the diverse learning foundations and growth needs of students. In practice, AI-guided learning algorithms have not been sufficiently optimized to meet the unique demands of mountain architecture teaching, resulting in difficulties in accurately identifying students' knowledge weaknesses, such as those related to mountain terrain modeling and BIM. Consequently, this leads to homogenized delivery of learning resources. Furthermore, teaching practices often fail to adequately consider individual student differences, lacking differentiated resource delivery for students with varying levels of foundation, thereby impeding the implementation of personalized teaching approaches and reducing overall teaching quality.

4.3. Insufficient integration of digital teaching resources and technologies in mountain architecture

The insufficient integration of digital teaching resources and technologies in mountain architecture represents a significant challenge in the integration of BIM and AI in teaching. This issue is primarily manifested by the relatively weak reserve of teaching resources and the inability of existing resources to achieve deep integration with BIM and AI technologies, thereby limiting the expansion of diverse teaching scenarios. For instance, existing teaching resources often consist of scattered BIM models and teaching materials, lacking dedicated content tailored to terrain adaptation and slope protection in mountain architecture. Additionally, these resources have not been integrated with AI-guided learning technologies, hindering the establishment of precise resource delivery mechanisms in teaching practices and diminishing the effectiveness of mountain architecture teaching^[7].

4.4. Disconnection between the practicality of integrated teaching and actual mountain engineering practices

The disconnection between the practicality of integrated teaching and actual mountain engineering practices poses a problem in the integration of BIM and AI in teaching. This issue is primarily characterized by the predominant use of classroom simulations and virtual operations in integrated teaching, with limited emphasis on strengthening connections with mountain engineering practices, resulting in weak practicality in course teaching. In practical teaching, BIM practical cases often rely on virtual scenarios, failing to incorporate elements such as real mountain construction projects, complex terrain, and construction challenges. Consequently, students struggle to gain practical experience, limiting the improvement of their practical abilities^[8]. Meanwhile, insufficient collaboration between schools and enterprises has hindered the establishment of off-campus practical bases, resulting in a scarcity of practical teaching scenarios and difficulties in enhancing teaching quality and effectiveness.

5. Optimization strategies for the integration practice of BIM and AI-guided learning

5.1. Optimize teaching platform functionalities to enhance adaptability to mountain scenarios

Optimizing teaching platform functionalities to enhance adaptability to mountain scenarios is crucial for promoting the integration practice of BIM and AI-guided learning and fostering teaching innovation. Therefore, it is essential to precisely align with the characteristics of complex terrain and diverse scenarios in mountain architecture and make targeted optimizations to teaching platform functionalities. Firstly, promote the optimization of the teaching platform's technological architecture by deeply integrating core functional modules such as BIM modeling, terrain simulation, and AI-guided learning within the platform. This integration should eliminate data barriers between modules and prevent disconnections between modeling and guidance processes. Additionally, the platform should focus on improving the mountain terrain simulation capabilities within the BIM module, ensuring support for practical operations such as contour line import, slope analysis, and terrain cutting. This will enable the simulation of real engineering scenarios in teaching practices, allowing students to intuitively understand the multifaceted impacts of mountain terrain on architectural design and construction. Secondly, enhance the adaptability of the AI-guided learning module to mountain scenarios by conducting AI model training that deeply aligns with mountain architecture

teaching objectives. This will drive the optimization of AI algorithms and effectively bridge classroom teaching with mountain scenarios. For instance, in teaching special knowledge related to slope protection and foundation treatment in mountain architecture, AI-guided learning can be utilized to deliver relevant BIM modeling cases and construction videos, assisting students in addressing terrain adaptation challenges during practical operations. This approach not only strengthens the adaptability of teaching content to mountain scenarios but also helps improve students' professional abilities and levels, enabling them to more efficiently complete mountain architecture teaching tasks ^[9].

5.2. Innovate teaching resource provision to meet practical needs in mountain architecture

In the context of intelligent construction, the integration of BIM and AI-guided learning in mountain architecture teaching necessitates innovative teaching resource provision to ensure alignment with practical needs. Therefore, teaching should revolve around the demands of mountain architecture education and establish an integrated teaching resource provision framework that combines “BIM + AI”. Firstly, diversify the types of teaching resources provided by deeply integrating resources such as BIM model libraries, AI-guided learning courseware, practical cases, and virtual simulation videos in teaching. Additionally, promptly supplement typical case resources in mountain architecture to ensure comprehensive coverage of BIM models for different terrains and architectural types. Core teaching points such as terrain processing, slope protection, and drainage design should be meticulously annotated within these resources to meet the practical teaching needs of mountain architecture. Secondly, strengthen the adaptability of resources to teaching by precisely aligning resource provision with the objectives of intelligent construction talent cultivation. This involves deeply integrating BIM modeling techniques, AI data analysis, and practical norms for mountain engineering into the teaching resource system. Furthermore, resources should be categorized and provided based on the professional learning needs of students with varying foundations and grade levels. For instance, focus on providing foundational resources for terrain modeling to lower-grade students, while emphasizing resources related to comprehensive practical operations and construction simulations in mountain architecture for higher-grade students. This ensures the targeted and effective provision of mountain architecture teaching resources, enhancing the quality of talent cultivation.

5.3. Improve the teaching evaluation system to strengthen the orientation of integrated practice

Improving the teaching evaluation system and strengthening the orientation of integrated practice are instrumental in promoting the integration of BIM and AI into mountain architecture teaching practices and ensuring alignment with educational reform trends in the context of intelligent construction. Therefore, it is essential to establish a comprehensive evaluation framework that combines process-based and summative evaluations. Firstly, drive the optimization of teaching evaluation indicators by comprehensively considering aspects such as BIM modeling capabilities, AI-guided learning application abilities, practical abilities in mountain architecture, and teamwork skills when evaluating mountain architecture teaching. Additionally, refine the scoring criteria for each indicator. For instance, when evaluating BIM modeling capabilities, focus on assessing the accuracy of students' mountain terrain modeling and the adaptability of architectural designs to the terrain during practical operations, reflecting their practical skill levels ^[10]. Secondly, promote innovation in evaluation methods by paying close attention to students' learning processes and outcomes, and establishing a “process-based + summative” three-dimensional evaluation model. In process-based

evaluation, focus on students' performance during BIM practical operations, AI-guided learning, group collaborations, and task progressions in the classroom. Utilize online learning platforms to meticulously record each student's learning trajectory, task progress, and practical performance, reflecting the specifics of their learning processes. Summative evaluation should assess students' abilities to apply BIM technology to advance projects based on comprehensive practical projects in mountain architecture, including indicators such as mountain architectural design, terrain simulation, and construction process planning, to comprehensively evaluate their practical application abilities. After completing evaluations, leverage the evaluation results to drive subsequent teaching mode optimizations, promoting the deep integration of BIM and AI into mountain architecture teaching and enhancing teaching quality and efficiency.

5.4. Deepen school-enterprise collaboration to expand integrated practice scenarios

In the context of intelligent construction, the integration of BIM and AI into mountain architecture teaching requires deepening collaboration between schools and enterprises to expand integrated practice scenarios. Firstly, establish a long-term cooperation mechanism between schools and enterprises. Strengthen collaboration between schools and enterprises related to mountain architecture, such as signing cooperation agreements with mountain architecture enterprises and digital construction enterprises. Clearly define the responsibilities of both parties in advancing talent cultivation. In this collaboration, enterprises provide real mountain construction project cases and BIM modeling projects, along with AI technical support, while schools are responsible for orchestrating curriculum teaching, strengthening technological research and development, and deeply aligning teaching practices with actual engineering projects in enterprises. This approach fosters a three-dimensional talent cultivation framework and effectively promotes the deep integration of BIM and AI in mountain architecture teaching. Secondly, expand integrated practice scenarios by leveraging engineering case resources from enterprises and theoretical teaching resources within schools. Collaborate with enterprises to establish off-campus practical bases and organize students to conduct practical operations at these bases. This allows students to deepen their understanding of BIM and AI technologies in real projects and strengthen their technological application abilities. During practical operations, enterprise mentors and school teachers provide tracking guidance to help students master the construction processes and industry norms of mountain architecture projects, thereby solidifying their professional skill foundations and enabling them to fully adapt to the demand trends for compound talents in the mountain architecture field under the context of intelligent construction.

6. Conclusion

Research has found that in the context of intelligent construction, the integration of BIM and AI-guided learning into mountain architecture teaching holds significant importance and value. It not only precisely meets the unique demands of mountain architecture teaching but also fully aligns with the objectives of intelligent construction talent cultivation. The multiple measures proposed in this paper, including platform functionality optimization, teaching resource provision, evaluation system improvement, and school-enterprise collaboration, contribute to promoting the deep integration of BIM and AI into mountain architecture teaching and driving teaching innovation. In the future, mountain architecture teaching will gradually evolve towards innovative development characterized by deep technological integration and precise scenario adaptation. Subsequent research can explore breakthroughs in areas such as the optimization of personalized algorithms for BIM and AI-guided learning and the construction of digital teaching scenarios

for mountain architecture, further enhancing the quality and efficiency of mountain architecture teaching.

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Research on the Integration Path of BIM and AI under the Intelligent Management Model at Construction Sites

Huiming Qin, Ying Peng*, Lianyuan Peng, Taolin Luo, Baoming Dai, Siyan Yu, Yifei Xu

Chongqing Institute of Engineering, Chongqing 400056, China

**Author to whom correspondence should be addressed.*

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Abstract: Currently, the construction industry has largely transitioned to an intelligent management model at construction sites. Among these, the applications of Building Information Modeling (BIM) and Artificial Intelligence (AI) technologies are the most prevalent in intelligent management. The integration of these two technologies can effectively address the challenges of traditional extensive construction management and enhance the efficiency of construction site management. This article first interprets the architectural design for the integration of BIM and AI technologies under intelligent management, clarifying the mechanisms of their integration. It then focuses on analyzing the core issues in the integration of BIM and AI at construction sites and proposes innovative optimization paths for the integration of these dual technologies, guided by problem-solving, to provide references for optimizing construction site management.

Keywords: Construction site; Intelligent management; BIM technology; AI technology

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1. Introduction

The application of BIM technology in intelligent management at construction sites can transform construction process management into a visual management form and construct virtual construction models through the collection of construction data. These models can be used to analyze the standardization and controllability of various construction processes, thereby enhancing the efficiency of construction site management. However, BIM technology management tends to lean towards a static management model, unable to accurately predict construction phases and future development trends. In contrast, the application of AI technology can mine, analyze, and integrate construction data through algorithms, enabling precise and rigorous predictions of construction trends and potential risks. It is evident that the application of AI technology can effectively compensate for the deficiencies of BIM technology in construction site management, thereby optimizing the intelligent management system at construction sites ^[1]. However, the current applications of BIM and

AI technologies at construction sites are overly simplistic and have not formed a systematic management system, limiting the application of the integration of these dual technologies. Based on this, the article will start with the current state of dual technology integration, explore innovative integration paths, and thereby solidify the technological foundation for construction site management.

2. Architectural design for the integration of BIM and AI under intelligent management

2.1. Overall design principles and objectives for integration

The architectural design for the integration of BIM and AI technologies must adhere to corresponding principles: First, the principle of scientificity. The application of dual technology integration should be centered around the management needs of construction sites and the mechanisms of technology integration to ensure that technology integration enhances management efficiency. Second, the principle of practicality. The application of dual technology integration should effectively address management issues at construction sites and improve management efficiency, avoiding the mere formality of technology integration. Third, the principle of synergy. Dual technology integration should establish a linkage mechanism from a complementary perspective to ensure the safe and orderly conduct of construction management work. Fourth, the principle of innovation. Intelligent management at construction sites under dual technology integration should break away from the traditional fixed mode of single technology application and create an innovative intelligent management model by combining the advantages of both technologies ^[2]. Meanwhile, the objectives of dual technology integration application should be clarified: First, to construct an integrated construction management platform that integrates information on on-site progress, quality, safety, and cost control to break down management barriers and ensure on-site control efficiency. Second, to create a panoramic intelligent control model for construction site management to simulate construction processes, thereby enhancing on-site construction management efficiency, strengthening engineering risk prediction, and promoting the effective implementation of intelligent control mechanisms ^[3].

2.2. Construction of a multi-level technology integration architecture

The integration architecture of BIM and AI under intelligent management needs to construct a multi-level system based on management needs. First, the data layer should be constructed to lay a solid foundation for the architecture. The task of the data layer is to construct a static model of the BIM construction design plan based on engineering construction parameters. Simultaneously, AI technology should be utilized to collect various material, labor, equipment, and environmental parameters during construction, forming a dynamic data analysis model. Second, the construction of the model layer can provide a systematic and practical carrier for dual technology integration. For example, it can build a dynamic model system for the virtual model of BIM technology, which differs from traditional static models by incorporating AI technology. This model can not only automatically extract and analyze data but also automatically adjust the model structure based on the analysis results. Third, the algorithm layer is the core of the application of dual technology integration. It can clean, filter, and process data in the BIM model through AI technology and accurately manage and predict on-site progress, quality, safety, and cost based on objective data, thereby effectively avoiding construction risks ^[4]. Finally, the construction of the application layer can provide application ports for dual technology integration. The key to constructing this layer is to clearly and three-

dimensionally display the management process at construction sites and provide a management operation interface for construction managers. Additionally, the control layer can intelligently detect the control effects of dual technology models and promptly rectify unreasonable content to ensure the continuous optimization of intelligent control work. To ensure a clearer presentation of the multi-level technology integration architecture, the architecture levels, positioning, and core parameters are summarized in **Table 1** below:

Table 1. Multi-level technology integration architecture table

Architecture level	Core positioning	Core parameters
Data Layer	Dual-technology integrated architecture foundation	Data collection accuracy $\geq 95\%$, data standardization rate 100%
Model Layer	Dual-technology integration carrier	Model accuracy level LOD400, model-site matching rate $\geq 98\%$
Algorithm Layer	Core of dual-technology control	Risk identification rate $\geq 92\%$, site management prediction accuracy $\geq 85\%$
Application Layer	Technical operation interface	Scene coverage rate 100%
Management and Control Layer	Closed-loop management and control	Hidden hazard rectification rate 100%

2.3. Construction of data interoperability and sharing mechanism

The application of data interoperability in the integration of BIM and AI ensures the depth and effectiveness of the dual-technology integration, thereby addressing the issue of data silos in construction. The construction of a data interoperability mechanism can be approached from the following dimensions: Firstly, enhance data processing. Standardize data within the integrated architecture of BIM and AI technologies to ensure uniform data standards, laying the foundation for data sharing in the dual-technology integration. Secondly, establish efficient and stable data transmission channels. Utilize communication technologies such as 5G and Wi-Fi to construct data transmission channels and data storage platforms, thereby providing favorable transmission conditions for technology integration. Thirdly, optimize data sharing mechanisms. Focus on creating an integrated platform for the entire construction process management workflow to ensure transparency in construction management data. Finally, establish a dynamic data management and control mechanism. The integrated architecture of dual technologies should automatically adjust the construction site management model based on specific project conditions, ensuring alignment between the model and the actual construction site, thereby preventing management deviations ^[5].

3. Core issues in the current integration of BIM and AI on construction sites

3.1. Progress control: Lagging integration and inaccurate dynamic control

The application of BIM and AI integration in construction progress control on construction sites suffers from insufficient management granularity, primarily manifested in the static process models used for BIM progress management, which cannot automatically update in response to changes in construction conditions and issues ^[6]. Additionally, the data extraction and application in AI technology do not fully leverage its automation capabilities, with most data still requiring manual input. This results in significant lag in the integrated application of BIM and AI.

3.2. Quality control: Superficial application and lack of granular control

BIM and AI technologies have not yet formed a deep integration mechanism in construction site management, limiting their application to single management scenarios in quality control and making it difficult to achieve full-process control. For instance, BIM technology is primarily used for detecting design drawings and creating 3D models, struggling to provide dynamic quality tracking based on construction progress. AI technology is solely applied to the visual inspection of projects, unable to predict and prevent construction quality issues. Moreover, the effectiveness of dual-technology integration monitoring is limited, necessitating manual inspection as the core method for ensuring quality inspection efficiency, which falls short of granular control ^[7].

3.3. Safety control: Insufficient collaboration and passive risk prevention

Predicting and preventing safety risks on construction sites is challenging due to their sudden nature, requiring the development of an early warning mechanism through technology integration. However, the current application of BIM and AI integration in construction site safety control is limited. BIM technology is mainly used for simulating construction models, identifying and analyzing safety hazards from a static perspective. AI technology focuses on identifying illegal operations in construction safety control, resulting in limited synergy between the dual technologies and difficulty in accurately combining static models with dynamic identification data, leading to weak risk identification capabilities ^[8]. Under this integration mechanism, construction site safety management still relies primarily on post-event control, with poor preventive effects.

3.4. Cost control: Inefficient data and weak dynamic cost control capabilities

The application of BIM and AI integration in cost control on construction sites is limited, with significant deviations from the requirements of full-project lifecycle management. BIM technology is primarily used for project budgeting and accounting, improving calculation accuracy and efficiency. However, it cannot form a dynamic cost control mechanism based on changes in material, schedule, labor, and other dimensional elements within the project. AI technology focuses on data capture, processing, and statistics for cost control, failing to leverage its deep mining and control capabilities. Moreover, data discrepancies and lack of synchronization between the dual technologies severely affect the accuracy of cost control. Additionally, insufficient integration depth between the dual technologies impacts their ability to compare budgets with actual cost expenditures in real-time, leading to budget identification lag risks and potential project financial losses ^[9].

4. Innovative optimization paths for BIM and AI integration on construction sites

4.1. Constructing a dynamic progress control innovation path for dual-technology integration

BIM and AI integration control technologies face issues of lagging control in construction site progress management, unable to effectively predict progress risks and potentially exposing construction enterprises to risks of default and overspending. To address these issues, a dynamic progress control model can be constructed based on the dual-technology integration mechanism. Firstly, utilize BIM models and AI dynamic data processing technologies to construct a dynamic progress monitoring model, embedding BIM's

process logic model and AI's information collection model to simulate the construction process through their collaboration. During model operation, AI provides timely and accurate data to the BIM model, enabling dynamic corrections and ensuring the model stays synchronized with actual construction conditions. Secondly, leverage BIM and AI collaboration to form an integrated progress control and detection system. BIM technology accurately and in real time annotates construction progress nodes to ensure visual and appropriate progress control. Meanwhile, AI technology generates real-scene comparisons of visual progress through real-scene rendering, facilitating multi-dimensional progress monitoring by control personnel. Additionally, this joint technology not only ensures progress control efficiency but also supports construction management traceability. Finally, establish a progress control review mechanism through dual-technology integration. After completing each construction node, deeply analyze and accurately calculate the progress control models and data using BIM and AI technologies to identify loopholes in progress control and provide detailed and effective references for subsequent progress control work.

4.2. Establishing a refined quality control optimization path for dual-technology integration

Quality control on construction sites is crucial, and the integration of BIM and AI technologies can construct a comprehensive monitoring model to accurately identify and analyze quality issues during construction and propose rectification suggestions. Firstly, utilize BIM + AI technology to simulate project processes and workflows during the pre-construction phase to achieve quality risk control. BIM technology primarily constructs engineering model simulations for civil engineering, electromechanical, and other processes in building construction, while AI technology embeds quality control thresholds, industry standards, and other parameters for each project node in the model, forming a quality supervision linkage. Once quality issues arise in the project, the model automatically issues alarm prompts, enabling proactive quality control. Secondly, utilize BIM+AI integration technology to construct a quality prevention and control mechanism during the construction phase. AI technology is responsible for quality appearance identification, while BIM handles coding control. Their collaboration quickly locates the position and component model of quality issues, establishing an integrated quality control mechanism for identification, location, rectification, re-inspection, and cancellation ^[10].

4.3. Improving a proactive safety control enhancement path for dual-technology integration

Intelligent management of construction site safety control emphasizes the principle of “proactive prediction and active management.” Therefore, in the development of BIM + AI integration, a comprehensive management mechanism needs to be constructed based on construction site control requirements, utilizing AI technology to accurately identify and integrate risks during construction and compile them into a risk list for subsequent supervision. For instance, AI technology can be used to sort out and identify the risk list, analyze various risk inductions, and mark key prevention and control areas on the BIM model. During construction, management personnel should proactively implement risk prevention and control work according to the model markings. Additionally, construct a BIM + AI construction safety closed-loop control mechanism. This mechanism applies AI visual identification and data capture technologies as its core, timely extracting information on on-site violation operations (non-compliant operations), machinery operation status, etc., and constructing a construction condition safety control database. BIM technology can then verify the model

based on the data information formed by AI, further refining construction safety hazards and providing a more robust safety barrier for subsequent risk level classification and prevention and control.

4.4. Creating a full-lifecycle cost control upgrade path for dual-technology integration

Under the integration of BIM and AI technologies, cost control on construction sites needs to optimize control paths from three dimensions: budgeting, cost control, and accounting. Firstly, during the construction budgeting phase, utilize the BIM + AI model to improve the efficiency of engineering quantity accounting. The BIM model comprehensively displays the usage of construction materials, project duration, and construction techniques, avoiding omissions or duplicate accounting and ensuring accounting accuracy. AI technology can continuously revise budget amounts through collaboration with the BIM model and comprehensive extraction and calculation of data information such as market material prices and material usage, avoiding budget deviations. Secondly, during construction, utilize the dual-technology integration system to establish a cost deviation prevention and control mechanism. BIM technology is used to integrate and classify various cost data during construction, keeping pace with construction progress and synchronously updating changes in various construction cost data. AI, on the other hand, uses the data from the BIM model to accurately calculate and compare cost variations, reasonably allocating construction resources based on the causes of deviations to achieve dynamic and accurate cost control objectives. Finally, construct a BIM + AI joint review model during the completion phase. This model summarizes cost and pricing data throughout the construction cycle and links cost control with other management work. BIM technology is responsible for simulating and replicating the construction process, while AI technology identifies and attributes weak points in cost control throughout the entire process and automatically generates cost control rectification reports to avoid the recurrence of cost control risks.

5. Conclusion

In summary, under the intelligent management model of construction sites, the integration path of BIM and AI is key to enhancing the precision and scientificity of construction site management. The application of BIM models and AI algorithms can construct dynamic engineering models, providing managers with visual mechanisms for construction progress, quality, safety, and cost control. This enables managers to effectively prevent construction site control risks through the construction of targeted management mechanisms. In the future, intelligent management of construction sites can combine the advantages of BIM and AI technologies to form a deeply integrated control mechanism, promoting the high-quality transformation of construction site management work.

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Local Development Models of Urban Villages in Xihu District, Hangzhou, from the Perspective of Planetary Urbanization: An Empirical Interpretation Based on the Three-Dimensional Framework of Spatial Configuration, Everyday Life, and Territorial Regulation

Kening Chen

China Academy of Art, Hangzhou 310000, China

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Abstract: Since the beginning of the 21st century, the theory of planetary urbanization that Neil Brenner of Harvard University and Andy Merrifield have developed has provided a way to study global urbanization with different epistemologies. No longer does it need to be restricted by the old urban-rural divide, so now this theory believes that cities and villages are all connected areas experiencing social and spatial changes without any fixed borders. This idea is very applicable to our country now; there are fewer barriers between cities and the countryside, and capital is spreading outwards. Urban villages have been called the ‘cancer’ of urbanization for a long time. In terms of planetary urbanization, they may be regarded as a local path of urbanization initiated by the rural population. They have served to support the country’s rapid urbanization, maintain social order, promote opening-up and reform, and deepen China’s integration with the world. Based on the redevelopment of urban villages in Xihu District, Hangzhou, this paper will present Brenner’s system of three-dimensional analysis of space, daily life and territorial regulation. Organize the Spatial Differences of the three types of urban villages in Xihu District and study the internal logic of the three differentiated redevelopment paths: demolition and reconstruction in Fangjiafan and Hengqiao; comprehensive improvement combined with the introduction of a financial-services cluster in Baishaquan; and the ongoing 2025 redevelopment of Shuangpu. Based on the above results, although Western planetary urbanization aims to build a “city without an outside” by eliminating the division between cities and the countryside, the local restructuring of Chinese urban villages should be considered in light of Brenner’s system, and the three basic institutional factors in China—collective ownership of land, central-local decentralization, and the agency of rural residents—must be taken into account. Therefore, there will be a change from exclusionary redevelopment to the ‘Inclusive Urban Village Redevelopment 4.0’ proposed by Professor Ye Yumin. A people-oriented way of arranging physical Space should be taken to integrate the daily life of the people and carry out multi-scale innovations in territorial regulation based on relational and network thinking. Only then will the urban-village areas be transformed and regenerated into high-quality ones. Research has promoted the

application of planetary urbanization theory in China and provided practical support for the planning of cities and towns and other links.

Keywords: Planetary urbanization; Urban village redevelopment; Localized model; Xihu District, Hangzhou; Inclusive renewal; Urban design

Online publication: Aug 6, 2026

1. Introduction: The epistemological turn in urbanization and the tensions of Chinese practice

From the beginning of the 21st century, the changes and spreads of urbanization around the world have become increasingly complex. Planetary urbanization has gradually gained popularity and is now a hot topic of research in Western cities for reshaping our ideas about cities. In the 2015 paper “Towards a New Epistemology of the Urban”, written by Neil Brenner and Christian Schmid, “extended urbanization” was first put forward. They aimed to replace the old agglomeration-diffusion binary method with a continuous-variable method and cover all parts of the rural, suburban, and even protected natural areas in the wide-area study of urbanization. Therefore, there has been much discussion in China. On the one hand, China’s urbanization rate has increased from less than 20% to more than 65% in only forty years; the speed of this growth is outstanding. At the same time, this small-scale urbanization has led to relatively low-quality urbanization, and although the physical distance between urban areas and rural areas is gradually shrinking, serious problems have arisen in the system of social institutions and psychological consciousness.

The Theory of Planetary Urbanization has flaws you just can’t ignore when you try to use it in China. Yao Huasong and other scholars point out that Brenner’s model, if just copied and pasted onto China, misses some key pieces—like the two-tier urban-rural system, collective land ownership, and the complicated back-and-forth between the central and local governments ^[1]. Because of this, Chinese scholars argue that we need to push past planetary urbanization and develop an independent framework tailored for Chinese urban studies. That’s where this study starts. You can’t just use a Western framework without thinking. Still, Planetary Urbanization gives us a three-dimensional approach that helps break down how urban villages are redeveloped in Xihu District. It also shows how you can adapt the model by adding Chinese institutional realities—keeping it relevant and grounded.

Urban villages are a very typical kind of China’s space, and thus serve as a suitable empirical site for research on this issue. The mainstream discourse has long considered them to be the opposite of urbanization. On the other hand, they are also local routes to urbanization where rural residents are the main actors and collective land serves as the material foundation. They have provided hundreds of millions of new urban residents with an affordable way of life in the city and served as a necessary buffer that allowed China to carry out rapid industrialization and urbanization under good social order. Hangzhou is the central city of the southern wing of the Yangtze River Delta and one of the main areas of the digital economy. Urban villages in Xihu District are among the larger in Hangzhou’s main urban area, with about 31,000 households and more than 150,000 residents. The redevelopment of this area will change the view of the West Lake Scenic Area and will also be one of the modernization tasks for megacity governance to address the new dual structure problem. Therefore, this paper investigates: From the general view of planetary urbanization, how

has Xihu District developed a local path for urban-village renovation that aligns with the front-line theory of urbanization around the world but is also in line with the institutional conditions in China? What are the corresponding problems of urban renewal and urban planning in our country?

2. Theoretical foundations: Planetary urbanization and the production of space

To learn about the actual situation in Xihu District, we first need to clarify what we mean by the core theoretical tool in this paper, namely planetary urbanization, and what kind of spatial philosophy it is based on. This is necessary for the school, and it will also provide a solid basis for the following case analysis.

2.1. Brenner's "new trinity"

Brenner's theory is not an idea developed in isolation; it is built upon previous work. It is a modern development of Henri Lefebvre's *The Production of Space* ^[2]. In short, the main propositions are a new concept, a new mechanism, and new analysis directions.

2.1.1. A new concept: The urban as a dynamic process rather than an inherent type

The first kind of urban planning usually divides the city into areas that are separated administratively or built. Brenner has changed this idea. In his view, the city should not be regarded as a fixed type of space but rather as many kinds of processes involving changes in society and space. Therefore, the division of urban areas needs to be constantly adjusted with changes in the environment. Today's city structure is the result of previous rounds of capital accumulation and also contains the latent force for new space arrangement. Brenner proposes that the city is a Space without definite borders in a more radical way. In the process of planetary urbanization, the urban-rural dichotomy has lost much of its meaning; most of the surface of the Earth is now an urbanized region, and the differences between regions are primarily due to different degrees of urbanization rather than essential characteristics.

2.1.2. A new mechanism: The interaction of concentrated, extended and differential urbanization

Brenner proposes that the dialectical interaction of concentrated urbanization, extended urbanization and differential urbanization should replace the traditional linear narrative of urban development. Differential Urbanization is to be conducted. Lefebvre drew upon the metaphor of nuclear physics and used the paired processes of implosion and explosion to describe differential urbanization, which are considered the socio-spatial manifestations of capitalist creative destruction. It will create new spaces and promote the organization of society and politics. The three mechanisms have developed unevenly and are thus being renewed continuously as the drive for urbanization on the planet.

2.1.3. New dimensions: Spatial configuration, everyday life, and territorial regulation

Brenner built upon the three sections put forward by Lefebvre in his study of the problem listed above to develop an urban analysis system. The former is included in and mutually constitutes the latter.

Spatial configuration is the material or 'hard' attribute of urbanization. With the development of new parcels, the renewal of older areas, the construction of facilities and other works, as well as changes in the form of land use, are changing commercially and socially. In terms of urban design and architecture, this is equivalent to architectural Design, building-cluster planning, and environmental place-making.

In daily life, it has been pointed out that cities are not only the creations of architects and planners but are continuously rebuilt by the people who live here. Changes in the social structure of urban areas are also caused by people's daily life, such as different ways of commuting, consumption patterns, etc. Therefore, the Urban Environment and Governance are also changed. Urbanization without regard for daily life will result in spatial alienation.

Territorial regulation is the direction of governance at all levels, such as the direction of global capital flow and national strategy, regional coordination, and local community governance. Regulations determine the allocation of resources in space reorganization and establish institutional limits on the daily life of the people.

The three-dimensional framework will be employed as the primary analysis instrument for the Xihu District cases and will be applied in all sections of this paper.

2.2. Theoretical origins in Lefebvre's production of space

Brenner's idea has been influenced by Lefebvre for a long time. Lefebvre believed that Space is not an indifferent Stage for the progress of society but is instead produced by society ^[2]. He put forward the well-known spatial triad of spatial practice, representations of space, and representational spaces. Government planning drawings are representations of Space in urban-rural renewal, and self-built houses and scenes of life in streets and alleys are representational Spaces that, with their interactions and conflicts, form Spatial Practices. Therefore, it can be concluded that there is no genuine rejuvenation of the physical economy, only a change in the allocation of power and capital.

3. The Chinese context: The urban-rural dual structure and the institutional origins of urban villages

Before applying the theory of Western planetary urbanization to China, we need to understand the specific conditions of Chinese urbanization. This is because of the special conditions of the institutional history and, more specifically, the prolonged existence of the urban-rural dual system.

3.1. Historical trajectory: From "localized industrialization" to autonomous urbanization

Marx mentioned in the Introduction to A Contribution to the Critique of Political Economy that modern history is characterized by the urbanization of the countryside, not the ruralization of the city, as was the case in antiquity ^[3]. Lefebvre believed that the development of capitalism was also an industrialized form of urbanization. Modernization in China was not the same as that in other parts of the world.

Under the Mao era, China focused on building an industrialized society and reduced people's consumption by controlling it, neglecting urbanization. Mao put forward the idea of localized industrialization: rather than having the rural population flow to the cities for work, industry should be developed in the countryside so that peasants can work there ^[4]. Fei Xiaotong's ideas about a large population, limited land, and the organization of labor and resources were also in line with this. Although this path of industrialization did not have corresponding urbanization, it

After the 1990s, with the rise of post-Fordism around the world and domestic reform of state-owned enterprises and worker layoffs, a large number of people moved from rural areas to cities. Unlike in the classical period, China's dual system of household registration and collective land ownership did not grant

migrants full urban citizenship immediately, and they still held homestead and collective-land rights in their original villages. Institutions have given the people of rural areas some power over their own urbanization. Instead of being absorbed by the city passively, they took part in the construction of new cities. The edge-adjacent factories in the Pearl River Delta and the village-enterprise and rental-housing economies in the Yangtze River Delta are typical cases of such agency ^[5]. Many urban villages in the area of Xihu District established township and village enterprises after the introduction of the Household Responsibility System in 1978, and quickly changed to service industries at the beginning of the 21st century. The Space of these people's homes shows the effects of self-built rental houses in autonomous rural investment.

3.2. Urban villages as a Chinese form of differential urbanization

Ebenezer Howard's three-magnets diagram in "Garden Cities of To-Morrow" proposed that the problem of urban-rural division could be solved by means of original urban planning ^[6]. The specificity of Chinese urban villages is that they are not idealized urban-rural hybrids but semi-urbanized areas under an institutional in-between state. Local villagers have been statistically reclassified as urban residents but still retain rural social customs and identity. Migrant tenants live in the city but are still excluded from some parts of the urban public service system institutionally. Both groups live in collective land and have formed their own social ecology together.

Ye Yumin and others have referred to it as a "new dual structure" ^[7]. There is a division between the developed areas of the central city and the marginalized areas in the suburbs, and also a separation among local urban residents with full urban rights and migrants who do not enjoy these rights. Urban villages are the space for the disadvantaged pole, and they often have the characteristics of 'three lows and two highs': low land-use efficiency, low industrial and technological level, and low resident income; at the same time, there are high crime rates and a large number of unauthorized constructions. Non-hukou residents make up 36.8% of the permanent urban population and 41.2% of the working-age urban population in China ^[8]. Therefore, urban-village redevelopment is not merely a spatial plan or an effort to beautify the city; it is a fundamental social undertaking that aims to develop the human capital and social integration of over two-fifths of the urban labor force.

According to Brenner's theory, differential urbanization in the West is often the result of capital's creative destruction of space and the subsequent social resistance. Due to the institutional environment in China, differential urbanization has formed a new dual structure and local informal housing supply. This structure has created the form of affordable housing for the people, but has also raised the risk of social division. It is therefore the logical beginning of the localization of planetary urbanization theory in China.

4. Empirical study: A typology and redevelopment history of urban villages in Xihu District, Hangzhou

Xihu District is one of the key urban areas in Hangzhou and therefore a typical place for studying urban-village redevelopment. Based on the above theory, this section will introduce some local urban villages and discuss the redevelopment work there.

4.1. Conceptual definition and geographical setting

The urban villages in Xihu District are the residential areas of the planned construction area of Hangzhou

that are still under the rural collective economic shareholding system and have retained village-committee institutions, or those that have been converted into communities without full separation of collective assets. Although these areas have been incorporated into the urban area through construction, they are still rural in terms of land ownership, management system, and social structure.

4.2. Typology based on spatial form and industrial characteristics

Based on field investigation and planning documents, the urban villages in Xihu District can be divided into three typical categories according to their distance from the urban center, the extent of land development, and the main livelihood mode. Therefore, there will be different developments and a more contextual design of the city.

(1) Type I

Fully built villages without the first-tier sector. These villages are in the area of the educational district and Huanglong Commercial Area, such as Huayuan, Gudang, Luojiashuang, and Jiulian. Most of the buildings are four to six floors high and have been built in a way that is close to the urban areas around them. However, due to the lack of coordinated planning and management, there have been uneven-aged constructions, with some “handshake buildings” being built close together and others “slivers of sky” being very narrow. There are no municipal utility connections yet, and the fire-access lane is narrow. Original villagers make up a small proportion of the population, and a large number of migrant workers live in rented houses here. The Space is close to urban standards, but daily life is still very busy and chaotic.

(2) Type II

Mixed villages with a small number of farms. These villages are usually in the areas that will be developed for urbanization in the near future, such as Wulitang, Zhuantang, and Xialongwei. They have the features of an urban-rural fringe; there is a mixed arrangement of single-family homes and low-rise buildings, and no single urban design system has been adopted. Residents have various farmer-worker identities. Some villagers are still involved in agricultural business, but most of the household income comes from non-agricultural work or rent. As the frontiers of urban development, these villages are at the forefront of renewal.

(3) Type III

Peripheral retained villages with considerable agricultural land. Most of the villages are located in the outer areas, such as Shuangpu Town and parts of Liuxia Subdistrict. They still have a relatively large share of agricultural land, have undergone relatively little urbanization, and retain more traditional rural forms. Although they are not the main focus of the redevelopment work at present, they are gradually being affected by the advancing wave of extended urbanization.

4.3. Overall scale and policy evolution

In the past, Xihu District had 91 urban villages, which made up one-third of the total in the main urban area of Hangzhou and housed nearly 31,000 households as well as over 150,000 people. Therefore, it will be a relatively large and complicated system project for the reconstruction. The development of the above is divided into three periods.

The first village-to-community conversion in the early 2000s was an administrative change; the village committee became a residents’ committee, and the villagers were redesignated as urban residents. The usual way of doing so failed to consider the property value of the collective land or the will of the villagers. As

a result, many nominal urban communities were formed in which the formal labels had changed, but the underlying institutional relations had not.

The five-year campaign from 2016 to 2020 was in line with the five-year plan for urban village construction in the main urban area of Hangzhou, and Xihu District started to carry out large-scale demolition work at that time. In 2017, agreements were signed for 42 villages and 12,101 households in one year, and this speed has been referred to as the “Xihu speed”. Although there has been a rapid change in space, social factors have been relatively ignored in this period.

In 2023, in line with the guiding opinions of the State Council, the high-quality development stage of urban village redevelopment in megacities and super-large cities began. Redevelopment has changed its form and is no longer a model of demolition and reconstruction; now, it generally incorporates conservation and improvement, demolition, inclusion, industrialization, long-term management, etc.

4.4. In-depth analysis of typical cases

4.4.1. Fangjiafan and Hengqiao: Demolition and reconstruction in the Zhuantang area

Fangjiafan and Hengqiao are both located in Zhuantang Subdistrict, next to the Xiangshan Campus of the China Academy of Art and the Zhijiang Campus of Zhejiang University. They have good locations and are therefore very close to the area where many culture and education centers are located.

Spatial Arrangement. Relocation in Fangjiafan began in 2009, and by this time, about 270 rural households and seven enterprises had been covered; Hengqiao followed in 2010, adding another 225 households and 12 enterprises. Redevelopment altered the Spatial Form. Low-rise rural housing was demolished and new high-rise apartment buildings, such as Dingbei Jiayuan and Hengqiao Shenheyuan, were built in their place. It is a typical case of concentrated urbanization, and consequently, the land price has risen.

Infrastructure and Services First. The first projects were mainly about selling land; these new ones have added public facilities. With the completion of the Zhijiang Campus of Xuejun Primary School, Shangsi Middle School, and two Zhuantang Kindergarten campuses, educational services have been offered at a level similar to those in the central city. At the same time, the construction was arranged according to the plan for social services.

Regulatory Adjustment. Zhuantang Subdistrict has established a fixed-price relocation system in the territorial regulations. Compensation is based on the policy, and there is no case-by-case negotiation^[9]. At the same time, the size of the household, number of registered residents, and compensation were also released publicly for transparency. On March 31, 2017, 1,432 households in the eight communities signed the relocation agreement in a single day, and 90% of the Party member households had already signed^[10]. By increasing transparency and setting a good example, Party members have reduced transaction costs and shown the modernization of grassroots governance.

4.4.2. Baishaquan: Comprehensive improvement and functional replacement

Baishaquan is in the west of Baoshi Hill, next to the Huanglong commercial area, and it is one of the new areas in the Xihu District’s renovation plan.

Problem Diagnosis. Before the redevelopment, 170 of the 185 buildings in the area were rented houses. There were many small restaurants, small hotels, and late-night food stalls in the neighborhood, and around 5,000 people lived here during the day and worked at night. Due to serious fire safety problems, the local

branch secretary of the Party reported that there were “powder kegs”.

A Non-Demolition Path. Fangjiafan was not all-weather demolition and reconstruction; Baishaquan was not either. Therefore, it chose to improve the whole thing and add functions. The measures taken were to demolish the 35,000 square meters of illegal buildings, carry out façade renovation and improvement of public facilities, and most importantly, change the low-end residential functions into a merger-and-acquisition financial district.

Balancing interests. Mobilization was the biggest problem. Property owners are afraid that the removal of illegal additions will reduce the floor area and rent. Therefore, the government offered a very good guarantee of an annual rental income of 400,000 yuan for the owners. It was much higher than the about 200,000 yuan the owners had made by subdividing and renting out their property. We must reduce the resistance.

Redevelopment Results. After opening in 2017, the Baishaquan M&A Financial District has been building a team of 176 enterprises to manage more than 100 billion yuan of funds. The 185 buildings have been redeveloped in the same cyan-grey, white, and black color system to maintain the original street and alley structure and create an architectural atmosphere. An Area has been set up as a small urban ‘bonsai’ near the Huanglong Commercial District. It is a case of differential urbanization without total demolition; after all the adjustments in space and function, land prices have risen sharply.

4.4.3. Shuangpu Banqiao-Hangjiang: The ongoing 2025 “Demolition plus industry” reset

In September 2025, the new round of redevelopment started in Banqiao and Hangjiang of Shuangpu Town, covering about 700 households. In accordance with the latest practice of the new State Council policy, it points to the future direction of urban-village transformation.

Plan first. The two previous rounds had already established the land-use purposes before the start of relocation. The land will be used to construct the Zhijiang Science and Technology Innovation City High-Tech Industrial Park and two senior high schools. Industrial Introduction was therefore placed before Spatial Reconstruction.

Transfer of cleared and serviced land. The model avoids the vacancy and inefficient use that often resulted from demolition before planning. By ensuring that land is cleared and serviced before transfer, industrial projects can be implemented rapidly.

A New Form of Inclusive Urban Village Redevelopment 4.0. In line with Ye Yumin’s idea of inclusive urban village redevelopment 4.0, this approach is to plan scientifically and develop through industry leadership, involving all sectors of society. In addition to changing the buildings, an organized system for industries will also be established here; it is hoped that excellent young people will be drawn to settle and work in high-tech fields.

5. Theoretical reconstruction: Extracting a localized model in the context of planetary urbanization

The three case studies show us how the theory of Western planetary urbanization has been altered and integrated in China. Brenner’s 3D structure will be employed to create a local model of the urban-rural development area of Xihu District.

5.1. Spatial arrangement: Brenner's theory proposes that capital circulation is carried out at the level of space. In China, it should also be in line with the national strategy and social order

The Need for Differentiation. The experience of Xihu District shows that no single redevelopment model is suitable for all. Highly integrated Type I villages can use a combination of demolition and renovation to fix problems with the old facilities and buildings. Transitional Type II villages are suitable for demolition and the start of industrialization, such as Shuangpu. Peripheral Type III villages should focus on all-round development, maintain rural culture, and develop urban agriculture or ecological tourism. The two kinds of plans show that the urban-rural construction work is being done in an organized way.

The Logic of Industry-First Planning. The typical pattern of property development is to obtain land, construct buildings, and sell houses; other industries are added later. Shuangpu model is based on industrial planning and urban renewal for the new economy. It will increase the economy of the country, lower the problem of dormitory towns, and create jobs.

Transmission of Architectural Culture. Baishaquan is also a good model for urban Design. It was not an indiscriminate demolition and rebuilding, but rather a planned design to reorganize all the areas and use an all-Chinese color system of cyan-grey, white, and black. It retained the small scale of streets and alleys but improved the quality of buildings to integrate new urban functions with the charm of old buildings.

5.2. Everyday life: From exclusionary redevelopment to inclusive renewal

This direction has the most novel content in the local model. The Western Plan for Urbanization will probably lead to some people losing their homes because of rising rents. Redevelopment of the urban-rural areas in China is beginning to explore a new road.

Private Rental Housing as a New Kind of Affordable Housing. The first redevelopment was not inclusive. The demolition of each area has led to many cases of displacement for low-income families; they have been forced to live further away and have thus increased their travel expenses, and these displaced families have formed new urban villages outside the city center. Ye Yumin's idea of minzu fang, or privately supplied rental housing, is another one. It is the surplus resettlement housing of the villagers that has been added to the affordable rental housing system by way of small-unit, long-term lease. Public rental housing and talent-oriented rental housing together form the three parts of the affordable housing system.

Policy Recommendations. In the future, there may be a quota for private rental houses in the redevelopment agreement of Xihu District. For instance, the first 20 percent of the floor area in each resettlement building will be reserved for the long-term rental of eligible migrant workers. Support services should also meet the living and other needs of new urban residents, such as families with children. Such measures would maintain the essential fine-grained labor and service network of the city, promote social integration among old and new residents, and give practical significance to the idea that cities are built by and for the people ^[11].

Continuity of Daily Life. Baishaquan was successful in part because it altered the local functions without destroying the old social order. Although the number of tenants has changed, the interests of the original residents have been protected, and new financial-sector professionals have found a good place to live. Soft Renovation is for renovation and maintenance.

5.3. Territorial regulation

No longer dominated by administrative authority, there is now negotiation and scaling of territorial regulations among many parties to manage space and daily life.

Innovation in Micro-Level Regulation. Xihu District has gained some grassroots governance experience in the redevelopment. The 16 work teams were divided, and each was in charge of a different house at Baishaquan; Zhuantang had a fixed-price plus full-disclosure system. Therefore, there was less information asymmetry and rent-seeking, and the decision could be made sooner.

Build Multistakeholder Co-governance. At present, the system is still a vertical chain connecting the district government, sub-district offices, and villages. The future direction should be a horizontal governance network of government guidance and multilateral negotiation. Organize tenant meetings to hear the people living here talk before rebuilding. During the redevelopment, a consultation platform should be set up that involves the village collective, villager representatives, new urban residents, market actors, etc., to discuss the selection of functions and compensation. After the redevelopment, the neighborhood co-governance committee will jointly manage the results.

Adjustment of Central-Local Relations. Redevelopment of urban-rural areas is a typical case of central-local cooperation. The central government issues the policy direction, and the local government will formulate the actual measures in accordance with it. As one of the main areas in Hangzhou City, Xihu District is an excellent location for policy experiments. Local experience and experimentation can be used to develop a toolkit of rules that will guide the design of national policies.

5.4 Summary of the Localized Model: Revising Brenner's Framework

Many changes have been made to Brenner's theory of planetary urbanization in the practice of Xihu District, as shown in **Table 1**.

Table 1. Comparison of Western planetary urbanization theory and the localized practice of Xihu District

Dimension	Western planetary urbanization (original framework)	Localized practice in Xihu District (revised framework)
Spatial configuration	Capital-driven unbounded expansion and emphasis on density and agglomeration.	Differentiation of Strategy and Industry-first Planning; Coordination of Efficiency and Equity; Attention to Architectural Culture and Ecological Conservation.
Everyday life	Gentrification and the Spatial Dispersal of the Disadvantaged.	Inclusive Renovation and privately-owned rental houses; Protection of the housing rights of new urban residents; Promotion of social integration and preservation of social networks.
Territorial regulation	The dual Logic of global capital and the state apparatus.	Consultative governance for all sides under the leadership of the Party; Grassroots governance innovation; A community of shared interests among the government, the market, villagers and tenants.
Core logic	A city with no outside; an end to the urban-rural division.	Gradually introduce the urban-rural dual-track structure in line with the actual circumstances and recognize the collective land ownership and the will of the rural population.

6. Discussion and conclusion

According to the theory of planetary urbanization developed by Brenner and Schmid, this paper will examine more than 20 years of urban-village redevelopment in Xihu District, Hangzhou. Based on the above analysis, the following three problems were found.

First, it turns the usual story around. Urban villages have been moved from the negative framing of an antithesis or ‘cancer’ of urbanization and are now considered local manifestations of Chinese differential urbanization. They represent the active participation of Chinese rural areas in urbanization under certain institutional conditions and have played an indispensable role in history.

Second, it is also a theory construction. The three-dimensional framework of spatial configuration, daily life, and territorial regulation was used to classify the three representative redevelopment paths in Xihu District systematically: demolition and reconstruction in Fangjiafan and Hengqiao; comprehensive improvement in Baishaquan; and the ongoing 2025 redevelopment in Shuangpu. The above framework is an analysis system for various practices and has provided some explanations in China.

Thirdly, it has a plan. In accordance with Ye Yumin’s idea of Inclusive Urban Village Redevelopment 4.0, three localized strategies have been put forward in this paper for the actual situation of Xihu District: differentiated redevelopment, inclusion of privately-owned rental housing, and multi-scale regulatory innovation. The above strategies can offer some practical references for urban-rural planning, architectural design, and urban governance to address the serious problems of conservation and renovation, efficiency and fairness, as well as the lack of coordination among departments of the government and the market.

However, the research is not perfect. First, it is only one area. Although the analysis is in detail, it is not extensive. In the future, it will be possible to compare Xihu District with Xian Village in Guangzhou, Dachong Village in Shenzhen, and the urban villages around Zhongguancun in Beijing to test the explanatory scope of a Chinese localization of planetary urbanization. Secondly, with the development of digital technology, rental platforms, ride-hailing, and on-demand delivery services have changed the rhythm of life for ordinary people and adjusted the way space is valued. Research on the digital dimension has not been carried out to this day.

By 2025, from the perspective of history, urban-village redevelopment has gone far beyond the purpose of making cities look good. It is an important work that promotes the development of Chinese modernization. It is to see whether the new dual structure can be established and how to build high-quality human resources for the next stage of development. The experience of Xihu District shows that China should not merely follow the trend of planetary urbanization in the world. It should still have theoretical self-awareness. Only by integrating the theoretical system of the West with China’s original institutional environment can a truly people-oriented path for urban renewal be established. This road is not only for Hangzhou but for all the rapidly urbanizing cities in China.

Disclosure statement

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Spatial Distribution Patterns of Traditional Villages and Their Influencing Factors in the Southeastern Shanxi Region

Wenjie Yu¹, Jichen Shen², Rong Peng¹

¹School of Urban Construction, Yangtze University, Jingzhou 434023, Hubei, China

²School of Urban Construction, Jingzhou University, Jingzhou 434020, Hubei, China

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Abstract: The study of the overall spatial distribution of traditional villages is of great significance for a comprehensive understanding of traditional villages from the perspectives of nature, economy, society, and culture. Taking the top six batches of national level traditional villages in Southeastern Shanxi as the research object, this study quantitatively investigates the factors affecting the spatial distribution of traditional villages using methods such as nearest neighbor index, Moran index, and quantitative geography. The study explores the factors such as terrain, watershed, and transportation that affect the spatial distribution of traditional villages. The results show that: 1) the overall distribution of traditional villages in Southeastern Shanxi presents a clustered geographical spatial feature, with a distribution pattern of “dual cores and one belt”. 2) The spatial distribution of traditional villages is the result of the combined effects of terrain, water systems, economic development level, transportation network, and other factors. The natural environment is the basic factor affecting distribution, while cultural economy is the internal driving force for village development. Based on the above results analysis, it is necessary to actively explore a cluster based protection framework for the current situation of traditional village protection in Southeastern Shanxi. According to the different degrees of impact of each element on traditional villages, the connection and role between each element should be strengthened as a reference for formulating differentiated policies.

Keywords: Southeastern Shanxi; Traditional villages; Spatial distribution pattern; Influencing factors

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1. Introduction

Traditional villages have rich material and intangible cultural heritage, and are relatively complete spatial forms created by humans to adapt to different natural environmental conditions. Their formation, distribution, evolution, and development showcase unique humanistic ecology, social development trajectory, and historical and cultural memory ^[1]. However, as China enters a stage of rapid urbanization, industrial civilization gradually infiltrates and devours agricultural civilization. The large number of traditional

villages in Southeastern Shanxi is difficult to effectively protect and is gradually declining, and there are weak connections between villages. Therefore, in-depth investigation and analysis should be conducted on traditional villages, and a comprehensive analysis and research of villages should be carried out. This is not only conducive to exploring methods for protecting traditional villages, but also has important theoretical and practical significance. In recent years, with the increasing attention paid by the country to historical and cultural heritage and the introduction of various policies, the Ministry of Housing and Urban Rural Development and the Ministry of Finance issued the “Notice on Doing a Good Job in the Demonstration Work of Centralized Protection and Utilization of Traditional Villages in 2022”, which further reflects the need to study the protection and development of traditional villages from a holistic perspective. Traditional villages are no longer separate individuals, but are organically connected with other traditional villages as a whole ^[2].

This article takes the Southeastern region of Shanxi Province, which has a strong correlation between culture and nature, as the research scope. The first six batches of national-level traditional villages are selected as the research objects, focusing on the spatial distribution characteristics and correlation analysis of traditional villages. Based on the identification of the overall spatial situation and pattern of traditional villages in Southeastern Shanxi Province, quantitative methods are applied to analyze the correlation between factors and traditional villages. The strength, types, and mechanisms of the correlation between factors and traditional villages are explored, providing a basis for the development of a comprehensive protection framework for traditional villages.

2. Research area, data and methods

2.1. Research area

The Southeastern region of Shanxi, also known as the Shangdang area, including Changzhi City and Jincheng City, is the intersection of the Han land in the Central Plains, northern ethnic groups, eastern coastal areas, and northwestern inland areas. It has diverse historical and cultural sources and obvious regional social characteristics. It is a relatively independent cultural and geographical unit within Shanxi Province. To the east is the Taihang Mountains, to the west is the Taiyue Mountains, and to the center are the Changzhi and Jincheng basins. The main terrain and landforms include basins, hills, mountains, and river valleys. The Qin River, Dan River, and Zhuozhang River that flow through them create fertile land and abundant water resources at the bottom of mountain streams; Four distinct seasons, mild climate, belonging to temperate continental climate; The suitable land and climate conditions make the two basins the core areas for urban agglomeration and agricultural development.

2.2. Research methods

The study of spatial characteristics in urban and rural planning and geography tends to construct geographic models to reveal them. Such as the nearest neighbor index, Moran index, Gini coefficient, etc ^[3]. Using ArcGIS spatial analysis tools and Excel, a quantitative study was conducted on the spatial distribution of traditional villages in Southeastern Shanxi, and kernel density calculations were carried out. This study explores the spatial distribution characteristics of traditional villages in Southeastern Shanxi and attempts to explore the mechanism of the evolution process of distribution space. The specific model interpretation is shown in **Table 1**.

Table 1. Spatial model and its geographic significance

Index	Model	Model definition	Geographical significance
Nuclear density analysis method	$f(x) = \frac{n}{nh} \sum_{i=1}^n K\left(\frac{x-x_i}{h}\right)$	x_i represents the point position coordinates of traditional village i ($i=1, 2, \dots, n$), n represents the number of traditional villages, h is the search radius calculated by kernel density, and k represents the kernel function;	Characterize the degree of balance in the density of each point element within a certain range around it.
Nearest neighbor index	$R = \frac{\bar{r}_i}{r_E} = \bar{r} \div \frac{1}{2\sqrt{\frac{m}{A}}}$	R represents the nearest neighbor index; r_i represents the average actual distance between each point and its nearest neighbor; r_1 is the actual distance between each point and the nearest point; r_E is the theoretical nearest distance; m is the number of points; A is the area of the region;	Study the degree of proximity between traditional villages as point targets in space. When $R=1$, it indicates that traditional villages are randomly distributed among each other; When $R>1$, traditional villages tend to be evenly distributed; When $R<1$, traditional villages exhibit clustering characteristics.
Moran index method	$I = Z_i \sum_{j=1}^n W_{ij} Z_j$	I is Moran's index; Z_i and Z_j represent the standardized values of the observed values of the i and j spatial units, respectively; W_{ij} is the spatial weight. Divided into four categories based on clustering relationships: high high clustering (HH); High Low Agglomeration (HL); Low high agglomeration (LH); Low Low Agglomeration (LL);	Characterize the spatial correlation between a point like feature and adjacent points.

3. Spatial distribution characteristics of traditional villages in Southeastern Shanxi province

3.1. Spatial distribution types

Using the nearest neighbor index to estimate the degree of proximity of traditional villages in the Southeastern Shanxi region, analyze the distribution types of traditional villages within the geographical scope, and deconstruct the spatial characteristics and distribution patterns of traditional villages from a macro perspective. Calculate the nearest neighbor index based on the average distance between the expected nearest elements for each element, using the “Average Nearest Neighbor” function in ArcGIS 10.4. The results are as follows: $r_1 = 0.396$, $r_E = 0.472$; $R = r_1/r_E = 0.83$, the ratio of the actual nearest neighbor distance to the mean is $R = 0.83 < 1$. Therefore, according to the geographical interpretation of the “nearest neighbor index” model in **Table 1**, traditional villages in Southeastern Shanxi Province generally exhibit a clustered distribution at the regional macro level. In order to further verify the accuracy of its results, based on the geographical interpretation of the “coefficient of variation” model in **Table 1**, the coefficient of variation of the Voronoi diagram in Southeastern Shanxi was calculated. The results are as follows: the average area and standard deviation of Voronoi polygons in southwestern Shanxi are 88.93 km^2 and 212.33 km^2 , respectively, and the coefficient of variation value is $238.75\% > 64\%$, indicating that traditional villages in Southeastern Shanxi are spatially clustered, which once again confirms the conclusion drawn from the nearest neighbor index. See **Figure 1**.

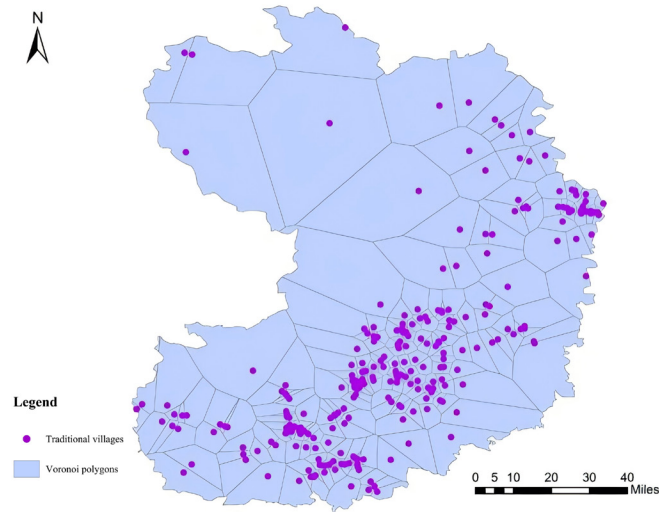
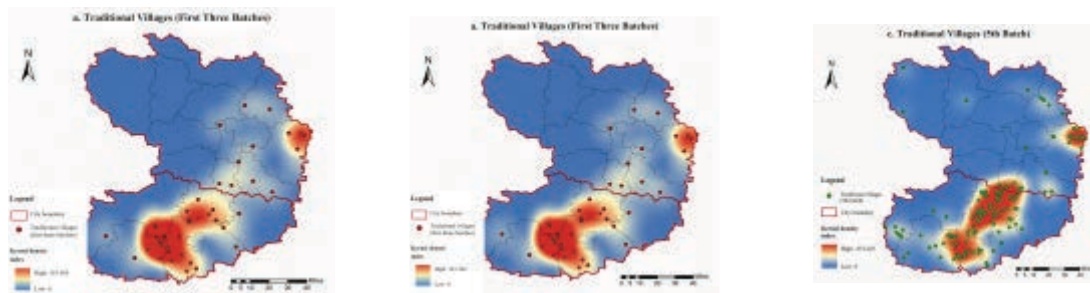


Figure 1. Voronoi polygon of traditional villages in southeastern Shanxi Province.

3.2. Spatial distribution balance

In order to analyze the spatial distribution density and balance of traditional villages in Southeastern Shanxi, ArcGIS 10.4 “Kernel Density” tool was used for kernel density analysis. From the overall spatial distribution of core density, traditional villages in Southeastern Shanxi have a higher distribution density in the Taiyue Mountain Zezhou Basin and Taihang Mountain Zhuozhang River areas, forming two obvious high concentration areas and a transitional diffusion zone, presenting an overall spatial structure of “two cores and one belt”. From different batches, the first three batches of traditional villages in Southeastern Shanxi initially clustered in the Zezhou Basin and Zhuozhang River Basin, with a small number of scattered villages in the central region; The fourth and fifth batches of traditional villages are further clustered based on the clustering areas formed in the previous three batches, consolidating and strengthening the core position of the two clustering areas; The sixth batch of traditional village core density shows a clear trend of diffusion from the core to the surrounding areas, forming a transitional diffusion zone connecting the two core clusters. See **Figure 2**.



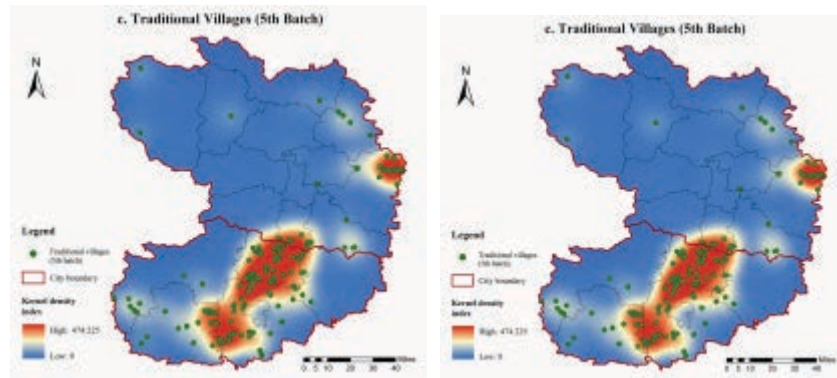


Figure 2. Distribution of nuclear density in southeastern Shanxi Province.

4. Factors influencing the spatial distribution of traditional villages

4.1. Natural environmental factors

4.1.1. Topography and geomorphology

As a fundamental element of the natural geographical environment, topography and landforms have influenced the distribution pattern and spatial structure of traditional villages. Overlay the distribution map of traditional villages in Southeastern Shanxi with the topographic map, extract the elevation information of traditional village landing points using ArcGIS 10.4 tool, and conduct spatial autocorrelation analysis of elevation using Anselin Local Moran's I tool [4]. The results of natural discontinuity grading indicate that there are three elevation ranges, with 139 traditional villages within the range of 744–1008 m, accounting for 52.85%, and 71 traditional villages within the range of 484–783 m, accounting for 26.99%. The spatial autocorrelation analysis of elevation has generated three types of clustered villages: high high, high low, and low low. Among them, there are a total of 73 clustered villages in the low low type, accounting for 27.75%, all distributed in areas below 743m, and forming village clusters in low-altitude alluvial plains, mountains, and mid-altitude mountainous areas, which are conducive to production and life and have a high degree of consistency with the overall distribution pattern of traditional villages. There are a total of 56 villages in the high high cluster, accounting for 21.29%, with the characteristics of “high altitude, low density”. They form a relatively homogeneous village cluster in the central area, which is less compact compared to the low low cluster villages. The reason for this is that the high high cluster villages are located in complex geographical locations with steep slopes, which to some extent separates the traditional spatial distribution pattern of villages and forms relatively dispersed village clusters.

The above analysis indicates a strong correlation between terrain and traditional village distribution. In areas with low terrain and flat terrain, villages are mainly engaged in agricultural production, which is influenced by water sources, soil, climate and other conditions. Terrain and landforms are the basis for creating these conditions. Therefore, the selection of village sites attaches great importance to the examination of terrain and landforms, such as Runcheng Village and Laoshen Village, which have gradually developed into relatively dense and compact village clusters; In the Shangdang Basin, which is rich in terrain and landforms, the basin area has good agricultural production and geographical location conditions. The densely populated villages formed by the Shangdang Basin have a clustered and homogeneous distribution characteristic. See **Figure 3**.

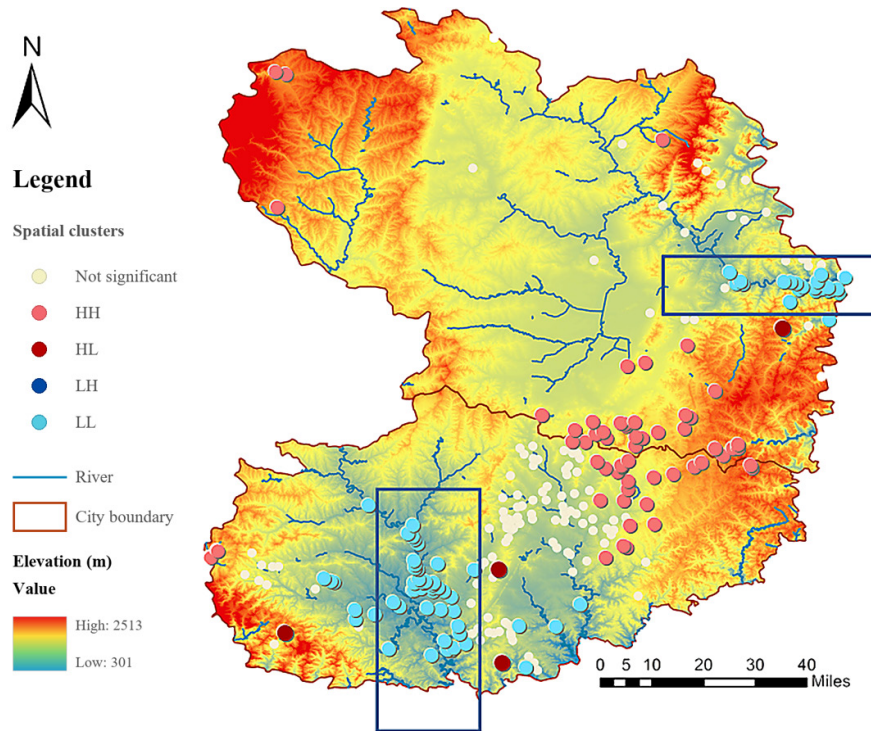


Figure 3. Autocorrelated LISA analysis of terrain and landforms.

4.1.2. Hydrology

From ancient times to the present, the vast majority of village settlements have been built on water, which not only affects the water resources and defense security of rural settlements, but also to some extent affects the site selection and development evolution of villages ^[5]. After multiple comparisons of data selection effects, a multi-ring buffering analysis was conducted on rivers in the Southeastern Shanxi region using circular distances of 2 km and 5 km. Within a 5 km radius of the water system, there are 190 traditional villages, accounting for 72.24%; There are 116 traditional villages within a 2 km radius of the water system, accounting for 44.10%; Village settlements have obvious characteristics of hydrophilicity and water tendency. (Figure 4 and 5)

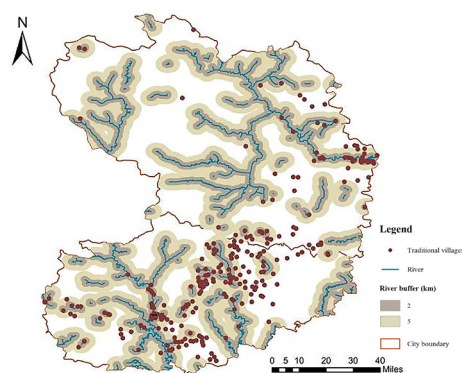


Figure 4. Analysis of multi-ring buffer in rivers

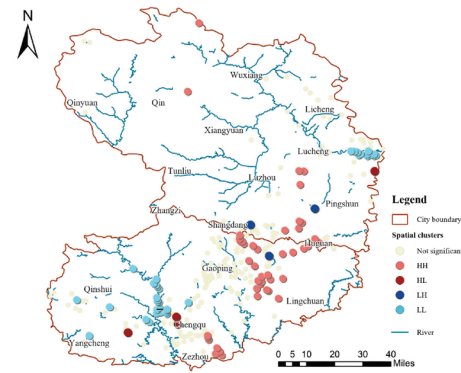


Figure 5. Autocorrelated LISA analysis of water system.

Secondly, spatial self-analysis was conducted on the water system, resulting in four types of village clustering, with a total of 37 villages classified as low low clusters, accounting for 14.07%; There are a total of 43 high type clustered villages, accounting for 16.35%; The low low cluster villages are concentrated in the Qin River and Zhuozhang River basins, while the high high cluster villages are more dispersed compared to the low low cluster villages. Although the dense part of the villages coincides with the central dense area of the distribution pattern, due to weaker correlation and interaction with the water system, the former village settlements are not as compact and tightly arranged as the low low cluster villages, further indicating that the water system is a key factor affecting the spatial distribution of traditional villages. From the perspective of spatial layout, the village clusters in both the Qinhe River Basin and the Zhuozhang River Basin have the characteristic of strip-shaped distribution along the main stream. Unlike the village clusters in the Zhuozhang River Basin, the Qinhe River Basin has a large number of river branches and a wide distribution, forming a spatial distribution pattern of small-scale aggregation around tributaries, in addition to the main stream.

4.2. Socio-economic factors

4.2.1. Transportation location

Road traffic is the material carrier for the mutual flow and interaction of various factors between urban and rural areas, playing a crucial role in the rise and fall of villages and the socio-economic development ^[6]. Establish a density attribute data table for various transportation arteries in the Southeastern Shanxi region in GIS, classify the road network density into natural discontinuity levels, and assign them to traditional villages in the region for spatial autocorrelation analysis. The results of spatial autocorrelation analysis show that there are a total of 73 high high type clustered villages, accounting for 27.75%, concentrated in the central part of the region, with a high degree of consistency with the village clusters formed in Gaoping City and Shangdang District. The impact of transportation on traditional village agglomeration is positively correlated. There are a total of 75 low type clustered villages, accounting for 28.51%, distributed in Qinsui, Yangcheng, and Pingshun counties with low road network density. Transportation has a negative correlation with the clustering of traditional villages. (Figure 6)

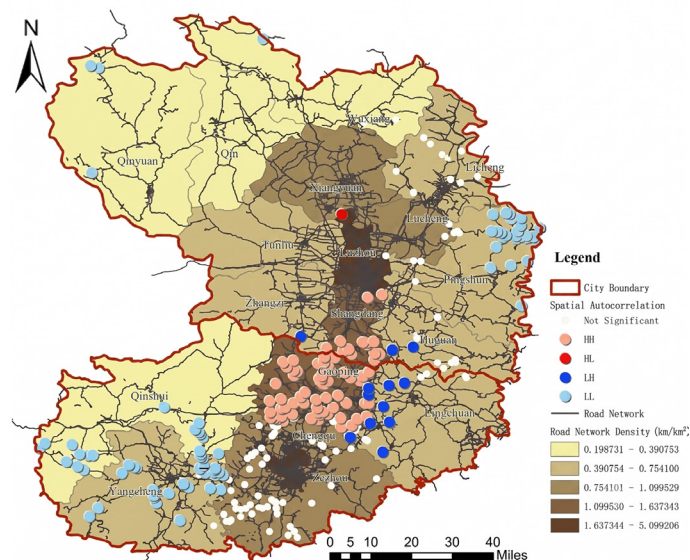


Figure 6. Autocorrelated LISA analysis of road network density.

The results indicate that there are mainly two types of village clusters, among which the formation of the central village cluster is due to the fact that there were post roads from Taiyuan to Zezhou that passed through Gaoping City and Shangdang District in the early Ming Dynasty, and became an important transportation route in Shanxi Province during the Qing Dynasty, laying a good foundation for the current dense transportation network in the central region. On the one hand, villages rely on their advantages of goods distribution and transportation hubs to grow and develop, with a higher degree of interaction and connection with the outside world, and relatively less difficulty in protection, thus creating the traditional village distribution characteristics of “high-density, high clustering” in the central region. On the other hand, the village clusters in the southwestern and eastern parts of the region are due to the low road network density and relatively poor accessibility and accessibility in the counties where they are located, resulting in an undisturbed and independent environment, thus forming the traditional village distribution characteristics of “low-density, low clustering”.

4.2.2. Per capita GDP

Integrate the gross domestic product and total population of each district and county in Southeastern Shanxi Province from the 2021 Statistical Yearbook, obtain the basic data of per capita GDP, use the natural breakpoint grading method for visualization, and overlay analysis with the overall layout of traditional villages. From the graph results, the top three counties in terms of economic development level are Qinchui County, Qinyuan County, and Xiangyuan County, with per capita GDP of 170000 yuan/person, 132000 yuan/person, and 123300 yuan/person, respectively. Among them, Qinchui County has 19 traditional villages, which are few in number and have not formed a dense high cluster of villages compared to Zezhou County. The economic development level of Pingshun County, Qin County, and Lingchuan County is relatively low, all below 30000 people per person. Among them, Pingshun County and Lingchuan County have 30 and 16 traditional villages respectively. The low low cluster villages are mainly concentrated in the Southeastern of Pingshun County. Although there are also some counties with low per capita GDP that have low low low cluster villages, their layout is relatively scattered, the density is small, and the compactness is low. (**Figure 7**)

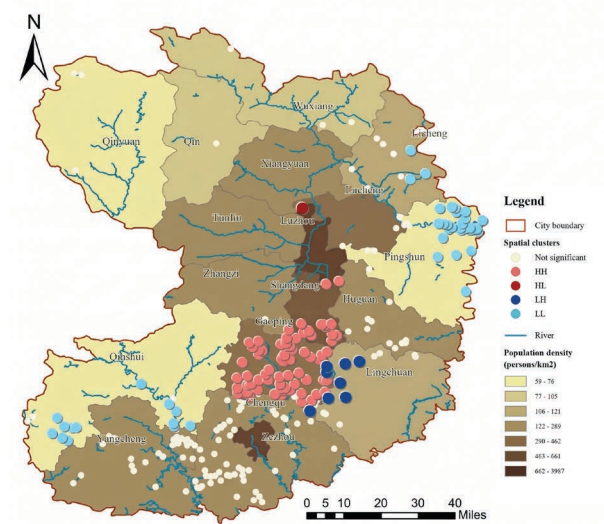


Figure 7. Autocorrelated LISA analysis of population density.

Overall, per capita GDP can indirectly reflect the level of economic development in a region and has a complex correlation with the distribution pattern of traditional villages. For example, although Zezhou County has a moderate ranking in per capita GDP, the correlation between traditional village agglomeration and factors such as water systems, topography, and transportation location is higher, and the correlation between economic development and it is weaker; The per capita GDP of Pingshun County, as an important factor, not only affects the density of road networks and the level of urban construction in the region, but also indirectly affects the distribution pattern of traditional villages.

5. Conclusion and reflection

The spatial distribution characteristics of traditional villages in Southeastern Shanxi are formed by the interaction of numerous factors, among which natural factors are the basis, and gradually social, economic, and historical cultural factors are the dominant influencing factors. The factors that affect the spatial distribution of traditional villages constitute a system of mutual interaction and influence. This article takes the first six batches of 263 traditional villages in Southeastern Shanxi as an example to analyze the overall spatial distribution pattern and influencing factors of their traditional villages. The results show that:

- (1) The overall distribution of traditional villages in Southeastern Shanxi presents a clustered geographic spatial feature, with an overall distribution pattern of “dual cores and one belt”;
- (2) The spatial distribution of traditional villages is the result of the combined effects of terrain, water systems, economic development level, transportation network, and other factors. Specifically, the natural environment is the fundamental element that influences the distribution pattern of traditional villages, determining their spatial structure and distribution patterns; Economic and cultural factors are endogenous factors driving the evolution and development of traditional villages.

Based on the research on the distribution characteristics and influencing factors of traditional villages in Southeastern Shanxi, there are three considerations for the protection of traditional villages in Southeastern Shanxi. Firstly, there are numerous traditional villages in Southeastern Shanxi with high cultural connections, and the overall distribution of villages presents a clustered pattern. Therefore, it is necessary to explore a cluster-based protection framework for traditional villages, integrate various resources such as culture, tourism, and infrastructure, so as to form a benign two-way flow between villages and village clusters, and drive the overall development of traditional villages in Southeastern Shanxi. Secondly, cluster development should be guided by higher-level planning and relevant planning, combined with the actual situation of the natural environment, historical and cultural circles, transportation location, and population distribution of villages in Southeastern Shanxi, to delineate contiguous protection areas and protection types, and to unify and integrate eligible villages. Thirdly, taking into account various factors that have varying degrees of impact on the location of traditional villages, differentiated strategies should be developed for the protection and development of villages based on their geographical environment characteristics, cultural features, and economic level differences. These strategies should strengthen the connections between various factors, protect and enhance the individual value of villages, and promote the overall value enhancement of traditional villages in Southeastern Shanxi.

Disclosure statement

The authors declare no conflict of interest.

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Evolution Characteristics of Stress Fields in Layered Surrounding Rockmass of Tunnels

Feng Li, Kang Qiu, Jiahao Ma, Yongbin Geng

China Railway Shanghai Engineering Bureau Group Seventh Engineering Co., Ltd., Xi'an, Shaanxi, China

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Abstract: Layered rock masses exhibit pronounced mechanical anisotropy, and bedding discontinuities can substantially alter excavation-induced stress redistribution and concentration around a tunnel, thereby increasing the likelihood of instability. In this study, a three-dimensional discrete-element numerical simulation platform was employed to investigate a tunnel excavated in layered rock with bedding dip angles of 0°, 30°, 60°, and 90°. The distributions and evolution of the vertical and horizontal stresses were examined for the four configurations. The results indicate that tunnel excavation causes marked redistribution of both the vertical and horizontal stress components. The disturbance is concentrated in the near-field region and gradually diminishes with increasing distance from the opening. Vertical compressive stress is primarily concentrated near the crown and invert, whereas horizontal compressive stress is mainly localized along the sidewalls and extends toward the arch shoulders and feet. Approximately symmetric stress patterns are obtained for bedding dip angles of 0° and 90°. By contrast, at 30° and 60°, the stress-concentration zones migrate along the bedding direction, producing a distinct asymmetry between the two sides of the tunnel. These findings provide a theoretical basis for stability assessment and support optimization in tunnels constructed in layered rock masses.

Keywords: Tunnel; Layered rock mass; Bedding dip angle; Stress redistribution; Numerical simulation

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1. Introduction

With the rapid expansion of transportation infrastructure in China, an increasing number of tunnels and underground structures are being constructed at greater depths, over longer distances, and under increasingly complex geological conditions. Layered rock masses are widely distributed in western and mountainous regions, where pervasive bedding planes, joints, and fractures produce pronounced anisotropy in mechanical behavior and failure response^[1,2]. Tunnel excavation disturbs the initial in-situ stress state and induces substantial stress adjustment around the opening. Once the localized stress exceeds the load-bearing capacity of the rock mass, cracking, spalling, and even large-scale instability may occur. A clear understanding of excavation-induced stress-field evolution in layered rock is therefore essential for identifying potential failure mechanisms and improving construction safety in underground engineering.

Considerable effort has been devoted to the mechanical behavior and failure mechanisms of layered rock masses. Liu combined three-dimensional discrete-element modeling with field monitoring for the three-lane, closely spaced twin tunnels of the Wutongshan project and quantified the effects of fault dip angles of 60°, 90°, and 120° on surrounding-rock displacement ^[3]. Chen et al. developed a three-dimensional unloading model for layered rock using an overlapping-domain continuum-discontinuum coupling scheme ^[4]. Their work demonstrated continuous transfer of mechanical information across the coupled domains and clarified the deformation and fracture patterns induced by tunnel unloading. Using a finite-element cohesive-zone model (FEM-CZM), Meng et al investigated how bedding-plane strength, spacing, position, and orientation govern principal stresses, energy evolution, and crack development ^[5]. Amadei examined the macroscopic anisotropy associated with stratification and discontinuities and proposed procedures for incorporating such effects into the interpretation of in-situ stress measurements ^[6]. For the Taihangshan Tunnel in layered sandy slate, Miao established a PFC2D excavation model and evaluated the influences of the lateral pressure coefficient, discontinuity spacing, and discontinuity dip on tunnel stability and failure mode ^[7]. Zhu analyzed a shield-tunnel model to characterize the loosened zone and deformation response of the surrounding rock under different bedding dip angles ^[8]. Gan used ABAQUS to assess the influence of bedding inclination and identified several dip-dependent failure modes, including tensile splitting, shear sliding, shear rupture across bedding planes, and splitting along bedding interfaces ^[9]. Liu et al. proposed a drawer-type mechanical model for inclined layered rock, together with a calculation method and identification criterion for geological bias loading, and subsequently clarified the governing factors and deformation-failure mechanism ^[10]. Based on the Dongfeng Road Tunnel, Wang et al. attributed the stability of horizontally layered surrounding rock to the combined effects of geological, construction, and engineering factors ^[11]. Zhang investigated structural loading, deformation, and deformation-control measures for the Nanzhushan high-speed railway tunnel ^[12]. The results showed that increasing the joint angle from 0° to 15° and 30° had little effect on the maximum vertical displacement but produced a more pronounced change in horizontal displacement.

Although previous studies have provided valuable insight into the strength characteristics, failure modes, and discontinuity-controlled behavior of layered rock, the effect of bedding inclination on excavation-induced stress-field evolution and localized stress concentration under complex in-situ stress conditions remains insufficiently resolved. In particular, the mechanisms by which inclined bedding alters the location of stress-concentration zones and generates asymmetric stress distributions around a tunnel require further clarification. To address this issue, three-dimensional discrete-element models were established for bedding dip angles of 0°, 30°, 60°, and 90°. The vertical and horizontal stress responses were systematically compared to identify the influence of bedding geometry on stress redistribution and to provide a theoretical reference for stability evaluation and support design in layered-rock tunnels.

2. Three-dimensional numerical model and simulation design

2.1. Model development

A three-dimensional discrete-element model was constructed to examine how bedding dip controls the stress response of the surrounding rock during tunnel excavation under high in-situ stress. The model dimensions were 40 m × 40 m × 10 m, and four bedding configurations were considered ($\theta = 0^\circ, 30^\circ, 60^\circ, \text{ and } 90^\circ$). The outer region was discretized using a characteristic element size of 2 m, whereas the mesh around the tunnel

was locally refined to 0.5 m. The tunnel adopted a straight-wall arched section with a clear width of 5 m and an overall height of 4.7 m. The crown consisted of a circular arc with a radius of 2.5 m, and the straight sidewalls were 2.2 m high. The resulting model geometry is shown in **Figure 1**.

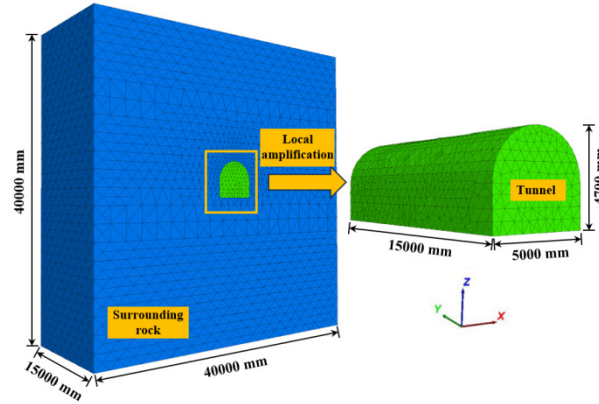


Figure 1. Numerical model.

The boundary conditions are illustrated in **Figure 2**. A vertical stress of 26 MPa (σ_v) was applied to the upper surface to represent the overburden stress, while the base was fixed in all directions. Normal displacement was constrained on the four lateral boundaries. According to the in-situ stress ratios $\sigma_h/\sigma_H = 0.8$ and $\sigma_H/\sigma_v = 1.2$, the minimum horizontal stress parallel to the tunnel axis was set to $\sigma_h = 24.96$ MPa, and the maximum horizontal stress perpendicular to the tunnel axis was set to $\sigma_H = 31.2$ MPa. The mechanical parameters of the surrounding rock mass are as follows: elastic modulus 25 GPa, cohesion 2.40 MPa, internal friction angle 35° , tensile strength 2.00 MPa, Poisson's ratio 0.30, and density 2.65 g/cm^3 . The normal stiffness and shear stiffness of the bedding planes are 5.8 GPa/m and 2.9 GPa/m, respectively, with an internal friction angle of 28° , and both cohesion and tensile strength equal to 0.02 MPa.

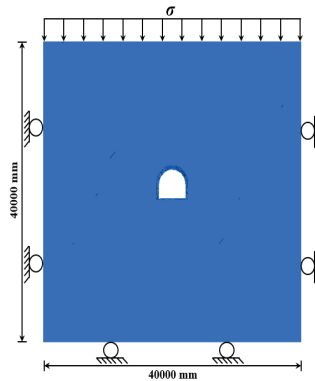


Figure 2. Boundary conditions.

2.2. Simulation cases

The numerical analysis focused on the excavation-induced evolution of the stress field in layered surrounding rock. The program interface was used to synchronously record the stress response across the tunnel section during the calculation. Four representative cases were defined according to the bedding dip angle ($\theta = 0^\circ$,

30°, 60°, and 90°) for comparative analysis, as presented in **Figure 3**.

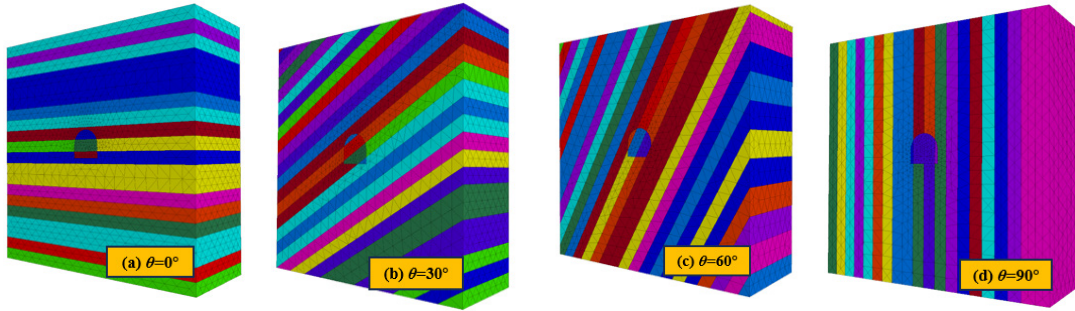
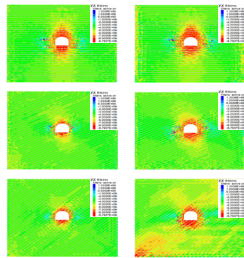


Figure 3. Numerical simulation scheme.

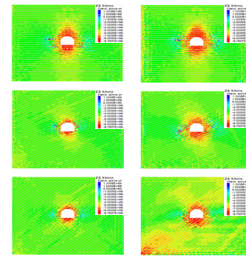
3. Stress-field response of layered surrounding rock

3.1. Vertical stress distribution

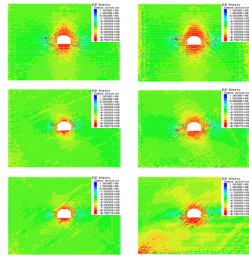
Figure 4 presents the vertical-stress contours for the four bedding configurations. Compressive stress dominates around the excavation, and the red and orange regions denote comparatively large magnitudes of vertical compression. Excavation disrupts the initial vertical stress field and generates pronounced concentration zones near the crown and invert, whereas lower stress levels occur locally around the arch shoulders and sidewalls. The stress contours become progressively more uniform away from the opening, indicating that the vertical-stress disturbance is largely confined to the near-field region. At $\theta = 0^\circ$, the concentration zones above the crown and beneath the invert are regular, and the responses on the two sides of the tunnel are nearly identical. At $\theta = 30^\circ$, these zones shift in the bedding direction, and a left-right difference begins to emerge. A similar bedding-controlled migration persists at $\theta = 60^\circ$, for which the extent of the concentrated stress differs on the two sides. At $\theta = 90^\circ$, the high-stress regions return to the crown and invert and recover an approximately symmetric pattern. Overall, bedding inclination does not change the dominant locations of vertical stress concentration, but it substantially modifies the position and geometry of the concentration zones. Symmetric responses characterize the 0° and 90° cases, whereas the 30° and 60° cases exhibit a clear bedding-oriented offset and asymmetric stress distribution.



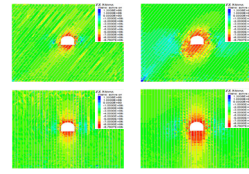
(a) $\theta = 0^\circ$



(b) $\theta = 30^\circ$



(c) $\theta = 60^\circ$

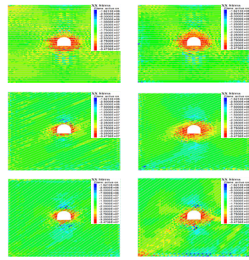


(d) $\theta = 90^\circ$

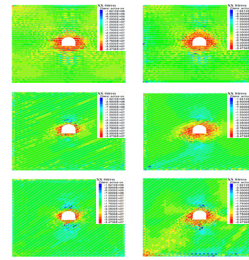
Figure 4. Vertical-stress contours in the surrounding rock at different bedding dip angles (Pa).

3.2. Horizontal stress distribution

The horizontal-stress contours are shown in **Figure 5**. Following excavation, horizontal stress is redistributed around the opening. The red and orange zones are concentrated mainly along the sidewalls and extend toward the arch shoulders and feet, while the horizontal compressive stress near the crown and invert is relatively low. As the distance from the tunnel increases, the stress field gradually approaches a uniform state, confirming that the excavation effect is concentrated close to the boundary. For $\theta = 0^\circ$, the high-stress zones adjacent to the two sidewalls have comparable extents and form an approximately symmetric pattern. At $\theta = 30^\circ$, the concentration zones are displaced along the inclined bedding; one side extends toward the arch shoulder, whereas the opposite side develops toward the arch foot. This directional offset remains evident at $\theta = 60^\circ$, and the positions and extents of the high-stress regions differ between the two sides. When $\theta = 90^\circ$, the concentration zones are again centred on the sidewalls, producing a nearly symmetric distribution.



(a) $\theta = 0^\circ$



(b) $\theta = 30^\circ$



(c) $\theta = 60^\circ$

(d) $\theta = 90^\circ$

Figure 5. Horizontal-stress contours in the surrounding rock at different bedding dip angles (Pa).

Comparison of **Figure 4** and **5** reveals distinct concentration patterns for the two stress components. Vertical compressive stress is concentrated primarily near the crown and invert, whereas horizontal compressive stress is concentrated along the sidewalls and extends toward the arch shoulders and feet. Both components remain broadly symmetric for $\theta = 0^\circ$ and 90° . At $\theta = 30^\circ$ and 60° , however, the concentration zones migrate in the bedding direction, resulting in pronounced stress asymmetry across the tunnel section.

4. Conclusions

A three-dimensional discrete-element model was developed to investigate the influence of bedding dip angle on stress redistribution around a tunnel excavated in layered rock. The principal findings are summarized as follows:

- (1) Tunnel excavation redistributes both the vertical and horizontal stresses in the surrounding rock. The disturbance is most pronounced close to the opening and decreases with distance. Vertical compressive stress is concentrated mainly near the crown and invert, whereas horizontal compressive stress is concentrated along the sidewalls and extends toward the arch shoulders and feet.
- (2) For bedding dip angles of 0° and 90° , the vertical-stress field is approximately symmetric, and the concentration zones near the crown and invert remain relatively regular. At 30° and 60° , the vertical-stress concentration zones shift along the bedding direction, leading to unequal distributions and different concentration extents on the two sides of the tunnel.
- (3) The horizontal-stress concentration zones are nearly symmetric around the two sidewalls at bedding dip angles of 0° and 90° . For the 30° and 60° cases, these zones are displaced along the bedding direction, extending toward the arch shoulder on one side and toward the arch foot on the other, which produces a marked left-right asymmetry.

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Disclosure statement

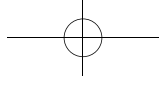
The authors declare no conflict of interest.

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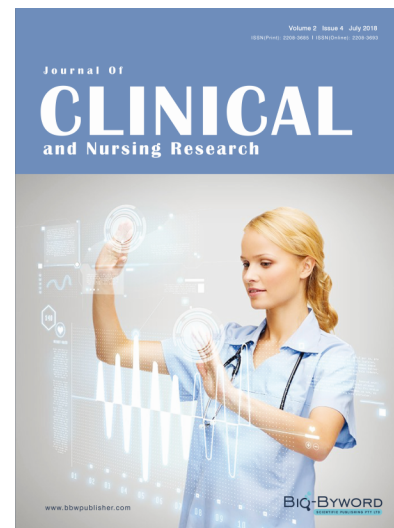
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