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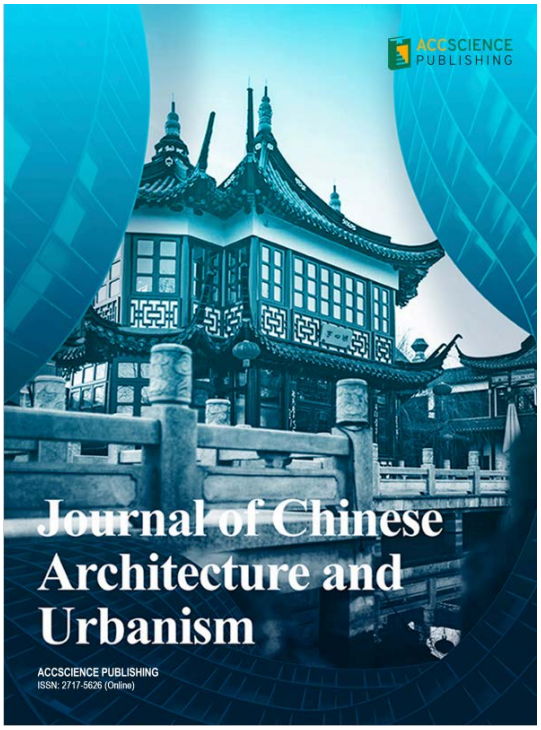

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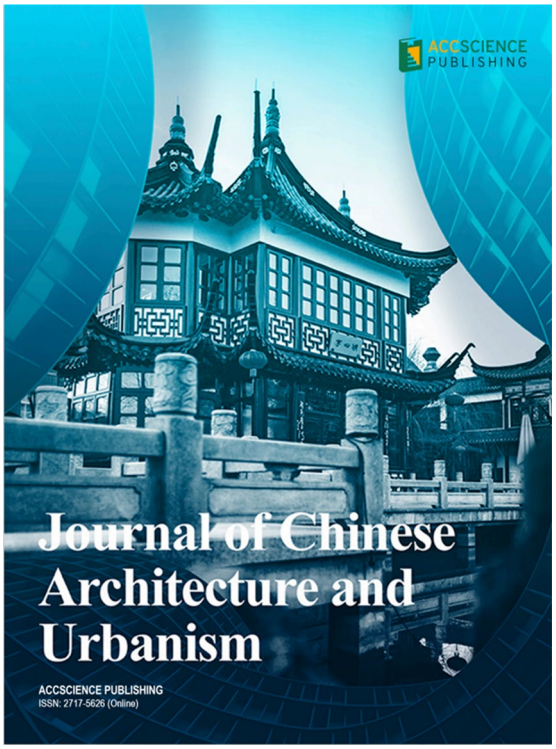

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A typical Chinese-styled building

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ORIGINAL ARTICLE

Research hotspots and paths of traditional houses in Huizhou, Anhui province, China: A visualization analysis using CiteSpace

You He, Mohd Jaki Bin Mamat*, Sha Liu, and Shuwen Mo

School of Housing, Building and Planning, Universiti Sains Malaysia, Penang, Malaysia

Abstract

As a representative of China's vernacular architecture with unique forms and rich cultural connotations, Huizhou's traditional dwellings have gained international recognition as a World Cultural Heritage site. These dwellings serve as a pivotal case study in exploring the dynamic relationship between globalization and local identity. This study employs CiteSpace software to visualize and analyze literature on traditional Huizhou houses published since 2000. We investigated publication trends and author and institutional collaboration networks and identified major research hotspots and their evolutionary paths at each stage by applying keyword co-occurrence, clustering, and emergence mapping. The results reveal three main phases in academic research on Huizhou traditional dwellings: from 2000 to 2010, studies primarily dissected architectural features and cultural connotations; from 2011 to 2020, research focused on the application of Huizhou's traditional architectural and cultural symbols within contemporary design; and from 2021 to 2023, preliminary exploration began into the industrialized development and spatial narratives of Huizhou architectural elements. Although research on Huizhou's traditional houses has yielded substantial insights, collaboration among authors and institutions remains limited, and theoretical innovation is insufficient. Future studies should prioritize multidisciplinary collaboration and quantitative analysis to advance the integration and sustainable development of theory and practice in this field.

Keywords: Huizhou traditional houses; CiteSpace; Hotspots and paths; Cultural heritage; Sustainable development

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1. Introduction

Cultural heritage is an invaluable asset passed down by ancestors throughout human history; it is meant for future generations and serves as a non-renewable and important resource with irreplaceable historical, social, and cultural values (Pérez-Gandarillas *et al.*, 2024). In 1972, UNESCO adopted the World Heritage Convention, which has actively contributed to the protection and restoration of the shared heritage of all humankind (Gruber, 1972). In 1976, the World Heritage Committee established the World Heritage List, and as of August 2024, there were 952 sites in the world on the list of cultural heritage sites, 40 of which are located in China.

With growing international attention in cultural heritage studies, the volume and diversity of related literature have increased dramatically (Syahrial *et al.*, 2024). Faced with vast amounts of data, the importance of scientific literature analysis tools has become increasingly prominent, especially visualization tools, such as CiteSpace, VOSviewer, and Biblioshiny, which play important roles in helping researchers understand complex knowledge structures, disciplinary evolution, and research trends (Tang *et al.*, 2024; Zeng *et al.*, 2023). For example, word frequency analysis and co-occurrence networks can help researchers identify hot research topics within a certain period, such as sustainable development in global cultural heritage preservation, tourism research, and digital technological innovations. Researchers can quickly identify influential academic groups and their main research results (Aboulnaga *et al.*, 2024; Lian & Xie, 2024; Zhang *et al.*, 2022; Zhang *et al.*, 2023). Visual scientific literature analysis tools play a crucial role in exploring cutting-edge academic trends (Zhou et al., 2024; Zhang & Zou, 2022). As an interdisciplinary field encompassing history, architecture, sociology, and other domains, these visualization tools allow researchers to track the evolutionary path of specific disciplines, monitor the expansion of cross-disciplinary research, identify academic gaps, and anticipate cutting-edge topics for future research (Rong & Bahauddin, 2023).

Local heritage architecture, as a unique dimension in global cultural diversity, not only demonstrates the wisdom of local architecture in adapting to the needs of nature and society – constituting the unique historical memory and cultural identity of the region – but also reflects the interaction between cultural specificity and global universal values (Kahvecioğlu & Arslan Selçuk, 2023; González Martínez, 2022). A cross-cultural and cross-regional comparative approach from a global perspective enables researchers to understand the commonalities and differences in the conservation of heritage buildings within different cultural contexts, promoting cooperation and coordination in global cultural heritage conservation at a macro level. It also helps scholars understand the challenges faced by heritage buildings across different regions, facilitating mutual learning and exchange among different cultures (Mohamed & Marzouk, 2023). Therefore, visual scientific literature analysis tools have great potential in local heritage building research to help scholars gain insights into the local characteristics of heritage buildings, their sustainable management practices, and practical activities (Adegoriola *et al.*, 2021). These tools further foster scholarly exchange and dialogue across cultures, widening the breadth and depth of global cultural heritage research (Morkūnaitė *et al.*, 2019; Nadkarni & Puthuvayi, 2020).

Despite the volume of existing research, many studies on the local cultural and historical context of heritage buildings lack systematic and comprehensive scientific literature analysis. This deficiency impedes the effective identification of key elements of local characteristics and their interrelationships. Consequently, visual scientific literature analysis tools remain underutilized and insufficiently applied in the study of local heritage buildings, highlighting a research gap and the need for further exploration (Zhou *et al.*, 2022).

2. Methods

2.1. Research area

Located in the southern region of Anhui province, China, the traditional houses of Huizhou are known as the "living fossil of Chinese architecture" (Zheng & Yan, 2011) for their distinctive regional characteristics, subtle design concepts, skilled construction techniques, and profound cultural connotations. These houses serve as the most intuitive physical carriers for understanding the social structure, family concepts, religious beliefs, and daily life of the region (Zhang *et al.*, 2011). They hold considerable value for studying the traditional culture of Huizhou and, more broadly, Chinese culture.

In 2000, the historical villages of southern Anhui, exemplified by Xidi and Hongcun villages in Yixian county, Anhui province, were successfully inscribed on the World Heritage List (Zhang &, 2013; Zhao *et al.*, 2018). Yixian county, one of the six historic counties of Huizhou, was founded in 221 BCE during the Qin dynasty (221 – 206 BCE). Nestled in a valley with beautiful natural environments, rolling peaks, and relatively isolated transportation, this geographic setting enabled Yixian county to preserve its independence and strong self-sufficiency over a prolonged period, contributing to its distinctive pattern of cultural and economic development (Zurndorfer, 1989). During the Ming (1368 – 1644) and Qing (1644 – 1912) dynasties, Huizhou merchants accumulated significant wealth through trade in commodities such as tea and timber across China (Du, 2015; Guo, 2022). Driven by the desire to honor their ancestors and return to their hometowns, these merchants invested their wealth in building and restoring homes, spurring rapid growth in Yixian county's economy, culture, and architecture. However, under the constraints of the feudal hierarchy at that time, even wealthy Hui merchants were restricted from constructing magnificent houses, so they turned to interior decoration. They intricately carved profound and exquisite designs on doors, windows, beams, and other architectural components, in contrast to the plain, simple, and understated exterior of the buildings (Zhang, 2016; Cao & Mustafa, 2023) (Figure 1).

Figure 1. The exterior and interior of traditional Huizhou houses. Source: Photos by the authors (2024)

Since the 1990s, research in China has increasingly explored the artistic features of wood, brick, and stone carvings in Huizhou's Ming and Qing dynasty architecture; along with the social and cultural contexts they embody (Wang, 1991). With the relocation of Yin Yu Tang, a historical house over 200 years old from Huangcun village, Anhui province, to the Peabody Essex Museum in the United States, where it opened to the public in 2003, the international academic community has also heightened its focus on the value, protection, and inheritance of Huizhou's traditional architectural cultural heritage (Li, 2014). However, rapid urbanization and industrialization have posed unprecedented challenges to the survival and development of traditional villages and architecture, with regional distinctions gradually disappearing (Li *et al.*, 2018). In 2021, the Chinese government issued the Opinions on Strengthening the Protection and Inheritance of Historical Culture in Urban and Rural Construction, urging all regions and departments to implement context-sensitive guidelines. In response to this directive, the Anhui provincial government formulated the Implementation Plan on Strengthening the Protection and Inheritance of Historical Culture in Urban and Rural Construction in 2023, emphasizing Huizhou's traditional architectural concepts and imagery as key tasks. Despite considerable research achievements in the field of traditional Huizhou architecture accumulated over the years, further exploration is needed to expand the depth and breadth of research (Fang & Li, 2022).

2.2. Research methods and tool

Traditional Huizhou houses, as a highly regional architectural type, have complex historical, cultural, and social backgrounds that require researchers to possess profound local knowledge. Research on traditional Huizhou houses involves multiple disciplines, including architecture, history, and cultural anthropology, each with its own methodologies. Some scholars focus on architectural form and spatial layout, while others interpret these houses on a sociocultural level. Therefore, scholars from diverse academic backgrounds and research experiences often apply subjective selection and classification criteria in their literature analysis (Xie *et al.*, 2022), highlighting the need for quantitative approaches in this field. Building on this basis, this study employs CiteSpace, a visual scientific literature analysis tool, to conduct a multi-dimensional bibliographic analysis of literature on Huizhou traditional houses. This approach mitigates the risk of overlooking important academic achievements due to individual research biases, ensuring a scientific and systematic selection and classification of literature. The analysis objectively presents research hotspots, evolutionary paths, and trends across different periods. However, as CiteSpace primarily captures overall trends and hotspots without delving deeply into content (Fang *et al.*, 2018), this study complements the quantitative findings with qualitative analysis of key literature, enabling an in-depth discussion of the unique value of Huizhou's traditional architectural culture, its methods of inheritance, and its current socially innovative applications. In doing so, this study offers fresh cross-cultural and interdisciplinary perspectives on China's regional architectural heritage and, potentially, on global cultural heritage.

Given that "traditional Huizhou architecture" is a term specific to Chinese regional architecture, this study selects China National Knowledge Infrastructure (CNKI) as the core database due to its comprehensive quantity, quality, and coverage of literature. CNKI is China's largest and most authoritative academic research platform, providing access to a wide range of resources, including journals, dissertations, conference papers, books, yearbooks, newspapers, and more, making it an ideal data source for bibliometric analysis (Liu, 2021).

The literature search spans from the year 2000 onward, using "topic" as the retrieval type. Search terms include "Huizhou traditional houses," "Huizhou-style traditional houses," and "traditional houses of southern Anhui," with the source category limited to "all periodicals." Due to limited data availability for 2024, the end year for retrieval was set to 2023, resulting in 1,458 search results. To ensure data authority and reliability, we screened out unauthorized, duplicated, and irrelevant documents, ultimately retaining 309 publications from the Chinese Social Sciences Citation Index, Chinese Core Periodicals List, Chinese Science Citation Database, along with 768 additional academic publications on Huizhou traditional houses, for a total of 1077. These publications were imported into CiteSpace V.6.2. R7 in "RefWorks" format. The research design process is illustrated in Figure 2.

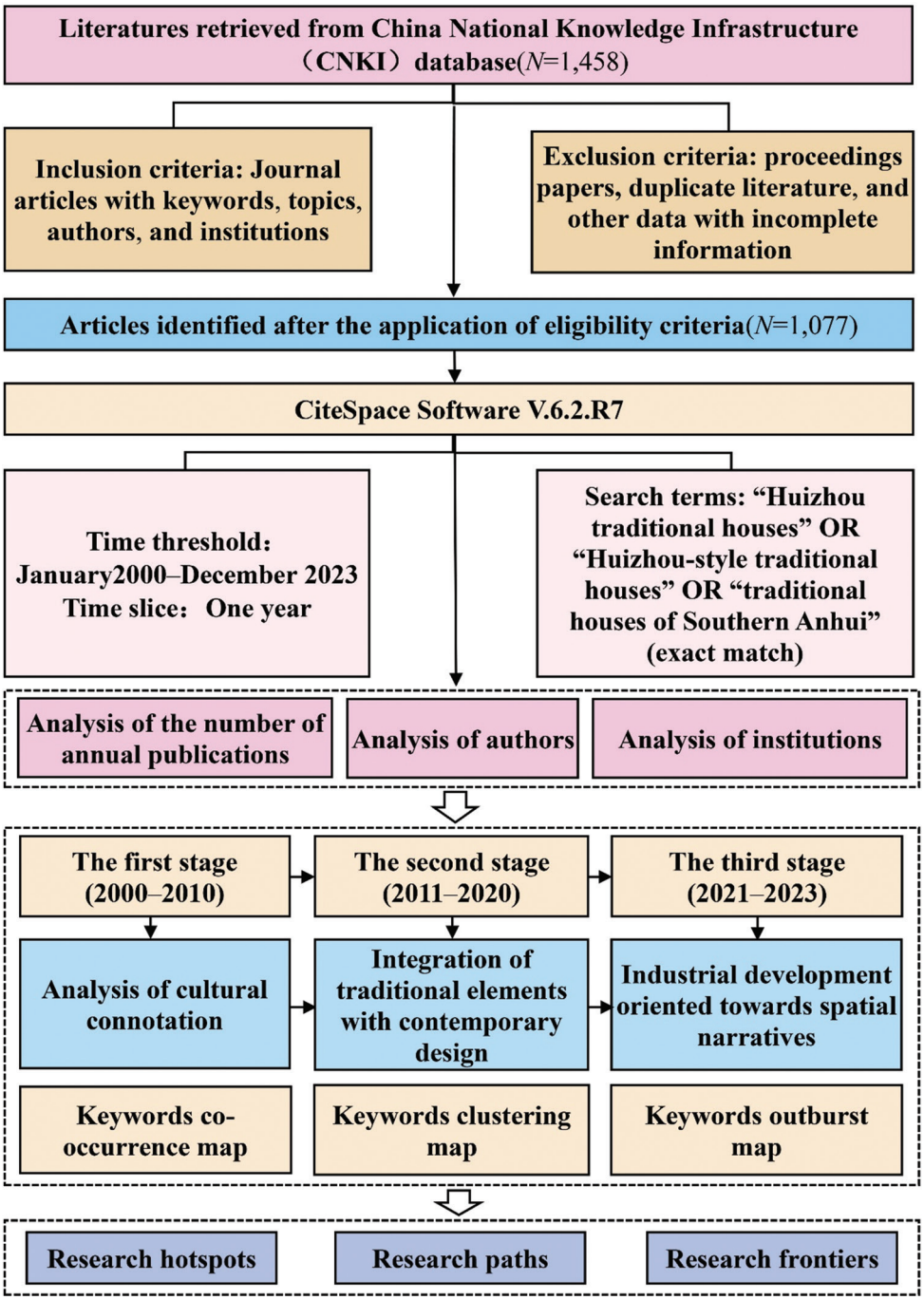

Figure 2. Outline of the bibliometric analysis research design for Huizhou traditional houses. Source: Chart by the authors

3. Results

3.1. Analysis of annual publication count

The annual publication count serves as an important indicator of a research field's development, reflecting both the continuity and the attention it receives (He *et al.*, 2018). Analyzing the annual publication volume allows us to effectively examine the research trends in the field of traditional Huizhou houses. As shown in Figure 3, despite fluctuations, the overall number of publications has increased over time.

Between 2000 and 2010, the annual publication count grew steadily, indicating that the inscription of Xidi and Hongcun on the World Heritage List in 2000 led to increased interest in traditional Huizhou houses. Both

central and local governments in China successively introduced relevant policies and regulations (Table 1), which significantly stimulated academic research and publications on traditional Huizhou houses. The Anhui Pavilion at the 2010 Shanghai Expo showcased Huizhou's culture, further highlighting the architectural value of traditional Huizhou houses, leading to a small publication peak in that year.

The publication count significantly declined in 2011 but remained at a relatively high level, increasing substantially in 2015 and peaking in 2016. This trend suggests that, after over a decade of research and accumulation, certain findings matured, leading to a temporary dip in interest. However, it also indicates that scholars maintained enthusiasm and commitment to research on traditional Huizhou houses. During this period, numerous local cultural and tourism activities in the Huizhou region attracted large numbers of tourists and cultural enthusiasts. In addition, several regulations and policies were revised and refined (Gao *et al.*, 2021). This dual impetus – supportive policies and a favorable social environment – spurred scholars to explore new directions and methods, leading to significant progress.

In 2018, there was a temporary decline in publications; however, the following 2 years saw a return to higher levels, indicating that traditional Huizhou houses remained a field of considerable interest and influence. After 2020, the publication count exhibited noticeable fluctuations and a downward trend, suggesting a rising demand for innovation and improvements in future research.

3.2. Analysis of authors and institutions

A bibliometric analysis of author and institutional collaboration networks helps understand the construction and distribution of research teams in this field. It also provides insight into the current state, potential, and research capabilities of affiliated institutions (Sun & Ni, 2023).

As shown in the author's collaboration network map (Figure 4), the number of nodes is 259, the number of edges is 54, and the density is 0.0016. This low density indicates limited collaboration among authors, with a characteristic of "small clusters, large dispersion."

Price's law (Equation I) was applied to calculate the number of core authors in this research field:

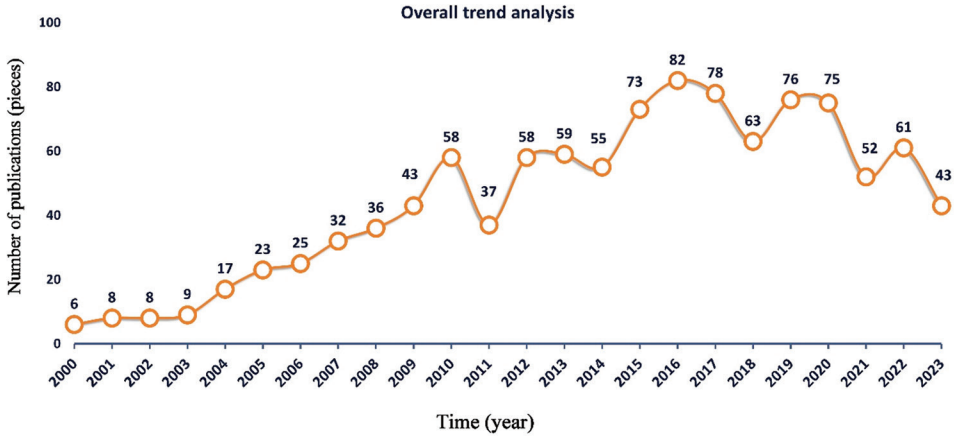

Figure 3. Annual publication count on traditional architecture in Huizhou from 2000 to 2023. Source: Graph by the authors

Table 1. Policies and regulations related to Huizhou traditional architecture (2000 – 2010)

No.	Policy title	Releasing authority	Releasing date
1	Cultural Relics Protection Law of the People's Republic of China	Standing Committee of the National People's Congress	October 28, 2002
2	Regulations on the Implementation of Cultural Relics Protection Law of the PRC	State Council of the People's Republic of China	July 1, 2003
3	Regulations on the Protection of Ancient Houses in Southern Anhui Province	Standing Committee of the Anhui Provincial People's Congress	July 1, 2004
4	Anhui Provincial Cultural Relics Protection Measures	Anhui Provincial People's Government	July 1, 2005
5	Regulations on the Protection of Famous Historical and Cultural Cities, Towns and Villages	State Council of the People's Republic of China	July 1, 2008

Figure 4. Author collaboration network map. Source: Network map by the authors

$$M \approx 0.749\sqrt{N_{\max}} \quad \text{(I)}$$

Where N_{max} represents the publication count of the most prolific author, and M represents the minimum publication count for core authors. According to CNKI data, the highest publication count was 25, yielding M≈ 3.745, rounded to an integer value of 4. Therefore, authors with at least four publications were considered core authors. Results indicate that 28 authors had a publication count of >4, collectively producing 184 publications and accounting for 17% of the total literature. Generally, a core author group is identified when publications by core authors constitute at least half of the total literature (Zhang & Liu, 2023). Overall, no core author group has been established. However, Figure 4 shows higher connectivity between Huang Kai and Zhu Mina, as well as between Bi Zhongsong and Li Yunzhang, indicating small-scale team collaborations.

In the institutional collaboration network map (Figure 5), the number of nodes is 241, the number of edges is 33, and the density is 0.0011, indicating limited collaboration among institutions. Using Price's law (Equation I), we calculated the core research institutions. According to CNKI data, the highest publication count of a single institution was 47, resulting in M≈5.13, rounded to an integer value of 6. Institutions with at least six publications were thus considered core institutions. Results showed that 18 institutions met this criterion, producing a total of 267 publications. The top five institutes accounted for 58.4% of the total publications from core institutions, reflecting significant differences in faculty strength and research capacity among them.

In this study, data from the top 10 authors and institutions were analyzed (Tables 2 and 3). As shown in Table 2, Huang Kai ranks first with 25 publications and has led several research projects focused on the protection and inheritance of Huizhou architectural cultural heritage, positioning him as a leading figure in this field. His research primarily examines the decorative arts of traditional Huizhou houses, especially the application of traditional Huizhou woodcarving, brick carving, stone carving, and other crafts in architecture, along with their cultural symbolism (Huang & Zhu, 2009; Li & Huang, 2020). Huang Kai combines qualitative and quantitative research methods, including theoretical research, case studies, fieldwork, and statistical analysis. For example, his study of Huizhou woodcarvings explores not only esthetic aspects but also sociological and cultural perspectives, analyzing how these exquisite carvings reflect Confucian values, family structures, and aspirations for a better life (Wei & Huang, 2023). He gathers primary data through fieldwork and evaluates the contemporary design value of Huizhou's cultural elements through quantitative analysis (Zhou & Huang, 2014). Beyond academia, Huang Kai is active in teaching and design practice, incorporating his research findings into education and practical applications, thus contributing to the inheritance, innovation, and design education of Huizhou architectural culture.

From a thematic perspective, most authors focus on the cultural connotations of traditional Huizhou houses

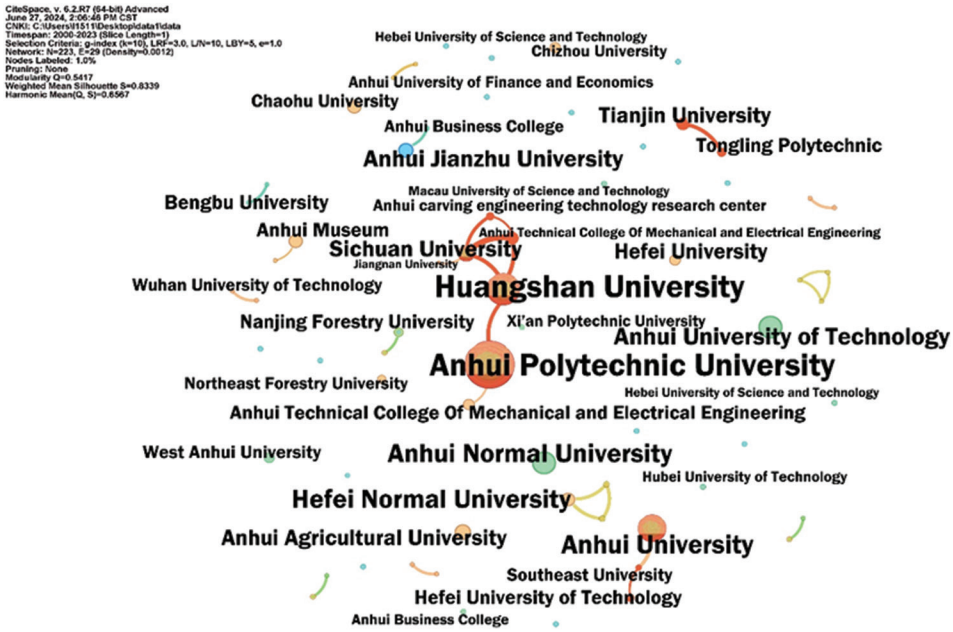

Figure 5. Institution collaboration network map. Source: Network map by the authors

Table 2. Data analysis of the top 10 authors

No.	Authors	Publications	Institutions	Research topics	Research methods
1	Huang Kai	25	Anhui Polytechnic University	Decorative arts and cultural symbols in Huizhou architecture	Qualitative and quantitative
2	Bi Zhongsong	12	Huangshan University	Conservation and restoration of Huizhou traditional houses; historical and technological inheritance of Huizhou architectural culture	Qualitative and quantitative
3	Zhu Mina	11	Anhui Polytechnic University	Digital inheritance and application of Huizhou sculpture art	Qualitative and quantitative
4	Lu Feng	11	Anhui Polytechnic University	Decorative art and cultural value of Huizhou traditional houses	Qualitative
5	Wang Wei	10	Anhui Jianzhu University	Spatial form and cultural characteristics of Huizhou traditional houses	Qualitative
6	Li Yunzhang	8	Sichuan University	Cultural connotation and architectural forms of Huizhou architecture	Qualitative
7	Liu Zhejun	7	Tianjin University	Cultural connotation of decorative wood carvings in Huizhou traditional architecture	Qualitative
8	Wang Zhiyi	6	Huangshan University	Types and cultural inheritance of Huizhou architecture	Qualitative
9	Yang Zeyin	6	Hefei Normal University	Wood carving art of Huizhou traditional architecture	Qualitative
10	Sun Qiang	6	Bengbu University	Restoration of wooden structures of traditional Huizhou houses and carving techniques	Qualitative and quantitative

and the transformation and application of these cultural elements in contemporary design. For example, Huang Kai and Zhu Mina concentrate on architectural decorative arts and their inheritance in contemporary design. Bi Zhongsong and Li Yunzhang emphasize the overall protection and cultural continuity of buildings, while Lu Feng explores the symbolic meanings of decorative elements of traditional Huizhou houses. Wang Wei examines architectural spatial form, and Liu Jun and Yang Zeyin focus on the protection and inheritance of Huizhou folk woodcarving techniques. Wang Zhiyi looks into architectural typology and inheritance, and Sun Qiang

Table 3. The top 10 institutions

No.	Institutions	Publications
1	Anhui Polytechnic University	47
2	Huangshan University	38
3	Anhui University	28
4	Anhui Normal University	24
5	Anhui Jianzhu University	19
6	Hefei University of Technology	17
7	Hefei Normal University	12
8	Anhui Agricultural University	11
9	Sichuan University	9
10	Tianjin University	8

investigates restoration techniques for traditional wooden houses in Huizhou. In terms of research methodology, the strong cultural and historical background of traditional Huizhou houses leads most authors to adopt qualitative approaches, such as literature review, case studies, and field investigations, for an in-depth theoretical analysis of decorative arts and cultural symbolism. Quantitative methods are applied primarily in studies on technology applications, contemporary design, and industrialization.

Table 3 reveals that Anhui Polytechnic University ranks first with 47 publications. Among the top 10 authors, three are affiliated with Anhui Polytechnic University, highlighting its significant achievements and outstanding influence in this field. Geographically, eight of the top institutions are based in Anhui province, likely due to both proximity to Huizhou and favorable local policies. The presence of two institutions outside Anhui demonstrates that Huizhou culture's influence has extended beyond regional boundaries, attracting wider academic attention. As shown in Figure 5, numerous nodes and connections link Anhui Polytechnic University, Huangshan University, and Sichuan University, indicating frequent academic exchanges and collaborations among these three institutions. Located near Huizhou, Anhui Polytechnic University and Huangshan University benefit from geographical proximity and access to academic resources for studying traditional Huizhou houses. Although Sichuan University is farther from Huizhou, as a key state-level university in Sichuan province, Southwest China, it brings strong interdisciplinary research capabilities and academic influence. Each of these universities has distinct academic strength: Anhui Polytechnic University focuses on the architectural decorative elements of traditional Huizhou houses and their cultural significance; Huangshan University emphasizes the protection and inheritance of local architectural culture; and Sichuan University excels in cross-regional comparative research. These three institutions have successfully established cross-university, cross-disciplinary, and cross-regional cooperation based on shared research interests and complementary resources, advancing the inheritance and development of Huizhou's traditional culture across different regions.

4. Discussion

4.1. Research hotspot

Keywords provide a concise summary of a study's theme, content, and ideas, serving as an important indicator in bibliometric research (Yang, 2023). Analyzing the co-occurrence and clustering of keywords in the literature related to traditional Huizhou houses helps clarify relationships between various themes within this field, offering an intuitive view of research hotspots and trends.

From the keyword co-occurrence map (Figure 6), it can be observed that the number of nodes is 174, and the number of edges is 225. Larger nodes indicate higher keyword frequency; more lines indicate increased co-occurrences between two keywords, and thicker lines denote stronger connections. Excluding the keyword "Huizhou traditional houses," which overlaps with the research theme, the keywords "cultural heritage," "architectural features," and "Huizhou woodcarving" appear most frequently. This finding indicates that research on traditional Huizhou houses encompasses not only the architectural esthetic and technical aspects but also emphasizes the cultural significance of these buildings and their role in bridging the gap between contemporary design fields.

The top 20 most important keywords were extracted according to frequency-ranking statistics, and their centrality was calculated. Nodes with high centrality indicate that the keyword plays a significant role in connecting multiple themes. Table 4 shows that the keyword with the highest centrality is "architectural decoration." Although not the most frequent keyword, it links several high-frequency keywords, thus playing a core role in research on traditional Huizhou houses.

To further analyze the research focus and hotspots of Huizhou traditional houses, CiteSpace was used to cluster keywords. After excluding the keyword "Huizhou traditional houses" to avoid thematic overlap, 10 clusters were identified, as shown in Figure 7. Smaller cluster numbers indicate higher research activity, as these clusters contain more nodes.

The clustering results indicate that the main research focus on traditional Huizhou houses involves integrating traditional architectural decorative elements into contemporary design to achieve cultural inheritance and innovation. Woodcarving components, a major decorative

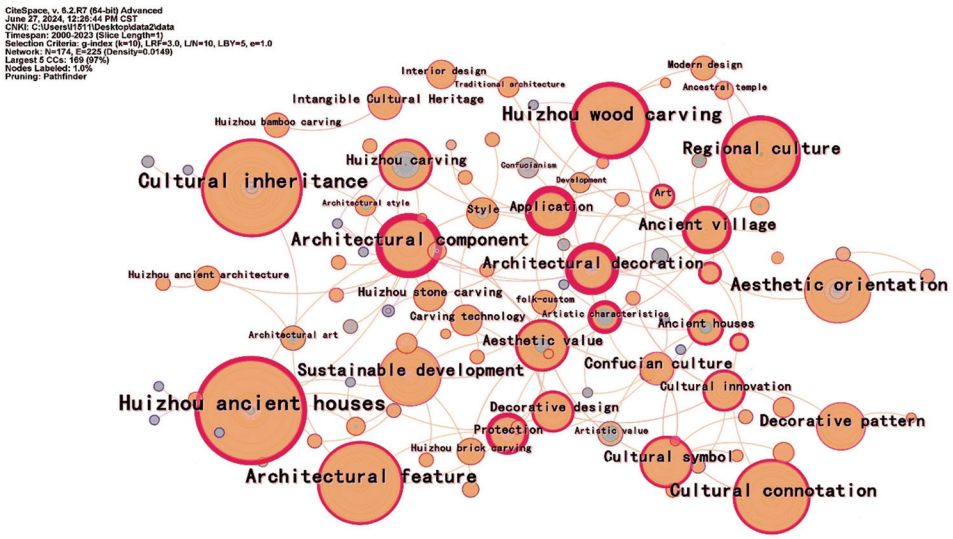

Figure 6. Keyword co-occurrence map. Source: Co-occurrence by the authors

Table 4. Statistics of high-frequency keywords

No.	Keywords	Frequency	Centrality
1	Huizhou ancient houses	140	0.3
2	Cultural heritage	95	0.21
3	Architectural features	79	0.16
4	Huizhou wood carving	73	0.26
5	Cultural connotation	72	0.18
6	Regional culture	70	0.23
7	Esthetic orientation	61	0.09
8	Architectural components	59	0.44
9	Sustainable development	49	0.09
10	Huizhou sculpture	42	0.16
11	Architectural decoration	35	0.54
12	Cultural symbols	32	0.18
13	Esthetic value	30	0.15
14	Application	28	0.48
15	Ancient villages	24	0.32
16	Decorative patterns	23	0.08
17	Innovation	18	0.2
18	Decorative design	16	0.18
19	Protection	15	0.28
20	Intangible cultural heritage	14	0.07

element in Huizhou traditional houses, carry significant historical information and cultural connotations, reflecting the life philosophy and esthetic values of Huizhou people. Huizhou woodcarving demonstrates a high level of craftsmanship, making it a representative of traditional craft recognized on China's National Intangible Cultural Heritage list. With strong visual appeal and artistic expressiveness, woodcarving components are often used as unique regional cultural symbols in contemporary design, preserving the essence of traditional culture while infusing it with new vitality. In the context of globalization, traditional Huizhou houses showcase the charm of Chinese regional culture to a global audience. Their increasing international influence enhances cultural identity and fosters national pride.

4.2. Research path

Burst terms refer to keywords whose occurrence or usage frequency significantly increases within a certain period, representing shifts in research hotspots during that time (Jiang, 2023). Analyzing these dynamic changes in burst terms helps trace the evolutionary patterns of research paths in traditional Huizhou houses and predict future research directions. This study used CiteSpace to generate a burst term map for keywords, as shown in Table 5. The map clearly displays the start and end times of the burst terms, dividing the research focus on traditional Huizhou houses into three stages.

4.2.1. The first stage: Analysis of cultural connotation (2000 – 2010)

During this period, research mainly focused on carving techniques in the architectural decoration of traditional Huizhou houses and their integration with traditional culture. Topics such as "woodcarving," "Confucian thought," and "esthetic orientation" emerged as prominent themes, leading to in-depth analyses of the cultural connotations embedded within these structures. The exteriors of traditional Huizhou houses are simple and

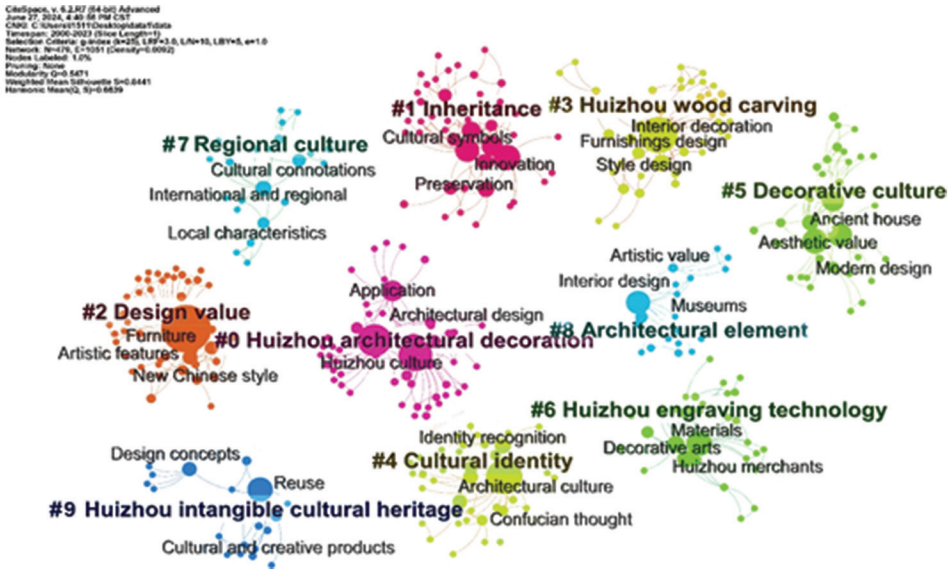

Figure 7. Keyword clustering map. Source: Clustering map by the authors

Table 5. Top 20 keywords with strongest citation bursts, 2000 – 2023

Keywords	Strength	Begin	End	2000 – 2023
Huizhou carving	4.3	2002	2010	
Confucian thought	2.56	2004	2008	
Huizhou merchants	2.12	2005	2007	
Architectural decoration	3.57	2005	2010	
Wood carving	2.51	2006	2011	
Esthetic orientation	2.79	2006	2008	
Protection	3.47	2006	2012	
Design value	2.28	2011	2016	
Innovation	2.71	2011	2016	
Application	2.88	2012	2015	
Contemporary design	2.48	2013	2017	
Cultural symbols	2.84	2015	2019	
Sustainable development	2.34	2016	2019	
Inheritance	2.4	2017	2020	
Decorative patterns	3.84	2017	2021	
Interior design	3.9	2017	2021	
Cultural identity	3.37	2018	2022	
Intangible cultural heritage	2.36	2019	2023	
Narrative	2.4	2021	2023	
Industrial development	2.12	2022	2023	

Notes: Blue indicates that the keyword received some research attention but did not reach the level of the most intense bursts. Red indicates a burst period, meaning the keyword became a research hotspot in the field during a specific period of time.

unadorned, contrasting sharply with ornate and exquisite interior decorations, which showcase distinct regional characteristics (Li & Hou, 2005; Lv, 2001). Traditional Huizhou houses are renowned for their carvings, typically found on column bases, beams, doors, windows, and railings. These carvings, which display high craftsmanship,

include flat, relief, and openwork carving techniques, with openwork carving being the most distinctive. This technique provides a multi-layered sense of depth in limited space, creating a strong spatial decorative effect (Cao & Ye, 2008; Wu, 2009). Traditional Huizhou houses reflect Huizhou merchant capital and patriarchal concepts, encapsulating the historical culture and spirit of their local society. Rooted in Confucian ethics, Huizhou culture is conveyed through wooden decorative components, which serve as the main material carriers of this culture. The carved patterns, using implicit artistic language, embody values such as loyalty, filial piety, integrity, righteousness, and aspirations for a prosperous life, revealing the Huizhou people's respect for Confucian traditions and esthetic preferences (Xie, 2009). Overall, research during this period provided profound and detailed insights into the local characteristics and cultural connotations of traditional Huizhou houses. Scholars also began exploring the potential for integrating decorative arts from traditional Huizhou houses into contemporary design.

4.2.2. The second stage: Integration of traditional elements with contemporary design (2011 – 2020)

In 2010, the 41st World Expo was held in Shanghai, China, with the Anhui Pavilion themed "Huizhou Culture Makes Life More Colorful." This event showcased the rich heritage of Huizhou culture while addressing contemporary societal needs, presenting an image that respects tradition while embracing the future and further enhancing the influence of Huizhou culture. During this period, keywords such as "contemporary design," "application," and "innovation" reflected key research hotspots. The architectural structure and interior spatial layout of traditional Huizhou houses not only embody a cultural philosophy of harmonious coexistence with nature but also incorporate contemporary ecological concepts, such as energy efficiency and heat insulation, offering significant inspiration and application value (Huang *et al*., 2017; Ji, 2012). Integrating traditional and modern techniques is crucial for the sustainable development of traditional Huizhou houses (Sun & Guan, 2012). The pursuit of cultural identity and recognition is a central theme for many today. Huizhou woodcarving patterns, with their distinctive shapes, colors, and materials, are easily recognizable and serve as artistic and functional regional symbols. These patterns can be reutilized in contemporary interior design, merging tradition with contemporary esthetics. The development of new Huizhou-style architecture that enhances cultural ambiance while meeting current demands demonstrates a creative exploration of localizing and modernizing vernacular architecture, which holds profound practical significance in inheriting Huizhou's traditional architectural culture (Guang, 2013; Zhao & Gao, 2013). She *et al*. (2012) explored the establishment of a 3D model database and information query platform to support the preservation and inheritance of Huizhou-style decorative arts. By applying digital information acquisition and processing technologies, their project provided technical support for preserving Huizhou culture and enabled innovative practices in related art designs, thereby promoting the global dissemination, application, and development of Huizhou-style decorative arts. Subsequently, on October 1, 2014, the Regulations on the Intangible Cultural Heritage of Anhui Province came into effect, emphasizing the optimization of the cultural ecological environment, enhancing regional cultural soft power, and advancing the inheritance and evolution of traditional crafts. Decorative carving, an important carrier of Huizhou's traditional architectural culture, has garnered widespread scholarly attention regarding its role in the preservation of traditional crafts. Shide *et al*. (2015) used Huizhou stone, wood, and brick carvings as examples to examine the impact of cultural, ecological, and environmental factors on the willingness to inherit traditional crafts, employing principal component analysis and logistic regression analysis. Similarly, Feng (2018) analyzed exquisite carving techniques and rich cultural connotations contained in the shapes and decorative patterns of column base carvings. Although column bases have largely lost their functional purpose in contemporary life, they continue to serve as decorative pieces, enhancing cultural value in homes, revitalizing intangible cultural heritage, and facilitating the inheritance of traditional culture. Despite Huizhou carving techniques being recognized as a national intangible cultural heritage, the field faces challenges, such as a shortage of skilled inheritors and limited industrial growth. Zhao (2019) proposed strategies for realistic reproduction, digital management, and dynamic protection through digital technologies, emphasizing the importance of talent cultivation, database improvement, and increased funding. Tang (2020) advocated for conceptual innovation, the adoption of new technologies to transform traditional industries, and government-enterprise collaboration to drive the transformation, upgrade, and high-quality development of the Huizhou woodcarving industry.

Supported by policies and social environment, this period saw strong research interest and enthusiasm for traditional Huizhou houses. Scholars pursued diverse research themes, and significant progress was made.

4.2.3. The third stage: Industrial development oriented toward spatial narratives (2021 – 2023)

As Huizhou traditional decorative arts increasingly enter the commercial market as consumer symbols, many design

products remain in mechanized, low-cost, imitative, and repetitive production modes. This approach emphasizes decoration at the expense of creativity and cultural depth, ignoring the uniqueness and social significance of Huizhou's traditional culture. Consequently, this practice often leads to esthetic fatigue and cultural alienation (Ren, 2021). Therefore, identifying more effective ways to apply and inherit Huizhou culture is crucial at this stage and in the future (Peng *et al*., 2021). The keyword "narrative" reflects scholars' new perspectives in their research. Scholars emphasize four key approaches to narrative in contemporary design: narrative context, narrative method, narrative content, and narrative carrier, all of which play significant roles in fostering cultural confidence (Chen, 2022). Lu *et al*. (2021) examined the cultural imagery and decorative motifs in Huizhou traditional houses, analyzing interior layouts, decorative sequences, and narrative logic. They concluded that traditional Huizhou houses form an architectural cultural system that combines ritual and secular elements. Li *et al*. (2022) explored the visual elements, rhetorical techniques, and narrative value of Huizhou woodcarving, revealing how images, patterns, and text serve narrative functions within these carvings.

In 2023, the Anhui provincial government introduced the Implementation Plan for Strengthening the Protection and Inheritance of Historical Culture in Urban and Rural Construction, prioritizing the promotion of the Huizhou historical building industry as a key initiative. Therefore, "industrial development" has emerged as an important keyword at this stage. The spatial narrative of traditional Huizhou houses is closely related to this industrial development. According to Lefebvre's theory of the production of space, the creation, transformation, and reproduction of social space are shaped by social forces, which in turn influence social structures and individual behaviors (Fang, 2023). The wealth accumulation of Huizhou merchants and their construction of houses exemplify material production within the cultural and architectural fields; in other words, the space of traditional Huizhou houses represents a cultural construction within social practice, where the production of meaning accompanies material production (Cheng, 2022). In crafting the "home" as a living space, traditional Huizhou houses deliberately construct a meaningful space imbued with deep cultural connotations and moral values. This deliberate cultural construction is achieved through visual narratives that reveal the endogenous spatial logic of Huizhou houses, influencing how people perceive and interact with them. For example, Huizhou wood carvings serve a role beyond mere decoration, constructing esthetic narratives and shaping narrative contexts and events through rhetorical techniques such as hyperbole, couplets, and metaphors. These carvings enhance spatial expression and experience, linking space with stories, memories, and identities (Fang *et al*., 2024). Huizhou wood carvings thus have the potential to enrich contemporary design practice by embodying creativity and expressiveness, offering a novel perspective for industrialization research. However, due to the different historical backgrounds of spatial production theory and Confucianism, and the inherent complexity of Huizhou's traditional residential architecture, understanding spatial, cultural, and social relationships across various theoretical frameworks presents challenges. This complexity lies in finding common ground at a deeper level between these theories (He, 2018), thereby revealing the socioeconomic structures underlying Huizhou's traditional architecture and elucidating the complex interactions between space, culture, and ethics. This multidimensional integration of theories presents new challenges for advancing the depth of research on traditional Huizhou houses.

5. Conclusion

Based on data from studies on traditional Huizhou houses published in CNKI from 2000 to 2023, utilizing information visualization software CiteSpace as a research tool, this study systematically reviews the research hotspots and trends in this field, arriving at the following conclusions:

(i) From 2000 to 2010, research on traditional Huizhou houses gradually gained momentum, with an annual increase in publications. Between 2011 and 2020, publication rates fluctuated, notably declining in 2011 but subsequently recovering in the following years, peaking in 2016 after a substantial increase in 2015. Despite a notable drop in 2018, the overall publication volume remained high, closely linked to national policies and social influences. From 2021 to 2023, publication numbers showed fluctuations and an overall decline, suggesting an increased demand for fresh research trends, methods, and innovation in the future.

(ii) Analysis of author collaboration networks reveals a relatively dispersed field, with several core authors establishing strong academic collaborations that form a foundation for research on traditional Huizhou houses. However, some early researchers did not continue with follow-up studies, and ongoing research requires greater depth and impact.

(iii) Research institutions are primarily concentrated in universities within the Anhui region, benefitting from regional proximity. However, collaboration across institutions remains limited, creating a loosely connected network. It is necessary to accelerate the integration of academic resources and establish a cohesive, interdisciplinary research system spanning institutions, regions, and disciplines.

(iv) Through keyword co-occurrence mapping and clustering mapping, the research hotspots and evolution processes of traditional Huizhou houses can be categorized into three stages. The first stage (2000–2010) focused on architectural features and cultural values of traditional Huizhou houses, emphasizing the importance of traditional culture. The second stage (2011–2020) explored the application and development paths of the cultural connotations of traditional Huizhou houses within contemporary society, including the design value of decorative arts, the inheritance of Huizhou carving techniques, and the sustainable development of Huizhou's traditional cultural symbols. The third stage (2021 – 2023) represents a comprehensive expansion of research from the previous two stages. Analysis of burst terms and recent policy guidelines reveals that current research hotspots are centered on promoting the industrial development of historical Huizhou buildings. The spatial narrative of traditional Huizhou houses has provided scholars with new research perspectives and methodologies. Scholars' attention to and understanding of traditional Huizhou houses varies across these stages, reflecting changes in research trends and offering valuable references for future research directions, thereby aiding in the inheritance and innovation of Huizhou's regional culture.

Overall, scholars have conducted extensive research on architectural decoration, cultural heritage, and technological applications, but collaboration between scholars and research institutions remains relatively scattered, lacking interdisciplinary, cross-cultural, and trans-regional teams. Currently, only a few dozen studies on traditional Huizhou houses are available on the Web of Science. Although the number has increased in recent years, most authors are from China, which restricts the depth and breadth of research on traditional Huizhou houses. The inscription of traditional Huizhou houses in the World Cultural Heritage list marks the international recognition of local architecture and its cultural value but also introduces the challenge of balancing universality and particularity within the global cultural heritage system. On the one hand, this system provides more opportunities for local culture to be showcased and to engage in broader cultural dialogues. On the other hand, local culture risks losing its essence due to the pressure of global tourism and commercialization. Striking a balance within the framework of global cultural heritage is a key issue for future studies on traditional Huizhou houses. Therefore, building closer connections between theory and practice, establishing interdisciplinary, cross-cultural, and trans-regional collaborative teams, and deepening the integration of qualitative and quantitative analyses are crucial for expanding and innovating research perspectives within the context of globalization.

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Conflict of interest

The authors declare they have no competing interests.

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Methodology: All authors
Formal analysis: You He
Writing – original draft: You He
Writing – review & editing: You He, Mohd Jaki Bin Mamat

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Availability of data

In the case of reasonable requests, the method of obtaining the original data can be consulted through the email of the corresponding author of this article.

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ORIGINAL ARTICLE

Pragmatic strategies for enhancing the implementation of urban and spatial planning: A case study of Jinan, Shandong, China

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Abstract

Efficient implementation of urban and spatial planning is essential for achieving sustainable urban growth. Nevertheless, various obstacles frequently arise, resulting in inconsistencies between planned objectives and their actual outcomes. This study focuses on pragmatic strategies to improve the implementation of urban and spatial planning, with Jinan, Shandong province, China, as a case study. By thoroughly analyzing existing challenges and prospective enhancements, the study aims to offer practical insights for improving the effectiveness and efficiency of planning initiatives in the city. Utilizing a combination of qualitative interviews, focus groups, and quantitative surveys, the study identifies significant barriers to implementation and explores viable solutions. By examining the experiences and viewpoints of diverse stakeholders involved in the planning process, the study offers targeted, practical recommendations tailored to Jinan's unique context. These findings contribute to a deeper understanding of the challenges faced in urban planning implementation and offer valuable guidance for policymakers, planners, and practitioners striving to improve planning practices in Jinan and other regions.

Keywords: Urban planning; Spatial planning; Plan implementation; Jinan; Shandong; China

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1. Introduction

Urban and spatial planning is crucial in guiding city development, promoting sustainable growth, and improving citizens' quality of life (Klopp & Petretta, 2020). Urban planning encompasses a variety of activities, including regulating land use, developing infrastructure, managing transportation systems, conserving the environment, and fostering social equity in urban areas (Grimm *et al.*, 2008). Effective strategic planning is crucial for addressing the intricate obstacles encountered by rapidly growing urban areas, encompassing population growth, economic integration, environmental deterioration,

and social disparity (Ward & Hardy, 2019). Despite its importance, nevertheless, the implementation of urban and spatial planning projects frequently faces numerous issues (Ginsburg & Koppel, 2020). These obstacles may manifest in various forms, including institutional fragmentation, resource constraints, conflicting stakeholder interests, and limited community engagement (Barossi-Filho *et al.*, 2021; Healey, 2003). Consequently, numerous planned initiatives fail to fully materialize, resulting in a disparity between urban plans and observed development outcomes (Parker & Healey, 2015).

China has experienced unprecedented urbanization, driven by rapid economic expansion and rural-to-urban migration (Yeh & Wu, 2019). Jinan, the capital of Shandong province, China, has undergone substantial changes characterized by widespread urbanization and infrastructure development (Chen & Ong, 2016). Nevertheless, urban and spatial planning in Jinan encounters obstacles similar to those in other Chinese cities, particularly in terms of implementation (Chen *et al.*, 2019).

This study aims to explore practical approaches to improve the implementation of urban and spatial planning in Jinan, Shandong province, China. To guarantee that planning efforts deliver real benefits for the city's residents, it is necessary to overcome obstacles to implementation and identify areas for improvement (Chen *et al.*, 2019). By conducting a thorough analysis of the factors impacting planning implementation in Jinan, this study seeks to provide practical solutions to address these issues.

This research aims to develop a comprehensive understanding of the intricacies associated with the implementation of urban and spatial planning, drawing on existing literature, theoretical frameworks, and empirical investigations (Healey, 2003). Utilizing a case study approach, it also seeks to generate specific insights applicable to planning practices and policies in Jinan and similar contexts (Wu & Webster, 2020). Combining qualitative and quantitative methods, such as interviews, focus groups, surveys, and data analysis, this study aspires to produce reliable findings that offer guidance to practitioners, policymakers, and researchers in their endeavors to improve planning implementation in Jinan and other urban areas, drawing on foundational works such as Grimm *et al.* (2008) and Chen *et al.* (2019). Ultimately, this study aims to make a meaningful contribution to advancing urban and spatial planning theory and practice, supporting sustainable and equitable urban development in Jinan and comparable cities in China and beyond.

2. Literature review

Theoretical frameworks on the implementation of urban and spatial planning offer a conceptual foundation for comprehending the intricacies of translating planning aspirations into actionable outcomes (Healey, 2003). A process-oriented approach prioritizes collaboration, stakeholder involvement, and adaptive management as crucial factors in achieving planning objectives (Innes & Booher, 2003). Furthermore, governance theories emphasize the significance of institutional structures, power dynamics, and decision-making processes in influencing planning outcomes (Pierre & Peters, 2000). Comprehensive, integrated approaches that take into account the social, economic, and environmental aspects of development are emphasized in key ideas and best practices in urban and spatial planning (Fainstein *et al.*, 2019).

Contemporary discourse revolves around themes such as sustainable development, smart growth, and resilience. Challenges in implementing planning involve issues such as institutional fragmentation, resource constraints, stakeholder disagreements, and limited community engagement (Healey, 2003; Barossi-Filho *et al.*, 2021). These obstacles frequently lead to delays, concessions, and suboptimal results, which diminish the effectiveness of planning interventions (Parker & Healey, 2015). Strategies for improving planning effectiveness include enhancing coordination among government agencies, mobilizing resources, fostering stakeholder collaboration, and encouraging meaningful community engagement (Klopp & Petretta, 2020; Roberts & Sykes, 2000). Furthermore, employing adaptive management strategies, leveraging technology, and integrating principles of equity and social justice are crucial to addressing intricate planning obstacles and achieving sustainable development objectives (Campbell, 1996; Healey, 2003).

This literature review offers a thorough analysis of the theoretical basis, key concepts, challenges, and strategies related to the effective implementation of urban and spatial planning in Jinan, Shandong, China. By synthesizing and critically assessing existing literature, this literature review establishes a valuable framework for analyzing real-world data and producing actionable insights that contribute to the advancement of planning theory and practice.

2.1. Theoretical frameworks for urban planning implementation

Understanding the complex processes involved in translating urban planning initiatives into practical outcomes requires a solid theoretical foundation (Healey, 2003). Several fundamental theoretical frameworks contribute to this understanding:

1. Rational planning model: This model views planning as a methodical and logical process driven by clear goals, thorough data analysis, and optimal decision-making (Pierre & Peters, 2000). It employs a top-down approach in which planners identify issues, set objectives, formulate strategies, and execute plans with minimal deviation from the intended trajectory.
2. Incrementalism: In contrast, the incrementalism model proposes that planning occurs gradually and in small steps rather than through extensive, long-term strategies (Lindblom, 1959). This approach recognizes the inherent intricacy and unpredictability of planning processes, emphasizing adaptability, responsiveness, and the capacity to learn from previous encounters.
3. Advocacy planning: This framework highlights the importance of planners as advocates for marginalized communities, promoting social justice (Davidoff, 1965). This paradigm prioritizes public involvement in decision-making, empowers communities, and advocates for policies that redistribute resources to solve disparities and promote equity in urban development.
4. Collaborative planning: Collaborative planning emphasizes the importance of partnerships and collaboration among diverse stakeholders. This model recognizes the necessity of consensus-building, negotiation, and shared decision-making to address complex urban challenges and achieve sustainable development goals (Innes & Booher, 2003).
5. Communicative planning: This approach emphasizes the importance of clear and honest communication among all involved parties, fostering mutual understanding, trust, and a shared vision for the city's future development (Healey, 1997).

These theoretical frameworks provide distinct viewpoints on planning processes, the responsibilities of planners and stakeholders, and the factors that impact planning results. By drawing insights from these models, urban planners can develop comprehensive, context-sensitive strategies for the implementation of urban and spatial planning, enabling them to effectively address the diverse requirements and difficulties facing modern cities.

3. Methodology

This study aims to enhance the implementation of urban and spatial planning in Jinan, Shandong, China, through a mixed-methods approach that integrates both qualitative and quantitative techniques. The research began with a literature review to identify relevant theoretical frameworks and best practices. The research design includes qualitative interviews with key stakeholders and quantitative surveys of affected communities. Sampling techniques consist of purposive sampling for interviews to specifically target experts and stakeholders and random sampling for surveys to gather representative feedback from the general population. Data collection was conducted through structured interviews and questionnaires. Data analysis employed thematic analysis for qualitative data and statistical methods for quantitative data. In addition, a cross-case analysis was conducted to compare Jinan's planning practices with those of other cities, deriving broader insights.

The study adheres to ethical principles, including informed consent and participant anonymity, and employs software tools to ensure rigorous data analysis.

The central research question guiding this study is: "What factors contribute to the poor implementation rate of contemporary plans?" The questions focus on identifying barriers to effective implementation in urban planning and exploring potential solutions.

It is hypothesized that increased stakeholder engagement and contextual adaptations can significantly improve planning outcomes. The hypothesis further suggests that the successful execution of a plan is heavily influenced not only by the effectiveness of the implementation stage but also by the foundation established during the preceding planning stages.

To analyze the main research question, this article addresses three sub-questions:

(i) What challenges are encountered during the implementation of a plan?
(ii) What key factors influence the implementation of a plan?
(iii) What strategies can be employed to enhance the implementation of a plan?

3.1. Statement of the problem: Challenges in the implementation of urban planning

The implementation of urban and spatial planning in Jinan, Shandong, China, faces several significant challenges that undermine its overall efficiency and effectiveness. A prominent issue is institutional fragmentation due to overlapping responsibilities across multiple government agencies, which leads to coordination problems, inconsistent planning efforts, and a lack of unified vision among stakeholders. As a result, planning initiatives often suffer from delays and inefficiencies. In addition, limited resources, including inadequate funding and staffing, further exacerbate these issues. This shortage of financial and human resources restricts the capacity to undertake and complete ambitious projects, often resulting in suboptimal outcomes or postponements. Conflicting interests among developers, citizens, and government authorities add another layer of

complexity, making it difficult to achieve consensus and effectively implement plans. The decision-making process is frequently hindered by competing agendas and power struggles. Moreover, inadequate community engagement significantly impacts the legitimacy and inclusiveness of planning procedures, failing to address the diverse needs and perspectives of local residents. This lack of engagement can lead to public resistance and reduced support for planning initiatives. Addressing these challenges is crucial for aligning urban and spatial planning efforts with Jinan's dynamic growth and development needs. Effective solutions must focus on improving coordination among stakeholders, securing adequate resources, fostering stakeholder collaboration, and enhancing community involvement to ensure that planning initiatives are both effective and responsive to the city's rapidly evolving urban landscape.

This study identifies several critical obstacles to effective implementation of urban plans in Jinan. Bureaucratic inefficiencies and regulatory complexities create significant barriers, causing delays and difficulties in acquiring necessary permits and navigating complex administrative procedures. These inefficiencies often slow project timelines and increase costs. Restricted financial resources further constrain the scope and quality of planning initiatives, preventing the full realization of ambitious goals and leading to compromises in project outcomes. In addition, challenges in stakeholder coordination hinder effective communication and collaboration among government agencies, developers, community groups, and non-profit organizations. This lack of alignment and coordination can lead to fragmented efforts and ineffective planning outcomes. In addition, socio-political factors, such as conflicting interests and internal power struggles, further complicate the decision-making process, impacting the overall effectiveness of planning initiatives.

To address these challenges, the study recommends several strategic interventions, including developing a more favorable regulatory framework, enhancing financial mechanisms to support planning projects, broadening stakeholder engagement to ensure widespread support, and promoting transparent governance practices. Investing in capacity-building, leveraging advanced technologies, and fostering a culture of continuous improvement is also essential for improving plan implementation. These measures aim to ensure sustainable urban development and enhance the quality of life for Jinan's residents by creating a more effective and responsive planning environment.

3.2. Rationale for studying Jinan, Shandong, China

Jinan, the capital of Shandong province, China, offers a compelling case for examining urban and spatial planning challenges and strategies due to its dynamic growth and development. The city's rapid urbanization and robust economic expansion have driven substantial infrastructure development and significant demographic shifts, creating a complex landscape for planning professionals and policymakers. Jinan's strategic location in eastern China and its role as a regional economic center further underscore the need for effective urban planning to manage its expansion, balance development with environmental sustainability, and promote social equity. The city's unique combination of growth pressures and planning challenges provides valuable insights into the practical difficulties of implementing urban plans in a rapidly evolving context. By studying Jinan, researchers can uncover critical factors that affect planning implementation and develop strategies to address similar issues in other Chinese cities experiencing rapid growth. The insights gained from Jinan's experiences contribute to advancing urban planning theory and practices, offering lessons that are applicable both within China and globally. Understanding Jinan's planning dynamics not only strengthens local strategies but also yields broader implications for managing urban growth and development in diverse contexts worldwide.

3.3. Case study: Jinan, Shandong, China

Jinan, the administrative center of Shandong province, China, is undergoing rapid urbanization and economic growth due to its advantageous location and significant regional significance in eastern China. As discussed, the city's urbanization is marked by substantial infrastructure expansion, population growth, and industrial development, resulting in considerable changes to its urban scenery and socioeconomic patterns. Nevertheless, Jinan's progress is accompanied by intricate planning obstacles, such as geographical disparities, environmental degradation, and social inequity.

Urban and spatial planning in Jinan is governed by a complex system of institutional arrangements involving multiple government organizations and ministries responsible for land use management, infrastructure development, and environmental protection. Key stakeholders include urban planners, government officials, developers, community leaders, and non-governmental groups. Nevertheless, the cooperation and partnership among these parties are frequently impeded by bureaucratic divisions, conflicting agendas, and power dynamics, resulting in fragmented planning endeavors and unsatisfactory outcomes.

Challenges encountered during the planning and implementation process in Jinan encompass insufficient resources, institutional fragmentation, stakeholder

disagreements, and low levels of community involvement. These obstacles manifest as delays, compromises, and inefficiencies in project implementation, which weaken the effectiveness of planning initiatives and exacerbate urban problems. Despite concerted attempts to address these issues, the implementation of plans in Jinan remains hindered by persistent obstacles, highlighting the need for innovative strategies and cooperative approaches to overcome them.

Data from interviews and surveys carried out in Jinan provide valuable insights into the intricacies of planning implementation and the viewpoints of various stakeholders. The data reveal several key themes, including the crucial role of coordination and collaboration among government agencies, the necessity for additional resources and capacity-building initiatives, the importance of meaningful community engagement, and the challenges of balancing economic development, environmental sustainability, and social equity. These findings offer unique insights into the dynamics of planning implementation in Jinan and provide actionable recommendations for improving planning effectiveness in the city.

3.4. Implications of spatial and urban planning regulation on local-level implementation

The spatial and urban planning regulations in Jinan, Shandong province, China, significantly influence local-level implementation, shaping the city's development path and affecting residents' quality of life. These regulations establish a systematic framework that directs land use, infrastructure development, and environmental preservation within the municipality. Jinan's planning policies aim to optimize land use, manage urban sprawl, and encourage sustainable growth patterns through zoning districts and land-use rules.

In addition, Jinan's urban planning regulations promote the establishment of livable communities by encouraging mixed-use developments, pedestrian-friendly districts, and accessible public areas. Furthermore, these policies are essential for safeguarding the city's cultural heritage monuments, natural landscapes, and biodiversity, thereby improving Jinan's unique character and appeal as a desirable place for living, working, and visiting.

Nevertheless, the implementation of spatial and urban planning legislation in Jinan encounters obstacles, such as limited resources, conflicting stakeholder interests, and administrative inefficiencies. Addressing these issues requires effective coordination and collaboration among government departments, private developers, community organizations, and residents. By fostering partnerships and encouraging inclusive decision-making procedures, local authorities in Jinan have the potential to optimize the beneficial effects of planning regulations on urban development, sustainability, and overall quality of life.

Table 1 provides a detailed summary of legislative acts and urban/spatial planning documents planned for implementation in Jinan, Shandong, China, from 2013 to 2023, along with their corresponding implementation periods. The legislative acts address critical areas such as urban development, land use laws, environmental protection, housing policy, transportation, economic development, and historic preservation.

At the same time, the urban/spatial planning documents provide targeted plans and recommendations to support the city's development objectives. These documents encompass a range of urban planning frameworks, including master plans, zoning ordinances, comprehensive mobility plans, sustainable development strategies, green infrastructure plans, urban renewal programs, parks and

Table 1. Legislative acts and urban/spatial planning documents in Jinan, Shandong, China (2013 – 2023)

Year	Legislative acts	Urban/spatial planning documents	Implementation period
2013	Jinan Urban Development Plan	Jinan Master Plan	2013 – 2020
2014	Land Use Regulations	Jinan Zoning Ordinance	2014 – 2023
2015	Environmental Protection Act	Jinan Comprehensive Mobility Plan	2015 – 2025
2016	Building Code	Jinan Sustainable Development Strategy	2016 – 2030
2017	Housing Policy	Jinan Green Infrastructure Plan	2017 – 2025
2018	Transportation Act	Jinan Urban Renewal Program	2018 – 2027
2019	Economic Development Strategy	Jinan Parks and Recreation Plan	2019 – 2028
2020	Historic Preservation Ordinance	Jinan Climate Change Adaptation Plan	2020 – 2030
2021	Affordable Housing Initiative	Jinan Public Space Improvement Scheme	2021 – 2027
2022	Energy Efficiency Standards	Jinan Digital Master Plan	2022 – 2030
2023	Smart City Initiative	Jinan Resilience Strategy	2023 – 2035

Source: Hypothetical data based on urban planning principles and practices

recreation plans, climate change adaptation plans, public space improvement schemes, digital master plans, and resilience strategies. Collectively, these legislative acts and planning documents establish a holistic, inclusive, and sustainable framework to guide Jinan's growth and development, guaranteeing the city's long-term prosperity and citizens' well-being.

3.5. Answering the research questions

The research questions and hypotheses in this study aim to uncover the complex factors contributing to the low implementation rates of contemporary urban and spatial plans in Jinan, Shandong, China. The study identifies several significant obstacles to effective plan implementation. Bureaucratic inefficiencies and regulatory complexities are major barriers, as complicated administrative procedures and overlapping regulations hinder the timely implementation of projects, leading to delays and increased costs.

Restricted financial resources also play a critical role; inadequate funding and limited personnel constrain the ability to undertake and complete ambitious projects, often resulting in compromises in scope and quality. Coordination challenges among stakeholders—including government agencies, developers, community groups, and non-profits—further complicate the planning process, as ineffective communication and collaboration lead to fragmented efforts and misaligned objectives. Socio-political factors, such as conflicting interests and power struggles, exacerbate these issues by complicating decision-making and undermining planning consistency.

The study highlights that successful implementation is not solely dependent on the effectiveness of the implementation stage but is also significantly influenced by the preceding planning stages. Stakeholder engagement and contextual adaptations are crucial in shaping planning outcomes, with varying interests and priorities impacting the success of initiatives.

To enhance plan implementation, the study recommends developing a more favorable regulatory framework with streamlined administrative processes and clear decision-making norms. Strengthening financial mechanisms is essential to overcoming resource limitations and ensuring adequate project funding and staffing. Expanding stakeholder engagement and participation procedures can foster inclusive decision-making and a sense of ownership among all parties involved. In addition, advocating for transparent and accountable governance structures can build trust and strengthen support for implementation efforts. Further, investing in capacity-building and leveraging advanced technologies can improve planning processes and outcomes. By addressing these challenges and implementing the proposed strategies, policymakers, planners, and practitioners can enhance the effectiveness and efficiency of urban and spatial planning in Jinan, ultimately contributing to sustainable development and an improved quality of life for the city's residents.

4. Analysis and discussion

The analysis of legislative acts and urban/spatial planning documents related to Jinan, Shandong, China, provides critical insights into the city's developmental trajectory and planning challenges. Qualitative data from interviews and surveys reveal several recurring themes crucial for understanding the implementation difficulties in Jinan. Key themes include the imperative for sustainable development, the urgent need for improved infrastructure, and the challenges posed by rapid urbanization. Stakeholder perspectives emphasize that collaborative planning and active community engagement are pivotal in addressing these issues effectively. Sustainable development emerged as essential for long-term urban viability, highlighting the need for planning that balances growth with environmental and social considerations.

Quantitative data analysis adds an empirical dimension, assessing the implementation status and effectiveness of various planning projects. These data provide insights into urban expansion patterns, land use dynamics, transportation trends, and environmental impacts, allowing for a more nuanced evaluation of planning efficacy. It helps identify which interventions have been successful and which require adjustment. For instance, statistical analysis may reveal discrepancies between planned objectives and actual outcomes, shedding light on areas where implementation has faltered. Comparing these findings with existing literature highlights both convergences and divergences. While some results align with established best practices and theoretical models, others point to unique challenges and opportunities specific to Jinan. This comparison stresses the need for context-specific solutions tailored to local conditions. Jinan's unique urban landscape – characterized by rapid growth and particular socio-political dynamics – requires customized planning approaches rather than one-size-fits-all solutions.

In summary, the analysis reveals that addressing Jinan's urban planning challenges necessitates a comprehensive strategy integrating economic development with environmental sustainability and social equity. The study advocates for adaptive and inclusive decision-making processes that accommodate emerging challenges and leverage opportunities for positive change. By aligning

planning strategies with local realities and stakeholder needs, this research underscores the importance of developing tailored solutions that enhance the effectiveness and efficiency of urban and spatial planning in Jinan.

5. Implications and recommendations

The study identifies significant barriers to effective plan implementation in Jinan, including bureaucratic inefficiencies, financial constraints, challenges in stakeholder coordination, and complex socio-political dynamics. These issues call for a strategic approach to improve planning practices and outcomes. Overcoming bureaucratic inefficiencies and regulatory complexities is crucial for timely and effective implementation. Streamlining administrative processes and simplifying regulatory requirements can reduce delays and facilitate smoother project execution. Financial constraints, a major obstacle, necessitate innovative financing mechanisms and more effective resource allocation to ensure that ambitious planning goals are attainable. In addition, the need for improved stakeholder coordination emphasizes the importance of establishing robust communication and collaboration frameworks among government agencies, developers, community groups, and nonprofit organizations. Addressing socio-political factors, such as conflicting interests and power struggles, are also essential for aligning diverse perspectives and achieving consensus.

The study recommends several practical strategies to address these challenges. First, developing a regulatory framework that promotes efficiency and transparency can help mitigate bureaucratic obstacles and improve planning implementation. Implementing financial strategies to enhance funding mechanisms and resource allocation will support the realization of planning objectives. Expanding stakeholder engagement and participation processes is critical to fostering inclusive decision-making and a sense of ownership among all involved parties. Establishing transparent governance structures will also increase trust and support for planning initiatives.

Investing in capacity-building programs and advanced technologies can further enhance the effectiveness of planning processes. In addition, promoting a culture of continuous improvement and adaptability will enable planners to respond to emerging challenges and leverage new opportunities. By implementing these recommendations, Jinan may improve the implementation of urban and spatial planning initiatives, leading to more sustainable urban development and an enhanced quality of life for its residents. These insights also offer valuable lessons for other cities facing similar growth and planning challenges, contributing to the advancement of urban planning theory and practice both within China and globally.

6. Conclusion

This study critically examined practical strategies for enhancing the implementation of urban and spatial planning in Jinan, Shandong, China, uncovering key insights through a detailed analysis of the city's planning context, legislative framework, and stakeholder dynamics. The research identified several critical obstacles to the effective implementation of urban plans, including administrative inefficiencies, limited financial resources, and conflicting stakeholder interests. These findings highlight the need for targeted interventions, such as streamlining regulatory processes, enhancing financial mechanisms, and fostering improved stakeholder coordination. The practical recommendations emphasize establishing clear regulatory structures, investing in skill development, and actively involving stakeholders in decision-making processes.

This study makes a meaningful contribution to the field of urban and spatial planning by offering a contextualized approach tailored to Jinan's specific challenges. By integrating theoretical frameworks with empirical evidence from the case study, it provides actionable guidance for planners and policymakers working in similar urban environments. However, the study acknowledges certain limitations, including its reliance on secondary data and its focus on a single case study, which may impact the generalizability of the findings. Future research could benefit from comparative studies across different cities in China or internationally to explore the effectiveness of various planning strategies. In addition, longitudinal studies that track the long-term impacts of planning projects could provide deeper insights into their enduring effects.

In conclusion, addressing the identified constraints and leveraging the insights gained from this research can advance our understanding of effective urban and spatial planning practices, contributing to more successful planning outcomes in diverse urban settings.

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Conflict of interest

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Availability of data

All data are available upon application/request.

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ORIGINAL ARTICLE

Impact of environmental parameters on moisture damage in plastered heritage buildings: A case study of Anchang historical town, Shaoxing, Zhejiang, China

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Abstract

Anchang historical town, a historic Jiangnan water town in Shaoxing city, Zhejiang province, China, is home to well-preserved heritage buildings dating back to the Northern Song dynasty (960 – 1127). Despite preservation efforts, environmental factors, such as high humidity, heavy rainfall, and prolonged sunlight exposure continue to cause material degradation. Addressing the deterioration challenges requires comprehensive analysis and diagnosis to identify root causes and ensure the sustainable restoration of these cultural relics. To investigate the deterioration of historical buildings in Anchang historical town, the research team employed instrument-based detection, software simulations, data integration, and other methods. Two cultural heritage buildings were selected as case studies: the former site of the Bank of China at Wangjiaqiao (BCW building) and the residence of He Gongsheng at Siqiao (HGS building). In this study, a comprehensive analysis was conducted at both macro- and micro-levels, utilizing building models and incorporating environmental parameters. Macroenvironmental factors, such as regional temperature, sunlight, climate, humidity, and soil type were examined. Simultaneously, microenvironmental data, including wall materials, wall temperature, wall humidity, and sunlight exposure, were collected to analyze the impact of factors such as site selection, proximity to water bodies and vegetation, building layout and orientation, and window placement. By employing statistical analysis, inductive reasoning, and other techniques, the study identifies the mechanisms underlying wall damage and predicts future trends. Ultimately, this study aims to provide data-driven insights for the development of scientifically sound preventive conservation strategies for cultural relics and buildings, thus guiding future restoration efforts.

Keywords: Heritage buildings; Deterioration assessment; Physical environment; Deterioration mechanism

1. Introduction

Anchang historical town, located in the Keqiao district of Shaoxing city, Zhejiang Province, China, is a well-preserved Jiangnan water town with a rich history. According to historical records, its origins date back to the Northern Song dynasty (960 – 1127). During the Ming (1368 – 1644) and Qing (1644 – 1912) dynasties, Anchang historical town played a significant political and commercial role in Shaoxing by attracting numerous merchants. Presently, many heritage buildings in Anchang (Figure 1) remain well-preserved due to the dedicated efforts of local government and residents to maintain and restore these historic structures (Silva *et al.*, 2017). Nevertheless, some buildings continue to suffer from degradation issues such as powdering, salt crust formation, and cracking. The humid climate and rainy seasons characteristic of the Jiangnan region exacerbate these problems, causing dampness and mold, which can lead to material deterioration, structural collapse, and decay. Prolonged sunlight exposure also accelerates the aging and cracking of building materials, detrimentally impacting both their structural integrity and appearance (Brambilla & Gasparri, 2021). Overall, the degradation of building materials is closely linked to environmental factors.

To investigate these issues, this study focuses on two historical buildings in Anchang historical town: (i) The former site of the Bank of China at Wangjiaqiao (BCW building) and (ii) the residence of He Gongsheng at Siqiao (HGS building). These buildings were selected as case studies to analyze the mechanisms of building deterioration and develop strategies for their sustainable preservation.

Recent structural assessments and analyses of historic masonry buildings have emphasized the importance of understanding their historical periods, construction processes, and geometric deformations. Structural analyses are typically combined with historical research, site inspections, laser scanner surveys, and deformation analysis to evaluate the effects of environmental factors such as landslides and identify the causes of damage and deformation. For instance, a finite element model was created by reconstructing the geometrically undeformed configuration of an entire church, removing all deformations identified through laser scanning (Sacco *et al.*, 2023). A qualitative-quantitative approach has also been used to assess building conditions by analyzing the photographic records, preparing damage identification tables, and classifying severe pathological manifestations using the gravity, urgency, and tendency (GUT) method.

The necessity of preserving historical heritage is underscored by the relationship between observed façade damage and the overall degradation of buildings (Souza

Figure 1. Map of Anchang historical town. Source: Drawing by Jie Wei

et al., 2023). Some studies have further utilized logistic regression modeling to predict heritage damage and evaluate the extent of building deterioration. Results from such models highlight the significance of parameters such as building age, type, style, and value in predicting the degree of deterioration, revealing correlations between these factors and heritage building deterioration (Chen *et al.*, 2023). Therefore, restoring the service life of these buildings requires comprehensive investigative analysis and diagnoses of root causes and contributing factors. Beyond visual diagnosis of pathological manifestations, the causes, origins, mechanisms, and appropriate treatment recommendations for these issues must also be thoroughly detailed.

A questionnaire survey conducted among local architects in the holy city of Karbala, Iraq, explored the relationship between architects as designers and various factors influencing the city's urban character (Farhan *et al.*, 2020). By examining the existing historical urban and architectural structures, the study uncovered major challenges threatening the traditional cultural and architectural identity of the city. Top-down and bottom-up strategies were proposed to preserve the historic architectural and urban characteristics of Karbala while simultaneously reviving its social and cultural activities and traditions (Farhan *et al.*, 2022).

To further investigate the factors contributing to heritage deterioration, the research team collected data on regional environmental conditions, including temperature, humidity, sunlight, wind speed, hydrology, and geography. Tests were conducted on deteriorated sections of heritage buildings' walls to gather specific data on temperature and humidity, among other factors. By employing statistical and inductive methods, the team identified the root causes of the deterioration (Karakale *et al.*, 2023;

Kim *et al.*, 2022). Moreover, by gathering and analyzing extensive environmental data and imagery, the team aims to uncover the mechanisms underlying the deterioration of cultural relics and buildings (Chen *et al.*, 2023). This analysis not only facilitates predictions about the future progression of such issues but also provides critical information for subsequent prevention and treatment measures, ensuring the sustainable preservation of cultural relics and buildings.

2. Environment and main building characteristics

2.1. Physical environment information acquisition

Macroenvironmental factors play a key role in the deterioration of heritage buildings, with geoclimatic conditions being particularly significant. Precipitation levels and sunlight exposure affect the relative humidity of the surrounding environment. Variations in relative humidity and temperature directly impact the water vapor content in the air and the dryness or wetness of heritage building surfaces (Fontenele *et al.*, 2022). For example, in humid climates, heritage buildings are more vulnerable to water vapor erosion, increasing the risk of moisture-related deterioration. Frequent fluctuations in humidity and temperature can cause the materials of heritage buildings to expand and contract, leading to deformation and cracks. Therefore, collecting and analyzing data on the physical environment of historic heritage buildings is crucial for understanding and mitigating their deterioration (Ksit *et al.*, 2022).

2.1.1. Meteorological parameters

Shaoxing City, located in the northern subtropical monsoon climate zone, experiences a typical monsoon climate. The region is characterized by a mild, humid, and rainy climate with ample sunlight and four distinct seasons throughout the year. In spring, frequent interactions between cold and warm air masses result in large temperature fluctuations. Summers are hot and humid, with concentrated rainfall during the rainy season, usually from late June to early July, leading to increased precipitation and air humidity (Gao *et al.*, 2021; Lallam *et al.*, 2023). Autumns see decreased humidity due to the influence of cold air from the north, while winters are colder with reduced precipitation, influenced by monsoonal activity (Zybała *et al.*, 2024).

According to the data from China Meteorological Data Network for the period 1991 – 2020, the average annual temperature in Shaoxing ranges between 15°C and 17°C. Recorded extremes include a maximum of 42.5°C and a minimum of −10.2°C (Figure 2). The frost-free period lasts approximately 230 to 270 days annually, and the average wind speed ranges from 1.5 to 2 m/s (Figure 3).

Meteorological data for Shaoxing was imported into Rhino software and processed using Grasshopper components. These components were used to visualize temperature, precipitation, wind speed, and other key data, creating intuitive graphical outputs. In addition, the data were uploaded to a charting webpage (dysprosium chart) to generate a mixed chart of folded lines and columns, providing a clear depiction of data relationships (Figure 4).

Shaoxing experiences its longest sunlight duration in July, while January sees the shortest. The city's relative atmospheric humidity remains consistently above 70% throughout the year, with an annual average of 76%. Average annual precipitation is approximately 1,300 mm, concentrated mainly in spring and summer, particularly during the rainy and typhoon seasons. The highest precipitation occurs in June (Table 1).

2.1.2. Topography

The topography of Shaoxing City is diverse and complex. The city is situated at the intersection of three major geomorphological units: the western and eastern Zhejiang hills and mountains, and the northern Zhejiang plains. The overall terrain is higher in the south and lower in the north, forming a geomorphological pattern of mountains enclosing basins and concentrated plains. This terrain structure resembles a "mountain" shape (Buda *et al.*, 2021). Anchang historical town, located in the northern part of Shaoxing city, is characterized by a relatively uniform plain landscape but a complex underground structure. This subsurface environment includes widely distributed layers of silt, soft soil, and hard soil, offering a diverse foundation for surface construction (Macamo *et al.*, 2024). The primary soil types in Shaoxing are red, yellow-red, and yellow soils (Table 2). These soils are loose in structure, with good water permeability and retention. They are generally water-retentive and acidic, with soil moisture levels reaching up to 0.40 m^3/m^3 in summer.

2.1.3. Hydrogeology

Shaoxing City is rich in rivers and lakes. Influenced by the orientation of mountain ranges and the subtropical monsoon climate, the rivers in Shaoxing are typically abundant with water. However, water levels vary significantly across seasons, with two distinct flood seasons each year. The upper reaches of the rivers are characterized by plentiful water resources, while the lower reaches are often affected by tidal influences (Nikolić *et al.*, 2024). The major rivers in Shaoxing include the Cao'e River, which flows into the Qiantang River, the Puyang River, and the

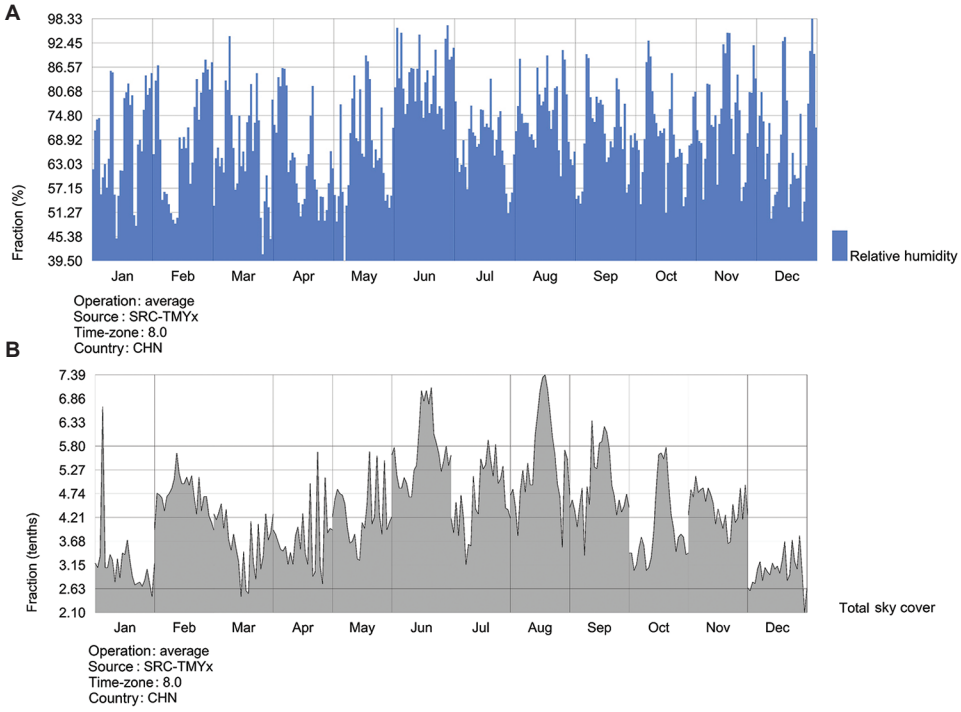


Figure 2. Meteorological data. (A) Atmospheric humidity. (B) Daily total cloud cover variation. Source: Drawing by Jie Wei and Ying Zhu

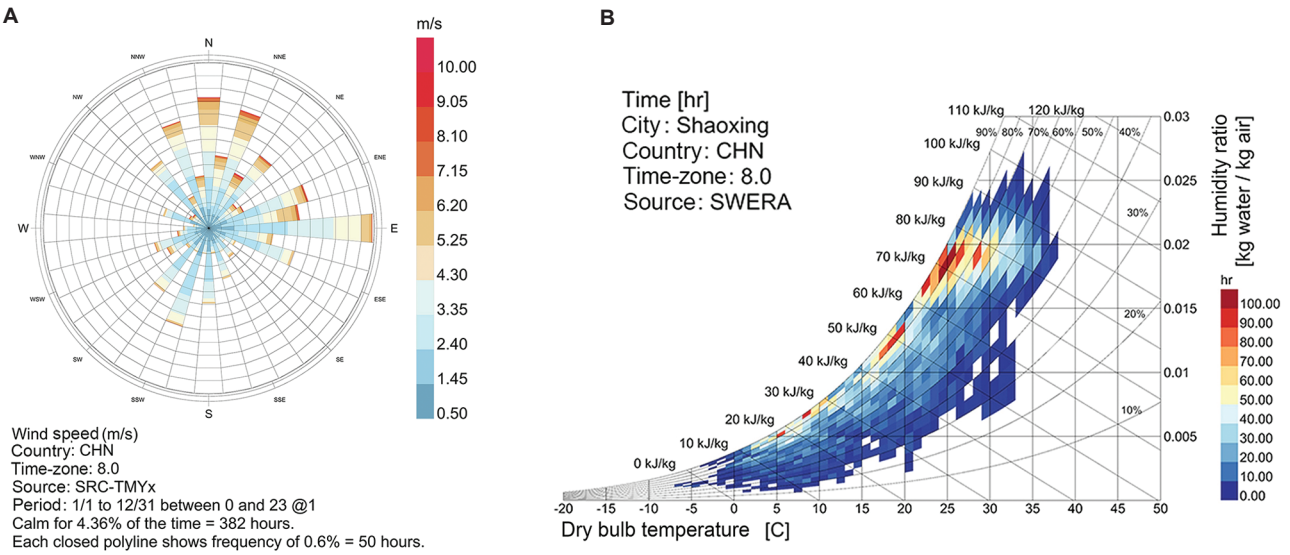


Figure 3. Meteorological data. (A) Wind speed. (B) Enthalpy-humidity chart. Source: Drawing by Jie Wei and Yihan Wang

Jianhu Lake system. Anchang historical town is crisscrossed by a dense network of internal rivers that connect through the Qiantang River to the Grand Canal, facilitating links to cities such as Beijing, Suzhou, Hangzhou, and Ningbo.

2.2. Image information acquisition

Collecting information on heritage buildings is a fundamental step in assessing architectural deterioration. This process not only helps document the current state of decay in heritage buildings but also provides a scientific basis for developing preservation strategies and maintenance measures to mitigate further deterioration (Ciuffreda *et al.*, 2024; Xia *et al.*, 2024; Zhang *et al.*, 2023). The research team documented wall deterioration in heritage buildings by photographing affected areas with a camera, measuring the extent of damage using a meter scale, and employing

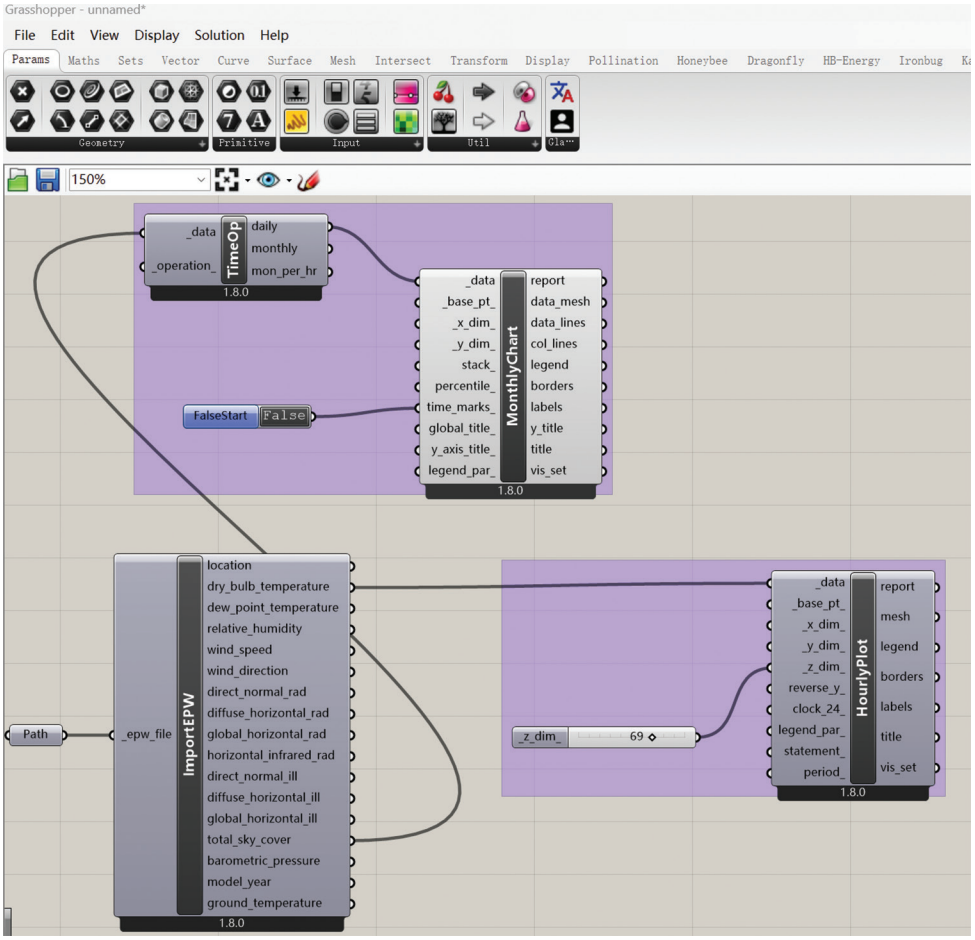


Figure 4. Grasshopper components for atmospheric humidity in Rhino software. Source: Drawing by Jie Wei

Table 1. Climatic data

Month	Average temperatures (0.1℃)	Extreme maximum temperatures (0.1℃)	Extreme minimum temperatures (0.1℃)	Average precipitation over the year (0.1 mm)	Maximum precipitation per month in a year (0.1 mm)	Minimum precipitation per month in a year (0.1 mm)	Average relative humidity (%)	Maximum wind speed (m/s)	Average wind speed (m/s)
1	5	25.5	−7.9	993	2,573	305	78	10	1.6
2	7.1	29.1	−4.6	895	2,291	275	77	12	1.8
3	11.2	33.9	−2	1,374	2,893	412	75	11.3	2
4	17.2	35	0.5	1,203	2,475	445	72	11.7	1.9
5	22.3	38.4	8.2	1,394	2,782	304	72	14	1.9
6	25.3	38	15.3	2,317	5,274	376	80	13.1	1.7
7	29.6	40.7	17.1	1,405	3,341	31	73	12.9	2
8	29	42.5	19	1,938	3,355	341	76	16.7	2.1
9	24.5	37.9	12.9	1,328	2,496	254	80	16.8	1.9
10	19.2	34	5.2	807	4,024	77	78	9.7	1.6
11	13.4	31.5	−2.4	807	2,457	141	78	10.2	1.5
12	7.3	24.8	−10.2	726	1,952	47	76	10.1	1.5

Table 2. Soil types in Shaoxing city, Zhejiang Province, China

Name of the soil	Soil class	Subclass name	Parent material
Red pine mud	Red	Red	Weathering of metamorphic rocks such as gneiss, schist, and mixed rocks
Sand sticky red mud	Red	Red	Coarse-grained granite, granitic porphyry weathered remnant slope deposits
Yellow and red soil	Red	Yellow-red soil	Remnant slope deposits of weathered materials, such as shale, schist, phyllite, siliceous mudstone, and siltstone.
Yellow slime	Red	Yellow-red soil	Remnant slope deposits of basalt, andesite porphyry, and other basement neutral rocks
Mountain yellow slime	Yellow	Yellow	Basalt, andesite, and other basement and neutral rock weathered remnant slope deposits
Oil yellow mud	Limestone (rock) soil	Brown limestone soil	Limestone weathering
Sour purple gravel soil	Purple soil	Acidic purple soil	Cretaceous reddish-purple sand shale and Jurassic purple conglomerate weathering
White rock sand	Coarse bone soil	Acidic coarse bone soil	Granite-weathered remnant slope deposits
Red gravel soil	Coarse bone soil	Acidic coarse bone soil	Remnant slope deposits weathered by light-colored tuff
Brown soil	Coarse bone soil	Neutral coarse bone soil	Basalt-type weathering
Bottom salty sand	Tidal soil	Gray tidal soil	Modern estuarine sediments
River mud	Tidal soil	Gray tidal soil	River tidal sediments (fluvial-marine facies)
Yellow powder mud field	Paddy soil	Cultivating paddy soil	Yellow-red soil reaccumulation of weathered shale
Old yellow tendon mud field	Paddy soil	Cultivating paddy soil	Quaternary laterite
Yellow mud field	Paddy soil	Cultivating paddy soil	Reaccumulation of yellow-red soil
Painted sand fields	Paddy soil	Flooding paddy soil	Shallow marine sediments
Red sticky field	Paddy soil	Flooding paddy soil	Red clay with weathered basalt (red soil)
Jiangtu mud field	Paddy soil	Flooding paddy soil	Fluvial mud (gray fluvial soil) developed in fluvial-marine sediments
Small powder mud fields	Paddy soil	Infiltration of paddy soil	Fluvial-marine sediments
Green powder mud field	Paddy soil	Desubmersible paddy soil	Fluvial-marine or lacustrine marine sediments
Wushan green purple mud field	Paddy soil	Desubmersible paddy soil	Lacustrine or lacustrine marine sediments

an infrared thermal camera (FLIR C5 SE-187, Flir system, Estonia to detect and map humidity levels. Over 20 heritage buildings in Anchang historical town, such as the BCW building, HGS building, and Suikang Chancery, were studied, and their patterns of deterioration were categorized. Among these, the BCW and HGS buildings were identified as particularly representative of the deterioration types, offering valuable insights into the underlying causes and mechanisms (Figures 5 and 6).

Figure 5. The former site of the Bank of China in Wangjiaqiao. Source: Photo by Si Chen (2024)

2.2.1. Morphological characterization of deterioration in heritage buildings

a) Deterioration patterns and types

Heritage buildings in Anchang historical town generally exhibit three main categories of deterioration caused by environmental factors: weathering, damage from humidity, and biological colonization.

- Alveolization: Alveolization is a form of differential weathering that occurs due to prolonged friction caused by wind-blown sand and gravel particles on building surfaces. This process gradually erodes the mortar, transforming its texture into a powdery

Figure 6. He Gongsheng's residence on Temple Bridge. Source: Photo by Si Chen (2024)

structure. Studies indicate that weathering-related erosion is the predominant deterioration pattern observed in Anchang's heritage buildings (Ioannidis *et al.*, 2022; Rek-Lipczynska, 2019). This phenomenon not only affects the visual appearance of the buildings but also exposes the structural layers, leading to further damage.

- Crust formation: Damage from humidity manifests as hollowing, cracking, salt crusting, dehiscence, and spalling, with salt crusts being the most prominent. Soluble salts and other substances within the building materials precipitate when water evaporates, forming crusts on the building surface. This process results in a whitening effect (Rodgers *et al.*, 2017). In severe cases, the surface layers of building materials disintegrate and detach, exacerbating structural damage.
- Biological colonization: This form of deterioration is primarily caused by mosses and molds, which grow on the plastered exterior finishes of masonry building walls and mortar joints. The dampness of building materials creates an ideal environment for biological growth, which subsequently covers the masonry surface and accelerates corrosion (Kuka *et al.*, 2022; Li *et al.*, 2020).

b) Morphological characterization of deterioration

Different building materials respond to environmental conditions with different deterioration patterns, reflecting distinct underlying mechanisms. Therefore, it is essential to analyze these patterns in relation to the materials used in similar environment settings (Fadeev & Nasybullina, 2020). The research team conducted a comparative analysis of the river-facing façade of the BCW and HGS buildings in the Anchang historical town. Since the interiors of these buildings had been renovated and repaired, the analysis focused exclusively on their exterior structures, which exhibited more pronounced signs of deterioration.

2.2.2. Assessment of degradation levels in heritage buildings

Following in-depth field research, a comprehensive and detailed assessment of degradation levels in heritage buildings within Anchang historical town was carried out. The research team employed various assessment methods, such as visual inspections, surveys, moisture measurements, and infrared testing, to quantitatively classify the extent of building deterioration. Four classes of deterioration were identified: extremely serious, very serious, generally serious, and slightly serious.

Using the riverside façade of the BCW building as a case study, notable differences in degradation levels were observed across different parts of the building (Figure 7). The stone masonry at the base of the wall exhibited the most severe deterioration, characterized by peeling and moss growth. These pathologies pose significant threats to the building's durability and structural stability. In contrast, the relief floral decoration on the frieze above the entrance displayed generally serious pathological features, such as salt efflorescence and mold (Junier *et al.*, 2017). The deterioration observed below the eaves was relatively mild, involving slight dampness affecting the wall surfaces.

2.2.3. Moisture detection on wall surfaces

The study included a detailed analysis of wall moisture levels in the BCW building. To ensure the accuracy and comprehensiveness of the data, the wall was meticulously measured in sections along horizontal and vertical axes (Liang *et al.*, 2023). Moisture data from the walls of the historic buildings were collected using a specialized moisture detector (Figure 8). The horizontal direction was divided into eight segments, labeled A through L, while the vertical direction was subdivided into 18 segments, numbered 1 through 18. Variations in humidity were noted at the horizontal junctions of different materials, particularly at points B and C (Figure 9), due to differences in the thickness of the footing material. Stable humidity data at the intersections of the vertical and horizontal segments were recorded. In addition, overall wall temperatures were recorded using an infrared thermometer, serving as a reference for data analysis. To minimize variability and enhance reliability, the recorded data were averaged over multiple measurements.

Based on the wall humidity measurements (Table 3), the study revealed a correlation between the height of the wall and its temperature and humidity. In general, walls closer to the ground exhibited lower temperatures and higher humidity, while those farther from the ground had higher temperatures and lower humidity (Dang *et al.*,

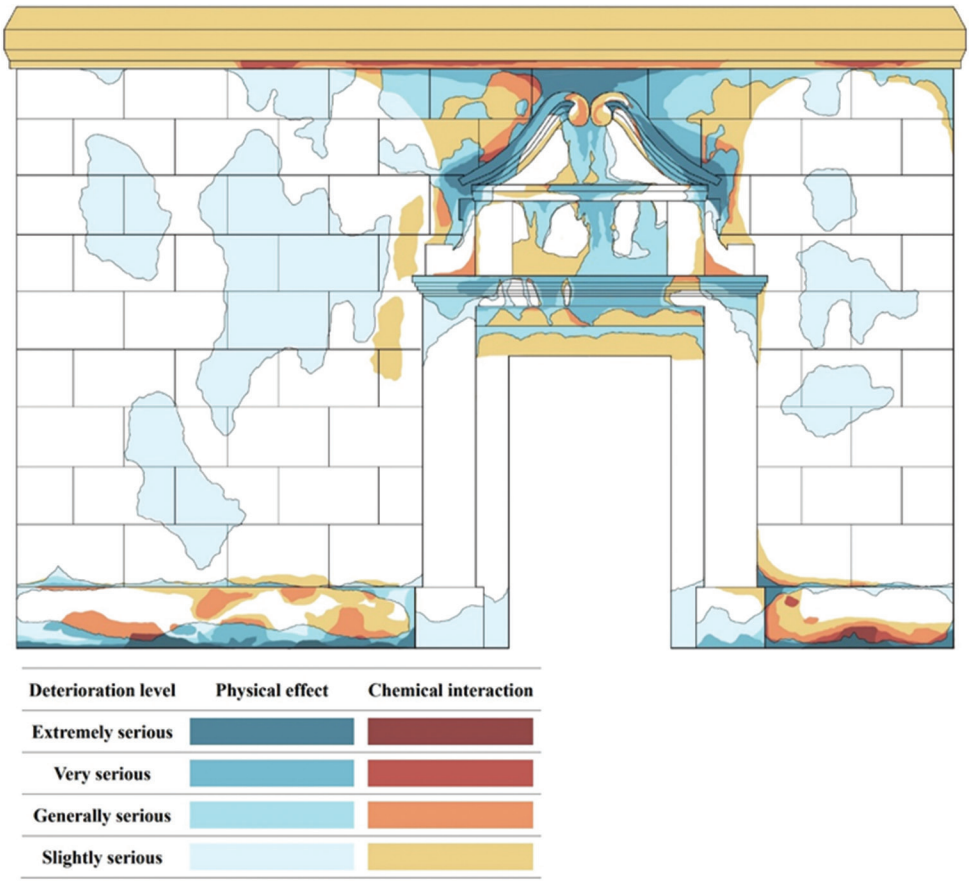


Figure 7. Degradation severity on the river-facing façade of the former site of the Bank of China Building in Wangjiaqiao, Shaoxing, Zhejiang, China. Source: Drawing by Ruxin Tang

Figure 8. The moisture detector used in the study. Source: Photo by Si Chen (2024)

2024). However, data beyond point H were excluded from further comparisons due to the wall's three-dimensional configuration at that point, which creates inconsistencies with other measurements. The combined data analysis revealed the following:

- A positive correlation between wall temperature and height
- A negative correlation between wall humidity and height
- Anomalies in moss-covered or deteriorated areas, where temperatures were lower and humidity higher than in unaffected areas at the same height (Figure 10).

Hydrogeology significantly influences the degradation of heritage buildings by affecting the stability of their foundations. Variations in the water table can lead to soil liquefaction or foundation settlement, increasing the risk of tilting or collapse. A high water table can also result in capillary water absorption by building walls and floors, which promotes corrosion, mold growth, and material expansion, thereby compromising the structure's stability and durability. Given these risks, it is imperative to incorporate hydrogeological information into the design and construction phases of preservation efforts and implement effective measures to safeguard the building from damage.

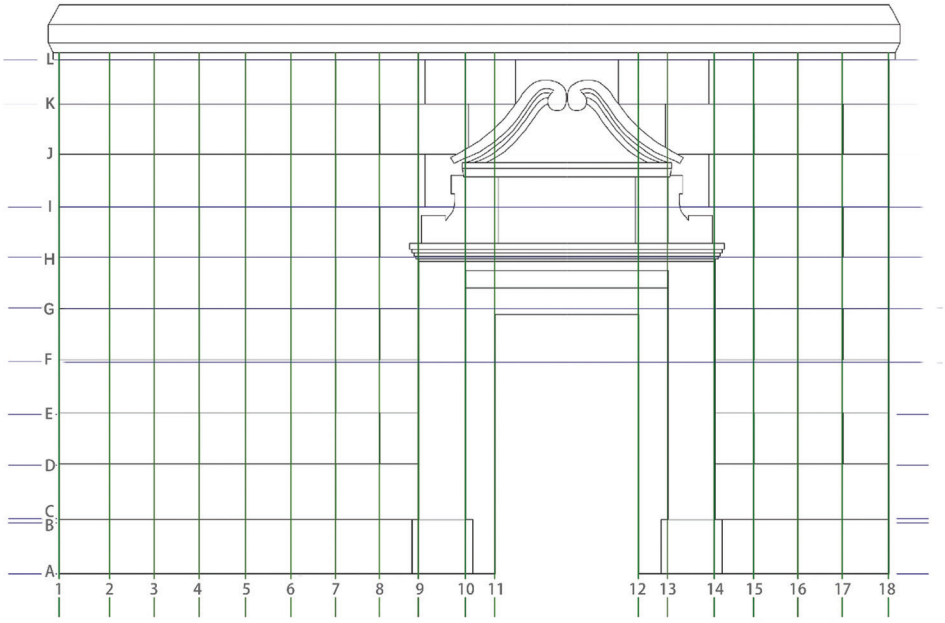


Figure 9. Humidity measurement points at the former site of the Bank of China Building in Wangjiaqiao (B and C are at different horizontal interfaces at the same altitude). Source: Drawing by Ruxin Tang

Table 3. Wall humidity data (%)

Landscape/Portrait	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
A	1.1	0.8	1.1	1.6	1.2	0.9	1.0	2.1	0.9	0.6	1.3	1.7	0.9	1.8	1.3	0.6	0.7	0.8
B	0.8	1.3	1.5	0.8	1.0	1.3	1.0	1.6	1.1	0.9	0.7	0.6	0.8	1.1	1.3	0.9	1.1	0.4
C	0.8	0.8	1.2	0.9	1.3	0.9	0.9	1.0	0.8	0.9	0.7	0.6	0.8	0.9	0.9	0.8	1.0	0.4
D	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.4	0.5	0.6	0.5	0.5	0.6	0.6	0.5	0.4	0.4	0.4
E	0.4	0.4	0.4	0.4	0.5	0.5	0.4	0.4	0.5	0.6	0.5	0.6	0.6	0.5	0.5	0.8	0.4	0.4
F	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.4	0.4	0.5	0.5	0.4	0.5	0.4	0.5	0.5	0.4
G	0.4	0.5	0.5	0.4	0.4	0.5	0.5	0.4	0.4	0.5	0.4	0.5	0.4	0.5	0.4	0.4	0.4	0.4
H	0.4	0.4	0.5	0.4	0.4	0.5	0.6	0.5	0.4	0.4	1.1	0.8	1.3	08	0.9	0.8	0.7	0.5
I	0.4	0.5	0.5	0.4	0.5	0.6	0.6	0.6	0.8	0.7	0.9	0.6	0.8	0.7	0.8	0.8	0.6	0.5
J	0.3	0.6	0.7	0.5	0.8	0.6	0.7	0.6	0.8	0.9	1.3	0.8	1.1	0.6	0.7	0.7	0.6	0.5
K	0.4	0.5	0.6	0.5	0.7	0.7	0.9	0.5	0.6	0.8	0.9	1.0	0.9	0.6	0.6	0.6	0.5	0.7
L	0.4	0.6	0.5	0.4	0.6	0.7	0.8	0.6	0.8	0.8	0.9	1.1	1.0	0.9	0.7	0.8	0.9	0.9

3. Results and discussion

3.1. Influence of temperature and humidity on building deterioration

3.1.1. Deterioration mechanisms of salt crystallization

Salt crystallization is a common issue in masonry buildings, characterized by phenomena such as powdering and surface efflorescence, which are particularly prominent in humid environments. The underlying causes of salt crystallization are multifaceted, involving several interacting factors. In moist conditions, soluble salts within masonry structures dissolve and migrate upward through capillary action. The cyclic process of salt dissolution and crystallization within walls causes expansion and contraction of the building material, resulting in internal loosening and eventual disintegration of the material's structure (Kim *et al.*, 2020; Li *et al.*, 2020; Yu, 2023). This process often manifests as a powdery layer on the wall surface and the formation of efflorescence. Over time, weathering exacerbates the phenomenon, causing layer-by-layer peeling and crumbling of the wall surface. Salt crystallization is further influenced by capillary water and

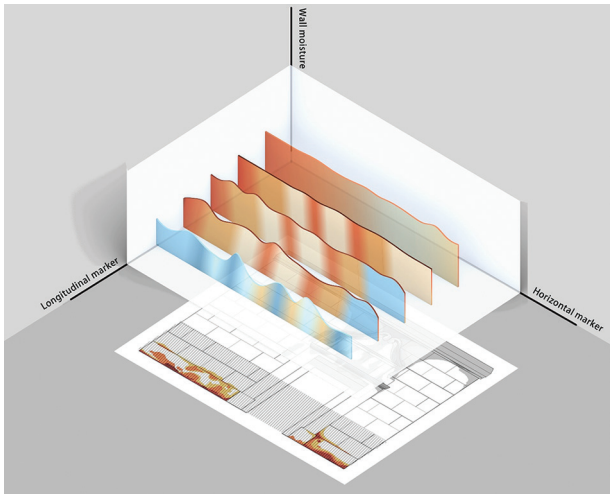


Figure 10. Footing deterioration and temperature change. Source: Drawing by Jie Wei

humid gases, which facilitate the migration of soluble salts within building materials. As water evaporates, these salts accumulate on the wall surface, forming whitish deposits. In severe cases, this can lead to corrosion, spalling, and structural degradation of the masonry surface.

The most prevalent form of degradation in heritage buildings is salt crystallization, often caused by wall dampness and water infiltration. In Shaoxing, heavy and frequent rainfall contributes to high moisture content in the walls of buildings, resulting in visible watermarks and darkened wall surfaces. As the moisture evaporates, internal salts precipitate and form efflorescence (Cozzolino *et al.*, 2022; Gunasdi *et al.*, 2023).

In limestone-based finishing materials, prolonged water vapor infiltration causes internal moisture to vaporize and expand, leading to hollowing, characterized by bulging, cracks, and surface flaking. Cracking typically manifests as fine lines or crocodile skin-like patterns, which can eventually lead to wall breakage and exposure of the structural layer. Dehiscence, observed near structural elements, manifests as vertical cracks that could compromise the building's structural integrity.

Notable differences in wall finishing materials influence deterioration patterns. For instance:

- BCW building: The walls are covered with cement mortar over brick, with a lime-faced base. Observed degradation includes salt crystallization, spalling, and biological colonization, such as moss and mold growth (Zhao & De Angelis, 2020).
- HGS building: The walls are finished with plaster, and the base is made of striped stone masonry. This building exhibits additional forms of deterioration, including powdering, hollowing, cracking, and dehiscence.

The comparative analysis of the BCW and HGS buildings is presented in Tables 4 and 5.

3.1.2. Deterioration mechanisms of finish shedding

The river-facing façade of the BCW building exhibits surface shedding of stone masonry blocks, caused by a combination of physical and chemical factors. Comparative analysis reveals that as the distance from the ground increases, the moisture content of the walls also increases, correlating with intensified masonry surface shedding. The porous and granular structure of the stone masonry block makes it highly absorbent. In humid environments, this moisture absorption compromises the adhesion between internal particles and the surface, leading to gradual loosening and eventual dislodging of surface materials under repeated evaporation cycles (Geng *et al.*, 2023). Similarly, the river-facing façade of the HGS building displays extensive plaster layer peeling and brick exposure. The subtropical monsoon climate of Anchang historical town—characterized by high humidity, heavy precipitation, and insufficient eave protection—exacerbates the deterioration of the plaster. Due to their interconnected pores, plasters exhibit high water absorption, which gradually reduces adhesion, leading to hollowing, cracking, and eventual detachment.

3.1.3. Mechanisms of deterioration development in moss encroachment

In high-humidity environments, the erosive effects of moss growth on building materials are significantly enhanced, especially in areas with evident watermarks. For example, the mortar plaster layer on the wall of the HGS building, with its high porosity and water absorption, creates ideal conditions for moss growth (Austigard & Mattsson, 2019; Murgul & Kamskov; 2017; Trovão *et al.*, 2020). As moss grows, its pseudo-roots invade the mortar's interior, enlarging pore spaces and forming cracks, further accelerating moss growth (Liu *et al.*, 2020). Similarly, the stone masonry on the river-facing façade of the BCW building, which shows localized breakage and detachment, provides a favorable environment for moss growth. In addition to physical damage, chemical interactions between moss and the lime content of the walls contribute to deterioration. Organic acids secreted by mosses react with the calcium carbonate in lime through acid-base neutralization, leading to corrosion, dissolution, and salt precipitation. These effects are especially pronounced at the base of walls and other lower structural components (Aloshan *et al.*, 2024; Łowińska-Kluge *et al.*, 2016).

3.2. Deterioration mechanisms of sunlight's effects on building materials

Sunlight is the most significant climatic factor affecting buildings, indirectly influencing other environmental

Table 4. Morphological analysis of deterioration on the river-facing façade of the former site of the Bank of China building in Wangjiaqiao, Shaoxing city, Zhejiang Province, China

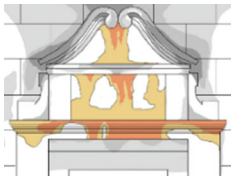
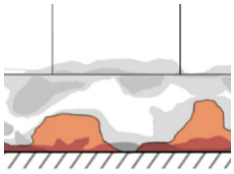
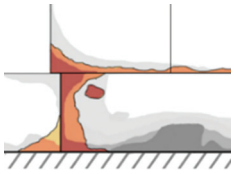
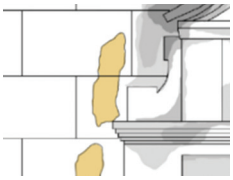
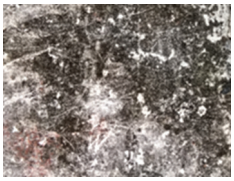
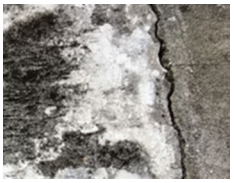
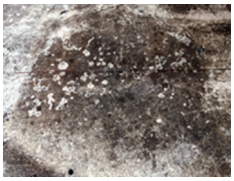
Typology	Weathering		Destruction by humidity	
Deterioration types	**Salt crystals**	**Exfoliation**	**Moss**	**Mold**
Illustrations				
Appearing site	Stoop	Stone masonry footing at 0~20 mm	Wall foundation upper	Middle of the wall
Illustrative statement				
Deterioration characteristics	When water evaporates, salts precipitate, and the surface whitens	Extensive crack of the facing, leaving the internal blockwork exposed	Moss adheres to the surface, trapping water and eroding the stone masonry footings	Mold adheres to the surface of the wall and darkens in color

Table 5. Morphological analysis of deterioration on the river-facing façade of He Gongsheng's residence in Temple Bridge, Shaoxing city, Zhejiang Province, China

Typology	Destruction by temperature and humidity			
Deterioration types	**Salt crystals**	**Blistering**	**Cracked**	**Pitting**
Illustrations				
Appearing site	Middle of the wall	Middle of the wall	Wall to doorway junction	Lower wall vegetation
Deterioration characteristics	The surface mortar structure is loose and powdery shedding	Water vapor infiltration causes the surface layer to bulge and eventually peel off	Cracks form when absorbed water evaporates from the surface	Salts and salt precipitate and whiten when water vapor evaporates
Typology	**Destruction by humidity**		**Biological colonization**	
Deterioration types	**Dehisce**	**exfoliation**	**Moss**	**Mold**
Illustrations				
Appearing site	Wall to doorway junction	Middle of the wall	Wall foundation upper	Lower wall vegetation
Deterioration characteristics	Vertical cracks in walls may affect building stability	Peeling of the top layer exposing the internal structure	The lower part of the wall is damp and has more moss attached to it	Wet surface with mold attached

conditions, such as humidity and temperature. To comprehensively analyze and compare sunlight's effects on buildings, detailed architectural models of the BCW and HGS buildings were created in Rhino software. These models facilitated an in-depth sunlight analysis using Ladybug Tools. By conducting field measurements and utilizing Ladybug Tools components in Grasshopper, meteorological data from Shaoxing City were imported to simulate sunlight hours, adjust parameters, and assess sunlight exposure under various conditions (Figures 11 and 12). The BCW building was selected for a comparative study of its façade insolation at different time points, including: during the months of the Great Cold Day (January), summer solstice (June), winter solstice (December), month with high precipitation frequency (March), and sunny month (July). In addition, climatic parameters such as precipitation days, precipitation levels, and air humidity in Shaoxing were incorporated into the analysis. These data were combined with wall insolation measurements to generate a comparative analysis chart of climatic conditions (Figure 13).

The results indicate that sunlight exposure on the walls of the BCW building peaked in June, with an average of 5.91 h of sunlight per day, whereas sunlight hours during January and December were nearly zero. Significant fluctuations in daily sunlight duration were observed throughout the year, demonstrating clear seasonal variation (Annila *et al.*, 2018). Field research corroborated these findings, showing that areas with shorter sunlight duration exhibited slightly higher levels of surface carving deterioration compared to areas with longer sunlight exposure, thereby confirming sunlight's role in architectural degradation.

Further analyses revealed slight differences in insolation conditions across different sections of the

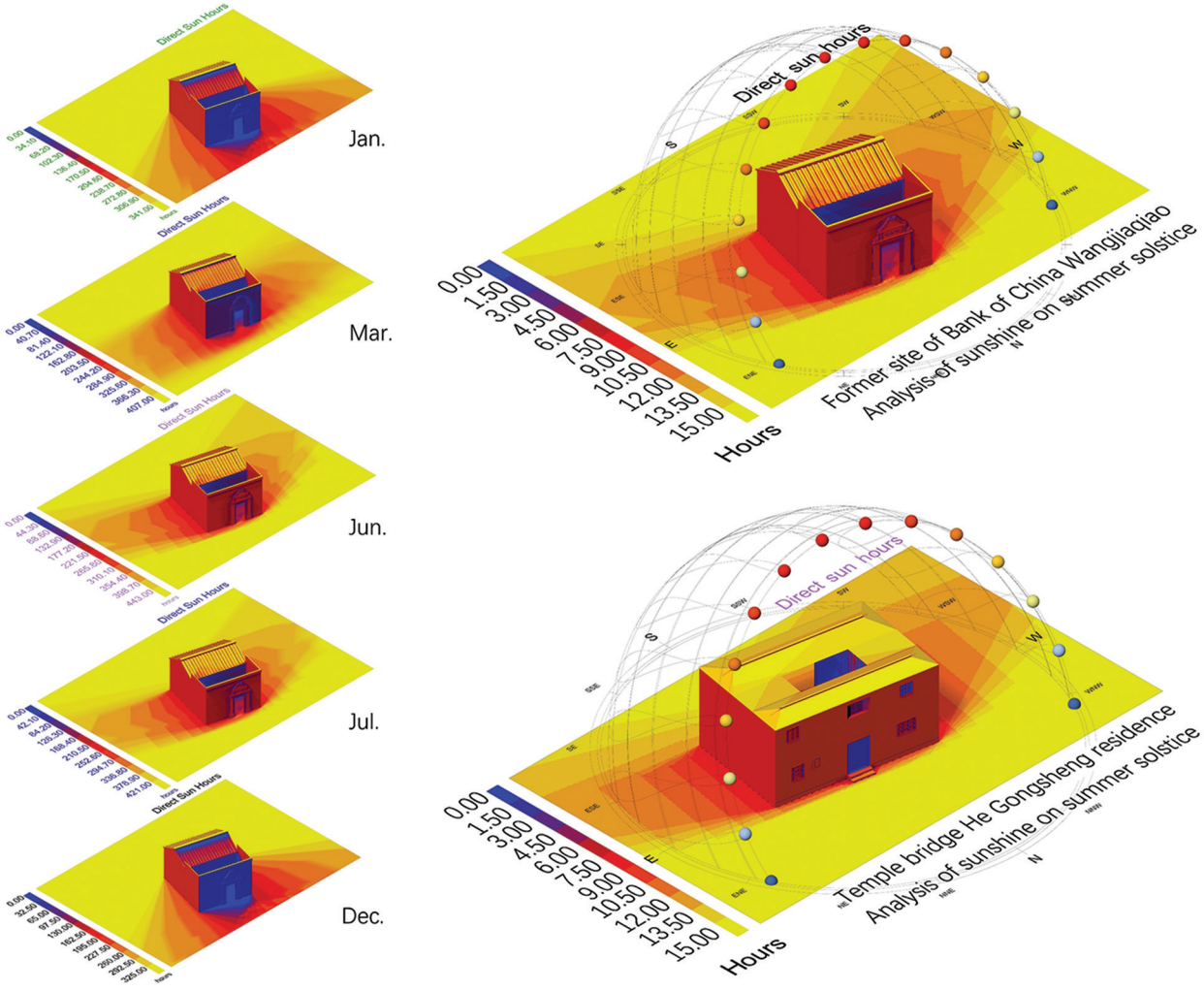


Figure 11. Comparative analysis of sunlight hours at different times. Source: Drawing by Jie Wei

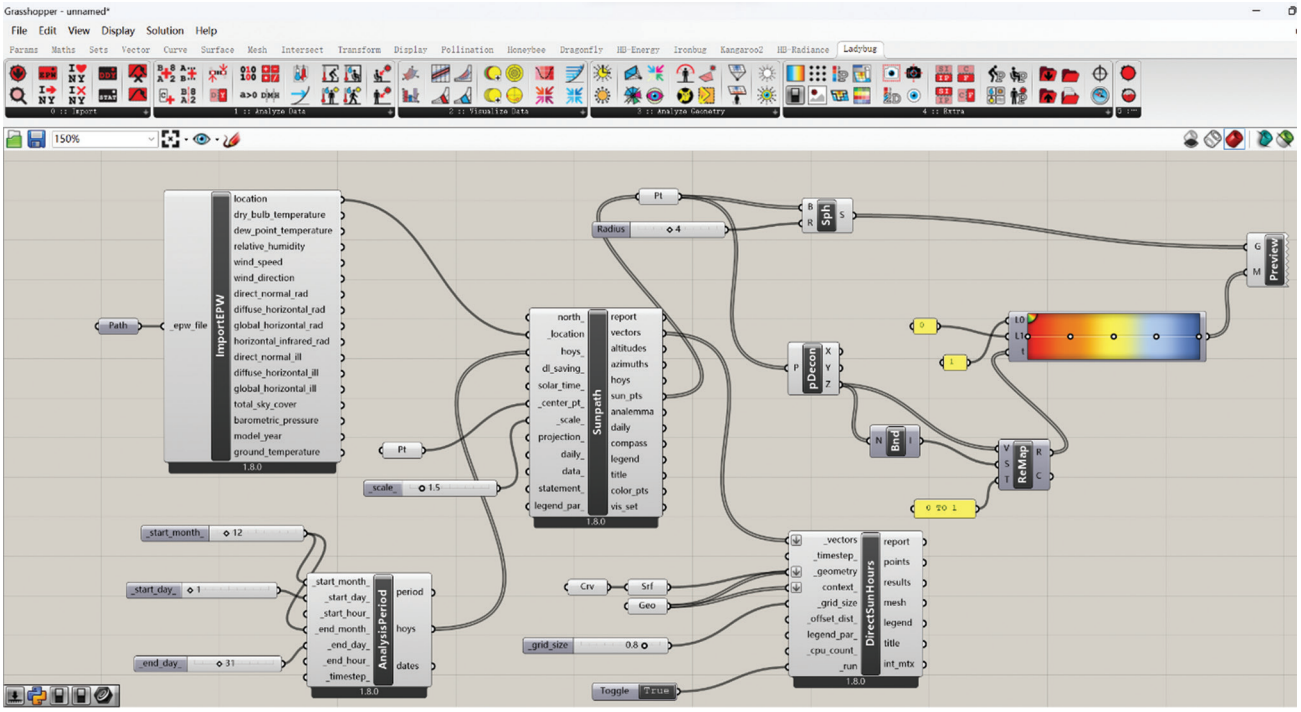


Figure 12. Grasshopper components for sunlight duration analysis in Rhino software. Source: Drawing by Jie Wei

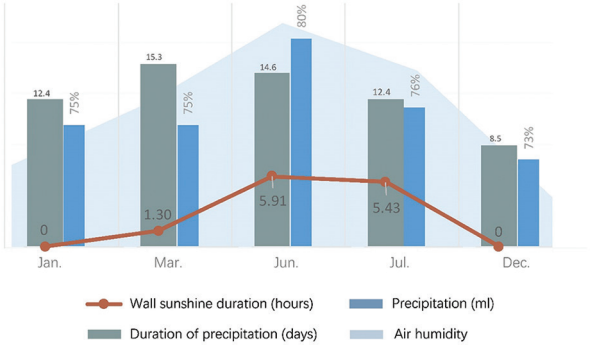


Figure 13. Variation of temperature and humidity at the measuring point. Source: Drawing by Jingwen Wang

same building façade, even under similar atmospheric humidity, precipitation, and groundwater and surface water conditions. These differences correlated with variations in deterioration severity. For instance, areas with shorter sunlight exposure and higher humidity, such as the depression below the doorway, exhibited more severe deterioration than areas with longer sunlight exposure, such as the doorway surface. These findings suggest that sunlight duration and humidity significantly influence the severity of building deterioration.

In addition to the humidity data collected at the BCW building, it was observed that Row A had undergone recent repair work due to cultural relic and building preservation efforts. This repair introduced variations in wall materials, complicating the establishment of a clear correlation between sunlight duration and deterioration severity. However, in Rows B and C, deterioration peaked at Column 14, which experienced the shortest sunlight hours and the lowest temperatures, further supporting a potential link between reduced sunlight hours and increased deterioration. Conversely, Rows D and E, shaded by signage and other structures, exhibited minimal deterioration, rendering it impractical to establish correlations between sunlight hours and degradation in these areas.

3.3. Impact of alveolization on building deterioration

Alveolization primarily manifests as erosion on the wall surface, where moisture reduces the hardness of wall materials, causing masonry mortar to loosen. Under weathering conditions, the wall surface exhibits powdering or flaking, exposing the structural layer and compromising the building's esthetics. Weathering accelerates building deterioration in several ways:

- Humidity and temperature: Wind induces rapid changes in humidity, particularly during dry summer conditions. Strong winds can remove surface moisture, causing desiccation and cracks in building materials, thereby accelerating the deterioration process.
- Abrasion: Wind-borne particles, sand, and dust

constantly abrade building surfaces, contributing to wear and tear on building materials. This abrasive action exacerbates the aging and deterioration of exterior walls, roofs, and other structural components.
- Exacerbation of deterioration: Wind can exacerbate existing building deterioration. For example, if salt is present in a building, wind-induced damage or peeling of surface coatings exposes building materials to corrosive substances such as salt and moisture carried by the wind, further accelerating erosion.

4. Conclusion and future perspectives

This study focused on two historical heritage buildings in Anchang historical town, investigating macroenvironmental factors and microdata related to the deterioration of various building components. It summarized and categorized the types and distributions of deterioration under various influences and discussed the underlying causes of architectural deterioration. In addition, the study aimed to offer actionable recommendations for the preservation of these heritage buildings by identifying the root causes of architectural deterioration. The key findings of the study are as follows:

- Classification of building deterioration: Analysis of the literature revealed that Anchang historical town, situated along rivers, encounters typical challenges faced by water towns. Building deterioration in such towns can be categorized into three primary types, with humidity-induced damage being the most prevalent. This form of erosion is evidenced by powdering, cracks, salt crust formation, dehiscence, and exfoliation. Moreover, damp building surfaces promote significant biological colonization, facilitating the growth of mosses and molds. Weathering, characterized by surface roughening and surface layer peeling, further contributes to the degradation of buildings.
- Impact of wet conditions: Wet conditions significantly increase buildings's vulnerability to deterioration. Relative air humidity and the water table are major sources of moisture affecting building masonry. Areas near the base of buildings, which are consistently exposed to dampness, are particularly susceptible to deterioration, such as cracking and uncontrolled moss growth.
- Sunlight duration and deterioration severity: The duration of sunlight exposure plays a critical role in determining the severity of deterioration in heritage buildings. Comparative analysis revealed that areas with limited sunlight exhibit higher humidity levels and more pronounced building deterioration.

This study underscores the intricate processes involved in building degradation and the significant challenges associated with repair and maintenance efforts. As efforts to protect cultural relics and buildings in China continue, numerous opportunities for further research remain. By shedding light on the mechanisms of heritage building deterioration in Shaoxing City, Zhejiang Province, China, this study offers a foundation for developing effective repair and maintenance strategies. These strategies aim to enhance the preservation and resilience of heritage buildings in the region.

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Conflict of interest

The authors declare they have no competing interests.

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Writing – original draft: Si Chen, Jie Wei, Ruxin Tang, Jingwen Wang
Writing – review & editing: Si Chen, Ying Zhu

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Availability of data

Data are available on request from the authors.

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The Shan-Shaan Guild Hall: A historical nexus on the Great Tea Route

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Abstract

Jia County, located in Pingdingshan City, Henan Province, is one of China's historical cities, known for its prosperous economy and thriving community of merchants and traders. Recognizing Jia County's geographical advantages, merchants from Shanxi and Shaanxi Provinces, renowned for their business acumen, funded the construction of the Shanxi-Shaanxi Guild Hall in 1693. This guild hall served as a multifunctional hub for business negotiation, sacrificial rituals to honor the gods, hospitality for guests, and fostering connections among Shanxi and Shaanxi businessmen, strengthening the exchange of economic and trade information. As an important architectural heritage site along the cultural route of the Great Tea Route, the Shanxi-Shaanxi Guild Hall holds immense historical and cultural value. The local government has initiated plans to preserve it as a public space for future generations. This article examines the Shanxi-Shaanxi Guild Hall in the context of the Great Tea Route as a cultural route. Drawing on archival research, field investigations, and semi-structured interviews, it delves into Shanxi-Shaanxi Guild Hall's tangible and intangible cultural characteristics and its historical relationship with the Great Tea Route. By uncovering the deeper value connotation of the Shanxi-Shaanxi Guild Hall, this study aims to provide new insights into the conservation of cultural heritage.

Keywords: Cultural route; The Great Tea Route; Shanxi-Shaanxi Guild Hall; Value connotation

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1. Introduction

The Shanxi-Shaanxi Guild Hall[1], also known as the Shanxi-Shaanxi Temple (山陕庙), is located on the north side of Xiguan Street (西关大街)[2] in Chengguan town

[1] Guild hall began to appear in Chinese cities during the Ming dynasty (1368–1644) as the result of a economic prosperity. Similar to their counterparts in Europe, these halls served as gathering places for immigrants (Steinhardt, 2019).

[2] Xiguan Street is part of the Xiguan historical and cultural district, which was designated as one of the second batch of provincial-level historical and cultural districts. The district encompass a protection area of 16.55 ha, with a core protection area of 8.2 ha, and includes 48 historical buildings. This ddistrict serves as the western gateway to the historical town of Jia county and functions as a traffic hub for Shanxi and Anhui merchants. It is also a key node along several historic routes, including the Great Tea Route, the ancient Salt Road, the historical land route for tobacco exports. Additionally, it once served as the residence of the People's Liberation Army during the liberation of Jia county. Xiguan Street, along with Lushan Lane (鲁山巷), Huangdao Lane (黄道巷), Camel Road (骆驼道), retains its original layout. The shops along these streets are predominantly wooden-planked houses, showcasing a vibrant commercial history and a wealth of cultural relics (Pingdingshan City Government, 2021).

(城关镇)[3], just outside the west gate of Jia County's historical town in Pingdingshan city, Henan Province, China. Positioned near the Qinglong River (青龙河) to the west and the Yinrujicheng River (引汝济城河)[4] to the south, it enjoys a geographically advantageous location with convenient transportation. In 1693, during the 32nd year of the Kangxi era (康熙年间; 1661 – 1722) in the Qing dynasty (1644 – 1911), 21 merchants from Shanxi and Shaanxi donated funds to build the Shanxi-Shaanxi Association Hall in Jia County. The Shanxi-Shaanxi Guild Hall features a three-entry courtyard, consisting of a theater, a bell tower, a drum tower that forms the main gate, the Guandi Temple (关帝庙)[5], and the Spring and Autumn Building (春秋楼). During the Jiaqing era (嘉庆年间; 1796 – 1821), it underwent reconstruction to expand its scale. However, it suffered significant damage during the Republic of China era (1912 - 1949) due to wartime destruction. After the establishment of the People's Republic of China in 1949, it was repurposed as a warehouse for the Food Bureau. In 2013, the State Council designated it as part of the seventh batch of national key cultural relic protection units (Henan Provincial Administration of Cultural Heritage, 2024). Today, the guild hall remains closed to the public to ensure the preservation of its cultural heritage. In 2019, it was officially recognized as a key heritage along the Great Tea Route (万里茶道)[6] (Henan Daily, 2019).

[3] The term "Chengguan (城关)" refers to the main traffic route located at the edge of a city's center (Hu, 2005).

[4] The term "Yinrujicheng (引汝济城)" translates to "build an aqueduct to bring water from the Ru river (汝河) to the town." This system was designed to irrigate farmland outside the town and to satisfy the water consumption needs within the town. According to the Jia County Annals, in the 45th year of the Wanli era (万历年间; 1573–1620), the Wanghou Canal (王侯渠) was constructed to divert water from the Yijian river (邑涧水). The canal followed the city trench, flowing from the town's west gate to the east gate (Guo & Jiang, 1975).

[5] Guan Yu (关羽), a famous general from the late Eastern Han dynasty (25–220), was renowned for his loyalty and righteousness. Posthumously, he was honored with the title "Guan Gong (关公)". Guan Gong originated from Yuncheng, Shanxi province, China, where he changed his family name. This connection to Shaaxi province has led to Guan Gong being deeply revered by merchants from Shanxi and Shaanxi.

[6] The Great Tea Route, also known as the "Ten Thousand Li (5,000 km) of Tea Road," was an essential trade route from the 17th to the early 20th century. Pioneered by merchants from Shanxi, the route linked Wuyi Mountain (武夷山) in Fujian province, China, to Russia, Central Asia, and even Europe. In 2014, China, Mongolia, and Russia initiated a joint project to seek World Heritage status for The Great Tea Route (Xinhua, 2014).

The Great Tea Route stretches across eight Provinces in China, covering over 14,000 km. Henan Province, located in the central section, plays a crucial role in transit transportation along the route. Within Henan, the route spans more than 700 km and over 200 immovable cultural relics related to the route have been identified (Zhang, 2022). The Shanxi-Shaanxi Guild Hall not only serves as a physical representation of the tea merchant culture of Shanxi and Shaanxi but also reflects the diverse ethnic and local cultures encountered along the route (Li, 2021).

As both a witness to and participant in this historic trade route, the Shanxi-Shaanxi Guild Hall in Jia County provided accommodations for traders, facilitated networking, supported information exchange, and contributed to the transmission of cultural traditions (Zhao *et al*., 2019). Today, Jia County is seeking to preserve its historical town, with the Shanxi-Shaanxi Guild Hall and Xiguan Street forming the core of its historical district. This initiative aims to develop tourism, create economic opportunities, and reinforce the cultural identity of the region. However, current conservation plans for the Shanxi-Shaanxi Hall and the Xiguan historical district are fragmented and rely on conventional approaches, lacking multidimensional and integrative strategies. This article aims to uncover the cultural connotations of the Shanxi-Shaanxi Guild Hall and Xiguan Street by examining their relationship with the Great Tea Route. Through this analysis, the study seeks to provide references for conservation planning.

2. Literature review

The concept of a "cultural route" was first articulated in 1993 with the nomination of the "Routes of Saint James" (*Camino de Santiago*) on the World Heritage List (Genovese, 2016). It was subsequently formalized by the International Council on Monuments and Sites (ICOMOS) in 1998 through the establishment of the International Scientific Committee on Cultural Routes (CIIC). In 2003, the category of "cultural route" was officially added to the Operational Guidelines for Heritage Convention. During a meeting of experts, the concept was defined as follows:

A cultural route is a land, water, mixed, or other types of route, which is physically determined and characterized by having its own specific and historic dynamics and functionality, showing interactive movements of people as well as multi-dimensional, continuous and reciprocal exchanges of goods, ideas, knowledge, and values within or between countries and regions over significant periods; and thereby generating a cross-fertilization of the cultures in space and time, which is reflected both in its tangible and intangible heritage (ICOMOS, 2008).

The study of cultural routes has been enriched by numerous cases both internationally and within China. In 1984, the United States Congress established the Illinois and Michigan Canal National Heritage Corridor, marking the first instance of a "heritage corridor" being legally protected (Asakawa *et al*., 2004). Similarly, the Route of Santiago de Compostela was inscribed on the World Heritage List in 1993 (Spanish section) and 1998 (French section). This route encompasses approximately 1,800 historically significant buildings, both religious and secular (UNESCO, 1993). The Quebrada de Humahuaca, a trade route used for over 10,000 years, was included in the World Heritage List during the 27th Session of the World Heritage Committee (UNESCO, 2003). In China, the Ancient Tea Horse Road (茶马古道) was recognized in 2013 as part of the seventh batch of national key cultural relic protection units by the State Council of the People's Republic of China (National Cultural Heritage Administration, 2013). Yiamjanya (2020) explored the industrial heritage along Thailand's railway corridor in Lampang Province, categorizing it into mining and railway heritage and exploring methods for preservation and reuse. These examples demonstrate that the cultural route perspective broadens the understanding of heritage, integrating both tangible and intangible elements, and facilitates the understanding of the impact of culture on places across space and time.

Today, the concept of cultural routes is widely used as a tool for preserving cultural heritage and supporting sustainable development in connected areas (Bogacz-Wojtanowska *et al*., 2019). For example, the restoration project of Via Appia adopted a model that contributes to sustainable tourism development (Dallari, 2018; Filetici, 2018). Cardia (2018) identified five ways in which cultural routes can support sustainable development goals, including (i) inclusive and sustainable economic growth; (ii) social inclusiveness, employment, and poverty reduction; (iii) resource efficiency, environmental protection, and climate change; (iv) preservation of cultural values, diversity, and heritage; and (v) promotion of mutual understanding, peace, and security.

The Great Tea Route, a vital component of China's route heritage, has recently become a prominent research focus. Current studies on the Great Tea Route address five main aspects (Sigley, 2023):

(i) The history of tea culture (Chen *et al*., 2008; Duan, 2010)
(ii) The economic history of the tea trade (Liang & Wu, 2005; Liu, 2007; Xiao & Peng, 2007)
(iii) The historical and geographical characteristics of the Great Tea Route (Han, 2012; Liu, 2015)
(iv) Value assessments (Deng, 2000; Huang & Ping, 2020; Liu & Zhong, 2016)
(v) Heritage conservation
(vi) Heritage conservation research has been categorized into three levels:
(vii) Macro: Heritage corridors (Chen *et al*., 2018)
(viii) Meso: Key towns (Li, 2021; Wei, 2017; Zhao *et al*., 2019; Zhu, 2011; Zou, 2020)
(ix) Micro: Individual buildings (Li, 2021)

Individual heritage buildings are further classified into six categories according to their relationship to the tea trade: transportation, production, housing, trade, religious beliefs, and political and diplomatic legacies (Zhang, 2024).

While existing research on the Great Tea Route largely focuses on the macro level, such as the route's specific path and overall heritage value for promoting its World Heritage status, micro-level studies on its impact on specific sites, such as the Shanxi-Shaanxi Guild, remain scarce. This study adopts a cultural route perspective to investigate the meso- and micro-level relationships between the Great Tea Route and the Shanxi-Shaanxi Guild Hall, including its tangible and intangible heritage. By doing so, the research aims to expand the value connotation of the guild hall and the Xiguan historical district, offering new insights into the conservation and revitalization efforts of the guild hall and the historical area.

3. Research method

This study employs a combination of archival research, fieldwork, and semi-structured interviews. The archival research focuses on collecting and analyzing a large volume of historical documents and records to explore the relationship between the Great Tea Route and the Shanxi-Shaanxi Guild Hall. Fieldwork and oral history were used to gather the memories and experiences of various stakeholders connected to the guild hall. Semi-structured interviews were conducted with residents, small business owners near the guild hall, staff members from the Ministry of Culture and Tourism Bureau in Jia County, and personnel from the Ministry of Housing and Construction in Jia County. These individuals possess detailed knowledge of the cultural relics in the guild hall.

The collected data, including literature, field research, and oral histories, were analyzed comparatively. This approach enabled an in-depth exploration of the tangible and intangible heritage associated with the Shanxi-Shaanxi Guild Hall. The analysis emphasized the guild hall's characteristics and cultural value in the context of its connection to the Great Tea Route.

4. The relationship between the Great Tea Route and Shanxi-Shaanxi Guild Hall in Jia County, Pingdingshan City, Henan Province, China

4.1. Location of the Shanxi-Shaanxi Guild Hall in Jia County

Huang & Ping (2020) divided the Great Tea Route into three sections: the southern, central, and northern sections. The southern section primarily served productive transport, the northern section focused on consumer transport, and the central section facilitated transfer and trade. Within Henan Province, the Great Tea Route traversed five paths south of the Yellow River, two of which passed through Jia County (Figure 1). One of these paths, known as the Bai River Line (白河线), originated in Xiangyang City (襄阳) in Hubei Province, following the Tangbai River (唐白河) before transitioning into the Bai River (白河) upon entering Henan Province. The second path, the Tang River Line (唐河线), passed through Shedian town (赊店镇), the most significant land and water transfer terminal along the route. This path, regarded as the primary route of the Great Tea Route, also began in Xiangyang City, following the Tangbai River before turning into the Tang River as it entered Henan Province (Henan Institute of Cultural Relics and Architectural Conservation, 2016).

The Shanxi-Shaanxi Guild Hall is located outside the west gate of Jia County, a critical transportation hub of the Great Tea Route during the Ming (1368 – 1644) and Qing dynasties (Fang *et al.*, 2021) (Figure 2). However, the *Jia County Annals* from the Kangxi era do not record its existence. It is not until the *Jia County Annals* from the Xianfeng era (1850 – 1861) that the guild hall appears, with mention of the Guandi Temple located within it. A staff member from the Ministry of Housing and Construction in Jia County explained that Shanxi-Shaanxi merchants initially competed with the local market for resources, causing tensions with local communities. As a result, the guild hall was established as an enclave beyond government control, a claim corroborated by historical records. For example, in the 42nd year (1778) of the Qianlong era (1735 – 1796), tribute materials were stolen from the guild hall, a remained-unsolved incident that led to the dismissal of dozens of officials. Subsequently, the Shanxi-Shaanxi Guild Hall became an official post station for the Qing government, a status it has maintained for over a century (Cheng, 2010).

The Ministry of Culture and Tourism Bureau in Jia County identified three reasons why the guild hall was constructed outside the city. First, the guild hall primarily served Shanxi-Shaanxi merchants, with food and lodging exclusively for its members. There was no need to attract outside customers. Second, merchants often transported

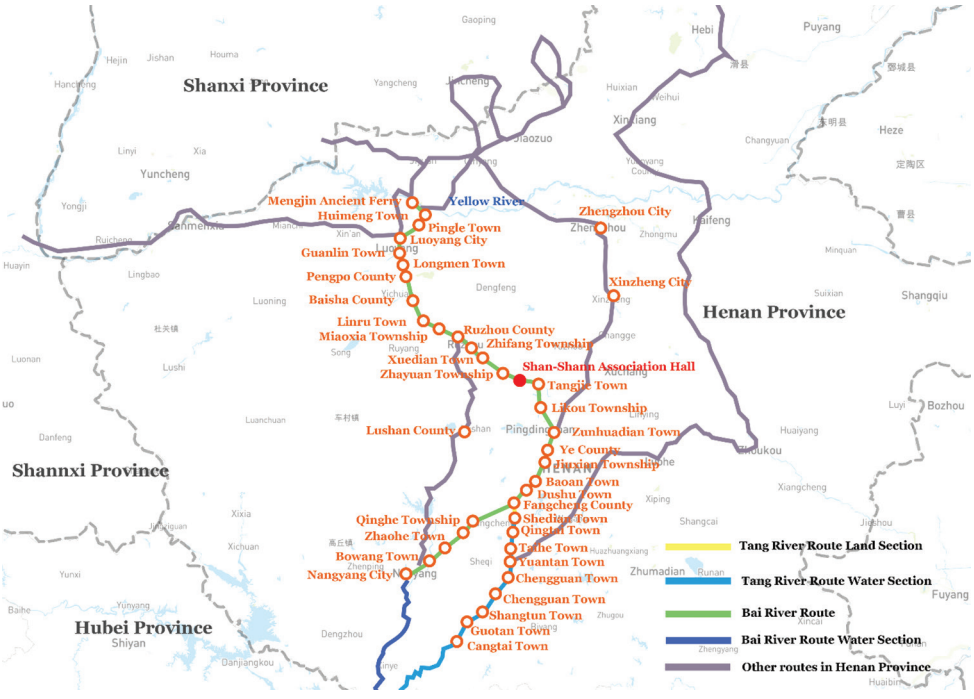

Figure 1. Two of the paths traversed the Great Tea Route through Jia County, Pingdingshan City, Henan Province, China. Source: Drawing by Yixin Wang based on the research of Henan Institute of Cultural Relics and Architectural Conservation.

Figure 2. Historical map of Jia County from the 9th year of the Xianfeng era (1860). Source: Drawing by Yixin Wang based on the historical map in the *Jia County Annals.*

valuable goods. The city, being a mix of diverse populations, posed higher security risks compared to the open, easily guarded surroundings outside the city, bordered by a flat River. Third, unlike the city gates, which adhered to fixed opening times, the guild hall's location outside the city allowed unrestricted entry and exit, accommodating merchants and travelers at any hour.

4.2. History of the Shanxi-Shaanxi Guild Hall in Jia County

The signing of the Treaty of Nerchinsk between Russia and China in 1689 marked the formal establishment of the Great Tea Route (Ding & Song, 2015). Four years later, in the 32nd year of the Kangxi period of the Qing dynasty (1693), 12 merchants from Shanxi and Shaanxi established the Shanxi-Shaanxi Guild Hall in Jia County (County, 1983). This guild hall emerged as a result of the Great Tea Route's development and growing significance.

In 1727, the Qing government signed the Treaty of Chaktu with the Tsarist Russian government, followed by the official opening of the market in Chaktu in 1728. This market became a vital hub for mutual trade at the Sino-Russian border. From that point, trade between the two countries began to flourish, providing the foundation for the gradual development of the Great Tea Route (Liu, 2007). The prosperity of the Great Tea Route brought significant wealth to Shanxi-Shaanxi merchants. Between the reigns of Kangxi and Qianlong, Shanxi-Shaanxi merchants established more than 30 Shanxi-Shaanxi guild halls in Henan Province, including Kaifeng, Luoyang, Zhoukou, Nanyang, and Pingdingshan (Zhang & Zhang, 2010). This prosperity is also evident in the renovation and expansion of the Shanxi-Shaanxi Guild Hall in Jia County during the 23rd year of the Jiaqing era (1819). This event is documented on the beam of the main hall in the guild hall (Figure 3) (Jia County Literature and Historical Data Research Committee of the CPPCC, 1987). The expanded complex included a temple yard, a backyard, and an east yard, forming three major architectural groups (Cheng, 2010).

The decline of the Great Tea Route began in the early 20th century. The collapse of the Jin tea company Dashengkui (大盛魁) in 1929 and a fire in the trading town of Chaktun in the 1920s marked significant turning points (Ding & Song, 2015). Correspondingly, the end of the Qing dynasty and the beginning of the Chinese Civil War brought increased warfare between warlords, widespread social unrest, and economic depression. Consequently, Shanxi-Shaanxi merchants abandoned Henan, returning to their hometowns to escape the turmoil. The Shanxi-Shaanxi Guild Hall in Jia County fell into decline, losing its former prosperity.

5. Characteristics of the Shanxi-Shaanxi Guild Hall from the perspective of the Great Tea Route

5.1. Tangible heritage characteristics

5.1.1. Transportation

The Great Tea Route passing through the Shanxi-Shaanxi Guild Hall in Jia County evolved from the Ancient Wanluo

Figure 3. The beam of the gate documents the date of reconstruction and the name of the craftsmen. Source: Photo by Jia County Government.

Road[7] (宛洛古道), which dates back to the Qin (221 – 206 BCE) and Han (202 BCE–9) dynasties (Xu & Jiang, 2001). Ancient Wanluo Road between Nanyang (南阳) and Ruzhou (汝州) split into two routes: a main road passing through Fangcheng (方城) and Ye County (叶县) to reach Ruzhou, and a convenient path through Lushan (鲁山), known as Sanya Road[8] (三鸦路) (Gong, 1991).

In addition to those official routes, field research and oral histories have revealed the existence of two additional roads that facilitated market expansion for Shanxi-Shaanxi merchants into the villages and towns surrounding Jia County (Figure 4). These two lanes, located on the north and south sides of Xiguan Street, are named after their origins: Lushan Alley (鲁山巷) and Huangdao Alley (黄道巷). Lushan Alley starts from Lushan County and passes through Baofeng County (宝丰县) and Guangkuotiandi village (广阔天地村) before reaching the guild hall. Huangdao Alley goes from Huangdao town (黄道乡) to the guild hall.

5.1.2. Production

Although Jia County was a transit hub rather than a tea production area, the influence of the Great Tea Route instilled a tradition of tea drinking among its residents. This cultural legacy also led to the establishment of tea reprocessing sites in the area. As shown in Figure 2, a tea factory was located on the east side of the road leading into the historical town of Jia County.

5.1.3. Housing

The merchants from Shanxi and Shaanxi Provinces, renowned for their business acumen, recognized the strategic importance of Jia County and donated funds to purchase land and construct the Shanxi-Shaanxi Guild Hall. The guild hall served multiple purposes: it was a base for merchants traveling across the country, a venue for negotiating business, a site for sacrificial rituals to attract wealth, a place to entertain guests, and a hub for strengthening connections among Shanxi-Shaanxi businessmen while exchanging economic and trade information.

The complex measures 105 m in length and 60 m in width, covering an area of 6,300 sqm (about 9.5 acres) (Cheng, 2010). It consists of 22 buildings, including 10 heritage structures (Pingdingshan City Government, 2019). The layout features three courtyards (Figure 5A) and includes prominent architectural elements such as the Screen Wall (Figure 5B), the Main Gate, the Bell and Drum Towers, the Main Hall, and the Spring and Autumn Building.

The first courtyard (Figure 6A) served as a public space. The gate and theater were integrated, with the gate on the ground floor and the theater on the 1st floor. The stage, facing north toward the interior of the courtyard, is directly opposite the main hall, establishing it as the visual focal point. The Bell and Drum Towers are 2-story brick-enclosed buildings with flying roof eaves and a hip-gable roof (*xieshan*; 歇山). Intricately carved brackets adorn their high pedestals. Positioned on either side of the theater, these towers once housed a bell and a drum, respectively, which no longer exist. The East Hall, a 1-story brick building with a flush-gable roof (*yingshan*; 硬山), is oriented from east to west.

The second courtyard contains the Main Hall (or Guandi Temple; Figure 6B), dedicated to the worship of Guan Gong. Facing south, this single-story structure features a hipped roof with five bays. Historical records indicate that a painted clay statue of Guan Gong was originally installed in the hall. The courtyard also includes 11 rooms on each side, referred to as West Wing and East Wing, both comprising 1-story brick buildings.

According to historical records, the main hall consisted of five rooms with a porch (Jia County Literature and Historical Data Research Committee of the CPPCC, 1987). However, the porch no longer exists. Interviews revealed that the porch was damaged at an unspecified time. During renovations, the Jia County Cultural Heritage Administration uncovered remnants of the porch's foundation, composed of grey bricks, while removing non-heritage structures. Unfortunately, these remains were roughly cleared rather than conserved.

The Spring and Autumn Hall (Figure 6C), located on the central axis in the third courtyard, is a 2-story brick building with an overhanging gabled roof (*xuanshan*; 悬山). Its prominent position indicates it is the most

[7] Ancient Wanluo Road, which historically connected Nanyang (Wan, 宛) and Luoyang (Luo, 洛), served as a significant transportation and military route in ancient times. Before the Qin dynasty (221 – 206 BCE), it was known as the Summer Road (夏道). From the Spring and Autumn period (771 – 476 BCE) onward, it became the primary southern route to the Central Plains Zhang & Pan (1976).

[8] In the local dialect, "Sanya" refers to a narrow passage between two mountains.

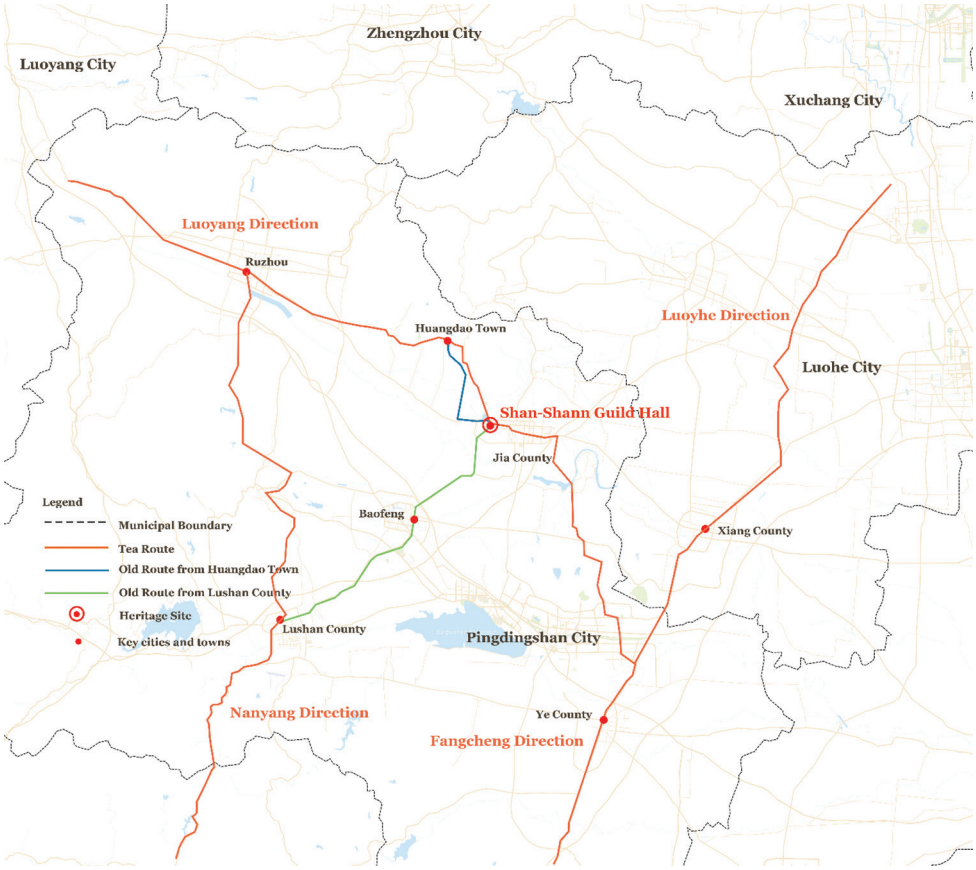

Figure 4. A map showing the old roads that passed within the vicinity of the Shanxi-Shaanxi Guild Hall. Source: Drawing by Yixin Wang based on Gong (1991) and oral histories.

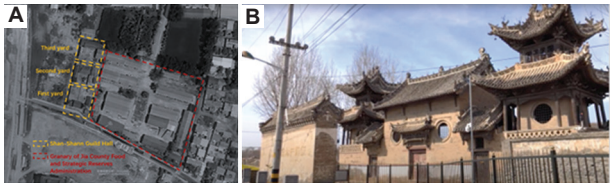

Figure 5. Courtyards and screen wall of the Shanxi-Shaanxi Guild Hall. (A) The courtyard layout of the Shanxi-Shaanxi Guild Hall. Source: Jia County People's Government. (B) Spatial alignment of the screen wall with the Shanxi-Shaanxi Guild Hall. Source: Photo by Yixin Wang (2022).

significant hall in the complex. The hall once housed a statue of "*Guan Yu reading the Spring and Autumn Annals at night* (关公夜读春秋)."

The esthetic value of the Shanxi-Shaanxi Guild Hall lies in its combination of commercial culture and architectural artistry. Constructed with brick, stone, and timber building materials, the complex reflects the refined construction techniques of the Ming and Qing dynasties, while also showcasing the financial strength of Shanxi-Shaanxi merchants (Figure 7A). The architectural design features vibrant and intricate wood carvings (Figure 7B), stone carvings, brick carvings (Figure 7C), clay sculptures, paintings, and hollowed-out patterns. These elements not only exhibit artistic excellence but also convey a sense of auspiciousness and sacredness. Collectively, they prominently embody the merchants' consciousness of embracing business integrity and honesty.

In addition to the existing buildings, historical documents indicate that an east compound was added during the reconstruction in the Jiaqing period. This compound reportedly included an inn, stables, and a barn (Cheng, 2010). However, the existence and specific functions of these facilities remain unverified. Based on the results of the semi-structured interviews, it is suggested that the east courtyard, located beside the Spring and Autumn Hall, may have been used for storage, accommodation, entertainment, and business negotiation. The Jia County Cultural Relics Bureau used detection equipment to investigate the area and found that the fence on the east side of the guild hall is slightly farther from the Spring and Autumn Hall's west wall than previously thought, possibly indicating the presence of a former eastern courtyard. This courtyard is speculated to have a parking area and kitchen for Shanxi-Shaanxi merchants. The parking yard likely

Figure 6. Courtyards of the Shanxi-Shaanxi Guild Hall. (A) Interior view of the first courtyard toward the theater; (B) Front view of the Main Hall; (C) Front view of the Spring and Autumn Hall. Source: Photos by Yixin Wang (2022).

Figure 7. Commercial culture and architectural artistry of the Shanxi-Shaanxi Guild Hall**.** (A) Reinforced building corners using locally sourced red stone strips. (B) Carved architrave (*efang*; 額枋) of the theater building. (C) Brick carvings on the flying roof eaves of the Bell Tower. Source: Photos by Yixin Wang (2022).

accommodated wagons and camel caravans managed by the hall's administrators, while a separate courtyard south of the street outside the hall served visiting merchants. However, some argue that the existence of an east courtyard would disrupt the symmetry of the guild hall's central axis.

5.1.4. Religious

Respecting deities is a fundamental function of the Shanxi-Shaanxi Guild Hall. Since Shanxi-Shaanxi merchants traditionally worship Guan Yu, the Shanxi-Shaanxi Guild Hall is often referred to as the Guandi Temple. Guan Gong was revered by the merchants not only as a symbol of loyalty and righteousness but also as a figure to mitigate homesickness and alleviate fears associated with market risks. His virtues encouraged ethical business practices and supported the development of economic and trade undertakings (Li & Cao, 2011). The influence of Guandi culture in Jia County is evident in the two painted clay statues of Guan Gong, located in the Main Hall and the Spring and Autumn Building of the guild hall. Large-scale rituals during important festivals, such as the Spring Festival, contributed to the recognition and acceptance of Guandi as a deity by the local population[9] (Guo & Jiang, 1975).

Beyond Guan Gong worship, the Great Tea Route brought significant population movements and cultural diversity to Xiguan Street, where the guild hall is located. This influx also led to the emergence of Daoist, Buddhist, and Islamic religious sites. According to oral history and field research, a Daoist temple called Ten-Direction Courtyard (十方院) is situated 500 m east of the guild hall. Further east, 150 m away, stands the Buddhist Temple of the Mother of the Five Dragons (五龙圣母庙), and near the historical Jia County wall lies the Xiguan Mosque (西关清真寺)[10] (Figure 8).

5.1.5. Trade

The location of Shanxi-Shaanxi Guild Hall in Jia County was chosen based on principles of Chinese geomancy (*fengshui*; 风水). To its south flows the Yinrujicheng River, believed to bring wealth and good fortune to the merchants. To the northwest stands the Funiu Mountain (伏牛山), reflecting the ancient wisdom of site selection based on environmental conditions.

The map of Jia County (Figure 2) highlights Xiguan Street, where the guild hall is located, as the primary east-west trade route in the region. This advantageous location established the street as an important commercial hub. Since the 5th year of the Shunzhi era (1644 – 1661) in the Qing dynasty (1648), a vibrant street market has operated in Jia County. Until 1978,

[9] On New Year's Day, the people of Jia county pay homage to the Confucian Temple (文庙), the City God Temple (城隍庙), the Chidi Temple (赤帝庙), and the Guandi Temple (关帝庙) after worshipping their ancestors and parents. In addition to folk worship practices, the Qing government provided an annual donation of 40 taels to the Guandi (Guo & Jiang (1975).

[10] In the 34th year (1908) of the Guangxu era (1875–1909) during the Qing dynasty, four mosques were located on North Street, Xiguan Street, Zhongtou town, and Sanlangmiao village.

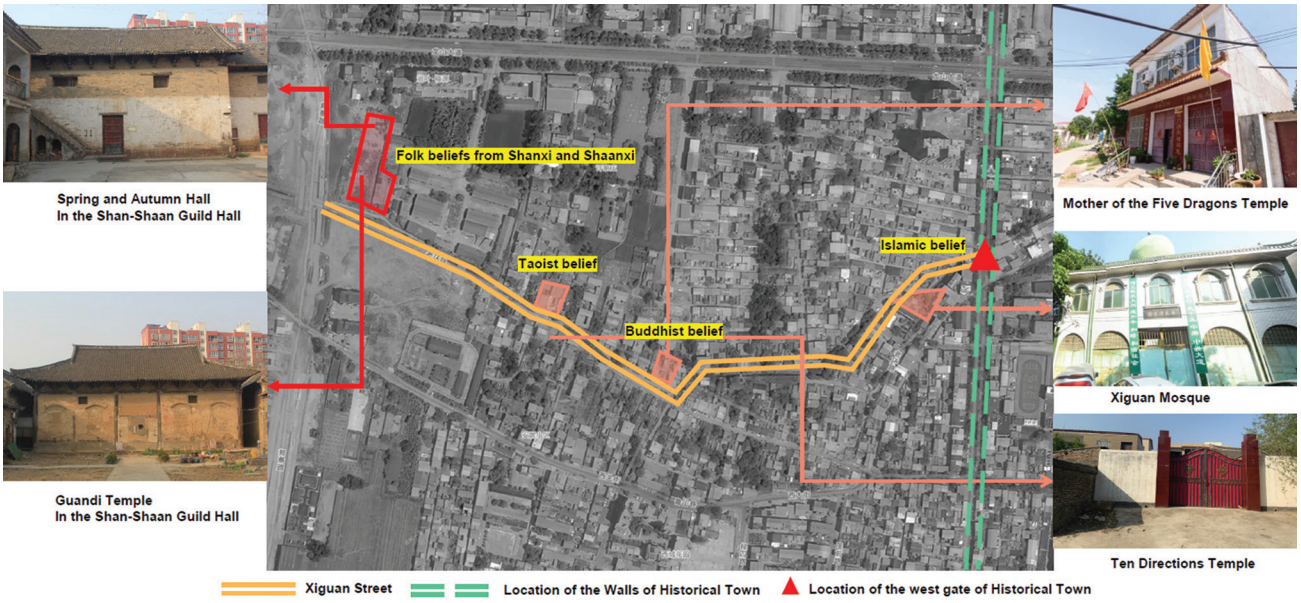

Figure 8. Religious heritage on Xiguan Street. Source: Drawing by Yixin Wang based on the field research and the historical map.

there were 26 markets across the County, operating 6,300 market days annually and generating a trading volume of ¥73.3 million yuan. Xiguan Stree*t al*so hosted a daily food market (Jia County Local Historiography Compilation Committee, 1996).

Residents recalled that Xiguan Street once included a beef and mutton market, flour and cooking oil processing factories, and a variety of businesses monopolized by Shanxi-Shaanxi merchants. These businesses included private banks, pawnshops, and dye houses, along with the trade of goods such as silk, tobacco, wine, grain, dried fruit, groceries, medicine, tea, and salt (Cheng, 2010). In addition to the regular bazaar, temple fairs brought significant commercial activities to the areas. These fairs[11] were held on February 3rd, March 7th, April 15th, August 3rd, and October 10th (Committee, 1996).

According to interviews, three large camel yards provided provisions and stabling for merchants' camel caravans arriving from across the country. These camel yards were located on both sides of the road in front of the guild hall and included the Sun family Camel Courtyard (孙家骆驼院), the Ma Family Camel Courtyard (马家骆驼院), and the Pan Family Camel Courtyard (潘家骆驼院) (Figure 9). This road became known as the Camel Trail (骆驼道) due to its critical role in facilitating trade. Goods transported along the Camel Trail included tea (60 – 70% of the total), tobacco[12], cotton[13], pottery[14], silk, and jade. This bustling commercial street, centered around the guild hall, was a testament to the economic prosperity of Xiguan Street over the centuries.

Residents also attribute the sweetness of tea in Jia County to the high quality of the water used for brewing. According to staff from the Department of Culture and Tourism, this water originated from Qinglong Lake, which flows west of the guild hall. Inside the guild hall, a hexagonal wooden Tea Pavilion (built in 1934) provided free tea to passing merchants and pedestrians. This pavilion symbolized the guild hall's importance as a commercial center in Jia County with a constant flow of merchants (Figure 9). Unfortunately, the tea pavilion was burned down by the Japanese army, and today, only a commemorative plaque remains in the guild

[11] Traditional temple fair activities in Jia country primarily revolve around worship, entertaining and rewarding the deities, and the trade of daily ritual objects and household goods (Li, 2002).

[12] Tobacco cultivation in Jia country began during the Tianqi era (1621–1627) of the Ming dynasty. By the Qianlong era of the Qing dynasty, it had developed into a significant economic product (Jia County Local Historiography Compilation Committee, 1996).

[13] Jia county is rich in cotton. Following traditional practices, rural women spin and weave cotton products, which are used for their own households and sold in markets and towns (Guo & Jiang, 1975).

[14] In the past, official kilns in Juntai town and Huangdao town (Jia County Local Historiography Compilation Committee, 1996).

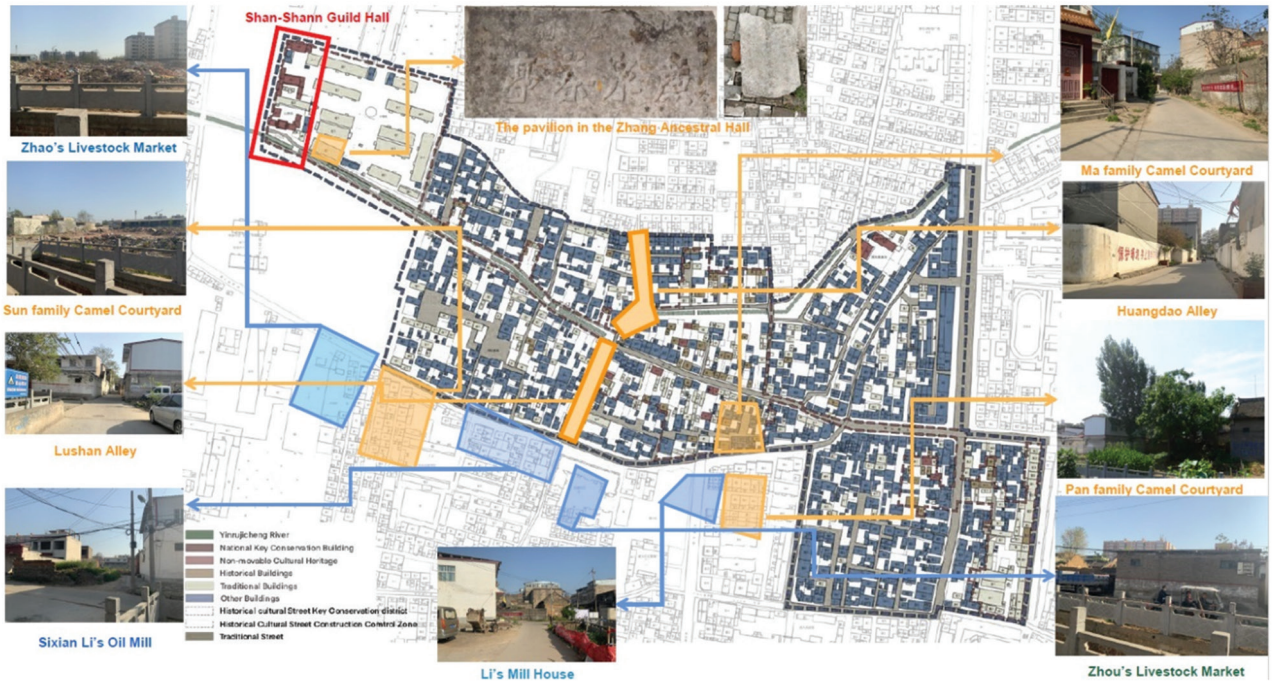

Figure 9. Trade heritage related to the Great Tea Route on Xiguan Street. Yellow areas represent trade heritage primarily serving traveling merchants, while blue areas indicate heritage serving the local population. Source: Drawing by the author based on the field research and the map provided by the Ministry of Housing and Construction in Jia County.

hall. Historical records indicate that the pavilion was established to commemorate Zhang Sanquan (张三铨), a County magistrate who donated funds for disaster relief in the 2nd year (1911) of the Xuantong era (1909 – 1912).

5.2. Intangible heritage characteristics

The complexity of cultural routes transforms them into significant manifestations of cultural heritage, combining tangible and intangible elements while emphasizing the central role of human interaction (Martorell Carreño, Alberto, 2003). The intercultural dynamics, interactions, and evolution of links between the cultures along the Great Tea Route and the local traditions of Jia County highlight the diversity of cultural heritage and the broader significance of the Great Tea Route as a cultural pathway.

5.2.1. Trade and commerce culture

In the land transport section of the Great Tea Route, the culture of horse caravans and camel caravans emerged to meet the demand for transporting goods (Jiang, 2022). The camel caravan culture is evident not only in the numerous camel courtyards that once existed but also in the Camel Trail south of the Shanxi-Shaanxi Guild Hall. This 10-m-wide and 500-m-long road, paved with red stones[15], stretched from the guild hall to the Xiguan Mosque. Unfortunately, according to the oral histories, the River south of the guild hall was diverted in 2008, and the red rocks along the road were removed and lost. The presence of these red rocks suggests that the current River channel was originally a road. In ancient times, this road was lower than the surrounding ground, making it difficult for pedestrians above to see merchants traveling along it or discern whether they carried large sums of money. This design served as a safety measure, deterring robbery and burglary. In addition, the locals referred to this road as a "ditch" (gou; 沟) in traditional provincial language, underscoring its unique structural features.

5.2.2. Religious culture

As mentioned earlier, Xiguan Street, which extended from the west gate of the historical town to the Shanxi-Shaanxi

[15] According to semi-structural interviews, the red stone used to pave the Camel Trail were sourced from Ziyun mountain (紫云山), located in the southeast of Jia county, Henan province, China. The striped red stone used to reinforce the Shanxi-Shaanxi Guild Hall building were also querried from this mountain. Since the reign of Emperor Shunzhi, the imperial court had extracted red stones from Ziyun mountain for construction purposes (Guo & Jiang, 1975).

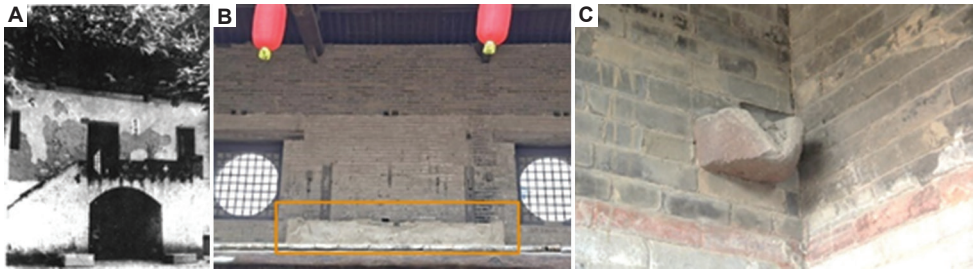

Figure 10. The theater at the Shanxi-Shaanxi Guild Hall. (A) Photograph of the theater building in 1984, showing the north side enclosed by a wall and featuring a staircase. Source: Photo by the Editorial Committee of the Henan Volume of the Chinese Opera Journal); (B) Photograph of the theater's sink, used for face washing and fire protection. Source: Photo by Yixin Wang (2022); (C) Photograph of the theater's drainage system. Source: Photo by Yixin Wang (2022).

Guild Hall, became a convergence point for various religious and folk beliefs. The Shanxi-Shaanxi merchants brought with them the worship of Guan Gong, while the movement of people along the Great Tea Route facilitated the spread of diverse religious traditions, such as Daoism, Buddhism, and Islam, in Jia County.

5.2.3. Food culture

Food, as an element of intangible cultural heritage, reflects not only the lifestyle of a region but also its agricultural practices and cultural depth. One of the most famous traditional dishes in Jia County is *heluo* noodles (饸饹面), which are heavily influenced by the eating habits of people from Shaanxi Province. These noodles are quick and easy to prepare and suited to the fast-paced schedules of traveling merchants. In addition, they are reputed to alleviate hangovers and soothe the stomach, making them a preferred choice for businessmen recovering from social gatherings. Another staple of the local food culture is *guokui* (锅盔), a pot-lid-shaped bun known for its durability and ease of transport – qualities highly valued by merchants on the move.

5.2.4. Opera culture

Henan Province of China once had nearly 3,500 traditional theater buildings, but only about 100 remain – a mere third of the number existed in the 1980s, as many have been destroyed over time. These theater buildings are significant not only as examples of historical Chinese architecture but also as vital carriers of Chinese opera culture. The most magnificent Qing-dynasty theaters in Henan were typically located within association/guild halls, reflecting the financial prosperity of merchants who could afford to construct exquisite and majestic venues (Xue, 2007). The well-preserved and intricately designed theater at the Shanxi-Shaanxi Guild Hall in Jia County is particularly valuable in this context (Figure 10).

Merchants frequently invited actors to perform at the Shanxi-Shaanxi Guild Hall for various occasions, including opening ceremonies, worship rituals, birthdays, and even as a form of punishment when someone broke trade rules—turning such events into communal entertainment (Chu & Ma, 2021).

As early as in the 12th year of the Republic of China (1923), local merchants, many of whom were noodle sellers, organized a Bangzi Opera[16] (梆子戏) troupe. According to interviews with a local restaurant manager, this troupe performed on the Riverbank in front of the guild hall on specific dates: the 7th and 13th days of March, the 3rd day of August, the 10th day of October, and during the Spring Festival temple fair. The audience was free to decide how much they wished to tip the performers. These performances are consistent with historical records, such as the County annals, which states:

"Since 1948, Chengguan Town has held temple fairs on the 3rd day of February, the 7th day of March, the 15th day of April, the 3rd day of August, and the 10th day of October every year." (Jia County Local Historiography Compilation Committee, 1996, pp. 357-358)

In addition to the merchant-organized troupe, a doll troupe (娃娃戏班), from Xiping County, performed in Jia County in the 20th year of the Republic of China (1931). The actors and actresses of this troupe stayed in the Shanxi-Shaanxi Guild Hall and were hosted by local residents, who provided them with meals (Editorial Board of Chinese Opera Records, 1992).

This article combines archival research, field research, and oral history to provide an in-depth exploration of the

[16] Leveraging the extensive networks of Shanxi-Shaanxi merchants conducting business across the country, opera performances held in guild halls gradually spread nationwide. Through these perfomances, local arts mingled and converged with traveling troupes, leading to the development of distinct regional opera styles such as Henan Bangzi, Hebei Bangzi, and Shandong Bangzi (Chen, 2018). Some scholars argue that Henan Yu Opera originated during the Qianlong era, evolving from the Bangzi operas as they blended with the local operatic traidtions in Henan (Song, 2006).

Table 1. Methods of exploring the value connotation of the Shanxi-Shaanxi Guild Hall and Xiguan Street

Theme	Content	Archival Research	Field Research	Oral History
The relationship between the Great Tea Route and Shanxi-Shaanxi Guild Hall in Jia County, Henan Province, China	Location of the Shanxi-Shaanxi Guild Hall in Jia County	The traffic center of the Great Tea Route; transformation from a folk hall to an official post station; located outside the west gate of the historical town	Located outside the west gate of the historic town	The reason why it is located outside the west gate of the historical town
	History of the Shanxi-Shaanxi Guild Hall in Jia County	The relationship between the fate of the guild hall and the rise and fall of the Great Tea Route		
The characteristics of Shanxi-Shaanxi Guild Hall from the perspective of the Great Tea Route	Tangible heritage characteristics	Important nodes of the ancient Wanluo Road; Lushan Lane and Huangdao Lane; the Main Hall used to have a porch; there used to have an east yard; mosque; Camel Trail; the source area of the red stone	Lushan Lane and Huangdao Lane; the position of the base of the columns of the building is still recognizable; Buddhist Temple; red stone	Lushan Lane and Huangdao Lane; the foundation of the pillar was removed and discarded during a previous renovation project; may have an east yard; Daoist Temple, Buddhist Temple, and mosque; camel courtyard; mill; Camel Trail
	Intangible Heritage Characteristics	Name of the troupe and performance time of the performance	Facilities for the opera performance	Origin of the name Camel Trail; reasons for changes in eating habits; the time, place, and cost of the opera performance

Shanxi-Shaanxi Guild Hall, Xiguan Street, and the Great Tea Route. These methods corroborate and expand the value of the connotation of the Shanxi-Shaanxi Guild Hall, as summarized in Table 1. By employing a community-centered approach and incorporating multiple narratives, the heritage site emerges as a vessel rich in social and cultural values (Smith, 2020).

6. Discussion

For a historic route to be classified as a cultural route, it must have facilitated exchanges of people, goods, ideas, knowledge, and values over a significant period of time (Genovese, 2016). As an important architectural heritage site of the Great Tea Road, the Jia County Shanxi-Shaanxi Guild Hall not only witnesses commercial prosperity but also creates a dynamic dialogue of ecocultural exchange, blending the cultures along the Great Tea Route with the local traditions of Jia County.

Route heritage tells the story of how diverse groups of people, through trade and migration, forged a collective identity (Sigley, 2021). Since the Yuan dynasty (1279 – 1368), Henan has hosted Hui communities, which grew significantly during the Ming and Qing dynasties (Hu, 2005)[17]. The prosperity of the Great Tea Route attracted more Hui people and stimulated commerce and trade in Jia County's Xiguan area. According to corroborated documentary records and field research, the Shanxi-Shaanxi Guild Hall played a central role in this economic ecosystem. Hui merchants sold beef and mutton at West Street markets to local restaurants, whose owners reinvested their profits in sponsoring opera troupes. These troupes performed at the Shanxi-Shaanxi Guild Hall, drawing more consumers to the markets and sustaining the commercial chain.

The most direct impact of the Great Tea Route was the exchange of goods. It significantly increased Chinese tea exports, making tea a central commodity in China's foreign trade. From 1817 to 1833, just before the Opium War, tea generally accounted for over 50% of China's export value (Huang & Ping, 2020). In addition to tea, caravans transported silk, fruits, and gold and silver utensils from the western regions. Jia County, situated in the fertile Central Plains, used the Great Tea Route to export locally produced goods, such as cotton, tobacco, grain, and distinctive pottery, to distant markets.

The architectural complex of the Shanxi-Shaanxi Guild Hall embodies the ingenuity of Shanxi-Shaanxi merchants and the craftsmanship of Jia County. The Shanxi-Shaanxi merchants strategically chose to build their guild hall outside the city's western gate, prioritizing convenience and efficiency. Its symmetrical north-south axis and three-courtyard structure were inspired by the traditional residential courtyard style in Shanxi. This design not only

[17] The Hui are known for their business acumen; however, they were historically prohibited from living within the city proper. As a result, they often settled along the city's main traffic routes (chengguan; 城关). This strategic choice not only addressed their housing needs but also facilitated their commercial activities. (Hu, 2005).

improved ventilation and daylight but also provided a high degree of privacy through its enclosed layout. The use of locally sourced red stones at the corners of the buildings, along with intricate wood and brick carvings, demonstrates the advanced construction techniques and expertise of Jia County craftsmen.

The Shanxi-Shaanxi Guild Hall, constructed along the Great Tea Route, was pivotal in spreading Guandi culture and promoting the exchange and fusion of theatrical traditions. The integration of guild hall and temple functions (*guan-miao heyi*; 馆庙合一) allowed these spaces to serve both commercial and spiritual purposes. The culture of "Guandi worship," inherited and developed by the Shanxi-Shaanxi Association of Jia County, provided significant spiritual support to Shanxi-Shaanxi merchants. This practice elevated the cultural importance of the guild hall, combining moral teachings from Confucianism, Daoism, and Buddhism, to foster local acceptance of commercial activities. Moreover, the Shanxi-Shaanxi merchants' passion for opera transformed the guild hall's theater into an important cultural hub, supporting the spread and localization of Bangzi Opera.

The Shanxi-Shaanxi Guild Hall also profoundly influenced the daily lives and habits of Jia County residents. The Guandi Temple made the guild hall a focal point of religious festivals, while its theater became a cornerstone of community entertainment. The tea culture that accompanied the Great Tea Route contributed to the proliferation of teahouses in Jia County[18], where residents gathered for tea drinking, card playing, storytelling, and opera performances. Making a pot of hot tea to relax after a long day became an enduring local tradition (Jia County Government, 2019).

Promoting cultural routes as a sustainable way to explore the Shanxi-Shaanxi Guild Hall and the Xiguan historical district can support sustainable development by harmonizing tourism activities with the conservation of tangible heritages, cultural traditions, and social well-being. An in-depth exploration of the Shanxi-Shaanxi Guild Hall's cultural connotation can enhance understanding and accessibility for local communities and tourists through educational activities, awareness campaigns, and events, both online and offline. These efforts align with the goals of Quality Education (SDG4) and Industry, Innovation, and Infrastructure (SDG9) (Lucchi *et al.*, 2024). Moreover, a thorough understanding of the Xiguan historic district can strengthen local identity and encourage community participation in the preservation and utilization of architectural heritage. This approach supports the goals of Sustainable Cities and Communities (SDG11) and Partnerships for the Goals (SDG17), fostering a sustainable future for Jia County and its cultural landmarks.

7. Conclusion

As a historical heritage of ancient transportation routes, a cultural route reflects the communication and exchange between cross-regional and cross-ethnic groups. This article explores the relationship between the Shanxi-Shaanxi Guild Hall and the Great Tea Route, enriching the cultural connotation of the Shanxi-Shaanxi Guild Hall through documentary research, fieldwork, and oral histories that corroborate one another.

Regarding the relationship between the Shanxi-Shaanxi Guild Hall and the Great Tea Route, the latter elevated Jia County from a transport hub to a thriving commercial town along the route. The Shanxi-Shaanxi Guild Hall evolved from a folk-led enclave to an official post, reflecting the economic and social exchanges fostered by the Great Tea Route. Analyzing the spatial characteristics of the Shanxi-Shaanxi Guild Halls in the context of the Great Tea Route reveals the route's influence on Jia County through the transport, processing, and trade of tea, as well as the provision of essential facilities for caravans, ensuring their livelihoods and spiritual sustenance.

Further examination of the intangible heritage associated with the Shanxi-Shaanxi Guild Hall highlights their role beyond commerce. Alongside their economic function, the guild hall fostered a rich cultural tapestry, including a diverse religious tradition and a vibrant culinary culture. These influences are deeply imprinted in the spatial layout of Jia County and continue to shape the daily lives of its residents.

A micro-level analysis of cultural routes not only complements the spatial narrative of the Great Tea Route but also provides diverse perspectives on the preservation of architectural heritage and the historic towns where it resides. However, the deteriorated state of the Shanxi-Shaanxi Guild Hall and the loss of the historical identity of Xiguan Street suggest that their cultural significance has not been adequately addressed in current conservation planning efforts. To address these challenges, future conservation planning for the Shanxi-Shaanxi Guild Hall and the Xiguan district should focus on several key areas. First, an in-depth elaboration of

[18] According to semi-structure interviews, during the heyday of the Qing dynasty, Jia county had nearly 100 teahouses of various sizes. These teahouses were primarily concentrated in the townships of Xiguan (西关), Zhongtou (冢头), Yaozhuang (姚庄), Tangjie (堂街), Li Kou (李口), and others. Today, Jia county is home to hundreds of teahouses, and the traditions of tasting and discussing tea remains a cherished practice among its people.

their cultural values should be undertaken to highlight their value connotations. Second, selective protective restoration and rehabilitation should focus on preserving the tangible aspects of their heritage. Finally, immersive cultural experiences should be planned to celebrate and sustain the intangible heritage linked to these sites. To achieve sustainable tourism, local authorities must further explore these proposals and implement initiatives that actively engage the local community in preservation efforts.

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Conflict of interest

The authors declare they have no competing interests.

Author contributions

Conceptualization: Yixin Wang
Formal analysis: Yixin Wang
Investigation: Yixin Wang
Methodology: Yixin Wang
Writing – original draft: Yixin Wang
Writing – review & editing: All authors

Ethics approval and consent to participate

The interview content of this study does not involve the privacy of the interviewees, and the interviews were not recorded.

Consent for publication

Not applicable.

Availability of data

The base map of the Great Road Map is from Mapbox (https://studio.mapbox.com/), and the satellite image in the analysis map is from the Ovitalmap platform (https://www.ovital.com/).These interviews are kept in the form of audio recordings, photographs, and transcripts, and are unpublished because of the interviewee agreements signed with the interviewees.

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ORIGINAL ARTICLE

Ting or Chinese pavilion: The history of a Chinese architectural type and its translation in transcultural scholarship

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Abstract

The translation of Chinese architectural types in transcultural scholarship faces two primary challenges: The ambiguous meaning of the term within its original cultural context and the broad connotations and usages of the corresponding English term, which often exceed those of the original. The Chinese architectural type *ting*, in particular, has been variously translated as "kiosk," "gazebo," and "pavilion" in previous scholarship. These translations, however, influenced by European architectural history, have led to inaccuracies, compounded by inconsistent references to other building types such as *ge* and *xie*. A chronological review of *ting*'s architectural reveals significant changes in its historical forms and functions. In the Han dynasty (206 BCE – 220 CE), *ting* was primarily a military facility of considerable height, later transitioning during the Wei-Jin dynasties (220 – 420) into a geographical landmark and a venue for literati activities. By the Tang dynasty (618 – 907), its elevated structure diminished, and its role in literati culture became more versatile. During the Song dynasty (960 – 1279), *ting* evolved into a roofed open structure, closely associated with *xie* in the *Yingzao Fashi*. By the Ming (1368 – 1644) and Qing (1644 – 1912) dynasties, *ting* had stabilized as "an architecture with a roof but without enclosing walls," characterized by its great flexibility in construction. This historical complexity makes coining a singular equivalent term for *ting* inadequate. Instead, this article advocates for thick translations that situate *ting* within its spatial-temporal context through illustrations, annotations, and detailed explanations, addressing its intricate historical and cultural nuances alongside related building types.

Keywords: Chinese architectural type; *Ting*; Chinese pavilion; Kiosk; Gazebo; Chronology of architectural types; Translation studies; Transcultural scholarship

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1. Introduction

In the *Oxford Dictionary of Architecture* (3rd. ed.), the Chinese architectural term *ting* (亭) is defined as a "Chinese pavilion, roofed, but with no walls" (Curl & Wilson, 2021, https://www.oxfordreference.com/display/10.1093/acref/9780199674985.001.0001/acref-

9780199674985-e-7023?rskey=MRbtp2&result=5448). This particular characterization converges with its definition in *Ciyuan* (辞源; *The Origin of Words*), which states that *ting* refers to "a small architecture with a roof but without enclosing walls" (He *et al.*, 2015, p. 210). Both definitions likely capture the typical imagery of *ting* as it appeared in private gardens during the Ming (1368 – 1644) and Qing (1644 – 1912) dynasties. For a contemporary audience, these descriptions might also evoke images of modern roadside civic kiosks or amusement park pavilions—single-story open structures designed for brief stop-offs.

From the perspective of architectural historians, however, an immediate acceptance of these definitions of *ting* could be misleading for English readers unfamiliar with its broad range of historical associations. In early Chinese history, the semantic implications of the Chinese character "亭" (*ting*) varied significantly from its modern counterpart. These linguistic and cultural origins deserve further attention to accurately interpret "*ting*" as a historical building type within traditional Chinese architecture, rather than relying on vaguely portrayed literary imagery.

Coining an English translation of *ting* is not a new phenomenon. Terms such as "pavilion," "kiosk," "gazebo," and even the Romanized name "ting" have been used since the 18th century, when architect William Chambers traveled to China and published his descriptions and illustrations of Chinese architecture in English. However, the meanings and connotations of these translations in English scholarship are further complicated by the history of Western building types and their associated stereotypes. For example, the term "pavilion" has been used to describe drastically different architectural forms in the East and West. The Chinese Pavilion in the Drottningholm Palace Park, Sweden, an 18th-century structure built in the chinoiseries style, exemplifies this disparity. Taking the form of a multi-story architectural compound with two wings (Figure 1), it serves today as one of the Swedish Royal Palaces. Its architectural composition is comparable to other multi-story Swedish royal buildings of the same era, such as Gustav III's Pavilion at Haga. However, this structure bears little resemblance to contemporaneous "pavilions" or *ting* in China, which were single-story, open structures commonly found in private gardens. This ambiguity extends to the work of the 20th-century Chinese architectural historian Liang Sicheng (1901 – 1972), who used "pavilion" as a translation for two drastically different types of *ting*. For example, he translated *Linshui tingxie* (临水亭榭) as "Water-front Pavilion," referring to an open structure depicted in Han tomb carvings that were designed for resting near water (Liang, 1984). In another example, he translated *Kongmiao Beiting* (孔庙碑亭) as

Figure 1. The Chinese Pavilion is on the grounds of the Drottningholm Palace Park, part of the Royal Domain of Drottningholm World Heritage Site. Source: Photo by Arild Vågen (https://commons.wikimedia.org/wiki/File: Kina_slott_October_2016_01.jpg)

"Stele Pavilion," an open structure housing memorial steles dedicated to Confucius in Qufu, Shandong. Simply applying the term "pavilion" to both examples creates unnecessary confusion and diminishes scholarly precision.

In search of a historically accurate translation of *ting*, this article reviews the chronology of both the architectural form and function of *ting* from the pre-Qin period (before 221 BCE) to the Ming and Qing dynasties, when the semantic meaning of this term ultimately stabilized as a simple open structure in private gardens. By thoroughly examining the correspondence between various translations of *ting* in previous scholarship and the history of *ting*, this article argues that coining a singular English translation of *ting* fails to capture the semantic complexity of its historical evolution. Therefore, scholars should exercise caution when using a single term in English literature to represent *ting*. This article highlights the significance and benefits of employing "thick translations" in the form of paratexts and footnotes, which offer context specificity and interpretability after translation. However, future efforts are required to negotiate a particular thick translation of *ting* that consolidates its semantic breadth as an archetypal building type in global architectural history.

2. From the pre-Qin period (before 221 BCE) to the Han (202 BCE – 220 CE) dynasty: A military facility with considerable height

The origins of the Chinese character for *ting* are a topic of debate. In Chinese oracle bone scripts, several characters possibly representing *ting* cannot be clearly differentiated in meaning (Guo, 2012). Wang Xiantang (1896 – 1960) grouped these characters with other oracle bone scripts that may refer to various forms of elevated architecture, construing their meanings based on the characters' formal compositions (Wang, 1985). During the Qin dynasty (221 – 207 BCE), characters resembling the

standardized character *xiaozhuan* (小篆; small seal script) for *ting* (Figure 2) appeared on bamboo and wooden slips (e.g., Figure 3). The visual form of these characters plausibly represents an architectural structure built on a vertical pillar, suggesting significant height.

In literary sources from the pre-Qin period to the Han (202 BCE – 220 CE) dynasty, *ting* mainly referred to a type of military facility that also functioned as a local administrative office, often with a high elevation. For example, in *Mozi* (墨子), a text compiled during the Warring States period (475 – 221 BCE), the chapter "*Zashou*" ("杂守"; "Varied Defenses"), which focuses on preparing civic and military structures to defend against enemy attack, is one of the earliest works to describe *youting* (邮亭), a type of roadside commuter architecture used by local officials. The text provides the following instruction (Chen, 2017):

> "*Youting* should be built rounded, with a height over three *zhang*, and its roof should be steep." (筑邮亭者圜之，高三丈以上，令倚殺) (Mo *et al.*, 2006, p. 953).

Figure 2. Anonymous writer, *ting* (Qin Xiao Zhuan Character [秦小篆]). Source: Xu (2020)

Figure 3. Anonymous writer, *ting* (Qin Jian Du Character [秦简牍], in *Fengzhen* [封診] *22 Daoma* [盜馬]). Source: Xu (2020)

According to the Qin dynasty's standard measurements, three *zhangs* (丈) correspond to approximately 7 m (22.7 ft) (Jiang, 2012). These instructions emphasize vertical elevation as a defining characteristic of this military *ting* structure.

In addition to the form of *ting*, Han-dynasty descriptions of Qin-dynasty administrative practices further documented its function. The *Gaodiji* (高帝紀; *Records of Emperor Gao*) in *Hanshu* (汉书; *Book of Han*) describes the geographical distribution and military function of *ting*:

> "According to Qin law, there is a *ting* every ten *li*. The senior, the chief officer of the *ting*, is responsible for its administration. The *ting* serves as a place to stop for dining and lodging during travel." (秦法十里一亭。亭长者，主亭之吏也。亭谓停留行旅宿食之馆) (Ban & Yan, 1962, p. 3).

This architectural form continued into the Eastern Han (25 – 220). The character of *ting* was first defined in *Shuowen Jiezi* (说文解字; *Discussing Words and Explaining Characters*) as follows:

> "*Ting* indicates that people live safely and stably. *Ting* has a building(s). The character is simplified from the character for "height." Its pronunciation is similar to 'ding.'" (亭，民所安定也。亭有楼，从高省，丁声) (Xu *et al.*, 2005, p. 282).

Echoing this definition in the *Shuowen*, the *ting*'s functional association with civilian safety and stability became particularly significant during the Eastern Han period. The literary sources cited above indicate that, during the Qin and Han dynasties, the primary function of *ting* was as military architecture with residential functions. As further specified by Chen (2018), this role extended to locations both inland and along military frontiers.

In addition to these literary sources, the early architectural form of *ting* is also reflected in funerary objects known as *mingqi* (明器). One notable example is a Han dynasty building model found in a tomb (Figure 4), now housed in the Newark Museum of Art, which provides a three-dimensional representation of a vertically elevated roof structure atop a rectangular platform. With all four sides unwalled, the model depicts a figure with a tall headdress seated solemnly in the center, tightly surrounded by four attendant figures. At the platform's edge, two crossbowmen face outward, their weapons extended over the balustrades. Beneath the platform, livestock or guard dogs are positioned on opposing sides. This arrangement plausibly corresponds to the description in *Hanshu*, wherein the central figure represents the *ting*'s chief officer, as the attendants are positioned within the

Figure 4. Anonymous craftsman, a tomb model of a pavilion with the red bird of the south, crossbowmen, guard dogs, and assembly, Han dynasty (206 BCE – 220 CE). Source: The Newark Museum of Art, New Jersey

space. The addition of guardians and animals reflects the definition in the *Shuowen*, which states that "*ting* indicates that people live safely and stably."

Synthesizing these findings, two key features of *ting* during the Qin and Han dynasties emerge. First, *ting* included long-term inhabitable spaces, serving as residences for the officers of *ting* and lodging for travelers. Second, based on the instructions in *Mozi*, the architectural features of *mingqi*, and *Shuowen*'s explanation that the character "*ting*" derives from the character for "height," *ting* structures likely featured considerable vertical elevation atop other structural foundations. It is crucial to note that these early features of *ting* are often overlooked in modern scholarly translations, which frequently reduce *ting* to a generalized historical building type.

3. Wei, Jin, and the Northern and Southern dynasties (220 – 589): Landmark and landscape

In texts composed between the 3rd and 6th centuries, *ting* continued to serve as a name for local officials and as a lodge for temporary accommodation. However, it gradually evolved into a type of architecture associated with spectacular natural landscapes and landmarks. In the *Shuijing Zhu* (水经注), a commentary on Chinese rivers and geography written during the Northern Wei (386 – 535) by Li Daoyuan (470 – 527), *ting* started to be recognized as a geographical landmark. For example, the chapter "Jishui" (济水) records:

> "There is a *ting* named Safety Ting (平安亭), 30 *li* (里) southwest of Bochang county, and therefore, it is a county." (Li & Shi, 2006, p. 173)

Similarly, in *Qishui* (淇水), Li Daoyuan transcribed from an earlier Han text, *Dili Fengsu Ji* (地理风俗记; *Geography and Customs*), stating:

> "There is a *ting* named Willow (柳亭) 50 *li* northeast of Gaocheng county, and therefore it is a county." (Li & Shi, 2006, p. 209)

These geographical accounts in *Shuijing Zhu* demonstrate that *ting* structures were significant landmarks for the local administrative divisions by the Northern Wei dynasty (386 – 535). However, the text does not clarify the specific architectural form of these *ting*.

Interestingly, records of the military function of *ting* became less prominent during this period. Beginning in the Wei-Jin (220 – 420) period, *ting* increasingly served as venues for local literati to gather, owing to their scenic locations and provision of temporary accommodation. For example, the Eastern Jin literati and calligrapher Wang Xizhi (c.303 – c.361) described in his prose *Lantingji Xu* (兰亭集序):

> "…[we] met at *Lan ting* to the north of Kuaiji Mountain to perform seasonal rituals. Gentlemen all attended, and both the young and the elderly all gathered together." (…会于会稽山阴之兰亭，修禊事也。群贤毕至，少长咸集) (Fang, 1974, p. 2099)

This famous prose of *Lanting* (Orchid Pavilion), written in the Eastern Jin period (317 – 420), illustrates the transition of *ting* from a semi-military unit to a cultural venue where literati socialized and expressed collective identities.

Despite this shift in function, the considerable height of *ting* as an architectural type continued to be remarked upon in the literature of the Northern and Southern dynasties (420 – 589). For example, a Liang dynasty (502 – 557) poet, Zhu Chao (birth and death dates unknown), wrote in his poem *Heyuandi Baihuating huai Jingchu* (和元帝百花亭怀荊楚; *Memorializing Jing and Chu in the Hundred Flower Ting with Emperor Yuandi*):

> "The *ting* is high. As I climb up, I can see incredibly far. The spring can be appreciated in the same way far and near." (亭高登望极，春心远近同) (Zhang, 2002, p. 50)

The poem highlights the considerable structural height of *ting*, which allowed Zhu Chao to enjoy expansive views of the natural landscape in spring. Similarly, Shi Hongyan (504 – 564), a poet of the Chen dynasty (557 – 598), composed a poem about climbing a *ting* called Wushengping (*Deng Wushengping Ting*; 登吴升平亭) (Zhang, 2002). Both poems reference *ting* as an architectural type requiring ascent, confirming its association with considerable height – either through its structural design or placement atop elevated natural features. As *ting* became more widely documented as landmarks and cultural venues in literary works, it underwent a transition from a primarily military facility to a space designed to accommodate travelers and celebrate cultural and natural landscapes during the Wei-Jin and Northern and Southern dynasties.

4. Tang dynasty (618 – 907): Flexibility and multi-functionality

During the Tang dynasty, *ting* evolved into an architectural type with diverse formal features suited to various social settings. Some *ting* structures likely retained considerable height. For example, Cao (2018) argues that a particular type of *ting* with a tall foundation (高阶基之亭) was constructed in imperial cities or temples. Cao believes that this type of *ting* usually flanked the main hall, possibly corresponding to an image in Mogao Cave 217 in Dunhuang, Gansu, China, completed during the High Tang period (713 – 755) (Figure 5). However, other scholars, such as Xiao (2002), identified the structure in Cave 217 as a different architectural type, such as *louge* (楼阁) or *gaotai* (高台). This scholarly disagreement highlights the historical ambiguity surrounding *ting* and similar architectural types due to structural resemblances.

Figure 5. Anonymous painter, *ting* (in white box) flanking the Main Hall in *Guan Wu Liang Shou Jing Bian* (观无量寿经变). Source: Dunhuang Grotto No. 217, Jiuquan, Gansu. E-Dunhuang (https://www.e-dunhuang.com/showmural/10.0001/0001/0001/0217/0001/0004/01, accessed August 21, 2024)

From the perspective of literati, Ouyang Zhan (755 – 800), an official and literatus of the mid-Tang period, provided a detailed description of *ting* in his writing *Ergongting Ji* (二公亭记). He wrote:

> A beautiful house should be called *ting*. It should be famous for [a view of] incredible landscape.…… Recent revivalists have been building *ting*. With respect to the pleasure it gives people [with natural scenery], *ting* is the same as *lou, guan, tai, and xie*. In terms of its construction, *ting* differs from these structures as it does not require the luxury of repeated vertical construction. Adding railings and balustrades suffices. Building a *ting* is simple, but its usage is broad. Wise men build them frequently. Once built, it must be located in a beautiful landscape. (胜屋曰亭，优为之名也。. 近代袭古增妙者，更作为亭。亭也者，藉之于人，则与楼、观、台、榭同；制之于人，则与楼、观、台、榭殊：无重构再成之糜费，加版筑槛栏之可处。事约而用博，贤人君子多建之；其建之，皆选之于胜境) (Ouyang, 1979, p. 27)

Ouyang Zhan emphasized that a *ting* should be located in beautiful scenery and preferred its structure to be simple, avoiding multiple stories. This belief indicates that the association of *ting* with high elevation may have diminished during the Tang dynasty. He also emphasized the versatile purposes of *ting*, a view corroborated by other Tang literary works. Tang literati favored *ting* as multi-functional facilities within private gardens or residential compounds, used for dining, resting, and leisure.

One notable advocate for constructing such *ting* was Liu Zongyuan (773 – 819), a politician and poet. In his essay *Liuzhou Dongting Ji* (柳州东亭记), Liu described how he developed an abandoned area outside the Liuzhou prefecture (柳州府) by constructing pleasant buildings, including a *ting* for use at different times of the day:

> …[I] constructed this *ting* in the middle [of all buildings], calling it the middle room. I reside in the morning room in the afternoon, in the afternoon room in the morning, and in the middle room during the middle of the day… (…作斯亭于中，以为中室。朝室以夕居之，夕室以朝居之，中室日中而居之..) (Liu, 1979, p. 774)

Although it may seem counterintuitive for Liu Zongyuan to reside in the *ting* directly under the midday sun, its location at the center of a four-piece architectural compound likely made it the most ventilated spot at

noon. Thus, Liu Zongyuan's *ting* was enjoyable even without natural scenery, possibly due to the simplicity and functionality of the residential compound, as characterized by Ouyang Zhan in his earlier writings.

In another essay, *Lingling Santing Ji* (零陵三亭记), Liu Zongyuan further argued that outings to enjoy natural scenery were particularly important for politicians, as being in a good mood would enhance their rationality and wisdom. He praised the versatility of three *ting* in the *Lingling* (零陵) county as follows:

> …So [Xue Cunyi] constructed three *ting*. Regardless of ascending or descending the mountain, cloudy or sunny days, the one at the top crowns the mountain peak, and the lower one hovers above a clear pond. [There, one could] change their clothes and enjoy carefully prepared food. [They are equipped with] all kinds of amenities. Guests are treated with friendly reception and accommodated in rooms. (…乃作三亭，陟降晦明，高者冠山巅，下者俯清池。更衣膳饗，列置备具，宾以燕好，旅以馆舍) (Liu, 1979, p. 738)

According to Liu's description, these *ting* served as multi-functional facilities that could be easily constructed in the wilderness, offering a full range of amenities for literati holding governmental positions.

Moreover, beginning in the Tang dynasty, *ting* was also built in imperial palaces for entertainment. Cao (2018) speculated that the *ting* depicted in the Dunhuang paintings (Figure 5) visually represents a structure where Emperor Dezong of Tang hosted royal banquets for his grand chancellor. This is corroborated by a description in *Nanbu Xinshu: Yi* (南部新书 • 乙) written by the Northern Song scholar Qian Yi (c.968 – 1026).

Returning to Ouyang Zhan's description, *ting* during the Tang dynasty demonstrated remarkable flexibility. They were easier to construct compared to other architectural types and were not necessary to be tall structures. The functions of *ting* during the mid-Tang dynasty, as stated in various literary sources, were broad—from observing as locations for literary appreciation and scenic observation to acting as temporary lodges. By the middle to late Tang dynasty, *ting* could take the form of architectural components within larger compounds, facilities with guest rooms, or simple standalone structures for rest and respite.

5. Song dynasty (960 – 1279): Accessing nature and intertwining with *xie*

During the Song dynasty, the form and function of *ting* were simplified and clarified. It was established as an open structure, ideally suited for brief stays.

In the Northern Song period (960 – 1127), *ting* became more integrated with the natural environment due to the removal of enclosing walls or the incorporation of penetrable elements such as balustrades. Architectural representations in Song paintings provide valuable insights into the structural features of *ting*. For instance, in *Eighteen Scholars of the Song Emperor Huizong* (宋徽宗十八学士图) (Figure 6), a painting attributed to Emperor Huizong himself, a wooden platform is depicted on the flat ground. Corner pillars support a roof, and within this open structure, a wooden stool is positioned, seemingly to hold changed clothes. The depicted structure stands independently beside a river, emphasizing its autonomy from an architectural compound.

Notably, the technical conception of *ting* evolved during the Song dynasty. Li Jie (1065 – 1110), the author of the Northern Song dynasty building manual *Yingzao Fashi* (营造法式), did not use the singular term *ting* to refer to this building type. Instead, he employed the phrase *tingxie* (亭榭), which likely denotes a combination of two distinct structural elements: *ting* and *xie*. In the *Zongshi* (总释; glossary) chapter of *Yingzao Fashi*, Li Jie references the early Chinese dictionary *Erya* (尔雅), stating: "if there is no room [constructed], it is called *xie*," and "if a *guan* (observatory) is square and high, it is called *tai*; if it has wood, it is called *xie* (观四方而高曰台，有木曰榭)" (Li, 2006, p. 8).

From these explanations, it can be inferred that during the Song dynasty, a lower wooden platform was referred to as *xie*. The term "*tingxie*," therefore, combines the wooden platform (*xie*) with the open-roofed structure (*ting*) built upon it. Therefore, the singular term "*ting*" in *Yingzao Fashi* likely referred solely to the roofed structure, excluding the underlying wooden platform (*xie*). This differentiation, which emerged after the Northern Song dynasty, reflects a shift in carpenters' understanding of *ting* as a structural

Figure 6. Zhao Ji, *Eighteen Scholars of Emperor Huizong of Song* (宋徽宗十八学士图), early 12th century, Northern Song dynasty (960 – 1127). Source: The National Palace Museum, Taipei (www.npm.gov.tw)

 https://doi.org/10.36922/jcau.4107

type distinct from its base platform, whether wooden (*xie*) or stone (*tai*).

In Song dynasty poetry, *ting* continued to be associated with natural landscapes. However, its function was increasingly described as a place for temporary rest rather than overnight lodging. This shift in usage is evident in the era's literary works. Southern Song dynasty poet Luo Yuan (1136 – 1184) wrote in *Wangmei ting* (望梅亭):

> "The green cliffs are amazingly crossing; the secluded pavilion invites a brief stay." (翠壁堪横绝，幽亭劝小留) (Fu, 1991, p. 28972)

Similarly, Han Biao wrote in *Ciyun Wutuiguan Ershou: Qiyi* (次韵吴推官二首 • 其一):

> "…Watching a chess match in a small *ting* located in the green mountain." (苍山小亭看弈棋) (Fu, 1991, p. 32509)

These lines emphasize the *ting* as a site for brief visits during mountain excursions. As *tingxie* structures in the Song dynasty were no longer fully enclosed, they were unsuitable for overnight stays, marking a significant departure from the functions of *ting* described in Tang-dynasty literature.

6. Ming and Qing dynasties (1368 – 1911): An open structure without rules

During the Ming dynasty, the construction and cultivation of private gardens became prevalent among government officials and literati. *Ting* structures were widely constructed and continued to be utilized for esthetic purposes, as Ouyang Zhan had described during the Tang dynasty. More importantly, *ting* became one of, if not the most, essential elements in private gardens. *Ting* in gardens was exquisitely elegant, often positioned to enhance the appreciation of artificial scenery. Notably, their architectural forms varied greatly and lacked strict regulations.

Ji Cheng (582 – c.1642), a prominent figure in private garden construction during the Ming dynasty, emphasized the flexibility of *tingxie* in his seminal work *Yuanye* (园冶), a foundational guide to private garden design. He noted: "The construction of [*tingxie*]. does not follow a specific rule; from triangular, rectangular…to cross-shaped *ting*, construct it according to appropriateness, and a simple blueprint is sufficient" (Ji & Chen, 2015, p. 123). This casual guidance is unique within Ji Cheng's manuscript; he rarely provided such flexible instructions for other architectural elements in private gardens. His focus on the adaptability of *ting* highlights how its architectural form was subordinated to its function and esthetic purpose. Similarly, the Ming-dynasty scholar Wen Zhenheng (1585 – 1645) mentioned *tingxie* in his work *Zhangwu Zhi* (长物志) in a chapter discussing the placement of refined objects for literati:

> "A *tingxie* cannot shelter [its interior] from rain and wind. Therefore, delicate objects should not be placed inside." (亭榭不蔽风雨，故不可用佳器) (Chen & Wen, 1984, p. 355)

These Ming-dynasty descriptions align closely with the modern definitions found in *Ciyuan* and the *Oxford Dictionary of Architecture* (4th. ed.), which describe *ting* as a flexible, open-roofed structure, consistent with the definition established earlier in this article.

During the Qing dynasty, *ting* retained its characteristic flexibility in both form and function. The size of *ting* varied significantly. On one end of the spectrum, large-scale, elaborate examples could be found in the Imperial Garden in the Forbidden City, such as the *Yujing ting* (御景亭), located atop an artificial mound. On the other hand, in the Qianlong Garden, two notably small *ting* structures contrasted sharply with the grand scale of *lou* and *ge* behind them (Figure 7). The shape of *ting* structures was equally flexible. In the Imperial Garden, rectangular *baosha* (抱厦) extensions were added to the fronts of two square-shaped Ming-dynasty *ting* – the *Fubi ting* (浮碧亭) (Figure 8) and the *Chengrui ting* (澄瑞亭) – creating irregular open structural compounds (The Palace Museum, n.d.). Other exquisite examples of structural flexibility of *ting* could also be found in noblemen's residences. For instance, *Banyue ting* (半月亭; Half-moon-shaped *ting*) in *Qiyefu* (七爷府) (Figure 9) was built in the shape of a half-moon. In summary, during the Ming and Qing dynasties, the form and function of *ting* continued to align with the definition established in the Song dynasty, with significantly enhanced creative designs.

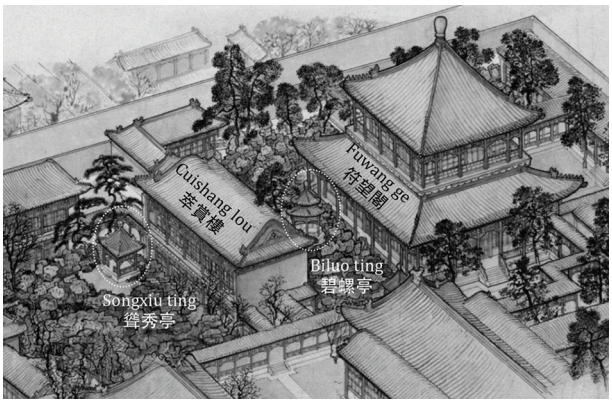

Figure 7. Anonymous painter. A bird's-eye view of the Qianlong Garden, 1980, the Palace Museum. Source: Redrawing by the authors (https://www.dpm.org.cn/dyx.html?path=/Uploads/tilegenerator/dest/files/image/8831/2009/0230/img0004.xml, accessed August 21, 2024)

Figure 8. *Fu bi ting* (浮碧亭), initially built during the Ming dynasty, with a frontal structure added in the Qing dynasty. The Forbidden City, Beijing. Source: Photo by Piao Shiyu (2024)

Figure 9. A garden pavilion with a Manchu prince, Qiyefu (七爷府), Beijing, 1922. Featuring the younger brother of the last emperor. Source: Sirén (1926)

7. A problematic translation history: "ting," "kiosk," "gazebo," or "pavilion"

The translation of architectural terms in transcultural scholarship is a critical yet challenging task, particularly for two reasons. The first challenge lies in the ambiguity of the term within its original cultural context. Unlike distinct technical elements or stylistic forms in Chinese architecture, such as bracket set components, the architectural type referred to as *ting* has evolved over time. It has also gradually converged with related terms and concepts, such as *ting*, *tai*, *lou*, and *ge*. This convergence has led to the formation of fixed phrases such as *tingxie*, an architectural type mentioned in *Yingzao Fashi*, and *tingqiao*, a traditional term still used by modern scholars. For example, Fu (2017) describes *tingqiao* as a type of bridge depicted in the Northern-Song painting *A Thousand Li of Rivers and Mountains*. While *tingxie* refers to various architectural structures, *tingqiao* denotes a specific type of bridge with one or more roofed structures atop it. The second challenge stems from the broad connotations and usages of the English terms chosen for translation, which often exceed the scope of the original Chinese language. For instance, the Chinese Pavilion in Drottningholm is an architectural complex with side wings. Its Swedish name, *Kina slott,* refers to a general type of palatial architecture, reminiscent of Gustav III's Pavilion at Haga. As a result, the architectural implications of the English name "Chinese Pavilion" may mislead readers as defined in the *Oxford Dictionary of Architecture*, where it mainly refers to the Qing-dynasty *ting*: a single-story, open structure commonly found in private gardens.

Given these challenges, translating *ting* is particularly complex because it intersects both issues. The architectural form and concept of *ting* entered Western knowledge during the early modern period in European history and the late imperial period in China through travelogs and journals written by European travelers. In 20th-century Western literature on Chinese gardens and architecture, the translation of the term "*ting*," or the assigned name for specific *ting* structures, was often handled *ad hoc* by scholars. They typically choose English terms that fit their discussions of the architecture's function or form. Common translations include "kiosk," "gazebo," and "pavilion," all of which reflect the aforementioned challenges.

Before modern translations, one notable early use of the term "*ting*" appeared in William Chambers' highly influential 1757 publication on Chinese architecture and cultural objects. Chambers, the first professional European architect to publish drawings of Chinese architecture, (Bald, 1950), defined *ting* as "the great hall of a house… also the great halls in a pagoda or temple" (Chambers, 1757, p. ii). This definition significantly diverged from the standard architectural form of a Qing-dynasty *ting*. Chambers further explained that "[t]he particular kind of structure which they call *ting*, or *kong*, is used indifferently in all sorts of edifices," suggesting he may have conflated three distinct Chinese architectural terms: *ting* (厅), *ting* (庭), and *ting* (亭) (Chambers, 1757, p. 3). His illustrations further support this conflation. Among the four types of *ting* he depicted, the first two resemble halls, the third appears to be an open structure in a temple, and the fourth represents garden structures (Figure 10). This conflation highlights the limitations of using Romanized terms such as *ting*, which can refer to multiple phonetically similar but semantically distinct Chinese terms. This ambiguity has continued to cause confusion among English readers and scholars unfamiliar with Chinese. Chambers'

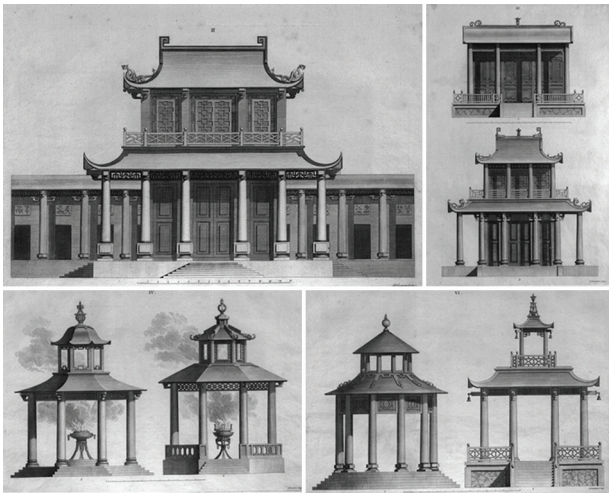

Figure 10. William Chambers. Designs for four types of *ting*. Source: Chambers (1757)

classifications illustrate a recurring issue inherent in the use of Romanized terms, even in modern scholarship.

In Western literature from the 20th century, "kiosks" and "gazebos" were frequently used to translate *ting*. For instance, the December 1894 issue of the American art magazine *The Decorator and Furnisher*, published by the Art Trades Publishing and Printing Co. in New York, described *ting* as "kiosks" accompanying rockeries in Chinese gardens (Haywood, 1894). Similarly, Von Erdberg referred to "gazebos" in her 1933 article on Chinese gardens built in Europe during the 18th century. Using the phrase "gazebos on hills for enjoying the view," Von Erdberg appears to equate *ting* with "gazebos" (Von Erdberg, 1933, p. 171). In another example, Hargett, in his 1988 work *Huizong's Magic Marchmount,* translated Emperor Huizong's *Chaoyun ting* as "Nesting-in-the-Clouds Kiosk" (Hargett, 1988, p. 21).

Similarly, Paolillo, in his 2003 article on *Yuanye* – a critical commentary on the construction of Ming-dynasty gardens discussed in **Section 6** – translated *ting* as "kiosk," highlighting that "*ting*" is a homophone of "停," meaning to stop (Paolillo, 2003, p. 229). According to Getty's *Art and Architecture Thesaurus*, kiosks are defined as "small, freestanding structures either open or partially enclosed, where merchandise is displayed, advertised, or sold" (Getty, n.d.). Paolillo's remark aligns with a quote from *Shiming* (释名) collected in *Yingzao Fashi*, implying that the Chinese character for *ting* not only shares its pronunciation with the character for "stopping" but also conveys a similar meaning, as people usually pause near a kiosk. Thus, the translation "kiosk" hints at interplay between the literary connotation of the Chinese character *ting* and the functional similarity between a *ting* and a kiosk.

In contrast, Getty defines "gazebos" as "small structures, usually roofed and open-sided, located in gardens or parks from which one may gaze out over the surrounding grounds" (Getty, n.d.). Based on these definitions, the term "kiosk" overly emphasizes the function of selling merchandise and information, making it an unsuitable translation for *ting* in the context of late imperial China, given its close association with gardens, viewing scenery, and open-sided architectural design.

Another common translation of *ting* is "pavilion." Alison Hardie's 1988 translation of *The Craft of Gardens* – a seminal work published by Yale University Press – provided a pivotal interpretation of *Yuanye*, Ji Cheng's guideline for constructing private gardens in the Ming dynasty. In her translation, Hardie grappled with the ambiguity of the term in its original cultural context. In chapter three, Ji discusses and contrasts several closely related building types – *tai* (台), *ge* (阁), *xie* (榭), *xuan* (轩), *ting* (亭), etc. To address this, Hardie assigned distinct single-world translations to each type. She used "terrace" for *tai*, "gazebos" for *xie*, "belvedere" for *ge*, and "galleries" for *xuan*, while reserving the most general term, "pavilion," for *ting* (Ji, 1988, p. 69). "Pavilion" appeared most frequently in Hardie's translation. Excluding footnotes, it was indexed 32 times, compared to six instances of "belvedere" and four of "gazebo" (Ji, 1988, p. 141 – 143). Moreover, Hardie's use of "pavilion" was flexible; she applied it not only to translate the single-word *ting* but also in phrases such as *tingxie* (Ji, 1988, p. 61, 69). This flexibility arguably reflects the versatility of *ting* in both function and forms, as described by Ji Cheng.

The translation of *ting* as "pavilion" is also prominent in other English-language scholarship on Chinese gardens. For example, in the spring of 1981, accompanying the construction of a Chinese-style garden in the Astor Court in the Metropolitan Museum of Art, New York, United States, an article on Chinese garden history and theory appeared in the 1980/81 *The Met's Bulletin*. In the article, *ting* was defined as "an open structure with a roof supported by pillars" and translated as "pavilion" (Murck & Fong, 1980, p. 42). Similarly, Morris's 1983 work *Gardens of China* frequently used the term "pavilion" as a translation for *ting*, employing the term at least 8 times. He used "kiosk" only once, to describe an ambiguous structure depicted in an architectural drawing by modern scholar Liu Dunzhen (Morris, 1983, p. 232, 273). In the 21st century, "pavilion" continued to dominate as the preferred translation for *ting* in Chinese garden scholarship (Fang, 2010, p. 153; Valder, 2002, p. 58). In Fu's 2017 *Traditional Chinese Architecture: Twelve Essays*, while *ting* does not appear as a standalone entry in the glossary, several phrases incorporate "pavilion" as part of their translation: "small pavilion" for *tingxie* (亭

榭), "square pavilion" for *fangting* (方亭), "pointed-roofed pavilion" for *doujian tingxie* (斗尖亭榭), and "bridge with one or more pavilions" for *tingqiao* (亭桥) (Fu, 2017, p. 368, 354, 378, 368).

Synthesizing these examples, "pavilion" is clearly the most widely employed translation of *ting* today. However, this translation is not without its issues. One significant problem lies in the existing connotations of "pavilions" as a distinct architectural form within European architecture and gardening. According to the *Oxford English Dictionary*, the primary definition of "pavilion" is "[a] tent or tent-like building," commonly "[a] large, stately, or ornamental tent, usually rising to a central point rather than a ridge" (Oxford English Dictionary, 2023, https://www.oed.com/dictionary/pavilion_n?tl=true). This definition introduces an inaccurate connotation of a soft, temporary, pointed structure, in contrast to the permanent, meticulously designed architectural nature of *ting* in Chinese gardens. Furthermore, in Harry Inigo Triggs's 1913 book *Garden Craft in Europe*, "pavilion" is synonymous with structures such as summer houses, arbors, banqueting houses, garden houses, and gazebos (Triggs, 1913, pp. 329-331). Although this interchangeability underscores the flexibility of the term in European contexts, it can lead to further misleading connotations of a multi-story inhabitable building when used as a translation for *ting*.

The second problem with the term "pavilion" is its use in English literature to translate another type of building known as *ge*. Structurally, however, *ge* is distinct from *ting*. Although *ge* can be found in gardens, it is also commonly built within Buddhist temples, where it serves as a space for housing Buddhist statues or storing sutras. A representative example is the Guanyin *ge* at Dule Temple (独乐寺), a Liao-dynasty (916 – 1125) multi-storied building enclosed by walls on all sides (Figure 11). In Nancy Steinhardt's *Chinese Architecture: A History*, Guanyin *ge* is translated as "Guanyin Pavilion" (Steinhardt, 2019, p. 139). Moreover, "pavilion" is the designated English term for *ge* in the glossary, while *ting* is entirely omitted as an entry (Steinhardt, 2019, p. 384).

This inconsistency in the use of translations in Western literature contributes to inaccurate conceptualizations of Chinese architectural types in transcultural scholarship. Rather than consistently assigning one English term to a specific Chinese architectural term, these translations are often used interchangeably throughout individual works. A prominent example is Maggie Keswick's 1978 *The Chinese Garden: History, Art & Architecture*, which groups all instances of *ting, xie*, and *tai* under the index entry "pavilions, gazebos, etc.," obscuring the distinctions between these architectural types in their original contexts

Figure 11. *Guanyinge* (观音阁), Dulesi, Jizhou district, Tianjin, China. Built in 984. Source: Photo by the authors (2024)

(Keswick & Jencks, 1978, p. 216). Similarly, in Paolillo's 2003 article about *Yuanye*, "gazebo" is used to translate *xie*, differentiating it from *ting* (Paolillo, 2003, p. 229). Adding further to the conflation, the term "kiosk" is also used to translate *xie* (Van Hecken & Grootaers, 1959, p. 374). Even in Alison Hardie's 1988 translation of *Yuanye*, English terminology is often interchangeable. For instance, in the entry on *tingxie* in chapter two, which discusses the layout of a garden, it states:

> "5. Pavilion [ting xie]
>
> A shady gazebo among the flowers, a quiet pavilion on the edge of the water—these are the quintessence of garden design…There is no set formula for pavilions nor any rule for their layout." (Ji, 1988, p. 61)

In her translation, "pavilion" is used to refer to both *ting* and *tingxie*, while "gazebo" is employed interchangeably with "pavilion." This flexibility undermines Hardie's efforts to assign distinct single-world translations to each architectural type, as outlined in chapter five. The near cross-referencing of "pavilion," "kiosk," and "gazebo" in translating *ting*, *xie,* and other similar architectural types illustrates how these terms are conflated, even in Chinese texts.

8. Toward a thick translation: Contextualization and visualization through translation

Research into the history of traditional Chinese architecture requires a competent understanding of and proficiency in translating complex texts from the source language. From its origins and development to its cultural agency in the

act of translating, translation studies have emerged as a flourishing field encompassing descriptive aspects – such as the styles in which literary works are translated across various times and places – practical aspects – such as how students learn to translate – and theoretical aspects – such as what constitutes a good translation (Bassnett, 2014; Bermann & Wood, 2005; Delisle & Woodsworth, 2012). Nonetheless, research in this field has mainly focused on translations within Western traditions, with an emphasis on literature and poetry. As observed by Dutton (2002), area studies in academia, especially Asian studies, largely depend on methodologies derived from other domains of Western knowledge and are burdened by a patchwork of transplanted theories. Encumbered by a plethora of historical challenges across affiliated disciplines, the development of a new methodology for translating architectural types remains in its nascent stages. Prominently different from translations of literature and poetry, which revolve around various aspects of textual meanings, visual and formal implications play a central role in the study of art and architecture. In other words, while literary scholars translate texts from source languages to target languages, architectural historians must also translate the visual and formal qualities expressed by architectural terms into the target scholarly context. Just as literary translators strive to preserve the full range of meanings within texts, a good translation in architectural history should comprehensively capture the visual potential in architectural terminology. Consequently, a purely literary translation of an architectural term offers only a preliminary grasp of the textual aspects and fails to address architectural historians' visual demands.

Instead of coining a uniform translation of *ting* for various contexts, one promising solution emerging in translation studies is the methodological approach known as "thick translation" (Appiah, 1993; Sun, 2017). Initially applied to the translation of culturally specific idioms and expressions, thick translation "seeks with its annotations and its accompanying glosses to locate the text in a rich cultural and linguistic context," thereby facilitating an academic translation that can be deeply understood, meaningfully interpreted, and, more importantly, inspire original imagination in the target language (Appiah, 1993, p. 817). More specifically, in the context of translating the Chinese language, Sun highlights that thick translation – incorporated through paratexts that embed the translated portions in the main text and through side notes, such as the translator's annotations and comments – can be helpful, though it must strike a balance with the efficacy of cross-cultural communication (Sun, 2017). A notable example of thick translation is found in the 1981 article on the history and theory of Chinese private gardens in the *Metropolitan Museum of Art's Bulletin*. In the article, the authors translated *ting* as "pavilion" and included a footnote explaining that *ting* is "an open structure with a roof supported by pillars," alongside an image of Wang Xizhi's Orchid Pavilion from a handscroll by Qian Xuan (1235 – 1300) (Murck & Fong, 1980, p. 42). The Met's detailed footnote is not only spatially and temporally specific in describing the architectural structure of *ting* but also satisfies art and architectural historians' visual demands by addressing *ting*'s modalities in historical representations. This serves as an exemplary attempt to render a thick translation effective for both general readers and scholars. However, this definition does not sufficiently address the confusion between *ting* and *xie*, the latter of which has also been translated as "pavilion" in prior scholarship. By adopting thick translation as a scholarly intervention, it becomes critical to include a brief statement addressing the intertwined histories of *ting* and other related building types, alongside further references to relevant sources. This approach can provide clarity in view of the problematic translation history of these terms.

9. Conclusion

In transcultural scholarship, a simple translation of a culturally specific term like *ting* does not adequately help English readers understand how it evolved as a building type in Chinese architectural history. In fact, a straightforward translation based solely on the semantics of an architectural type such as *ting* cannot accurately capture its meaning, as this meaning arises from the complex history of its architectural forms and functions. Therefore, a comprehensive review of the evolving history of an architectural term, as well as the history of its translation and historical usage, is essential for achieving a culturally accurate translation. According to the review, both the architectural form and function of *ting* underwent significant changes from the pre-Qin period to the Ming and Qing dynasties. Structurally, *ting* evolved from a tall building during the Warring States period to a geographical landmark and venue for literati activities during the Northern and Southern dynasties, and ultimately became a flexible, open structure in gardens during the Ming and Qing dynasties, which aligns most closely with its modern definition in the *Oxford Dictionary of Architecture* and *Ciyuan*.

Functionally, *ting* transitioned from a compound with military and civic purposes during the Eastern Han dynasty to a space for comfortable stays and banqueting during the Tang dynasty. By the Northern Song dynasty, *ting* became a structural form in *Yingzao Fashi* used in conjunction with other building types such as *xie*, and eventually, it evolved into a simple, open, freestanding structure. Its

close connection to the appreciation of natural beauty persisted from the Northern and Southern dynasties through to the Qing dynasty. The modern definition of *ting* – "an architecture with a roof but without enclosing walls" as described in *Ciyuan* – is rooted in roofed architectural elements found in Ming private gardens (He *et al*., 2015, p. 210). However, this article does not aim to provide a thorough discussion of the depictions of *ting* in paintings, nor does it serve as a comprehensive architectural survey. Instead, carefully chosen examples of *ting* from various periods are used to demonstrate the semantic range of the term as a distinct type that should not be conflated with other building types that have existed independently in European architecture.

Although widely employed in modern scholarship on Chinese gardens, typical English translations such as "pavilion," "kiosk," or "gazebos" are less precise terms for *ting* upon close examination. These terms can be misleading when used as equivalents to *ting* because they are cross-referenced with other building types, such as *ge* and *xie*, and because their original connotations in English do not align with those of *ting*. Furthermore, the Romanized term *ting* was conflated with various architectural types by the 18th-century European architect William Chambers.

Nevertheless, this is not to suggest that a close examination of Chinese architectural terms renders them impossible to translate. In theory, the use of a thick translation, which provides a specific cultural context in which the concept is historically situated, is preferable to a one-word, thin translation that centers solely around the semantics of the term. Illustrations and annotations, as well as brief explanations of the intertwined history of *ting* and related building types, can serve as effective methods for rendering thick translations. Future efforts are required to develop a coherent method for selecting and applying thick translations that effectively integrate definition, annotation, and translation in transcultural scholarship. This will tremendously benefit readers and scholars by fostering a culturally specific understanding of terms such as *ting*.

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Writing – original draft: Dustin B. Chen
Writing – review & editing: All authors

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ORIGINAL ARTICLE

Analyzing the relationship between the 18th-century Beijing hutong system and urban landmark roads using spatial network analysis: A case study of Dongcheng district

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Abstract

The hutong system, originating during the Yuan dynasty (1271 – 1368), has undergone significant transformations while retaining its essential role in urban functionality and social interactions. Despite extensive qualitative studies on its historical and contemporary dynamics, quantitative analyses of its original configurations and integration with Beijing's broader road network remain limited. This study examines the *Qianlong Jingcheng Quantu* (Emperor Qianlong's Complete Map of Beijing), a detailed cartographic representation of Beijing drafted in the 15th year (1750) of Qianlong's reign (1735 – 1796), which provides critical insights into historical urban planning. Using spatial network analysis, the research measures regional accessibility and demonstrates how the hutong system, through a series of orderly spatial connections, integrates with landmark roads to form a complex yet highly accessible urban spatial network. The analysis reveals that the high mobility efficiency within the intricate hutong system is rooted in its structured spatial connections with landmark roads. These connections facilitate dynamic interactions between the hutong system and the extensive urban road network, thereby enhancing the overall functionality and flexibility of Beijing's urban development.

Keywords: 18th-century Beijing; *Qianlong Jingcheng Quantu*; Hutong system; Landmark road; Spatial depth; Spatial network

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1. Introduction

Hutongs (胡同; *hutong*), the unique traditional streets and alleys of Beijing, trace their origins to the construction period of Yuan Dadu (元大都; Grand Capital of the Yuan dynasty [1271 – 1368]), established in 1276. These narrow, winding paths have borne witness to China's transition from a feudal society to a modern metropolis, playing a pivotal role in shaping urban functionality and fostering social interactions. Academic interest in Beijing's hutongs spans diverse dimensions, such as their historical evolution, social ambiance, cultural attributes, and spatial configurations. A review of the literature

reveals a consensus that Beijing's hutong system has transformed into a more visually complex and chaotic network, driven by urban expansion and demographic growth, as demonstrated in the studies by Deng (2005), Li (2009), and Wang (2020).

Despite its seemingly complex and often convoluted layout, some research suggests that the hutong system demonstrates remarkable efficiency and utility in everyday use. For example, Chen and Cai (2008) methodically categorized and delineated the complexities of hutongs from a typological perspective, uncovering inherent linkages and spatial regularities that significantly enhance their navigability and utility. Similarly, Zhang's (2011) survey-based study on elderly residents in hutong areas found that only 11 percent of respondents reported transportation-related inconveniences in these environments, reflecting overall satisfaction with the area's accessibility. Further, Zhang (2022) examined pedestrian preferences in Beijing's historic cultural districts, such as Dongsi, Xianyukou, Nanluoguxiang, Shichahai, and Guozijian. The findings revealed that 37.66 percent of respondents prioritized transportation convenience as the key reason for choosing walking, underscoring the hutong's transit-friendly design. More recently, Wang *et al.* (2024) highlighted the hutong system's excellent accessibility, particularly in facilitating mobility for elderly residents.

However, it is important to recognize that these studies primarily employ qualitative methodologies and lack sufficient quantitative data to substantiate their findings. While they collectively affirm the hutong system's multifaceted convenience, their focus is largely on the spatial and functional dynamics of contemporary urban hutongs in Beijing, often neglecting the system's original configurations. In addition, these analyses overlook the dynamic interplay between the hutong system and the city's extensive road network, which is essential for enhancing traffic efficiency and convenience.

This study argues that the hutong system demonstrates high efficiency and traffic convenience due to its spatial organizational relationship with the urban landmark road network. This relationship facilitates dynamic interactions between the hutong system and the broader urban road network, enhancing individual mobility and overall traffic efficiency. However, a significant gap in the literature remains—the absence of a comprehensive quantitative analysis of this spatial-organizational relationship.

In modern urban planning, the hutong system also plays a unique role in promoting sustainable urban development and integrated community management. Its intricate network offers valuable insights for optimizing urban traffic systems. The refined spatial organization of hutongs enhances community functionality and improves residential living conditions. Moreover, their preservation and adaptive reuse not only maintain the city's historical character but also foster livable environments for residents, reinforcing social connections and preserving the city's cultural identity.

For instance, a study by Liu *et al.* (2019) analyzed the spatial form of hutongs by comparing two modern residential areas with two hutong areas of similar size. The study found that hutongs exhibit a flexible variety of road layouts and a clearly layered, networked road system. These characteristics emphasize their advantages in openness and shared use. Based on these findings, the study proposed strategies for modern residential area planning, including the implementation of tiered road systems, innovative road form designs, and residential environment optimization. These strategies provide practical references for implementing open policies in residential areas.

In contrast, Jiang *et al.* (2021) highlighted that modern residential communities often adopt closed management systems. While these systems address safety concerns, they also fragment urban road networks and create monofunctional communities. Traditional lilong (里弄; *lilong*) and hutong neighborhoods, however, demonstrate the advantages of open-block designs, fostering neighborhood interactions and enabling seamless spatial transitions. Through an analysis of public open spaces in Shanghai's lilong and Beijing's hutong, the study by Jiang *et al.* (2021) proposed strategies for modern residential areas. These include controlling the scale of small residential units, developing multi-layered spatial structures, diversifying residential functions, and adopting a "broadly open, selectively closed" management model.

While these studies provide valuable planning suggestions, they primarily rely on qualitative analyses of hutong spatial layouts. The absence of quantitative data limits a deeper understanding and accurate assessment of the organizational characteristics of these spaces. Therefore, the formulation of specific policies and planning strategies may lack the necessary scientific rigor.

Building on this discourse, the present study utilizes reliable historical data from the *Qianlong Jingcheng Quantu* (乾隆京城全图; Emperor Qianlong's Complete Map of Beijing) and employs spatial network analysis to transform urban roadways into a structured network of nodes and links. It quantitatively analyzes the spatial connections between the hutong system and landmark roads by measuring the accessibility of specific areas. By integrating historical documentation with contemporary analytical techniques, this study not only corroborates earlier research findings with empirical evidence but also

introduces innovative methods and perspectives to deepen our understanding of the fundamental characteristics of the hutong system.

In addition, this study explores strategies for protecting and effectively utilizing these traditional spaces amid rapid urbanization. Its goal is to preserve the cultural value and functionality of hutong while enhancing residents' quality of life. By integrating quantitative and qualitative research methods, this study aims to provide empirical evidence to urban planners and policymakers, supporting the sustainable development and modernization of hutongs.

2. Research methodology

This study utilizes spatial network analysis methods to examine the spatial connectivity between the hutong system and landmark roads using quantitative data. The research is structured into four distinct phases to achieve this goal.

The first phase involves abstracting the urban road system, a critical step given the complexity and vast information contained within urban spaces. To facilitate effective analysis, it is essential to distill only the necessary information from this extensive dataset. This process streamlines the complex urban road network for clearer observation and analysis (Lee & Chi, 2014).

To effectively discern the structural characteristics of the study area, the road structure depicted in the *Qianlong Jingcheng Quantu* was abstracted. As shown in Figure 1, roads are represented as links, while intersections are represented as nodes. It is important to note that this study focuses on the spatial connections between the hutong system and landmark road. When transposed into a network of links and nodes, the analysis centers on the relationships between specific nodes and links. Attributes such as road width and direction are omitted from the links, as each node in the network merely represents a junction point and its connectivity to the links.

Following the abstraction of the road system, the second phase identifies landmark roads to delineate the study area. In Lynch's (1964) seminal work, *The Image of the City*, landmarks are defined as distinctive and memorable physical elements within urban landscapes, serving as aids for urban navigation and spatial orientation. Building on this framework, this study introduces the concept of "landmark road," which not only facilitates traffic circulation but also significantly influences navigation and visual perception.

Landmark roads possess specific design attributes that enhance their prominence and recognizability. Typically, these roads are notably wide and aligned with major urban axes, either east–west or north–south, making them visually striking and easy to identify. Their design not only improves functional efficiency but also enhances the spatial legibility of the city. As Kevin Lynch highlighted, effective landmarks distinctly stand out from their surroundings. Landmark roads, due to their widths, lengths, and directional orientations, naturally function as dynamic landmarks, guiding both visual attention and movement.

The selection of landmark roads should therefore account for their dual roles as visual guides and navigational aids. Based on these theoretical foundations, this study uses width, continuity, and clear directional orientation as criteria for determining a road's suitability for designation as a landmark road. Roads that are wider, exhibit greater continuity, and possess clear directional qualities are considered most suitable for designation as landmark roads.

The third phase involves developing metrics to assess regional accessibility. This study quantitatively analyzes the spatial connections between the hutong area and landmark roads by evaluating their accessibility. Developing relevant metrics is necessary for this evaluation.

"Space depth" is a core concept in space syntax theory, which measures the topological distance between spatial elements—specifically, the minimum number of turns required to reach

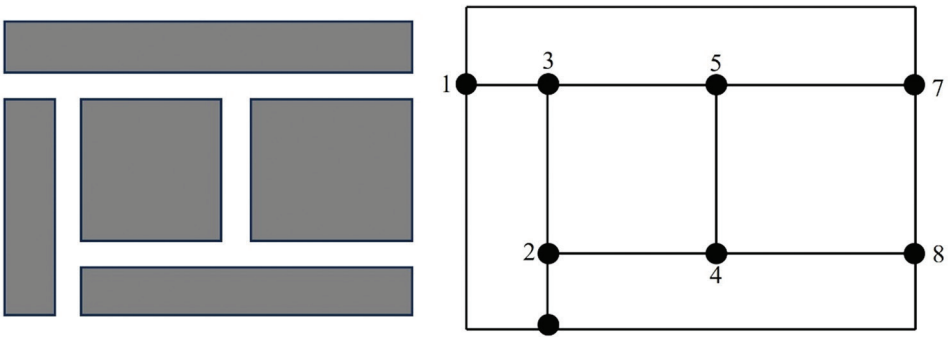

Figure 1. Fictional urban system (left) and spatial network (right). Source: Drawing by the authors

other spaces from a particular location within the system (Hillier, 2008). For example, in a typical urban layout, a turn represents a decision point at an intersection, while a node denotes specific places such as entrances or junctions. Within this theoretical framework, accessibility is assessed based on the number of turns needed to reach another space. Fewer turns indicate higher accessibility.

In a network composed of nodes and links, the depth value of a node is defined as the number of nodes that must be traversed to reach other nodes in the network. A smaller depth value, indicating fewer nodes to be passed through, suggests higher accessibility. Conversely, a larger depth value implies lower accessibility, as more nodes must be traversed.

Numerous studies have shown that human spatial cognitive abilities significantly decline after three directional changes, a finding that shapes our methodological approach (Guo & Wang, 2012; Lu, 2013). According to spatial syntax theory, the farthest distance humans can effectively perceive while navigating a space is known as the "three-step spatial depth." This theoretical framework supports the use of the "3-step spatial depth" metric as a standard tool in research to evaluate levels of spatial accessibility. From a spatial cognition perspective, the "three-step spatial depth" metric effectively captures the limitations of human perception and cognition in complex environments. It also provides a quantifiable measure to evaluate how environmental layouts affect human navigational efficiency and spatial orientation. By applying this metric to the hutong area and landmark roads, we can identify which parts of the network facilitate easy navigation and which may pose cognitive challenges to pedestrians, offering insights to guide urban design improvements.

When the spatial depth value stays within a three-step range, it indicates higher accessibility. Conversely, values exceeding the three-step range indicate lower accessibility. Therefore, this study adopts the "three-step spatial depth" metric as a measure of spatial accessibility.

The fourth phase involves calculating the regional accessibility index. This step entails computing the spatial depth value for each node within the targeted area relative to the landmark roads. The overall accessibility level of the area is assessed by counting the number of nodes with a spatial depth value of < 3 steps. This analysis reveals whether a consistent spatial organizational relationship exists between the hutong area and the landmark road.

3. Abstraction of the road system and selection of landmark roads in 18th-century Beijing

To effectively study Beijing's road system in the 18th century, this research abstracts the road network depicted in the *Qianlong Jingcheng Quantu* into a network of links and nodes. In this abstract model, roads are represented as links, while intersections are depicted as nodes. Notably, these links exclude physical attributes such as road width and direction, focusing on connectivity and network structure.

Observation reveals that the road network of 18th-century Beijing comprised wide, straight avenues and narrow, winding, irregularly arranged alleys. The broader, straighter streets were typically named "Avenue," "Street," or "Small Street," reflecting a specific street hierarchy. Avenues were approximately 37 m wide, while smaller streets measured approximately 18.5 m wide (Lu & Baik , 2020). In contrast, the narrower and more irregular paths were referred to as "Hutong." Based on the previously outlined characteristics, landmark roads were identified as those with sufficient width, high continuity, and clear directionality. Therefore, this study designates the wide, straight streets depicted in the *Qianlong Jingcheng Quantu* as landmark roads (Table 1). Moreover, determining the names and widths of streets distributed along the city walls presented challenges. However, the alignment of these streets with the remains of the city walls provides evidence of their excellent transportation functionality and clear directionality. Therefore, the streets distributed along the city walls were also included in the selection of landmark roads (Figure 2).

4. Calculation and evaluation of spatial network analysis index

In a network of links and nodes, this study explores the relationship between the hutong system and landmark roads by measuring the spatial depth between nodes in the hutong area and those on landmark roads.

To assess accessibility, this study used the "3-step spatial depth" as the benchmark for determining the adequacy of access within the hutong system. In addition, to evaluate the overall accessibility of the hutong area, the number of nodes that can reach landmark roads within a spatial depth of three steps or fewer was counted. A higher number of accessible nodes indicate better accessibility within the hutong area, while a lower count suggests poorer accessibility. Based on these accessibility levels, the spatial connectivity between the hutong system and landmark roads was examined to identify inherent regularities.

The evaluation involved the following steps:

(i) Spatial depth values between nodes were calculated using AutoCAD software and a self-developed application. Due to the large number of nodes, a computational program was created to handle the calculations. The process is illustrated in Figure 3.

Table 1. Landmark Road Evaluation Criteria of Beijing in the 18th Century

Type of road	Width by rule	Continuity	Direction guide	Landmark road
Avenue	37 m	Straight	Very easy	√
Street/Small street	18.5 m	Straight or slightly crooked	Easy	√
Street on the inner side of the city walls	Not clearly defined	Straight	Very easy	√

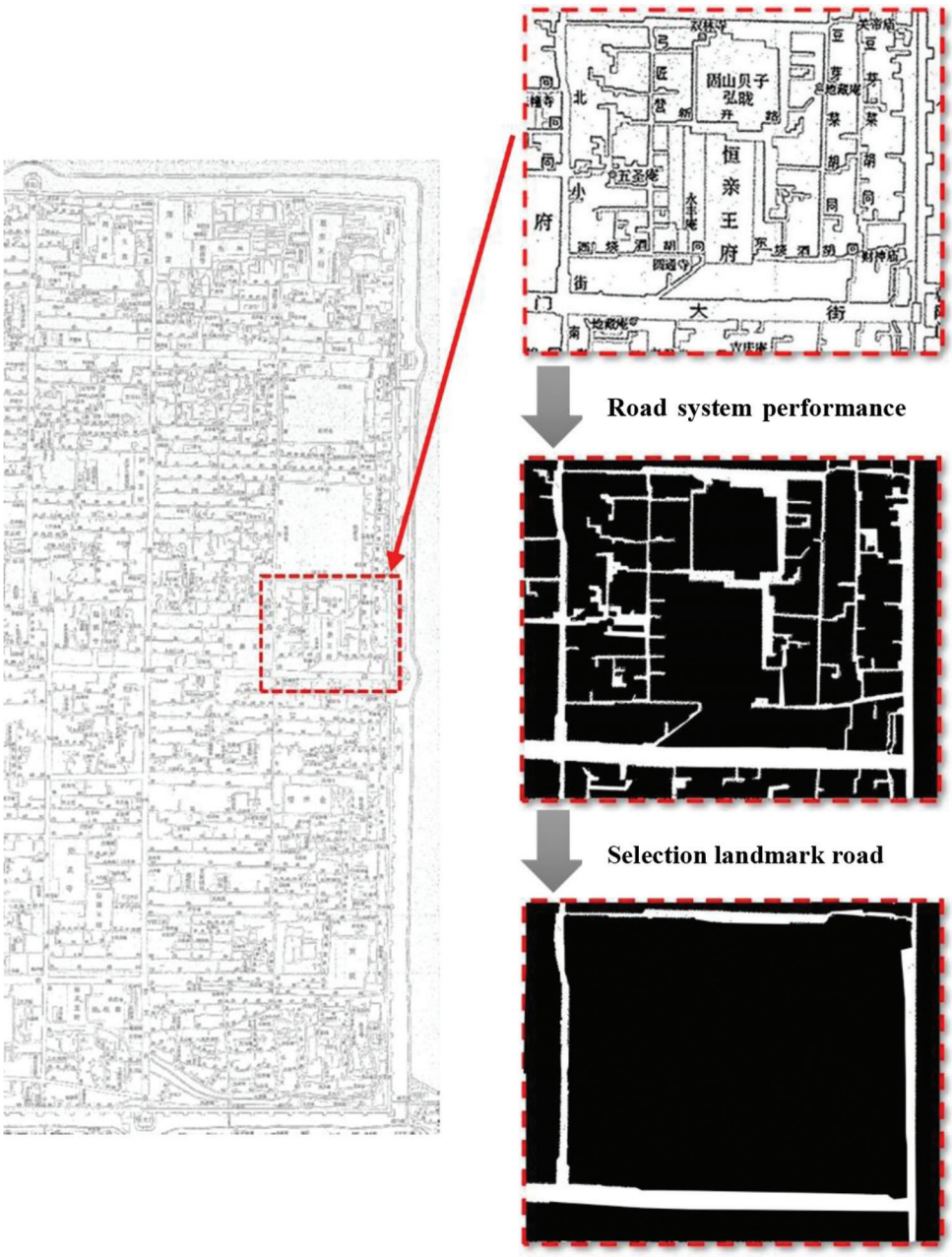

Figure 2. The selection process of landmark roads in 18th-century Beijing. Source: Drawing by the authors

The process consists of two steps: First, the urban road system is represented as links using AutoCAD software. Next, an application developed in a programming language converts the network structure as shown in Figure 3 into a matrix format (Table 2) for computational analysis.

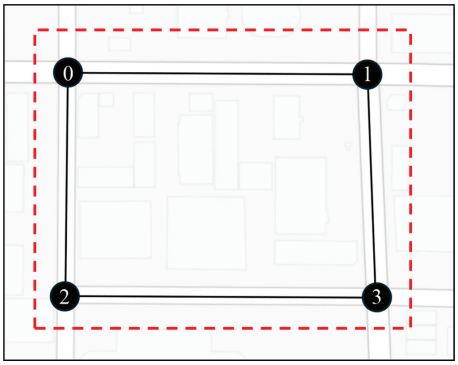

Figure 3. Spatial network of urban road system. Notes: ▭ represents analyzed region; ▬ represents link; ● represents node. Source: Drawing by the authors

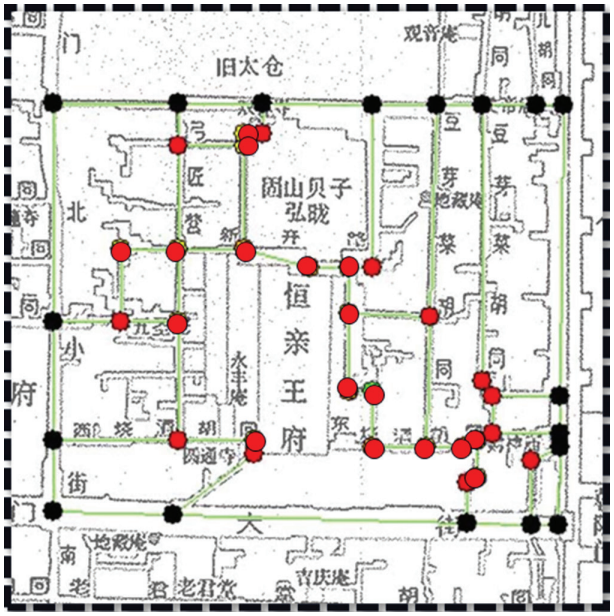

Figure 4. Hutong system and landmark roads in the spatial network. Notes: ● represents origin point on the landmark roads; ● represents hutong intersection. Source: Drawing by the authors

In this matrix, the numbers represent topological distances (or spatial depth values) between nodes (Figure 4):

- A distance of 1 is assigned between adjacent nodes.
- A distance of 0 is assigned between a node and itself.
- A value of 9999 represents disconnected nodes.

For example, the value in the second row and third column of the matrix (1, 2) indicates that nodes 1 and 2 are not directly connected.

Further calculations based on this matrix provided the spatial depth values between all nodes. For example:

- The depth from Node 0 to Nodes 1 and 2 is 1, while the depth to Node 3 is 2.
- The depth value between Nodes 1 and 2 is 2, and the depth from Node 1 to Node 3 is 1.
- The depth between Nodes 2 and 3 is 1.

Table 2. Matrix representation of the spatial network

Node no.	0	1	2	3
0	0	1	1	9999
1	1	0	9999	1
2	1	9999	0	1
3	9999	1	1	0

Table 3. Depth values between nodes

Node no.	Depth value
0 – 1	1
0 – 2	1
0 – 3	2
1 – 2	2
1 – 3	1
2 – 3	1

The specific results are presented in Table 3.

(ii) The minimum spatial depth between each node in the hutong area and landmark roads was determined. As illustrated in Figure 4, each red node corresponds to 18 black nodes, each representing a unique spatial depth value. The smallest of these values was selected as the spatial depth value for each red node relative to the landmark road.

(iii) Using the minimum spatial depth values, the number of nodes within each area that fall within a spatial depth of three steps or fewer was counted. To visualize the results, nodes were categorized and color-coded as follows:

- Black: Nodes along landmark roads (depth=0).
- Red: Nodes with a depth value of 1.
- Yellow: Nodes with a depth value of 2.
- Orange: Nodes with a depth value of 3.
- Green: Nodes with a depth value >3.

This visualization provided an intuitive way to assess the accessibility of the hutong system and identify spatial patterns relative to landmark roads. Nodes with lower depth values indicated better accessibility. By observing the proportion of nodes in each color, the spatial accessibility of the area could be easily evaluated.

5. Data analysis

This study examines the spatial relationship between the hutong system and landmark roads in Beijing's Dongcheng district in the 18th century, using visualized images and data.

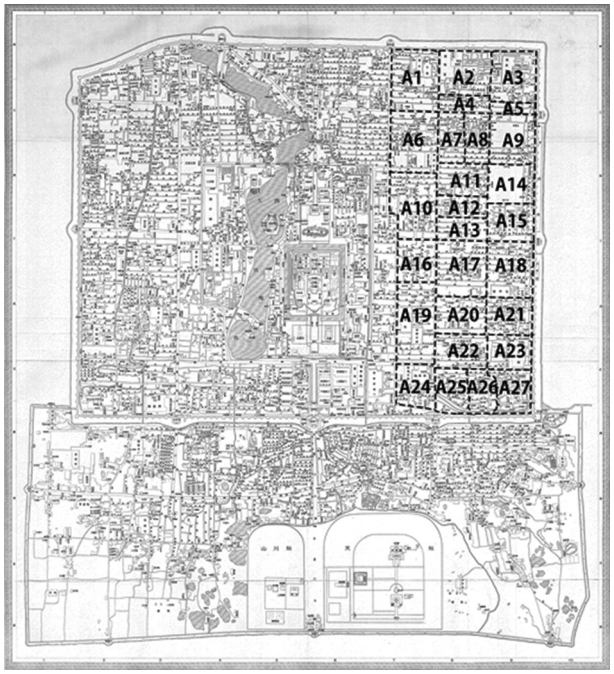

Figure 5. Distribution of landmark roads in Dongcheng district, Beijing, China, in the 18th century. Source: Drawing by the authors

Figure 5 illustrates the distribution of landmark roads within the study area, while Table 4 provides spatial depth data for the nodes in each area. Figure 6 visualizes these depth values for the hutong system. To explain the data in Table 4, we use Area A15 as an example, with its visualization shown in Figure 7.

In Table 4, the number 29 for Area A15 represents the total number of nodes in the area, excluding the origin point on the landmark road (indicated by the black node in Figure 7). The number 12 signifies that 12 nodes have a spatial depth of one step from the origin point. These nodes are marked in red in Figure 7. The value of 41.4 percent reflects the proportion of these nodes relative to the total number of nodes, excluding the origin point.

The number 23 indicates that 23 nodes have a spatial depth of two steps or less from the origin point, including those with depth values of 1 and 2. Nodes with a depth of two steps are highlighted in yellow in Figure 7, and 79.3 percent reflects their proportion relative to the total node count, excluding the origin point.

The number 28 represents the nodes within a spatial depth of three steps or less from the origin point, encompassing depths one, two, and three steps. Nodes with a depth of three steps are marked in orange in Figure 7, and 96.6 percent reflects their proportion relative to the total node count, excluding the origin point.

Finally, the number 1 represents a single node with a spatial depth exceeding three steps from the origin point, marked in green in Figure 7. This constitutes 3.4 percent of the total number of nodes, excluding the origin point.

The final row of Table 4 summarizes the total number of nodes at various depth values across all areas. For example, the number 307 represents the total number of nodes located at a depth of one step from the origin point across all areas, while the number 948 indicates the total number of nodes, excluding the origin point. The percentage reflects the proportion of nodes at a specific depth relative to the total number of nodes, excluding the origin across all areas. For instance, 32.4 percent represents the proportion of nodes at a 1-step depth (307 nodes) compared to all nodes excluding the origin (948 nodes).

The results of the spatial depth value analysis (Table 4) show that the hutong system has evolved into a network structure consisting of 948 nodes, composing links and nodes. Among these, 796 nodes are located within a spatial depth of three steps or less from the landmark road, accounting for 84 percent of the total number of nodes. In contrast, 152 nodes have a spatial depth greater than three steps from the landmark road, accounting for 16 percent of the total number of nodes. This result indicates that over 80 percent of the hutong intersections in Dongcheng district, Beijing, China, in the 18th century exhibited high accessibility.

Upon examining the distribution map of landmark roads in Dongcheng district, Beijing, from the 18th century (Figure 5) and the spatial depth value analysis results (Table 4), it becomes evident that landmark roads divide Dongcheng district into 27 regions. In 20 of these regions, over 80 percent of the nodes have a spatial depth of < 3 steps from landmark roads. However, in regions A2, A3, A21, A22, and A24, fewer than 70 percent of the nodes meet this criterion (Figure 8). These findings indicate that most of the 27 regions exhibit excellent accessibility to landmark roads, revealing a clear spatial connectivity pattern between the hutong system and landmark roads in Dongcheng district in the 18th century.

The spatial depth value analysis (Table 4) also reveals the accessibility challenges in Areas A2, A3, A21, A22, and A24, where the proportion of nodes with a spatial depth value of < 3 steps to landmark roads is 67 percent, 67.2 percent, 54.3 percent, 68.1 percent, and 69.4 percent, respectively. Although more than half of the nodes in these areas meet this criterion, their accessibility is comparatively lower than in other areas. These five areas also have a relatively high total number of nodes, with 94, 61, 70, 47, and 36 nodes, respectively, indicating a greater

Table 4. Spatial depth values in the hutong system

Area	Spatial depth ≤1		Spatial depth ≤2		Spatial depth ≤3		Spatial depth >3		Total number of nodes
	Number of nodes	Proportion (%)	Number of nodes	Proportion (%)	Number of nodes	Proportion (%)	Number of nodes	Proportion (%)	
A1	19	41.3	34	73.9	46	100	0	0	46
A2	20	21.3	43	45.7	63	67	31	33	94
A3	19	31.1	33	54.7	41	67.2	20	32.8	61
A4	9	45	18	90	20	100	0	0	20
A5	6	66.7	9	100	9	100	0	0	9
A6	14	34.1	30	73.2	39	95.1	2	4.9	41
A7	10	35.8	18	69.2	25	96.2	1	3.8	26
A8	7	22.6	19	62.3	27	87.1	4	12.9	31
A9	10	52.6	18	94.7	19	100	0	0	19
A10	13	32.5	28	70	37	92.5	3	7.5	40
A11	12	66.7	18	100	18	100	0	0	18
A12	7	20.6	17	50	27	79.4	7	20.6	34
A13	5	71.4	7	100	7	100	0	0	7
A14	7	70	9	90	10	100	0	0	10
A15	12	41.4	23	79.3	28	96.6	1	3.4	29
A16	9	40.9	19	86.4	22	100	0	0	22
A17	16	43.2	32	86.5	37	100	0	0	37
A18	15	30	34	68	47	94	3	6	50
A19	10	33.3	21	70	29	96.7	1	3.3	30
A20	5	41.7	10	83.3	12	100	0	0	12
A21	12	17.1	25	35.7	38	54.3	32	45.7	70
A22	9	19.1	20	42.6	32	68.1	15	31.9	47
A23	10	32.3	21	67.7	29	93.5	2	6.5	31
A24	10	27.8	19	52.8	25	69.4	11	30.6	36
A25	14	33.3	28	66.7	38	90.5	4	9.5	42
A26	12	46.2	21	80.8	26	100	0	0	26
A27	15	25	29	48.3	45	75	15	25	60
Total	307	32.4	603	63.6	796	84	152	16	948

number of road intersections. In addition, the proportion of green nodes (nodes requiring more spatial transitions to reach landmark roads) is relatively high at 33 percent, 32.8 percent, 45.7 percent, 31.9 percent, and 30.6 percent, respectively. These green nodes are predominantly located at the center of the area, surrounded by tortuous roads. Moreover, the scarcity of black nodes (nodes with direct and highly connected paths to landmark roads) results in limited selectable paths. Consequently, these green nodes must traverse multiple intermediate nodes to access black nodes, increasing their spatial depth and reducing the overall accessibility of the entire area. For instance, Area A21 features numerous internal road intersections but few intersections along landmark roads, along with a scarcity of well-connected roads, resulting in significantly lower overall accessibility (Figure 9).

In contrast, Area A16 (Figure 10) features a chaotic and irregular hutong distribution, indicating weak spatial logic. However, it contains a notable exception: a straight hutong near the center effectively connects the landmark road in the north–south direction. This particular hutong fulfills two crucial roles: serving as a guide and enhancing spatial connectivity between the area and landmark roads. As a result, residents can access landmark roads within three spatial transitions, significantly improving the area's overall accessibility. In contrast, Areas A2, A3, A21, A22, and A24 lack such a guiding hutong, which limits their connectivity to landmark roads.

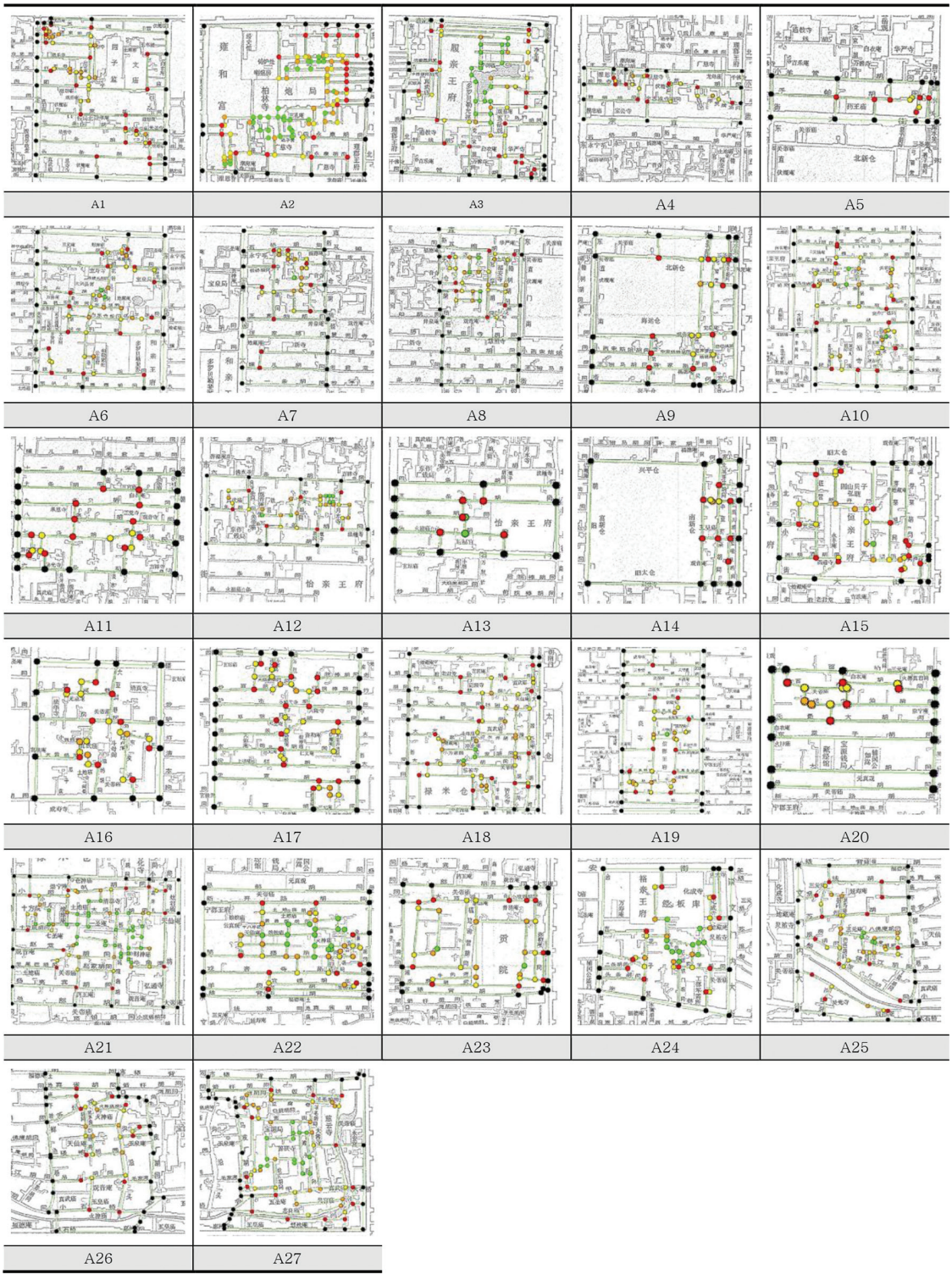

Figure 6. Visualization of spatial depth values in the hutong system
Notes: Black circles: Nodes along landmark roads (depth = 0); Red circles: Nodes with a depth value of 1; Yellow circles: Nodes with a depth value of 2; Orange circles: Nodes with a depth value of 3; Green circles: Nodes with a depth value >3. Source: Drawings by the authors

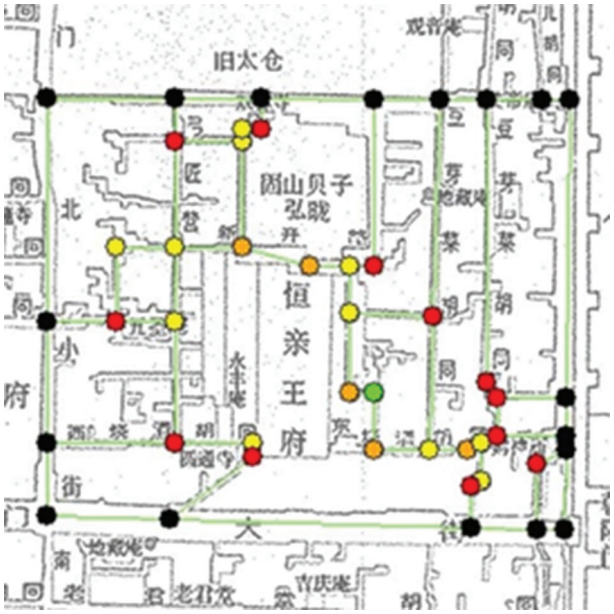

Figure 7. Visualization of Area A15
Notes: Black circles: Nodes along landmark roads (depth = 0); Red circles: Nodes with a depth value of 1; Yellow circles: Nodes with a depth value of 2; Orange circles: Nodes with a depth value of 3; Green circles: Nodes with a depth value >3. Source: Drawings by the authors

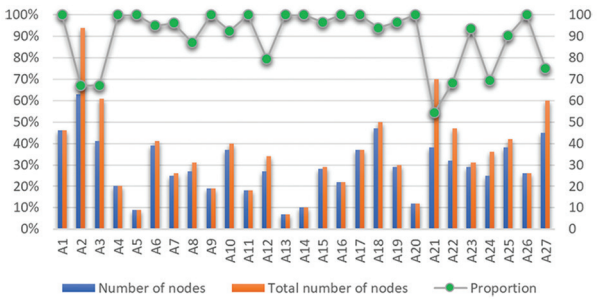

Figure 8. The proportion of nodes within a 3-step spatial depth. Source: Graph by the authors

6. Limitations

This study explores the relationship between the hutong system and the urban landmark roads in the Dongcheng district, Beijing, China, in the 18th century, based on an abstraction of spatial structure. However, there are inevitable limitations associated with the abstraction process, particularly in presenting link attributes. At present, the links mainly reflect road connectivity without accounting for critical characteristics, such as road width, traffic volume, frequency of use, and direction. As a result, the evaluated accessibility should be interpreted as relative rather than absolute.

Despite these limitations, the basic relationship between the hutong system and landmark roads identified through network analysis remains reasonable. To enhance the accuracy and depth of future research, it is necessary to incorporate additional attributes such as road width, frequency of use, and traffic volume into subsequent analyses. By integrating these detailed parameters and applying more rigorous data analyses, we aim to revisit the existing results for a more comprehensive and precise understanding of the spatial dynamics.

Figure 9. Visualization image of Area A21. Source: Drawing by the authors

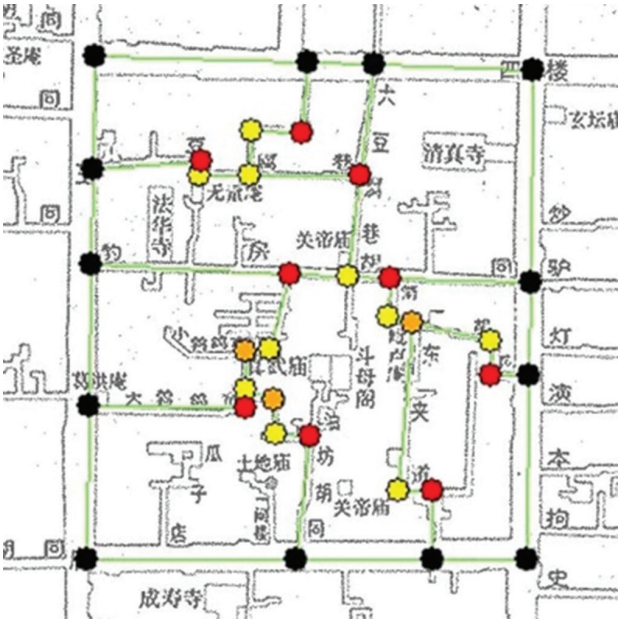

Figure 10. Visualization image of Area A16. Source: Drawing by the authors

7. Conclusion

The hutong system of 18th-century Beijing evolved from foundations laid during the Ming dynasty (1368 – 1644). Influenced by urban development and population growth, this system expanded and became increasingly complex. However, recent scholarship suggests that, although Beijing's hutong system appears complex, it demonstrates high efficiency and convenience in practice. Most existing studies rely on qualitative research, lacking the quantitative analysis necessary to validate these claims. Although certain studies have applied quantitative methods to investigate the convenience of hutong areas, they predominantly focus on specific parts of modern Beijing's hutong areas. As a result, these studies fail to represent the broader hutong system, neglect the original layout, and overlook the dynamic interaction between the hutong system and the extensive urban road network. Consequently, they fail to fully reveal how the hutong system achieves high mobility efficiency despite its complexity.

Building on this premise, the present study argues that the high efficiency and traffic convenience of Beijing's 18th-century hutong system were significantly influenced by its spatial connection to the city's landmark roads. Utilizing the *Qianlong Jingcheng Quantu* map, which accurately reflects the 18th-century road structure of Beijing, this study utilizes spatial network analysis and regional accessibility indicators to quantitatively analyze the spatial connections between the Dongcheng district's hutong system and landmark roads.

The findings are summarized as follows:

i. During the 18th century, the road network in Beijing's Dongcheng district transformed into a network of links and nodes, represented by 948 nodes within the hutong system. Among these, 796 nodes (84% of the total) had a spatial depth value of three steps or fewer from landmark roads. This finding reveals a distinct and regular spatial relationship between the hutong system and landmark roads, reflecting a well-defined spatial organizational logic despite the system's apparent complexity.
ii. The 18th-century Dongcheng district was divided into 27 areas by landmark roads. Of these, 20 areas had over 80 percent of their nodes within a spatial depth of three steps or fewer from landmark roads. However, in five areas, this percentage was notably lower. This discrepancy can be attributed to the presence of numerous shorter hutongs in these five areas and a lack of routes connecting directly to landmark roads. Furthermore, the absence of highly connected hutongs increases the topological distance between these spaces and landmark roads, thereby diminishing the accessibility of these areas.
iii. Urban development and population growth during the 18th century led to the emergence of new hutongs in Beijing, expanding upon those established during the Ming dynasty. This expansion introduced complexity to the hutong system. Despite this complexity, the spatial organization between the hutong system and landmark roads facilitated effective integration with the broader urban road network, maintaining high levels of traffic convenience.
iv. By introducing the concept of "landmark road," this study highlights how the complex hutong system achieves high traffic efficiency in practical applications. Quantitative analysis of regional accessibility uncovers a consistent spatial organization relationship between the hutong system and landmark roads. This spatial organization allows the complex hutong system to interact dynamically with the broader urban road network in daily operations, thereby enhancing the overall traffic efficiency of the area.

The findings of the present study have significant implications for urban design and planning. The interaction between the hutong system and urban landmark roads demonstrates that effectively integrating a dense road network can significantly enhance overall traffic flow and efficiency. Therefore, in urban expansion and the renovation of older districts, introducing small, multi-directional roads—similar to those in the hutong system—can improve internal circulation, reduce traffic congestion, and increase the accessibility and flexibility of large-scale urban road networks. By adopting the spatial layout strategies of the hutong system, planners can create more adaptable and efficient urban spaces.

In addition, the hutong system demonstrates how compact spaces can support community coherence. Modern urban design can leverage this model to create environments that facilitate both transportation and community interaction. Hutongs are not only vital components of urban cultural heritage but also serve as essential elements in contemporary urban design. By integrating the historical characteristics of hutongs into modern designs, cities can preserve their cultural identity while addressing functional requirements.

The quantitative data presented in this study serve as an important reference for policymakers and urban planners. In responding to the challenges of an aging society and the transformation of older urban areas, measures such as adding convenient facilities and optimizing public spaces at high-accessibility intersections should be considered. These strategies can enhance transportation convenience, improve residents' comfort, and simultaneously protect and utilize

cultural heritage. This comprehensive approach will contribute to creating a more sustainable and livable city in the future.

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Conflict of interest

The authors declare that they have no competing interests.

Author contributions

Conceptualization : All authors
Formal analysis : All authors
Investigation : All authors
Methodology: All authors
Writing – original draft : All authors
Writing – review & editing : All authors

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Availability of data

The authors confirm that the data supporting the findings of this study are available within the article.

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ORIGINAL ARTICLE

Computational urbanism and the spatial evolution of Dashilar, Beijing, China

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Abstract

Beijing's urban development follows a cyclical pattern, reflecting its evolution from ancient dynasties to modern times and highlighting the challenges of balancing historic preservation with contemporary urban growth. The Qianmen Dashilar area in Beijing, China, rooted in the traditional hutong system, exemplifies these challenges and serves as a focal point for exploring strategies to harmonize heritage conservation with dynamic urban transformation. This article examines the evolution of the Dashilar area during the urbanization process, focusing on the transformation of its urban structures and courtyard houses. It aims to address the long-standing challenges of preservation and regeneration faced during the area's urban transformation. To tackle these issues, the article proposes the use of computational methods to establish dynamic urban models based on modulated urban programs and crowd flow dynamics. By developing three computational urban prototypes – cell aggregation, mixed blocks, and node control – through site analysis and data collection, this study re-establishes the connection between the urban grid and urban programs while revitalizing courtyard spaces. These methodologies aim to balance the preservation of Dashilar's traditional urban fabric with the diverse living demands arising from urban growth. In doing so, the article advocates for a multi-dimensional approach to safeguarding the area's cultural and historical heritage while supporting its future urban regeneration and evolution.

Keywords: Urban regeneration; Design prototype; Evolution; Urban dynamic model; Computational urbanism

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1. Introduction

Beijing's urban development follows a cyclical pattern reminiscent of the growth rings of a tree, expanding and evolving incrementally over time. This evolutionary trajectory can be traced from the Jin (266 – 420) and Yuan (1271 – 1368) dynasties through the Ming (1368 – 1644), and Qing (1644 – 1912) dynasties. Transforming ahistorical capital, such as Beijing, inevitably presents challenges, such as managing historic central living areas, balancing traditional urban features with modern elements, and preserving these characteristics while fostering a harmonious relationship with contemporary urban development. This research focuses on the Dashilar area in Beijing, China, using

hutongs as a conceptual starting point to explore the significant crises and challenges associated with Beijing's rapid urbanization (Figure 1).

Over the course of a 5-year study, we aimed to challenge conventional design approaches and identify the dynamic factors shaping and influencing urban development, including economic growth, environmental considerations, and population mobility and migration. Cities, as continuously evolving systems, differ significantly from the broader natural environment (Verebes, 2013). Rejecting the notion of cities as static and unchanging entities, we propose that cities grow, change, and evolve (Verebes, 2009) in response to a variety of influencing factors (Figure 2).

2. Methods

The present study investigates how transitions in urban programs, population shifts, changes in family structures, and evolving neighborhood relations internally drive urbanization, manage the impact of social factors, and enable the development of digital models for prototype analysis. The study primarily focuses on three key areas (Alexander *et al*., 1977):

(i) Neighborhood dynamics: How modifications within courtyard houses and changing neighborhood relations foster new communication models and spatial connections. Could these changes lead to novel forms of spatial agglomeration?

(ii) Adaptive use of hutongs: How do hutongs, as an embodiment of modern life, adapt to evolving living demands and diverse activities by revamping their programs?

Figure 1. The texture of Dashilar zoning and the old city of Beijing. The labels represent different blocks in the Qianmen Dashilar area, Beijing, China. Cyan blocks represent developed areas, while brown blocks represent underdeveloped areas. Source: Zoning overlay by the authors (satellite imagery from https://www.tianditu.gov.cn/)

(iii) Impact of public facilities: How do public facilities, such as public toilets, influence the evolution of the entire hutong fabric?

Throughout the study, we address the dynamic factors influencing urban development and aim to create a fluid, circular urban system shaped by these factors. Digital technology plays a crucial role in orchestrating intricate, dynamically interactive urban environments within existing urban landscapes. Utilizing digital tools, we generate and manage these dynamic models to better understand these interactions (Ball, 2001) (Figure 3).

2.1. Urban traffic force field

Cities evolve and transform through the interplay of various forces within a dynamic force field, encompassing factors such as terrain, road traffic, and program layout. Transportation operates within a specific transportation field; the field's strength reflects not only the volume of commuting on different roads but also the convenience of transportation and the potential noise hazards across various regions (Jagutis *et al*., 2023). Furthermore, changes within the transportation field are influenced by the hierarchical structure of roads, their spatial organization, and fluctuations in population density (Figure 4).

2.2. Grid system

A city's grid system serves as the foundational framework for its development. A robust urban grid system must adapt to changes in program distribution rather than remain rigid and static. As program distributions evolve, land values naturally shift. A dynamic grid system that actively responds to these changes in land value aligns more effectively with the current state of urban development.

In this context, the outcomes of program distribution are conceptualized as point force fields, which influence a predetermined homogeneous spatial grid system. This approach allows the grid's configuration to evolve dynamically in response to shifts in both program distribution and land value (Figure 5).

2.3. Local discretization

Through the integration of program distribution and the grid system, optimal building volumes, and spatial divisions of roads are achieved, establishing the fundamental form of building volumes. However, while various programs occupy space densely, the overall program distribution often exhibits significant variations in density. At the micro level, local program distributions lack differentiation and spatial diversity. To address this limitation, we employ cellular automata, a spatiotemporal discrete local dynamics model. This model is reconstructed by establishing a series

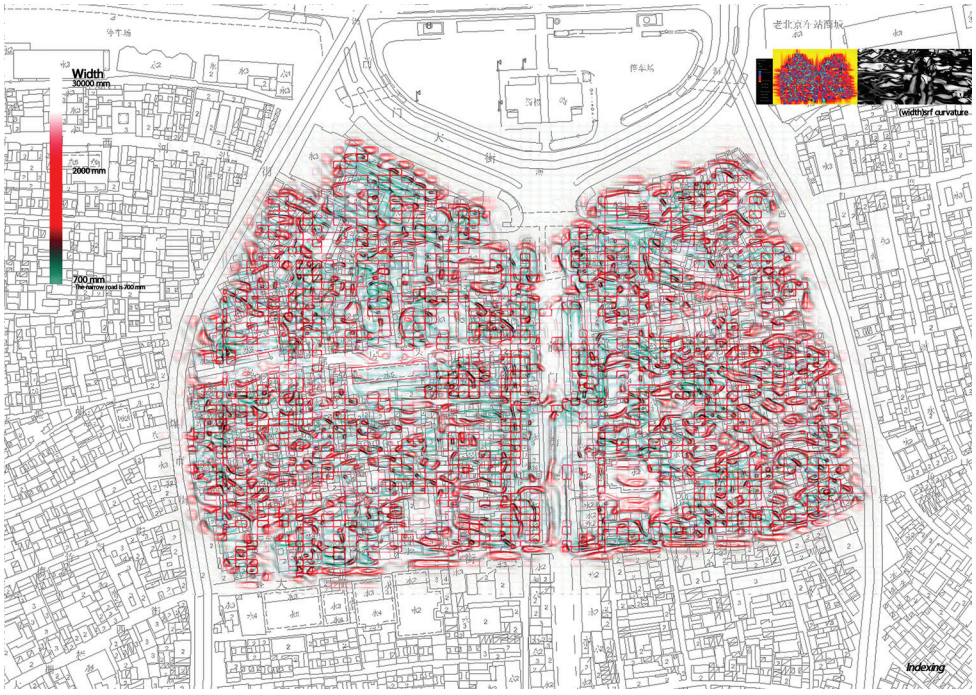

Figure 2. The increasingly complex courtyard layout of Dashilar area, Beijing, China. Source: Drawing by the authors

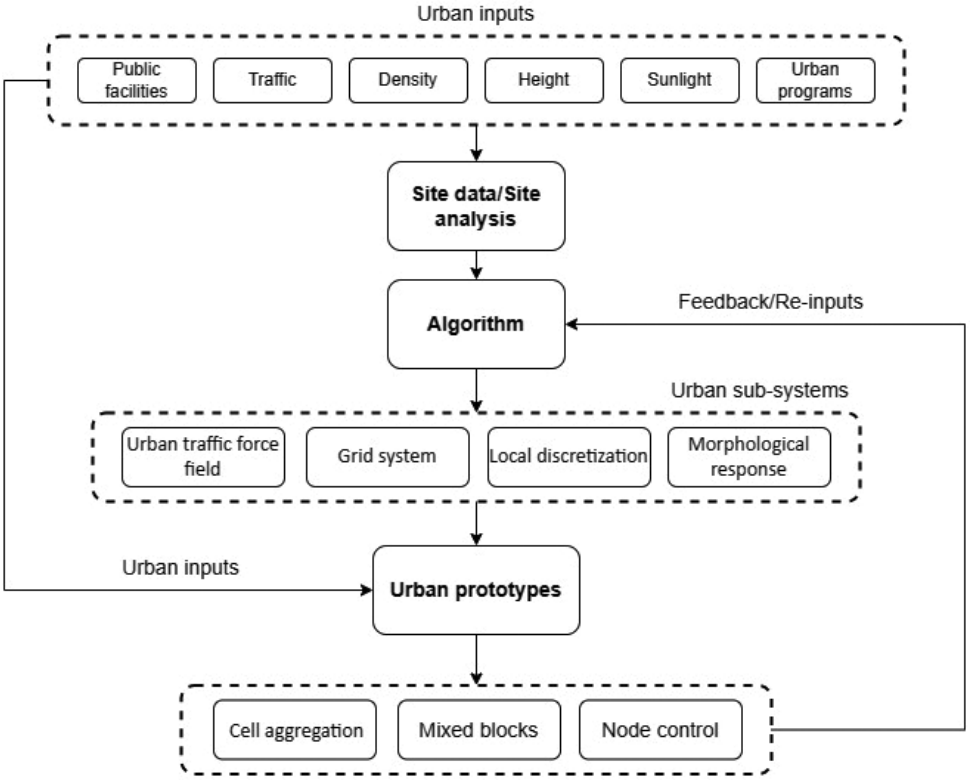

Figure 3. The overall framework of the study demonstrates the establishment logic of urban computing models, as well as the correlation between input parameters and output results. Source: Drawing by the authors

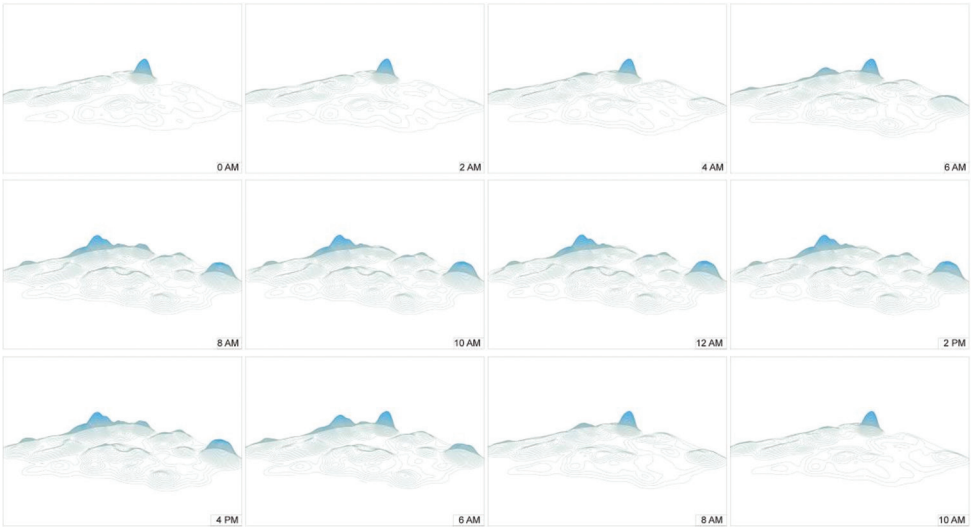

Figure 4. The changing state of the traffic field within a 24-h period of time. Source: Drawing by the authors

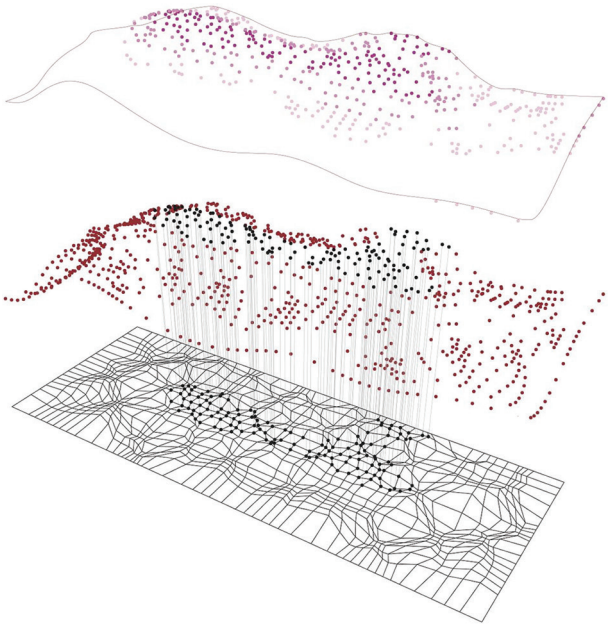

Figure 5. Governing and communicating the transformation of hutong spaces through urban force fields. Source: Drawing by the authors

of rules: each cell within the regular grid assumes a limited set of discrete states, adheres to uniform operational rules, and updates synchronously based on predefined local regulations. The interactions among a multitude of cells, governed by these simple rules, drive the evolution of the dynamic system.

The cellular automata model features the discretization of time, space, and state, with each variable assuming only a limited number of states. Changes in state are governed by rules localized in both time and space (Shen & Ye, 2024).

By regulating the density of updated outcomes, the original program layout is adjusted to produce fully dense volumes locally. Subsequently, by assessing the density and porosity of these new volumes, more varied and appropriate spatial patterns are achieved. These patterns are tailored to specific programs at a highly microscopic level (Figure 6).

2.4. Morphological response

During the generation of the grid system, information is effectively transformed into spatial structures. Although the grid system serves as a control mechanism that influences the overall spatial form at the macro level, it does not accurately reflect how architectural forms respond to external factors. Architectural forms, as the external manifestation of buildings, should dynamically respond to relevant influences, such as transportation networks. To address this, a model governed by unified principles should be established to articulate the relationship between these factors and urban forms, thereby regulating morphological changes. This approach ensures that as cities evolve, architectural forms concurrently undergo appropriate transformations. Beyond architectural form, terrain emerges as another crucial element in spatial shaping (Bentley & Corne, 2002). By reorganizing terrain slopes, rainwater harvesting and flood prevention capabilities can be enhanced. In addition, terrain collaborates with architectural forms as part of the earth's landscape, adapting to environmental changes and giving rise to new spatial forms (Figure 7).

3. Prototyping

Following the economic reforms and opening-up period, long-time residents of Beijing increasingly vacated

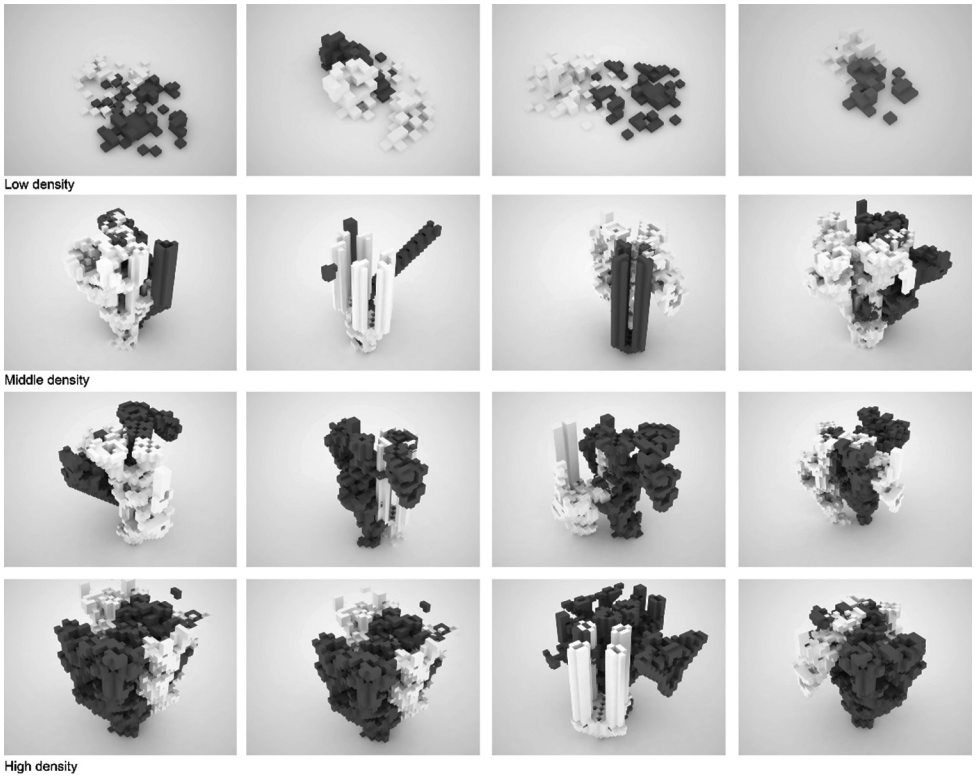

Figure 6. Different programs evolve and integrate under the influence of time and the urban force field. Source: Drawing by the authors

their homes in the old neighborhoods, leading to an influx of migrants from various cities and countries who adapted to these areas. Agrarian settlement patterns were thoroughly dismantled, and hutongs were modified to maximize living space within confined boundaries. The traditional Confucian enclosure-style courtyards, once central to family construction, rapidly diminished and nearly vanished. Hutongs subsequently became stages for diverse groups competing for living space, resulting in new settlement patterns that emerged from the cultural remnants of the existing urban fabric. This transformation shaped a cityscape characterized by distinct generational layers (Figure 8).

Close observation of changes on a larger scale reveals that, alongside the dramatic population increase, most courtyard houses have lost their original spatial configurations. This alteration has led to the widespread emergence of large, mixed-use courtyards. Haphazardly constructed private residences have proliferated within these courtyard houses, further fragmenting family spaces. Over time, these already disorganized courtyard areas have become even more fragmented as the next generation matures (Rudofsky, 1964). The initial alterations primarily affected annex rooms and surrounding walls, which were expanded to accommodate additional residents. Subsequently, wing rooms and inverted dwellings were enlarged and repurposed as storage spaces, bedrooms, or bathrooms (Yu, 2017) (Figure 9).

3.1. Cell aggregation

The commercial renovation of the Dashilar area in Beijing, China, required comprehensive analysis and reconstruction. The extensive demolition and redevelopment of Qianmen Street sparked significant debate. In line with the vision of creating a vintage-style street, the original commercial main street was completely demolished and rebuilt to restore an architectural form and ambiance reminiscent of the Qing dynasty's commercial street.

During the renovation, the architectural heritage of the Dashilar area was systematically dismantled and discarded. The vibrant urban life that once flourished in the area could not be revived, as contemporary residents lacked the memory and understanding of the city's historical identity. The sense of place and subjective experiences within the neighborhood were entirely obliterated as planners sought to channel popular emotions into fabricated narratives through new construction and commercial mediums. The once-vibrant spaces were transformed into entirely artificial collective memories, with the commercial area serving

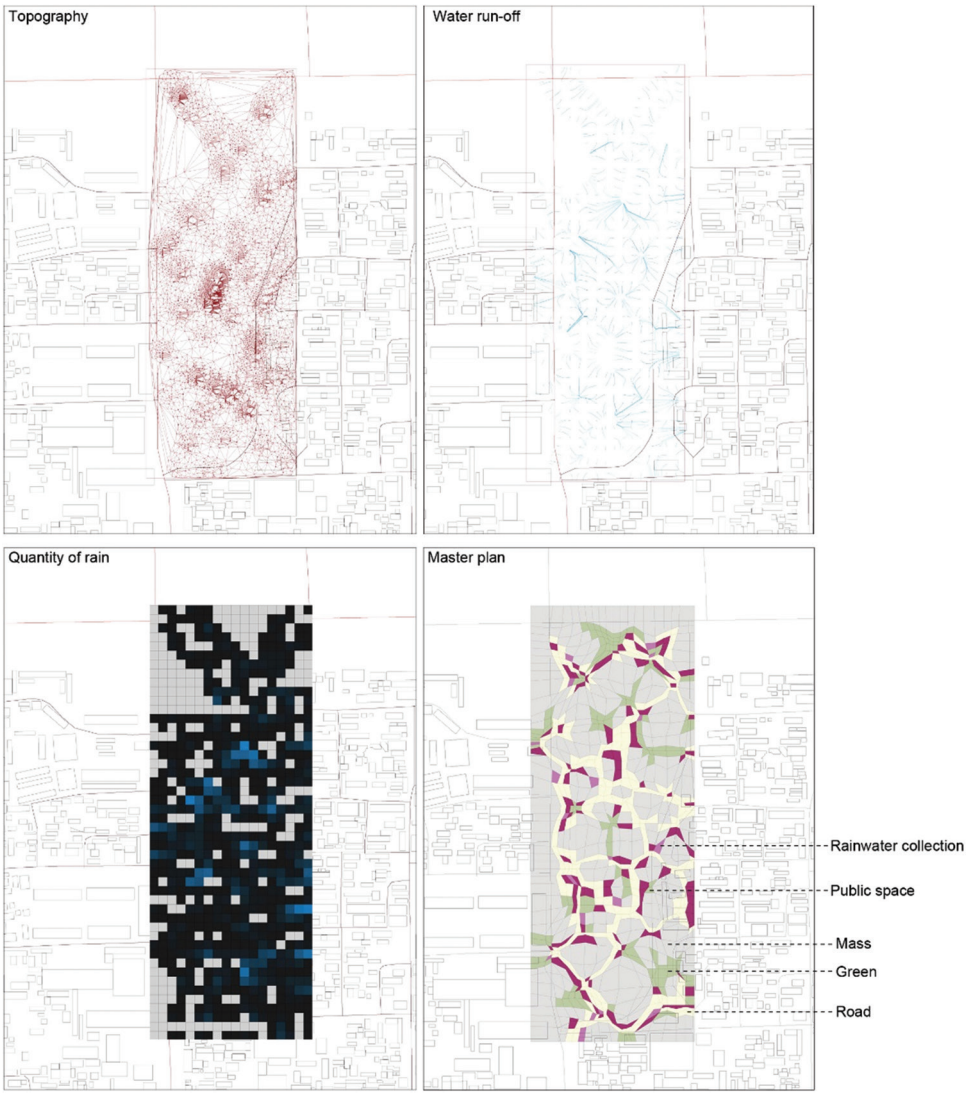

Figure 7. By reorganizing terrain slopes, an adaptive landscape is generated to more effectively collect rainwater and prevent waterlogging. Source: Drawing by the authors

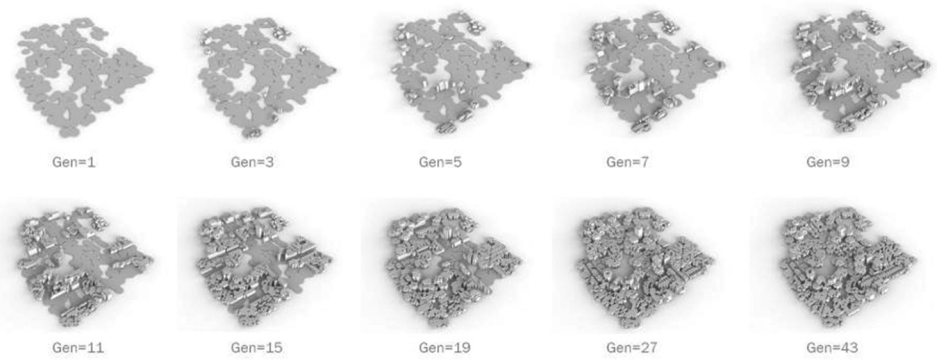

Figure 8. Exploring the evolution of urban morphology in the Dashilar area, Beijing, China, as density increases via cellular automata. Source: Drawing by the authors

merely as a site of consumption, a parody of history, and a reimagining of symbolic values.

Large-scale demolitions and developments, driven by commercial interests, often inadvertently overlook the continuity of time and space within hutong neighborhoods, neglecting the dynamic shifts and flows of life in these areas. Furthermore, the current program layout exists in a state of hybridity, with no clear boundaries (Zhao, 2016). Greater hybridity in an area leads to more diverse human activities and content. This mixed, boundary-less, and mutable spatial organization resist large-scale, human-driven development and necessitates nuanced control mechanisms (Delanda, 2016). To simulate microscopic processes of fragmentation, the cellular automata digital model was employed, incorporating Conway's Game of Life algorithm. This model quantitatively observes how individual cells grow, divide, evolve, mutate, and die under the influence of neighborhood rules and temporal factors. By controlling growth patterns and density, the processes of growth, fragmentation, and variation in the Dashilar area were substantially replicated (Figure 10).

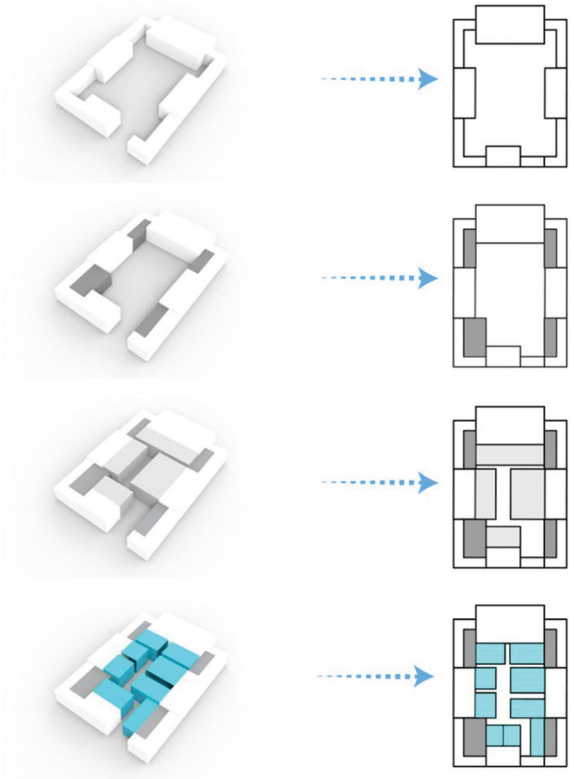

Figure 9. With the increase in population, additional construction was carried out inside these courtyard houses. Source: Drawing by the authors

The courtyard houses can be conceptualized as part of a larger grid. Due to historical constraints on two-dimensional expansion, land resources have become increasingly scarce (Che *et al.*, 2022). Envisioning the future expansion of hutongs into three-dimensional spaces – particularly within the broader Dashilar area – raises significant questions about the emergence of new forms under predetermined residential plot ratios. Notably, three-dimensional cellular automata employ 26 adjacent neighbors to govern the vitality of central cells, ensuring a more accurate representation (Shen & Ye, 2024) (Figure 11).

At the urban scale, even sophisticated abstract systems face practical challenges. Relying solely on cellular

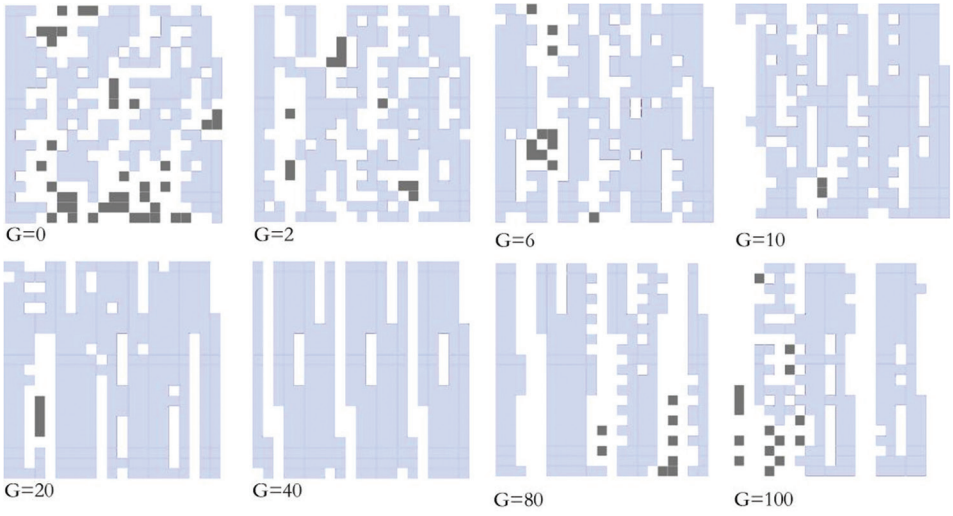

Figure 10. Using cellular automata to simulate hutong blocks, the model progresses from discrete to regular as population and programs change, culminating in the formation of new hutong block morphologies. Source: Drawing by the authors

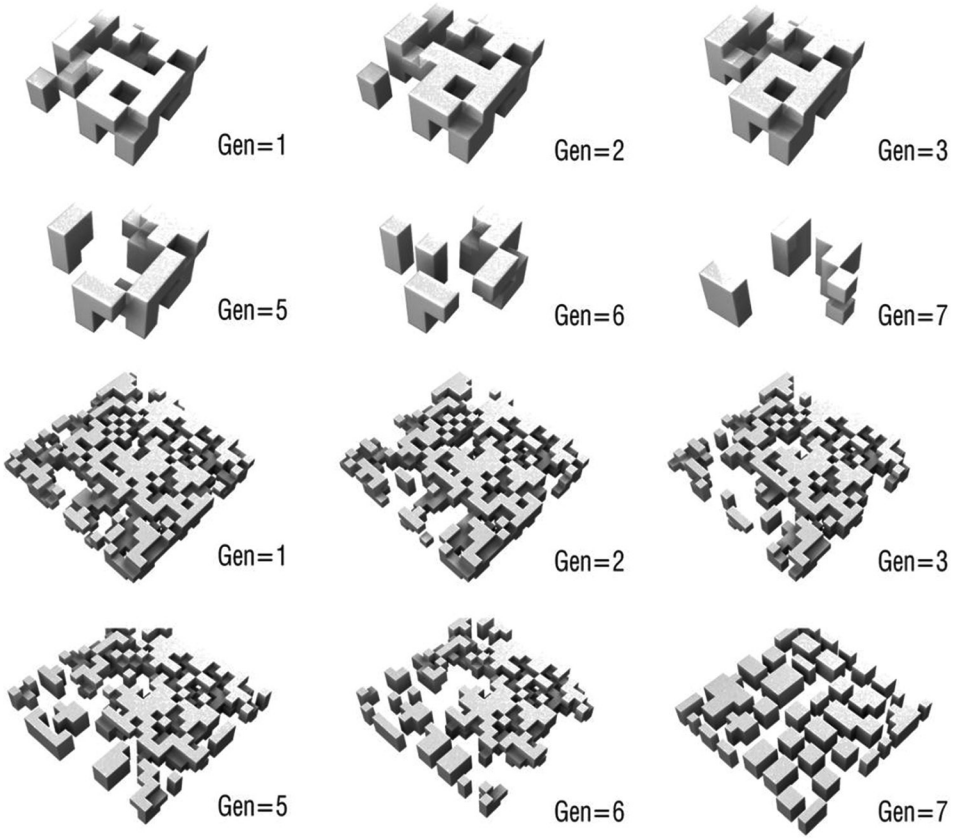

Figure 11. Investigating the spatial manifestation of diverse properties and programs in monomers across various scales and their processes of aggregation and evolution. Source: Drawing by the authors

automata as a uniform grid is insufficient for effective urban design; therefore, additional regulatory elements tailored to the unique characteristics of different sites are necessary. In Dashilar, spaces are initially divided into residential, commercial, and public spaces, as well as various road types. These areas are further subdivided into grids of varying sizes based on differing building scales and densities, with building density determined by specific regulations (Zhang *et al.*, 2023).

At the micro level, lifestyle patterns directly influence spatial scales. Residential areas are represented as larger grids, with high- and low-density areas ranging from 6 m × 6 m to 3 m × 3 m. In contrast, commercial areas feature denser grids, primarily ranging from 4 m × 4 m to 2 m × 2 m. The spatial relationships, fine-tuned by these regulations, closely mimic urban conditions. Commercial spaces exhibit greater design flexibility (Figure 12).

In this urban model, the underlying logic begins with the smallest residential unit and evolves through cell growth and aggregation. The hutong exemplifies a responsive urban spatial organization model that adapts dynamically to its surroundings (Baek & Zhang, 2021). Unlike the static, singularly residential spatial organization of traditional courtyard houses, this urban model features a sensitive and highly adaptable program distribution. Subtle changes in environmental or social factors prompt shifts in program distribution, reconstructing new urban formations and adapting to changes in social organization (Maki, 2009). This dynamic process fosters vibrant urban spaces.

3.2. Mixed blocks

We envision a city model in which the distribution of programs is neither clearly defined nor static; rather, it embodies a dynamic pattern that evolves in response to various influencing factors. This model maintains a blend of block activities and content in constant flux, spontaneously generating spaces with mixed programs, diverse spatial characteristics, and multiple modes of activity across underground areas, ground-level spaces, and high-rise buildings. For this study, we selected a typical neighborhood as the research site to explore innovative mixed-use models.

The evolution of hutong blocks is influenced by interplay of factors, including activities, demographics,

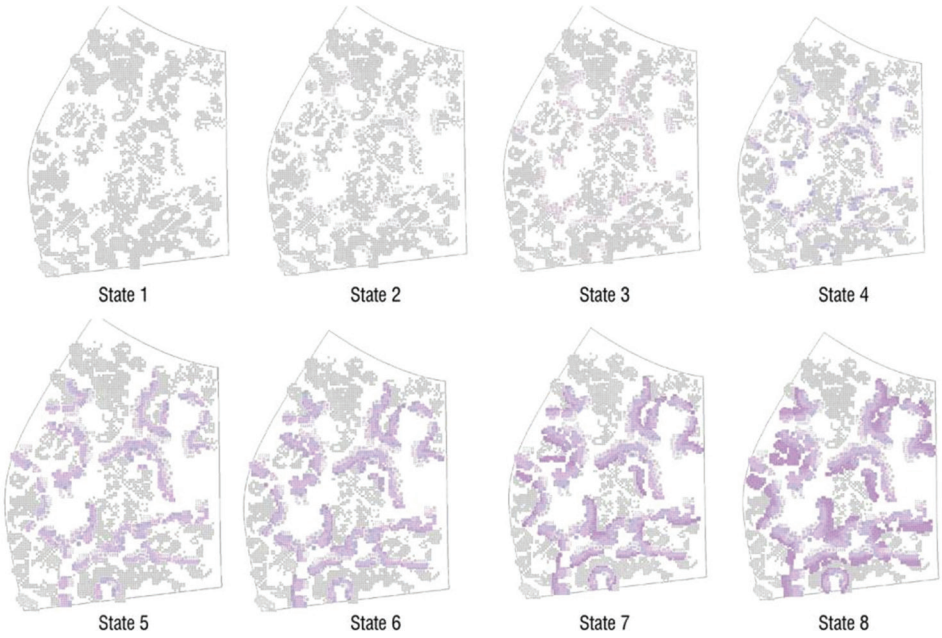

Figure 12. The evolution of the gradual mixed-use development of commercial and residential spaces in the Dashilar area, Beijing, China. Source: Drawing by the authors

social connections, infrastructure, and business models, all interacting within an "urban force field." This concept illustrates the interrelations among various elements through a dynamic "field" (Mayne, 2011) (Figure 13).

At the urban scale, the programmatic content of hutong blocks inherently generates a force field driven by crowd activities. The intensity of this force field is represented vertically by the volume of diverse population flows and horizontally by the accessibility and potential interference range of population movement across various areas. Furthermore, variations in this force field emerge from the interaction between the hierarchical structure and spatial organization of roads, alongside fluctuations in population density (Figure 14).

At the architectural scale, a program distribution field emerges, where each program inadvertently influences the arrangement of others, while undergoing reciprocal transformations. For instance, the success of a bakery on a particular street may attract a substantial customer base, encouraging the establishment of new shops in the vicinity. Conceptually, each establishment can be viewed as an independent "point force field." The relationships among programs emerge from the variations in the properties of these force fields, with each program's location and characteristics dynamically influenced by others. This interaction also impacts broader factors, such as increased land value (Figure 15).

This prototype addresses the evolving organization of urban programs within mid-scale urban environments, specifically hutong blocks, driven by urban force fields. Program layout should not be perceived as a fixed, quantitatively distributed scheme with static boundaries. Instead, it must be flexible and adaptive, allowing the programs within a building (or room) to dynamically respond to, modify, and evolve in reaction to changes in the surrounding environment. By defining the interrelationships among programs and their influencing factors within the hutong block, each program can independently assess the value of spatial areas and occupy the most suitable zones until achieving an optimal overall program distribution (Deleuze & Guattari, 1988). Any change in a single factor triggers corresponding adjustments (Rowe & Koetter, 1978; Thuer & Nam, 2023). These shifts, in turn, influence each program, fostering a dynamic mechanism of continuous evolution and interaction. This mechanism transcends the limitations of traditional courtyard blocks, which are relatively closed and characterized by singular programs. Consequently, reorganizing urban programs initiates changes in social organizational structures, addressing the challenges posed by urban structural transformations in traditional blocks (Figure 16).

3.3. Node control

Since the Dashilar area became a venue for Beijing Design Week in 2012, its transformation has entered a

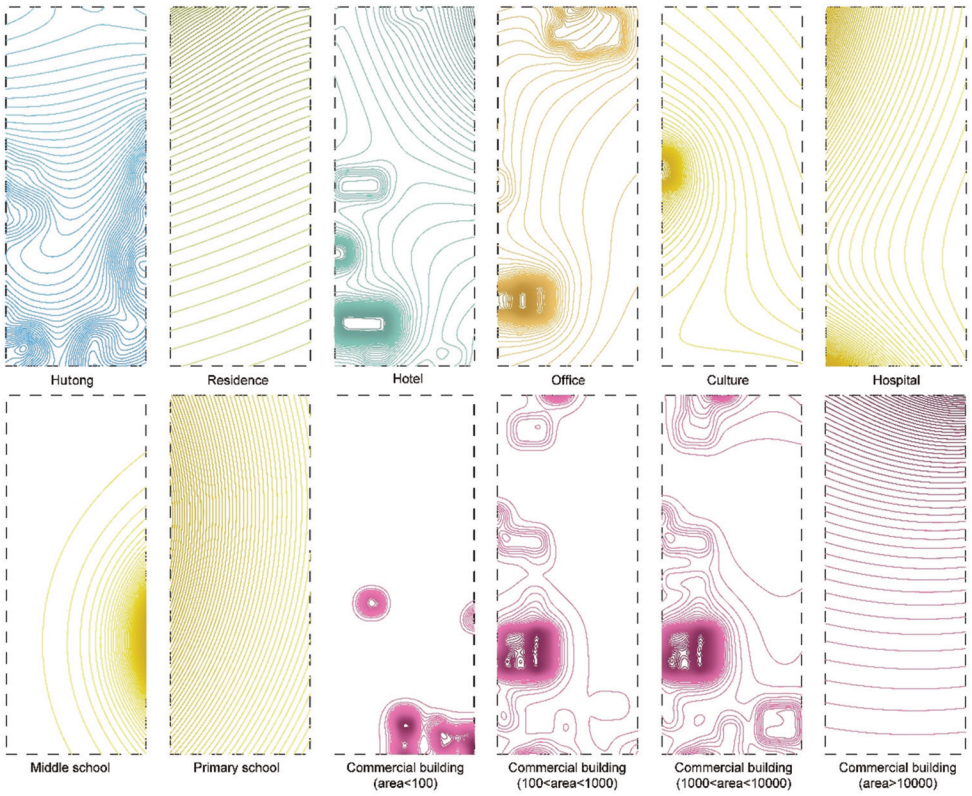

Figure 13. The force field distribution results from nine distinct urban programs in the surrounding districts. Source: Drawing by the authors

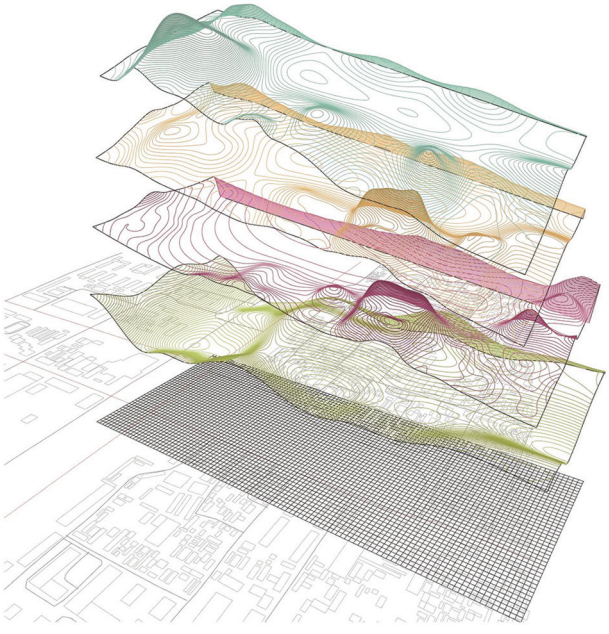

Figure 14. The urban force field, shaped by the evolution of urban programs over time, is superimposed on the site. Source: Drawing by the authors

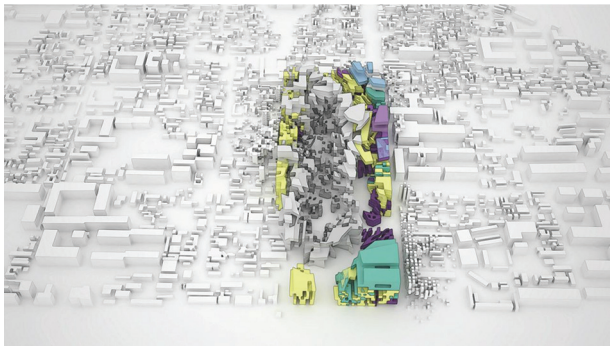

Figure 15. The urban morphology of the mixed-block prototype showcases a variety of programs and a block organization characterized by multi-scale density and porosity. Source: Drawing by the authors

phase of micromanipulation. The development approach has gradually shifted from large-scale demolition and construction to a point-based model of content replacement, giving rise to the emergence of numerous "acupuncture and moxibustion-style" interventions that stimulate cultural and creative spaces.

Cultural and creative spaces, boutique shops, and art installations are continually being integrated into the Dashilar area, progressively transforming it into a tourist destination. However, this integration has solely prioritized market consumption and economic gains, often neglecting the core objective of urban renewal:

improving the neighborhood's overall living conditions and environment.

To address this issue, we propose a novel approach based on infrastructure-focused "acupuncture and moxibustion" updates aimed at increasing public awareness and fostering sustainable urban development. Our entry point focuses on public toilets in the hutongs, which hold a unique status within the area. The spacing, density, and coverage of these facilities directly affect residents' daily convenience. As a critical piece of infrastructure, they also serve as a means to mediate social relationships (Figure 17).

By positioning public toilets as control points, we influence the grid of hutongs and roads through adjustments in distance, impact range, height, and direction. This approach bridges the interface between the traditional hutong layout and a new grid system. No longer singular or linear, the hutongs evolve into a multidimensional, circular pattern. In practice, these "nodes" can take various forms, such as shared spaces, neighborhood squares, gardens, or even new government facilities. As nodes, they influence the road network, green spaces, and foundational urban maps of the hutong blocks. The relationship between these "nodes" and the surrounding urban spaces can be quantitatively defined using simulations, based on specific logical relationships, fostering the growth of new "nodes" within traditional neighborhoods (Pasquero & Poletto, 2012). This process enriches the diversity and complexity of urban evolution (Figure 18).

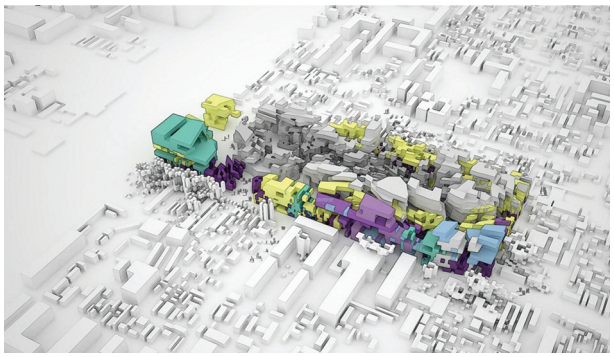

Figure 16. Along the main streets, driven by commercial and office formats, the size and height of the blocks gradually increase. Source: Drawing by the authors

In parallel, the spatial and social structure of traditional courtyard houses in the Dashilar area has gradually transformed, transitioning from single-family units to mixed-family arrangements. This transformation necessitates the development of public service facilities and infrastructure to support evolving social dynamics. On a broader urban scale, this prototype examines the potential future development of hutong blocks. As the density of public toilets increases, they could evolve into new, comprehensive architectural settlements, accommodating a range of functions such as office, residential, and commercial spaces. The enclosed squares preserve the tradition of shared spaces while simultaneously transforming into access points for underground areas. The multidimensional interplay of various courtyards fosters the emergence of innovative office and living models within the evolving fabric, preserving traditional self-sufficient

Figure 17. The distribution of public toilets and road grids in the Qianmen Dashilar area. Notes: Red dots: Courtyard house units; Blue dots: Major shops; Green dots: Small shops; Dark brown dots: Public toilets. Source: Drawing by the authors

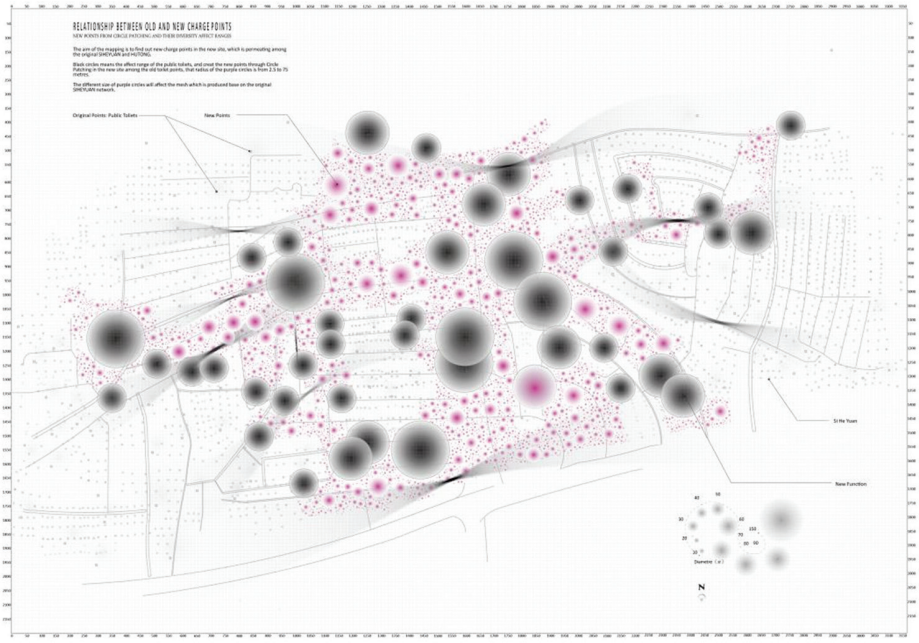

Figure 18. As the distribution of public toilets becomes more rational, a new control node system is established. Notes: Grey circles: Public service facilities and infrastructure, with public toilets functioning as nodes, the radius size of the circles indicates their range of influence and relative weight; Pink circles: The growth of courtyard houses. Source: Drawing by the authors

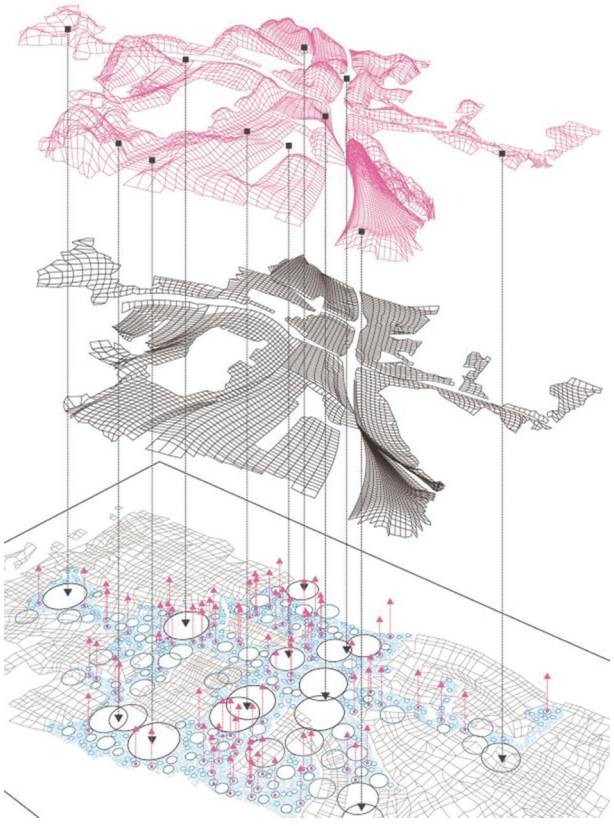

Figure 19. Influenced by the new node control system, the multifaceted interplay of various courtyards fosters the emergence of a new office and living paradigm within the evolving landscape. Source: Drawing by the authors

lifestyles, enclosed communal spaces, and diverse cultural patterns while accommodating mixed populations within confined spaces (Reiser & Umemoto, 2006). Importantly, while guiding and influencing the surrounding lifestyle, these developments gradually create new urban communal spaces and stimulate novel forms of social organization. Under the influence of dynamic factors, these formations have the potential to evolve in a more rational and organic manner (Li *et al*., 2023) (Figure 19).

4. Conclusion

Following the extensive real estate development of the early 20th century, the intensity and scope of capital operations in the Dashilar area gradually diminished. In recent years, attention has shifted toward the emergence of high-quality cultural and creative spaces, which have been celebrated as an effective strategy for the preservation of hutongs. However, a sober reflection on Dashilar's 600-year history reveals that the existence and genesis of these cultural and creative spaces are intricately tied to the capital market's exploitation of the area's original historical context.

Initially, cultural spaces arose as a form of resistance to capital-driven forces and as a counteraction to the precarious conditions of the neighborhood. Their aim was to transform into authentic cultural industries, designed to dismantle and resist the pervasive influence of capitalist power.

The revitalization and preservation of Dashilar's hutongs also necessitate a re-evaluation of the modern urban development models that gained popularity in the 1990s. Intriguingly, the goal of preservation extends beyond transforming these areas into essential cultural features of the city. Rather, it represents an act of reflection and a facet of the globalization process. The preservation of hutongs, which embody a unique urban space, should transcend their physical form and infrastructure.

Therefore, several intriguing conclusions can be drawn from the long-term study of the Dashilar area:

(i) The research focuses on the fundamental connections between the preservation and renewal of the Dashilar area through the lens of computational models. By establishing three urban computational models, we explore the relationship between new communication models and spatial developments driven by the integration of courtyard houses. This exploration extends to the redistribution and organization of hutong streets and urban programs. Public toilets, as essential infrastructure in hutongs, are emphasized as key nodes influencing the evolution of the urban texture.

(ii) Urban computing models excel in linking site-specific data to abstract urban formations. By processing site data and applying algorithms, these models function as abstract machines that integrate diverse urban factors – including transportation, urban programs, climate, sunlight, and hydrology – to produce abstract urban organizations. In this context, urban computing models do not present traditional forms of urban layout or design; instead, they facilitate the translation of data across temporal and spatial dimensions.

(iii) Contrary to top-down administrative planning, which often leads to the destruction of certain blocks through large-scale demolition and development, this study presents an alternative approach: a gradual evolution from the bottom up. This method aligns more closely with the 600-year historical transformation of the Dashilar area. The emerging urban spatial structure preserves the original hutong logic, dynamically revitalizes the hutong ambiance, expands residential space, enhances living quality, reunifies fragmented family spaces, reduces demolition costs, and alleviates social tensions. Simultaneously, the increased space and the introduction of new urban functions can, to some extent, rejuvenate the urban context of Dashilar. This revitalization honors the memories of former communal life and residential subjects, reconstructs the consciousness and identity of the neighborhood, strengthens the connection between users of new commercial spaces and original residents, and rekindles the community's vitality. Encouragingly, during the research process outlined in this article, local governments and community organizations gradually began adopting some of the strategies proposed in the study, embracing the progressive "micro-renewal" approach. Over 5 – 6 years, several vibrant hutong neighborhoods, such as Yangmeizhu Xie Street, gradually emerged.

Certainly, it is important to note that the study encompasses a relatively limited number of neighborhoods. The collected data primarily focuses on physical aspects, while social data collection is notably scarce. In addition, there is a lack of extensive empirical data to validate the proposed method.

Future research will direct attention toward the following aspects:

(i) The research will expand the urban computing model by integrating social variables such as social structure, population composition, occupation, and historical culture. It will also validate the model's potential applications within specific-scale blocks. This will provide valuable evidence for urban planners and local governments to implement multi-dimensional urban control measures, including building height, density, allocation of urban functions, and public service facilities.

(ii) After integrating social variables into urban computing models, it will be possible to analyze the relationship between physical spatial changes and social structural transformations. Simultaneously, from a sociological perspective, the study will assess the limitations of these computing models and investigate the ethical implications and potential social impacts of their application in urban planning.

The study of the highly complex historical area of Dashilar is destined to be a long-term endeavor. Historically, research on this quarter has often overlooked discussions on preserving the associated way of life, forms of interaction, and grassroots social dimensions (Chung *et al.*, 2002; Obrist *et al.*, 2011). The future of Dashilar will be characterized by either radical transformation or stagnation and solidification. For our research, it is essential to consider how to adapt to a built environment where some elements remain constant while others evolve (Chu, 2020).

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Conflict of interest

The authors declare they have no competing interests.

Author contributions

Conceptualization: Feng Xu
Formal analysis: Weiwei Mao, Yuchen Zhu
Investigation: Liu Xiao, Pingshan Qu
Methodology: Feng Xu
Writing – original draft: Feng Xu, Liu Xiao, Pingshan Qu
Writing – review & editing: Feng Xu

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Availability of data

Data will be made available from the corresponding author upon reasonable request.

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ACCSCIENCE PUBLISHING

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ORIGINAL ARTICLE

Leveraging heritage conservation for development: A case study of the Tonglushan ancient copper mine site in Daye, Hubei, China

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(This article belongs to the *Special Issue: Regenerating Views, Values, and Visions in Countryside Conservation in Chinese Societies*)

Abstract

The Tonglushan ancient copper mine site, the first mining and smelting archeological site discovered in China, holds significant value as evidence of advanced copper extraction techniques and sophisticated social organization in Chinese Bronze Age civilization, dating back thousands of years. However, its discovery during modern mining operations has raised persistent challenges over the past 50 years regarding the preservation of archeological remains, the methods of protecting them, and their potential utilization to drive coordinated urban and rural development in the region. Drawing on fieldwork conducted between 2016 and 2017 in the Tonglushan area, this study uses the local practice of protecting Tonglushan's archeological heritage as a lens to explore the relationship between cultural heritage conservation and regional development. By examining the complex process of preserving or relocating archeological remains *in situ*, this article presents practical considerations within the context of China's modern industrialization. As mineral resources become increasingly depleted and public interest in cultural heritage grows, the local government has sought to leverage archeological heritage as a catalyst for developing cultural tourism and achieving place-making. This study provides insights into transformation strategies for resource-dependent regions.

Keywords: Tonglushan; Heritage conservation; Industrial transition

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1. Introduction

The history of settlement development since the Industrial Revolution demonstrates that rural areas are often drawn into the industrialization process, leading to regional urbanization. In resource-based cities, the demands of modern industrial production can rapidly attract a large population and drive the swift construction of industrial towns, transforming rural wilderness into vibrant mining hubs. The case of Tonglushan exemplifies this transformation.

In the 1960s, the discovery of rich copper and iron deposits in the Tonglushan area spurred significant government investment in mining. This investment quickly transformed the once-rural area into an industrial hub. However, this early phase of industrial development proved unsustainable. As mineral resources were gradually

depleted, the once-thriving industrial towns began to decline in the 1st decade of the 21st century. Consequently, identifying sustainable development approaches became an inevitable necessity for the region's transformation.

Within the broader context of modernization, China's interpretation and application of the World Heritage Convention have progressively facilitated the implementation of a diverse range of heritage projects. These projects are considered a primary driving force in transforming the socio-economic structures of heritage sites and promoting regional development (Evans & Rowland 2014). Archeological sites, often located outside urban centers, have emerged as significant catalysts for urban and rural development, particularly through historic urban branding (Hsueh, 2013; Law, 2023; Wang, 2015).

The Tonglushan ancient copper mine site, discovered within the Tonglushan mining area, preserves relics of copper mining from the Spring and Autumn period (770 – 476 BCE). Recognizing its historical significance, the local government has designated the site as a key resource for cultural tourism.

This article examines the heritage protection practices at Tonglushan – an ancient mining site located within a modern mining area – as a case study to explore the relationship between cultural heritage and regional development. In addition, it reconsiders the significance of heritage value at national, local, collective, and individual levels.

From the summer of 2016 until August 2017, the author conducted fieldwork in Tonglushan. The fieldwork involved living in the community, observing the daily lives of miners and farmers, participating in cultural heritage preservation efforts, and conducting in-depth interviews with participants from various backgrounds.

1.1. What is Tonglushan?

Tonglushan, also known as Mt. Verdigris, is a hilly area situated 5 mi in Daye County, Hubei province, China. Facing Daye Lake and located near several streams, Tonglushan lies in the middle reaches of the Yangzi River. According to local chronicles from the Ming (1368 – 1644) and Qing (1644 – 1912) dynasties, the area was historically recognized as a site of copper production.

The mountain features a high, flat summit, large rocks, and purple-red soil. After heavy rains, copper-green ore would wash down from slopes, giving the mountain its name, *Tonglushan* (铜绿山) (Chen & Lin, 1971). Historical documents indicate that while the mountain was officially controlled by the government, local residents also engaged in mining activities.

In modern usage, "*Tonglushan*" refers to multiple entities and facilities. These include the Tonglushan Mine Company and the Tonglushan Ancient Copper Mine Site Museum. Geographically, the Tonglushan area covers a production zone that supports two mining companies, one steelworks, two building materials factories, four rural villages, and three residential units for industrial workers.

In addition, Tonglushan features an archeological museum, which has served as a public cultural facility since the 1980s. Today, the majority of the land is used for industrial purposes, followed by residential buildings and a small portion of arable land.

2. The industrialization process of Tonglushan area

Since 1950s, China has prioritized the development of heavy industry, especially the search for mineral resources to support metal industries, such as steel production. Following a geological survey that discovered rich copper and iron deposits in the Tonglushan area, located in the southeastern part of Hubei province, the Ministry of Metallurgy officially established a mine there in 1965, employing approximately 1,400 workers. By 1971, the first phase of the open-pit mining project had started production, and the number of mine workers had increased to 3,033 (TMC, 1995). Over time, Tonglushan transformed from a rural countryside into an industrial settlement centered around state-owned mining companies, township mining enterprises, and services catering to the mining workforce. The local population primarily consisted of miners, their families, and nearby farmers.

2.1. Changes in land functions

Based on related literature and field interviews, the Tonglushan area in the 1940s and 1950s was primarily composed of lake rice fields and mountainous areas, where tenant peasants - primarily from a family surnamed Cao - cultivated the land. At that time, transportation to the County town, located 3 km away, required a wooden boat. A 1970 satellite photo (Figure 1) also shows the presence of typical southern rice fields[1]. However, the discovery of rich mineral resources triggered rapid industrialization in the region.

This shift is reflected in land use changes. According to Zhou *et al.* (1996, p. 13): "The state-owned mining

[1] This image is based on a snapshot from the USGS website (https://earthexplorer.usgs.gov/), last accessed on December 3, 2018. The original photo is credited to: U.S. Geological Survey, Department of the Interior/USGS.

Figure 1. Satellite image of the Tonglushan area in 1970. Source: USGS EarthExplorer (Copyright © USGS EarthExplorer. Reprinted based on the image downloaded from the website: https://earthexplorer.usgs.gov/, last accessed December 3, 2018)

area alone expropriated 6,049 *mu*[2] of land from local farmers. The cultivated land in Rock Village was reduced from 3,000 *mu* to 200 *mu*, the original 1,600 *mu* of land in Copper Village was reduced to 0 *mu*, and the 1,200 *mu* in Quantang village now has only 600 *mu* remaining." In addition to the state-owned mines, the area saw the establishment of 10 township enterprises, with each village operating its village-run enterprises, including ore-cutting workshops, beneficiation plants, smelters, and other primary processing factories. As a result, a large amount (almost 4 sqkm) of agricultural land was destroyed due to mining activities. Furthermore, soil erosion caused by open-pit and underground mining, combined with soil and water pollution from mineral sorting and separating processes, rendered the Tonglushan area unsuitable for agriculture.

After 4 decades of resource-intensive development, the region's mineral reserves have been drastically depleted, resulting in a severe shortage of exploitable minerals. Many industrial and mining sites have been abandoned, leaving behind approximately 300 million tons of metal tailings (DLCC, 2014). The expansion of underground mining areas, subsidence zones, and heavy metal pollution forced the County government to apply for Daye's designation as one of the first resource-depleted cities in China (Chen, 2009; China's State Council, 2013). The reuse and rehabilitation of industrial and mining wasteland remain significant challenges, and large state-owned mining enterprises in the region continue to struggle for survival.

2.2. Changes in residents' lives

The Tonglushan area experienced notable prosperity due to mining activities, which significantly altered local lifestyles and expedited urbanization. The region transitioned from being classified as an "Industrial and Mining Special Zone" to the "Tongshan Commune." By 1984, the area had evolved from five dispersed natural villages into a town named Tonglushan, covering 8 sqkm and housing a population exceeding 23,000 (Tao, 1997). It encompassed major domestic enterprises, such as Tonglushan Copper-Iron Mine, Shitouzui Iron Mine, County Steelworks, and others (Lei, 2019). However, due to the depletion of copper reserves, the town was dissolved in 2001 and restructured into different communities under the jurisdiction of the Jinhu subdistrict.

During the height of mining activity in the 1990s, more than 80 percent of the local population was employed in mining-related industries. State-owned mines, smelters, and ironworks accommodated tens of thousands of employees in five newly built workers' villages, which were equipped with independent kindergartens, primary schools, secondary schools, and hospitals. The workers' village was built in stages: two-story single dormitory buildings were constructed in the 1960s, 4-story townhouse apartment buildings followed in the 1970s and 1980s, and 7-story buildings were introduced in 1998 (Wu, 2015).

[2] *Mu* (亩), a traditional Chinese unit of area used primarily for measuring land. One *mu* is approximately equivalent to 666.67 sqm.

The rapid expansion of mining activities also necessitated the construction of new roads and railways, linking Tonglushan to the nearby City of Huangshi and the provincial capital, Wuhan. The region was among the first rural areas to implement public services, such as electricity (introduced in 1994) and tap water in Huangshi City.

Although traditional rural houses remained, many nearby farmers transitioned to work in self-operated mineral processing facilities, ore-crushing factories, and smelting plants, with minimal engagement in agriculture. Improvements in living standards were also evident in education and social insurance. For instance (Zhou *et al.*, 1996):

- Copper Village and Rock Village were pioneers in Huangshi City in providing free primary education, and
- Copper Village introduced a retirement and medical insurance system as early as 1982.

Since 2008, changes in both domestic and international economic conditions have contributed to a gradual decline in the Tonglushan area. The workforce in state-owned mines has decreased to one-quarter of its former level, and nearby township-owned, village-operated, and private factories have ceased operations. With the implementation of new environmental policies, many former farmers who lost their land have either resumed small-scale agricultural activities or sought alternative sources of income.

3. The Tonglushan archeological site in modern mining areas

3.1. The Tonglushan ancient copper mine site

During the initial phase of mine construction, workers discovered ancient mine shafts with exposed timber supports. Nevertheless, it was not until 1971, when a mine manager sent two large copper axes – unearthed during production – to the Museum of the Chinese Revolution, that subsequent archeological excavation efforts were brought in (Fan & Kong, 1993).

The Tonglushan ancient copper mine site has undergone two major phases of excavation: the first between 1974 and 1985, and the second between 2012 and 2019. Archeologists discovered ancient shaft structures across 10 ore bodies designated by the Tonglushan Mine Company. Excavations revealed seven open-pit mines and 18 well-preserved underground mining areas.

The findings (Figure 2) included a complex system of underground mining facilities, comprising vertical shafts, horizontal tunnels, and inclined shafts, all supported by timber structures. These facilities also incorporated drainage mechanisms and ventilation solutions. In addition, archeologists discovered sophisticated lifting devices and copper smelting furnaces (Zhou *et al.*, 1988), along with more than 1,000 artifacts, such as wooden, stone, and copper tools, as well as pottery. Radiocarbon dating indicates that mining at Tonglushan started at least as early as the late Shang dynasty (1300 – 1046 BCE) and continued until the Western Han period (206 BCE – 9 CE) (Huangshi City Museum, 1999).

The Tonglushan site holds immense historical significance as the first scientifically excavated mining and smelting site in China. It provides evidence of organized copper mining and smelting conducted by labor forces over 3,000 years ago, as well as the advanced mining and smelting techniques employed by skilled individual craftsworkers. These discoveries offer important historical information relating to some of the most central aspects of China's Bronze Age civilization. Scholars have described the site's discovery as having "opened up a new field of Chinese bronzeware research and a new field of Chinese archeological research" (Xia & Yin, 1982, p. 1), marking the foundation of archeometallurgy in China.

3.2. Preserving ancient mining remains in modern mines

From the 1950s to the 1980s, China prioritized the development of heavy industry, accumulating capital by maintaining price scissors between industrial and agricultural product prices, imposing high taxes on rural areas, and enforcing separate household registration systems for urban and rural residents (Zhao, 2010). The Tonglushan Copper Mine Company recognized as a high-quality state-owned mine, played a critical role in national industrial production.

Preserving the Tonglushan ancient copper mine site as proof of China's ancient copper mining achievements was relatively uncontroversial during the 1970s. A joint expert committee recognized that: "Its discovery further proves the splendor of Chinese Bronze Age civilization, provides invaluable scientific data on the history of copper mining and smelting, and conclusively demonstrates that Chinese Bronze Age civilization developed independently, countering the theory of foreign origins" (Guo, 1981, p. 65).

At least two joint negotiations held in 1979 and 1981 focused on which archeological remains of Tonglushan – Ore Body No. 11 or Ore Body No. 7 – should be preserved.

In 1982, the State Council officially designated the site of Ore Body No. 7 as a national key cultural relic protection unit. Subsequently, in 1984, the Tonglushan Ancient Copper Mine Site Museum was established to oversee the archeological remains. This museum became China's third archeological site museum, following the Banpo Site and

Figure 2. Tonglushan ancient copper mine and artifacts. Source: Photo by the author (2016)

the Terracotta Warriors of the First Qin Emperor in Xi'an City, Shaanxi province, China.

Despite its academic significance, the museum's proximity to active mining operations – as close as 8 m – has posed significant challenges. Beneath the archeological remains of Ore Body No. 7 lie approximately 1.39 million tons of copper ore and 640,000 tons of ironstone, valued at an estimated 1 billion Chinese yuan (Hui *et al.*, 2023). To preserve the archeological site, the Tonglushan Copper Mine Company had to adjust its open-pit mining plans, set new boundaries, connect open-pit mining with underground infrastructure, and manage ground pressure and underground flooding. Concerns were raised that *in situ* preservation could significantly impede the mine company's production and profitability over an extended period (Leng, 1999). As a result, some advocated for the site's relocation and the museum's restoration elsewhere.

Opponents of relocation – primarily scholars from cultural, historical, and archeological backgrounds – argued for preserving the site's original integrity. They emphasized the unique historical and cultural legacy of the Tonglushan ancient mine, describing it as an embodiment of the Chinese national spirit and a part of humanity's shared heritage. Huang (1989, p. 79) noted: "The original Tonglushan ancient copper mine site covered approximately 20,000 sqkm, and less than 2,000 sqm have been preserved – a very small portion." Relocating the remaining relics, they argued, would compromise the site's essence by severing the connection between the ancient mining and metallurgical relics and the mine itself. Moreover, they highlighted the technical challenges: the relocation and off-site preservation of the complex shaft and tunnel system lacked sufficient technical support at the time, which would hinder efforts to achieve World Cultural Heritage status (Huang, 1989).

After 8 years of stalemate and multiple rounds of negotiations, the State Council approved the *in situ* preservation of Ore Body No. 7 in August 1991. It also recommended establishing a coordination committee to oversee the balance between site protection and the operational challenges posed by the mine's production and further development (China's State Council, 1991).

4. Site museum as a means to integrate heritage preservation and countryside development

Unlike the recent trends of "museum fever" and "cultural tourism fever" in China, the Tonglushan Ancient Copper Mine Site Museum, located in the suburbs of an inland County town, has long served primarily as a public cultural institution. After the State Council formally approved the *in situ* preservation of the site in 1991, the museum's primary responsibilities shifted to ensuring the safety of the archeological site and protecting features, such as water flow and the ancient timber pit supports (Shi & Wang, 1994; Shi, 2003). To enhance public engagement and improve the exhibition of the site, additional features were gradually integrated. These features included simulated archeological exploration pits, models of underground shafts and tunnel structures, modeled smelting furnaces, and two small exhibition rooms showcasing mining- and smelting-related artifacts unearthed from the site (Figure 3).

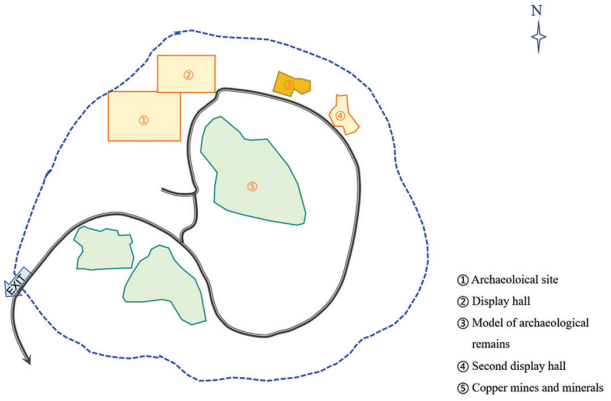

Figure 3. Map of the Tonglushan Ancient Copper Mine Site Museum before 2010. Source: Drawing by the author

While some miners recalled visiting the site museum during their childhood, sometimes as part of school assignments, local children were also known to climb over the wall to play. However, the museum's most frequent visitors were public officials from various government units. Few ordinary residents from the County were willing to pay for admission. According to records, "from 2002 to 2006, the average annual number of tourists visiting the Tonglushan Ancient Copper Mine Site Museum was 12,000" (THUPDI, 2011, p. 7), resulting in limited ticket revenue and minimal income from the souvenir shop.

From the 1990s to the early 21st century, the work at the site museum mainly focused on adhering to the protection scope defined in official documents and ensuring the safety of the heritage within the museum walls. In the meantime, China's reform and opening-up process accelerated, culminating in the country's admission to the World Trade Organization. This milestone spurred the exploitation of underground mineral resources in the Tonglushan area for integration into the global metal market, resulting in rapid and intense changes in the surrounding landscape beyond the museum walls.

Due to the demands of mining production, many ancient relics outside the site museum were destroyed. While the ore bodies preserved within the museum walls remain intact, "the ancient relics discovered in the ore bodies of I, II, III, IV, XI, and Xiaoyanyinshan were mined into a vast open-pit mine, measuring 1,605 m in length from north to south, 570 m in width from east to west, with a maximum depth of 94 m, and a surface area of 641,060 sqm" (Chen &Wu, 2014, p. 22). In addition to state-owned mining enterprises, numerous village-run operations and private mining factories engaged in the metal mining industry (Figure 4). A former museum employee recounted, "Around 2001, nearby villagers

Figure 4. View of the mining company and miners' community. Source: Photos by the author (2016)

mined around the site, even hollowing out and collapsing part of the museum wall." Furthermore, city and provincial news often reported ground cracks and fissures at the Tonglushan Ancient Copper Mine Site Museum. Reports described "the most severe collapse area measures over 20 m in length and 1.2 m in depth," while "the surrounding rock of the ancient mine site also collapsed, causing cracks in the roofs of the site museum, staff quarters, and other buildings, along with numerous fissures in the exhibition hall that resulted in broken display cabinets" (Zhang & Chen, 2008).

Experts identified two main causes for the site's structural damage. First, investigations revealed that the prolonged exposure of the open-pit mining slope on the west side of Tonglushan left unaddressed, led to ongoing deformation. This accelerated deformation of the slope directly contributed to the ground cracks at the ancient mine site. Second, frequent and complex mining activities in recent years (including both open-pit and underground mining) were exacerbated by illegal and cross-border mining, further accelerating slope and ground deformation (Liu *et al.*, 2014).

As a result, on July 1, 2007, the site museum closed for 3 years of renovations. At the same time, the Tonglushan ancient copper mine site was removed from China's tentative list for potential inclusion as a World Cultural Heritage site.

Beyond the challenges faced by the weak site museum infrastructure, companies and local residents primarily focused on rapidly extracting economic benefits from the underground mine. According to statistics, the number of ore mined in 2007 decreased by 45.9% compared to 2001, largely influenced by market prices (DLCC, 2014). After 40 years of intensive mining, the region's mineral resource reserves have been sharply depleted. Estimates suggest that the remaining resources can sustain mining operations for fewer than 9 years (Zou, 2009). Consequently, numerous underground mining areas, subsidence zones, and heavy metal pollution sites have emerged, contaminating the soil and nearby water bodies. These environmental challenges,

combined with economic and resource limitations, have redirected public focus toward the transformation and development of a green economy. Increasingly, the ancient mining and smelting sites are being reconsidered as valuable cultural resources.

5. Promoting tourism in the name of archeological site conservation

In 2010, the Tonglushan Ancient Copper Mine Site Museum was reopened, and the responsibility for protecting and managing the site was transferred to the newly established Promotion Bureau at the County level. Reflecting on earlier assessments from 2001, a private organization known as the Bronze Culture Promotion Association was founded in the Tonglushan area. This organization asserted that "for more than 20 years, the value of the Tonglushan site and the full utilization and development of resources have not been satisfactory" (DBPA, 2004, pp.13-14). They attributed this shortfall to a management system characterized by conflicting priorities: on the one hand, an excessive focus on conservation led to overprotection, while on the other, a permissive attitude toward neglecting development stifled enthusiasm from both the local government and the community (DBPA, 2004).

The challenge remains: how can archeological sites be utilized to generate economic benefits? For the Tonglushan ancient copper mine site, this question is particularly pressing, as the absence of exquisite cultural relics limits its appeal to visitors. Consequently, developing tourism around the site has emerged as a significant challenge for the Promotion Bureau team. To address this issue, the Promotion Bureau, in collaboration with local economic institutions, initiated a series of strategic measures. The first step involved gradually shutting down private mining enterprises in the surrounding area, applying to expand the site's protective boundaries, and implementing ecological management for both the surface and subsurface environments. These efforts culminated in the Tonglushan ancient copper mine site being reinstated on China's World Cultural Heritage Tentative List in 2012 as part of the Huangshi Industrial Heritage Area. The second step entailed formulating a new archeological site protection plan, which included expanding the land under effective management and engaging experts from relevant fields to deliberate a comprehensive tourism strategy.

5.1. Renovation and updates to the site museum

Based on interviews with long-term employees, the exhibition content of the Tonglushan Ancient Copper Mine Site Museum, newly renovated in 2010, remains largely unchanged from its previous iteration. Visitors can still view the ore body, the ancient diggings, and two exhibition halls within the museum. However, upon a deeper analysis, the author found that the Promotion Bureau has implemented several changes aimed at engaging with local mining culture and fostering connections with the old industrial communities. These changes can be summarized as follows (Figure 5):

(i) Relocated entrance: The main entrance of the Tonglushan Ancient Copper Mine Site Museum has been relocated. The previous entrance, situated in the southwest near the open-pit mining area, was far from residential areas. The only access road was primarily used by large vehicles associated with mining companies, and public transportation was unavailable within a 20-min walk. The newly opened entrance now faces east and is located closer to a nearby village, improving accessibility. However, visitors must climb 144 steps from the entrance to reach the museum, making the start of their visit physically demanding.

(ii) New public bus route: To further improve accessibility, the Daye County Government constructed a new highway connecting Spring Village to downtown Daye County and established three bus routes serving the Tonglushan area. Notably, Bus Line No. 16 now provides direct service between the County's high-speed railway station and the site museum.

(iii) Integration of digital technology into exhibitions: The exhibition hall of the museum has incorporated new digital technologies to enhance visitor engagement. A key addition is an interactive e-book that simulates the experience of reading a physical book, featuring touchscreen displays with locally relevant documents about copper. This innovation aimed to educate visitors about Tonglushan's extensive history of mining and smelting. Additionally, an animated video illustrating the bronze ware production process – from copper mining and smelting to casting – has proven notably popular. Information screens have also been installed, allowing visitors to access explanations during self-guided tours. However, the operation and maintenance of this digital equipment present challenges for the County government. For instance, devices purchased and installed in 2010 frequently malfunctioned, and during the author's year-long fieldwork, the e-book machine was never observed in working condition. Furthermore, after-sales technical support is only available from companies based in Wuhan, with no local services in Daye. As a result, the high maintenance costs have placed considerable strain on the museum's budget.

(iv) Museum ticket pricing: The newly reopened site museum charges an admission fee of 40 Chinese

Figure 5. Key features of the Tonglushan Ancient Copper Mine Site Museum. Source: Photos by the author (2016)

yuan per person. Discounts are available for seniors and minors in accordance with national policies, while residents of the Tonglushan area can visit at half price upon presenting their identity cards. However, many locals perceive the admission fee as excessive, given the County's economic conditions. Miners and farmers, in particular, argue that the site museum should be free for local residents, stating: "It used to be free before 2010, and if there had been no mining company, there would be no ancient copper mine site" (Mr. C, personal communication, June 22, 2017). Consequently, many residents visit the site museum only when hosting guests.

Although precise visitor statistics are unavailable, field surveys and interviews with ticket office employees suggest that the museum receives approximately 30,000 visitors annually. Of these, roughly 30 percent are free visits arranged for schools, institutions, government agencies, mining companies, and village committees.

5.2. Formulation and implementation of the overall planning for site protection

To preserve the Tonglushan ancient copper mine site and promote the coordinated regional development of the area, the Promotion Bureau commissioned a professional organization to conduct research and formulate a cultural relic protection plan for the site. Serving as a guiding and normative document for future efforts, the plan was approved and implemented by the State Administration of Cultural Heritage in 2011.

The special protection plan significantly expanded the planning scope of the Tonglushan ancient mine site to 5.557 sqkm, a substantial increase from the 0.055 sqkm designated in the 1990s. Since 2011, staff from the provincial Archeological Institute has conducted new archeological surveys and excavations within the planning area. These efforts uncovered new smelting sites, kiln sites, miners' footprints, and a cemetery dating to the Spring and Autumn period (Hubei Provincial Institute of Cultural Relics and Archeology, 2013; 2015). Notably, the discovery of the Sifangtang site marks the first ancient miners' cemetery found at a pre-Qin period (before 221 BCE) mining site in China. This significant discovery provides reliable evidence regarding the individuals who developed and used the Tonglushan ancient copper mine over the course of 1,000 years. More importantly, cultural relics unearthed during this round of excavations are displayed in the Tonglushan Ancient Copper Mine Site Museum, addressing the previously limited collection of artifacts. While over 70 artifacts are currently housed in the museum, more than 10,000 artifacts remain in municipal and provincial museums. This development significantly enriches the museum's collection and improves its ability to display local relics.

The protection plan identifies key deficiencies in the previous site museum, stating that it "has limited display content, lacks effective touring route, does not adequately convey the connotations of bronze culture, and fails to meet tourist needs" (THUPDI, 2011, p.7). To address these issues, constructing a new site museum building within

the designated control zone became a central element of the Promotion Bureau's plan to leverage the region's rich mining and metallurgical heritage as a catalyst for regional development.

The construction of the new site museum building has spanned nearly 9 years, encompassing site selection, architectural design, construction, and exhibition display. Significant enhancements have also been made to the landscape design within the core protecting section of the Tonglushan site (Figure 6). The new façade, inspired by the underground shafts of the Tonglushan archeological site, complements its historical significance. The main entrance has been relocated to the north, and the original eastern exit has been redesigned as a parking area, greatly improving visitor convenience. In addition to semi-exposed features such as the Yanyinshan mine and the Ore Body No. 7, visitors can now observe *in situ* archeological discoveries, including hundreds of Spring and Autumn period tombs belonging to miners and a collection of miners' barefoot prints.

The new museum exhibition comprehensively explains how copper was discovered and utilized in the Tonglushan area. It explores themes such as the region's mineral resources, ancient prospecting methods, mining technology, and smelting techniques. By linking the mining and smelting remains of Tonglushan during the Shang and Zhou (1046 – 256 BCE) dynasties to the ritual and musical cultures and metal resource utilization of the Chinese Bronze Age, the exhibition emphasizes how Tonglushan copper provided essential material support for the illustrious Chinese Bronze Age civilization. Officially opened to the public in June 2023, the exhibition received the 2023 National Museum Top Ten Exhibitions as an Excellent Promotion Award (China Cultural Relics News, 2024).

While the site museum represents a notable achievement, it has so far only realized 0.9 percent of the stated scope of the protection plan. Approximately 90 percent of the designated land remains occupied, primarily by the Tonglushan Mine Company. This issue persists despite the protection plan receiving central governmental approval. Changing land use remains a common problem in contemporary China, especially for state-owned sites such as the Tonglushan ancient copper mine site, which operates at the provincial level and is not managed by the local municipal government.

Although all private mining enterprises in the County have been closed since 2010, factories and abandoned industrial sites operated by village enterprises remain in a state of disrepair. The new archeological and museum construction projects have utilized portions of cultivated land from local villagers, with compensation provided for land requisitions.

5.3. The aborted Bronze Town project

The protection plan proposed expanding the exhibition potential of the Tonglushan area by incorporating several attractions in addition to the original museum. These included a modern open-pit mine display area, visits to the mine company's buildings, ecological grassland converted from the tailings pond, and a reclamation area created from the landfill (Figure 7)[3]. Despite the proposed land use adjustment plan, modern mining companies in the region remain operational, albeit at reduced capacity, rendering these areas unsuitable for regular tourist visits. The presence of underground mining equipment near the open-pit area further complicates the creation of scenic attractions and hinders cohesive tourism planning at the local level in Tonglushan.

Periodic calls for self-guided tourism development in the region have surfaced. To reconcile the conflicting priorities of archeological site protection and the continued operation of the mining company, the Promotion Bureau concentrated its construction efforts on available plots in the northern sector of the protection area and along the Changliu stream. Daye County, where the Tonglushan area is situated, has recently experienced rapid economic growth, emerging in 2015 as one of the top 100 County-level regions in China. The local government envisioned a modern urban landscape characterized by high-rise buildings, wide roads, and vibrant lighting. In line with this vision, the Changliu stream in the Tonglushan area was designated as a cultural landscape of the County, aiming to incorporate green spaces and waterfront developments emblematic of modern urban living. Consequently, an investment company proposed a plan to develop the unoccupied land on the north and south banks of the stream.

Drawing from the development plan for the Daming Palace Site in Xi'an (Hsueh, 2013), the investment company envisioned branding Tonglushan with an image of "cultural and tourism integration." This plan was further aligned with the "characteristic town" (*tese xiaozhen*; 特色小镇) program launched by the central government in 2016, framing the project as a "Bronze Town." (HBSJ, 2017) Scenic spots on the north and south banks of the Changliu stream were planned to center around ancient mining institutions and cultural heritage sites historically significant to Daye County. Historical records mention historical cities or management institutions such as "Zhangshan Ancient

[3] This sketch is based on the "*The Site Protection Plan of Ancient Copper Mine for Tonglushan in Daye City, Hubei*"2011: fig.30. The original picture is in Chinese with details, the author modified it after permission from the Tonglushan Ancient Copper Mine Site Museum.

Figure 6. Aerial view of the Tonglushan Ancient Copper Mine Site Museum. Source: The Tonglushan Ancient Copper Mine Site Museum (Copyright © 2024 The Tonglushan Ancient Copper Mine Site Museum. Reprinted with permission of The Tonglushan Ancient Copper Mine Site Museum)

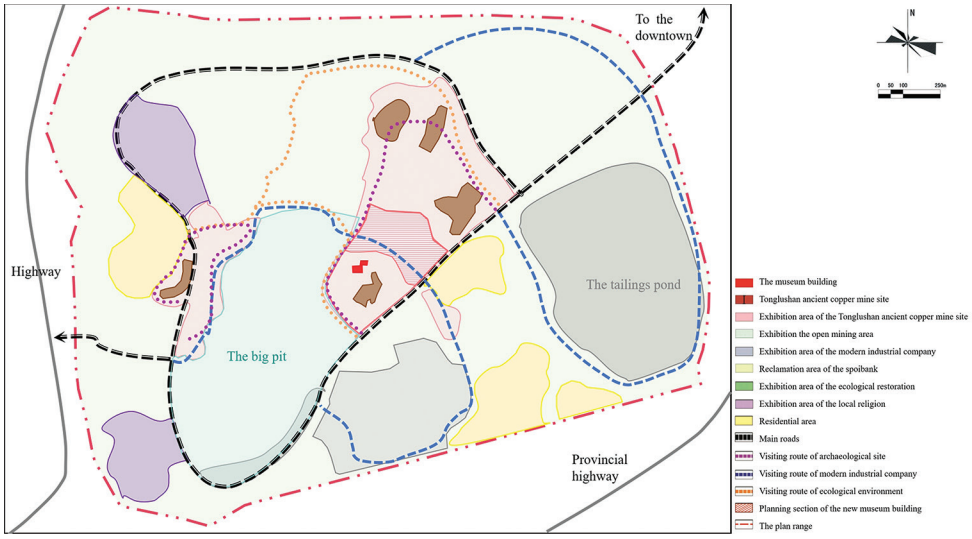

Figure 7. Exhibit plan of Tonglushan ancient copper mine site. Source: Drawing by the author (based on the author's fieldwork from 2016 to 2017)

City" from the Han dynasty (202 BCE – 220 CE), "Qingshan Institution" from the Southern Tang dynasty (937 – 976), "Tieshanzhai" from the Song dynasty (960 – 1279), and "Antianlu" from the Ming dynasty. The project aimed to restore and reconstruct these ancient buildings (Figure 8). Notably, the management even proposed restoring buildings such as Chuwangcheng—remnants of the Chu state capital located hundreds of kilometers from Tonglushan—despite limited documentation and foundational remains. The northern shore of the Changliu stream was planned for development as a mineral product trading center for Central China, with malachite from Tonglushan as the main commodity. This endeavor was complemented by plans for additional business facilities, including a luxury hotel and a performing arts center.

To foster broader engagement, the Promotion Bureau invited mining companies and members of nearby village committees to participate in a preliminary consultation meeting for the Bronze Town project. Following the meeting, a rendering of the proposed town was displayed at the entrance of the site museum. As shown in Figure 8, the plan envisions a garden-like urban environment with high vegetation coverage, a beautiful ecological setting, and a blend of mining and metallurgical cultural heritage with modern living.

Figure 8. Illustration of the northern part of the Bronze Town plan. Source: Drawing by the author (based on the photo and field notes from spring 2017)

However, the project also entails the demolition of two villages on the south bank of the Changliu stream, raising concerns among residents about relocation compensation. In addition, residents have expressed doubts regarding how the remaining, non-demolished portions of the village will align with the envisioned urban esthetics. Questions also persist about the relocation of mining companies. In anticipation of compensation tied to the project's blueprint for Tonglushan, some residents have even resorted to creating "nail households" (*dingzihu*; 钉子户, meaning holdouts).

Despite limited media coverage regarding the Bronze Town in Tonglushan, the project has not materialized since its proposal. The central government's characteristic town initiative emphasizes the support of distinctive industries. However, the depletion of mineral resources in the Tonglushan area diminishes the likelihood of the Bronze Town project – envisioned as a trade hub for the ornamental malachite – becoming a core industry in the near future. Moreover, reconstructing structures that span over 3,000 years of history, many of which lack specific architectural forms, poses significant design and construction challenges. These challenges further hinder the area's potential economic development, as the project struggles to attract ordinary tourists.

Practically, the abandoned industrial land lacks the compelling historical narratives found in places such as Xi'an (Zhu, 2018), where visitors can imagine a specific glorious past. Consequently, attracting significant investment from the central government or private enterprises has proven particularly challenging.

6. Conclusion

This article explores the multifaceted nature of Tonglushan, encompassing its role as a modern mining site, residential area, and archeological site while delineating the region's urbanization process. From the perspective of industrial transformation, it presents the area's efforts to transition from reliance on heavy metal industries to fostering regional sustainable development through archeological cultural heritage.

The case of Tonglushan provides experiences and lessons for the coordinated development of other mining heritage sites in China and beyond, particularly in three key aspects.

First, achieving recognition as a World Heritage Site should not be regarded as the definitive measure of cultural heritage value. Cultural heritage should not be viewed as a fixed noun but rather as a dynamic verb, reflecting the processes of debates, compromises, and meaning construction among stakeholders with interests and perspectives (Harrison, 2008; Smith, 2006). While the value of the Tonglushan ancient copper mine site has been widely acknowledged – leading to its inclusion on the preliminary World Heritage list, subsequent removal, and eventual re-entry as part of the Huangshi Industrial Heritage – it has never officially entered the formal "World Heritage Application" process. This ongoing ambiguity highlights the

need for further clarity regarding the correlation between the interpretation of archeological site values and the Outstanding Universal Value of World Cultural Heritage.

Second, identifying pathways for transformation poses a global challenge for resource-depleted cities. In China alone, there are 92 mineral/metallurgical resource-based cities, with a combined population of approximately 154 million (Zou, 2009). Transformation necessitates not only reconstructing industrial economies and undertaking ecological restoration but also redefining development paradigms. In the case of Tonglushan, the discovery of archeological sites within modern mining operations has become a pivotal factor, enabling advocacy for World Heritage status and the promotion of cultural tourism through site museums and parks. Although direct economic benefits may not yet be apparent, this dual approach offers a pathway to ecological and cultural restoration in declining mining areas.

Third, it is essential to re-center discussions on local significance. A marked disparity exists between the archeological heritage value of Tonglushan – dating back thousands of years – and the economic and social significance of its modern mining operations in recent decades. Official heritage discourse typically focuses on relics and material remains to underscore Tonglushan's importance in the broader narrative of Chinese history and civilization. However, as Herzfeld (1991) notes, local heritage discourse emphasizes the lived experiences of individuals and families in their immediate environmental contexts. For residents of the Tonglushan area – whether miners or farmers – the mines have been both a source of livelihood and a cause of environmental and social decline in the post-mining era. To retain residents and foster a sustainable community, future cultural heritage practices must incorporate grassroots voices and address local concerns.

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Conflict of interest

The author declares that she has no competing interests.

Author contributions

This is a single-authored article.

Ethics approval and consent to participate

This research is part of the author's doctoral dissertation and has received ethical approval (Approval ID: 2016.03) from the relevant institutions. The institutional review committee thoroughly evaluated the research proposal, which outlined the study's objectives, methods, participant recruitment, and data handling procedures. All interviewees were fully informed about the study's purpose, potential risks, and data usage. They were provided with clear, comprehensible information and given the opportunity to ask questions before formal publication. Verbal consent was obtained before each interview reported in this article.

Consent for publication

Verbal consent for publication was obtained before each interview reported in this article.

Availability of data

The data for this article primarily come from public sources, including books, journal articles, newspapers, and online social media, as well as "internal publications" shared with the author by informants. In addition, she collected in-depth interview transcripts during her fieldwork in Tonglushan, along with hard-copy news articles that were not officially published. All materials used are non-political in nature and respect individual rights. Part of original data from public publications can be obtained from the author upon reasonable request.

Further disclosure

Part of the findings was presented at the 4th Biannual Conference 2018, organized by the Association of Critical Heritage Studies at Zhejiang University, Hangzhou, China, from September 1–6, 2018. The presentation, titled "Conservation of heritage in China: A case study of Tonglushan archeological site," was delivered by the author.

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ORIGINAL ARTICLE

The role of personal and collective factors in driving residents' willingness to engage in tourism at cultural heritage sites: A case study of the Ming Tombs Scenic Area, Beijing, China

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Abstract

Cultural heritage sites, celebrated for their unique historical and cultural significance, are increasingly recognized as key drivers of tourism development. Local residents, as crucial stakeholders, play a pivotal role in the sustainable development and conservation of these sites through their emotional and behavioral engagement. This study delves into the multifaceted determinants – spanning individual and collective levels – that influence residents' willingness to engage in cultural heritage tourism. Focusing on the Ming Tombs Scenic Area in Beijing, China, a UNESCO World Heritage site, this research draws on data from 202 meticulously collected and validated questionnaires completed by residents. By integrating the cognitive–emotional–behavioral framework with community embeddedness theory and employing structural equation modeling, this study identifies the pivotal factors driving residents' willingness to engage in tourism development. The findings underscore the substantial influence of residents' cognitive evaluations of heritage values on their emotional attachment to the locale, which, in turn, shapes their behavioral intentions toward tourism development. Furthermore, the research reveals that community embeddedness significantly impacts both residents' perceptions of heritage value and their behavioral intentions. This research emphasizes the necessity of aligning residents' personal sentiments with broader community dynamics to promote sustainable tourism development at cultural heritage sites. The insights provide valuable guidance for policymakers and industry professionals in achieving a delicate balance between cultural heritage preservation, community welfare enhancement, and economic development within the heritage tourism sector.

Keywords: Cognitive; Emotional; Behavioral; Community embeddedness; Cultural heritage sites

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1. Introduction

The notion of World Heritage encompasses a diverse array of cultural artifacts, monuments, and natural landscapes recognized globally for their exceptional significance and universal values. This prestigious designation is categorized into three distinct categories: World Cultural Heritage, World Natural Heritage, and Mixed

(Cultural and Natural) Heritage. World Cultural Heritage sites, distinguished by their historical significance, distinctiveness, and irreplaceability, have become major tourist attractions. These sites function as essential platforms for cultural preservation and environmental conservation while also contributing significantly to job creation and national prestige (Zhang & Yang, 2022). The development of tourism at these heritage sites has become a strategic goal, with cultural heritage tourism emerging as a crucial tool for shaping regional, national, and historical identities at an ideological level. Cultural heritage tourism fundamentally involves the perpetuation of cultural values, enabling the recognition of the multifaceted significance and functions of cultural heritage. It also integrates these resources into the self-expression and daily lives of local communities (Brooks *et al.*, 2023).

China, with its 59 World Heritage sites – comprising four mixed cultural and natural heritage sites, 15 natural heritage sites, and 40 cultural heritage sites – stands as one of the leading nations in World Heritage representation (Tan *et al.*, 2023). The national promotion of heritage tourism, coupled with China's cultural and tourism integration policy, has positioned heritage tourism as a crucial avenue for grassroots economic growth and the inventive transformation of the country's rich traditional culture. This initiative has emerged as a significant domain of inquiry and application within the tourism sector in recent years. The development of cultural heritage tourism has revealed intrinsic contradictions and conflicts, reflecting its growing diversity and complexity. Both cultural and natural heritage resources face challenges related to development and protection, along with tensions between residents and visitors. Cultural heritage sites often struggle with issues of rehabilitation and utilization (Azzopardi *et al.*, 2023). Balancing development with preservation, as well as exploring methods to enhance the value of cultural heritage, has become a pressing concern within the academic community (Gražulevičiūtė, 2006). Scholarly research has increasingly shifted its focus from the conservation of "objects" to a "people-centered" paradigm, emphasizing community involvement and personal emotional investment. This paradigm shift underscores the importance of human-centered conservation strategies that acknowledge the contributions of local communities and visitors to the sustainable maintenance and appreciation of cultural heritage assets (Li *et al.*, 2020a).

Local residents play a dual role as pivotal stakeholders within the ecosystem of cultural heritage sites. Their activities, in conjunction with the heritage site itself, form the core of the tourism attraction, showcasing the local cultural landscape, distinctive features, and historical attributes. In addition, their perceptions of the place, emotional attachments, and willingness to engage in tourism development significantly influence visitor experience and the progression of the local tourism sector. The active participation of local residents in sustainable heritage tourism is crucial to the conservation of World Heritage sites, community development, and the rational utilization of tourism resources. Empirical studies frequently use analytical methods such as multiple regression analysis (Nunkoo *et al.*, 2020), structural equation modeling (Wang *et al.*, 2024), and fuzzy set qualitative comparative analysis (Fan & Cheng, 2020) to explore these dynamics. These investigations typically focus on the intrinsic characteristics of individuals and the features inherent in heritage sites (Rojas-de-Gracia & Alarcón-Urbistondo, 2020). They concentrate on socio-demographic indicators, site-level cultural practices, political trust, and local attachment (Farhan *et al.*, 2020). Furthermore, residents' behavioral habits have attracted considerable academic attention, with research primarily examining factors influencing their attitudes and behaviors toward the development and preservation of heritage sites (Askarizad & Safari, 2020). This line of research includes studies on their perceptions of the benefits and impacts of various tourism modalities in heritage sites. Nevertheless, there remains a significant gap in understanding residents' cognitive assessments of the fundamental value of heritage sites.

Residents' favorable views toward tourism development at heritage sites are influenced by a complex interplay of factors, encompassing both personal perceptions of tourism's effects and the social structures and relationships that define their lives. The notion of social embeddedness is especially significant, as it affects perceived value gains, power dynamics, and interactions among individuals within heritage site communities. This perspective offers a new method to examine residents' motivations and behaviors during the tourism development process at cultural heritage sites.

Despite this, much of the current body of research has primarily concentrated on individual views and behaviors, with limited attention to the role of community group organizations. This oversight may hinder a comprehensive understanding of the broader social dynamics that can either support or impede tourism development initiatives.

To fill this research gap, this study focuses on the villages of Zhaoling and Changling, located within the Ming Tombs scenic area, a UNESCO World Cultural Heritage site in China, as a case study. Using structural equation modeling, this study examines the factors influencing

value perception, emotional attitudes, and community embeddedness that motivate residents' willingness to participate in heritage tourism development. The aim of this study is to provide theoretical insights and practical recommendations for the sustainable development of heritage tourism by performing a comprehensive investigation into the factors influencing the tourism development behavioral intentions of residents at heritage sites. Furthermore, it seeks to foster harmonious coexistence between communities and heritage sites. The findings of this research clarify the role of community embeddedness in shaping residents' support for tourism development, emphasizing the necessity of addressing both individual and collective viewpoints. By enhancing the comprehensive understanding of social dynamics in heritage site tourism, this study offers essential information for policymakers and practitioners striving to reconcile the frequently conflicting objectives of preservation, community welfare, and economic development.

2. Theoretical hypothesis

2.1. Cognitive–emotional–behavioral impact in tourism

The cognitive–emotional–behavioral paradigm, developed in the 1950s and 1960s within the field of cognitive psychology, has been widely adopted in tourism studies to clarify the processes influencing an individual's behavioral intentions in tourism (Wang *et al.*, 2020). This theoretical framework asserts that a person's intention to act is the result of their cognitive evaluation of particular tourism-related stimuli, followed by an emotional reaction, and culminating in a behavioral decision (Wu & Liang, 2020). Scholars have utilized this framework to guide the development of tourist destinations. For example, Lee (2016) illustrated that tourists who interact with the local environment are inclined to develop empathy for historical and cultural narratives, thereby augmenting their emotional engagement. Similarly, Gursoy *et al.* (2019) demonstrated that perceptions of tourism's advantages and disadvantages strongly influence residents' emotional reactions to tourism projects. Moreover, Almeida-García *et al.* (2016) demonstrated that individuals with higher educational attainment and a deeper comprehension of their locale are more inclined to actively participate in local tourist activities.

The cognitive–emotional–behavioral theory is equally applicable to cultural heritage tourism. According to this theoretical framework, a person's intention to engage in tourism stems from their cognitive evaluation of a heritage site's value, the emotional response it provokes, and the ensuing behavioral decisions made. In cultural heritage tourism, a community's assessment of a site's worth is instrumental in forming emotional connections between individuals and the place, which ultimately affects their intention to engage in tourism activities.

Residents' perceptions of heritage sites are shaped by the interaction between tourism development and the local human–environment relationship. This perception is multidimensional, encompassing the cultural (Qiu *et al.*, 2022), social (Sánchez-Carretero, 2013), and economic (Petronela, 2016) values of heritage sites. Based on their perceptions of heritage tourism, residents develop emotional bonds to heritage sites, which include heritage identification, place attachment, a sense of responsibility, and recognition of the economic benefits derived from tourism. These affective attitudes consequently influence residents' participation in tourism activities, with their emotional responses being crucial for the preservation and development of heritage sites (Buonincontri *et al.*, 2017).

Behavioral outcomes are further shaped by numerous factors, including the perceived benefits of tourism, the transmission of traditional values, the quality of host–guest interactions, and the level of official backing (Grey & Kuokkanen, 2020). Empirical evidence substantiates this theoretical perspective. For instance, Kisusi & Masele (2019) found that inadequate awareness of cultural heritage values and apathetic attitudes among residents can hinder tourism development at heritage sites. In contrast, Qiu *et al.* (2019) identified a positive correlation between residents' views of cultural heritage values and their attitudes and willingness to engage, with attitudes acting as a mediator in the development of willingness to participate and value perceptions. Similarly, Jaafar *et al.* (2015) noted that residents' pride in their heritage sites and aspirations for improved living standards contribute positively to the development and conservation of these sites, as shown in their analysis of residents' perceptions of sustainable conservation activities.

Based on these findings, the development of tourism at heritage sites should be underpinned by educational and promotional strategies aimed at enhancing residents' recognition of the inherent value of their cultural heritage. These strategies should also foster positive emotional connections to heritage sites and encourage active engagement in their preservation and promotion. Simultaneously, it is essential to evaluate feedback mechanisms that integrate these behaviors into the protective and managerial frameworks of heritage sites. Such a comprehensive approach is critical for promoting the preservation and revitalization of cultural heritage while concurrently improving residents' quality of life.

In light of the aforementioned considerations, this study proposes the following hypotheses:

H_1: The perceived value of cultural heritage considerably and positively affects emotions related to cultural heritage.

H_2: Emotions toward cultural heritage substantially and positively affect behaviors related to tourism development at cultural heritage sites.

2.2. Community embeddedness in heritage tourism

The notion of "embeddedness," first proposed by Karl (1990), posits that economic conduct is not isolated but is deeply intertwined with social interactions, cultural traditions, political structures, and institutional frameworks. Polanyi's (2018) argument has been essential in recognizing that economic behaviors are influenced by and embedded within a broader social context. Subsequent scholars, including Granovetter & McGuire (1998), have expanded on this notion, emphasizing that economic actions, outcomes, and institutions are significantly influenced by the personal relationships of the individuals involved and the broader network structures in which these relationships exist. This viewpoint situates economic activity within the social fabric, underscoring the interaction between economic and social domains. At the community level, embeddedness manifests through the seamless integration of social organizations, service facilities, and cultural practices within the community's environment (Wang & Li, 2024). This integration encompasses not only the physical merging of spaces but also the accrual of social capital, the formation of social networks, and the cultivation of social trust. The essence of community embeddedness is characterized by cognitive, relational, structural, and institutional dimensions:

- Cognitive embeddedness reflects the shared values and beliefs of residents, influenced by cultural heritage.
- Institutional embeddedness refers to policy elements, including governance norms and power structures, relevant to the conservation and development of tourism assets.
- Relational embeddedness underscores the social connections and interactions among community members.
- Structural embeddedness focuses on individuals' social statuses and roles within the community.

Together, these dimensions affect residents' views, ultimately shaping their attitudes and behaviors regarding local tourism development.

In contemporary academic discussions, community embeddedness theory has gained prominence in explaining the multifaceted dynamics of tourism phenomena. Scholars such as Zuo *et al.* have identified that the relative deficiency in capital, managerial expertise, and technological skills among residents of tourist destinations often creates imbalanced power dynamics. These disparities emerge between governments, developers, and resident stakeholders in designing participatory frameworks for tourism. Such imbalance can erode community embeddedness in tourism development, fostering a sense of alienation and resentment among residents. Consequently, this undermines their collective identity and hinders the sustainable progression of local tourism projects (He, 2024; Zuo, 2013). Jiang *et al.* (2024) have asserted that community self-organization, facilitated by tourism development, provides a vital platform for resident self-governance, enhancing the community's inherent competitive advantage. This is essential for realizing the self-interests of community advocates in tourism development. Similarly, Lan *et al.* (2021) revealed that local residents' positive perceptions of the benefits derived from tourism development significantly bolster their affective solidarity and encourage their participation in value co-creation activities. Žuvela *et al.* (2023) emphasize the pivotal role of the public sector, whose active involvement in both the development and conservation of cultural heritage significantly contributes to the sustainable preservation and enhancement of heritage assets. Emotional bonds forged among residents foster a strong sense of community, instilling intrinsic motivation to actively participate in the co-creation of tourism value.

To foster sustainable tourism development, it is essential to adopt a holistic approach that considers the extent and significance of community involvement. Moreover, it is essential to enhance individuals' cognitive and emotional engagement with tourism through educational efforts and cultural outreach programs.

The scholarly investigation of residents' attitudes toward tourism development frequently neglects a crucial aspect: the mediating effect of the local organizational environment on individual behavioral reactions. The theory of community embeddedness asserts that human actions are neither entirely independent of social context nor wholly restricted by social standards (Granovetter, 1985). Instead, these actions are inextricably connected to specific, contemporary social structures and the dynamics of social relationships (Li *et al.*, 2020b).

At the intersection of tourism and heritage conservation, community embeddedness acts as an external element influencing the behavioral decision-making of individuals involved in heritage tourism. Communities, as stewards of cultural heritage, establish both formal and informal structures that significantly impact the behavioral decisions

of those involved in heritage tourism (Yan & Chiou, 2021). The degree of institutional embeddedness varies across communities, leading to diverse decision-making processes and developmental paths in the tourism sector (Butler *et al.*, 2022; Ghahramani *et al.*, 2020). Disparities in the integration of informal systems are notably pronounced, and when these systems become detached, the effective incorporation of external formal systems becomes crucial to harmonizing the development of heritage assets with community interests.

Utilizing the village as the primary unit of community embeddedness highlights the difficulties of limited community benefits and satisfaction, as well as the unequal distribution of gains. These elements, thus, intensify the community's marginalization in the tourism development of cultural heritage sites (de Luca *et al.*, 2021). Consequently, it is essential to augment community involvement in tourism development. This can be achieved by expanding the scope and diversifying the methods of community participation, strengthening community capacity development, and establishing a management framework that integrates the perspectives of diverse stakeholders with varying interests.

In light of these considerations, this study proposes the following two hypotheses:

H_3: Community embeddedness in cultural heritage sites enhances the perceived value of cultural heritage.

H_4: Community embeddedness in cultural heritage sites positively affects the willingness to engage in tourism development at these sites.

This study develops a conceptual model to illustrate the mechanism influencing residents' willingness to engage in tourism development at cultural heritage sites (Figure 1). The model is grounded in the cognitive–emotional–behavioral theory and community embeddedness theory, informed by the preceding analysis and the four proposed hypotheses.

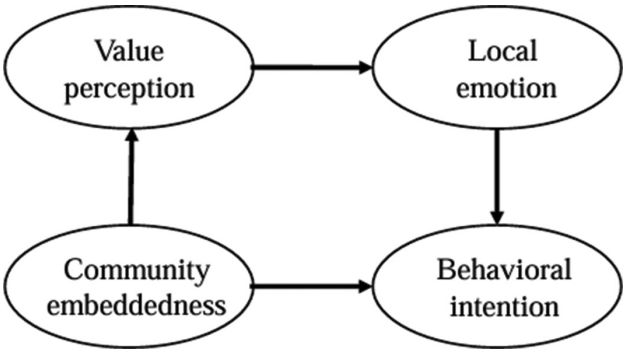

Figure 1. A cognitive–emotional–behavioral framework for the effects of community embeddedness. Source: Diagram by the authors.

3. Methodology

3.1. Research location: The Ming Tombs scenic area, Beijing, China

This study examines the behavioral intentions of rural residents surrounding the Ming Tombs scenic area regarding their participation in heritage tourism development. The Ming Tombs, a significant legacy of the Ming dynasty (1368 – 1644), comprises 13 imperial mausoleums located 42 km northwest of Beijing's city center in Changping district (Figure 2). Recognized as one of the greatest imperial burial complexes worldwide, the site includes the mausoleums of emperors and empresses. In 2003, UNESCO designated it as a World Heritage site.

The construction of the tombs spanned over two centuries, commencing with the Changling mausoleum in the Yongle period (1402 – 1424) and concluding with the Siling mausoleum under the reign of the last Ming emperor, Chongzhen (1627 – 1644). Since the 1950s, the Beijing Municipal Government has spearheaded initiatives to promote tourism development in the region. Today, nine of the thirteen mausoleums are open to the public.

The Ming Tombs scenic area is renowned for its primary attractions, which include the tombs themselves, associated temples, scenic mountain landscapes, and the historical ambiance of the surrounding rural setting, enriched by the cultural heritage of its residents. In 2011, the site received a 5A certification from China's Ministry of National Tourism, signifying the highest quality rating for tourist destinations. In 2019, the site recorded 2.46 million visitors.

As a national cultural relics protection site, the Ming Tombs scenic area is governed by strict conservation regulations that restrict developmental activities. Currently, only three mausoleums – Dingling, Changling, and Zhaoling – along with the Sacred Way leading to the tombs, are accessible to tourists. This selective accessibility reflects the delicate balance between heritage preservation and tourism development.

The mausoleum system extended beyond the main tomb structures of the imperial mausoleums to encompass a variety of auxiliary service organizations and administrative entities. These roles included positions such as mausoleum commanders, supervisors, temple ceremonial commanders, and provision officials, as well as institutions responsible for landscaping and gatekeeping services, and households tasked with mausoleum upkeep (Magli, 2019). These entities ensured the security and maintenance of the mausoleums by deploying personnel near the tombs.

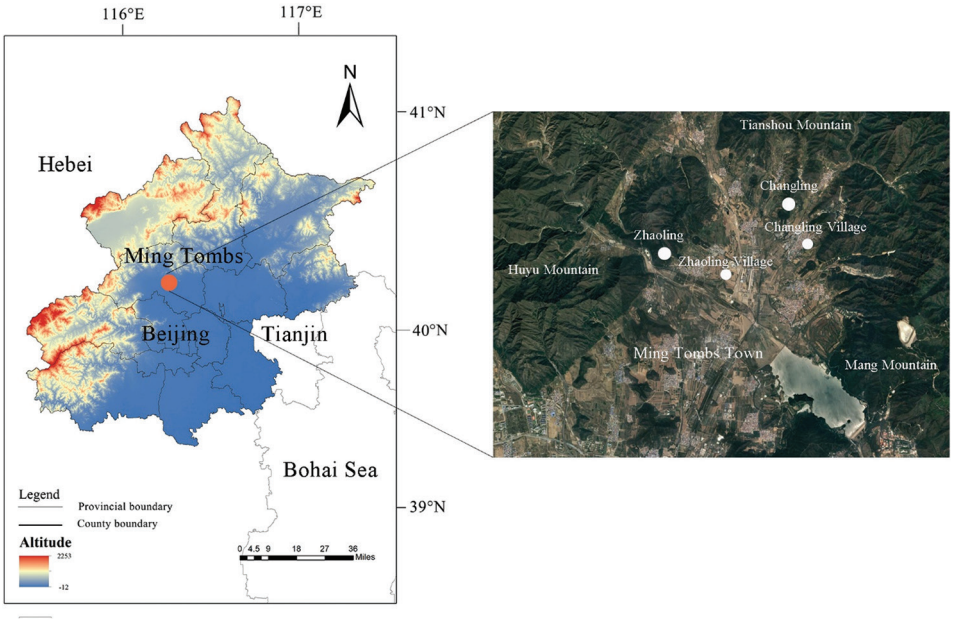

Figure 2. Location of the Ming Tombs scenic area, Beijing, China. Source: Left: Map obtained from the National Platform for Common Geospatial Information Services of China; Right: Google Maps.

Over the centuries, the descendants of these original mausoleum custodians have flourished, leading to the emergence of mausoleum villages in the surrounding area. These settlements, frequently named in honor of the corresponding tombs – such as Deling village, Yongling village, Zhaoling village, Xianling village, and Changling village – stand as enduring reminders of this historical legacy. An analysis of current village demographics reveals that the descendants of the original mausoleum custodians continue to constitute a substantial portion of the local population. Today, these villages have embraced tourism development initiatives, demonstrating their ability to adapt while preserving their historical and cultural heritage.

3.2. Variable measurement

A survey was conducted to evaluate residents' awareness and emotional attachment to their heritage, the level of community embeddedness, and their views on tourism development. The questionnaire comprised two main sections.

The first section gathered basic sociodemographic information, including gender, age, educational qualifications, involvement in the tourism sector, personal monthly income, primary income source, residency status, and lineage to the original mausoleum custodians.

The second section addressed four key components that are aligned with the study's conceptual model (Table 1):

(i). Residents' perceptions of heritage value: This component was evaluated using three items based on Taylor's (2004) classification, examining residents' perspectives on the cultural, economic, and social significance of the heritage.

(ii). Residents' emotional responses to the heritage sites: Emotional responses were assessed using three criteria (Ganji *et al.*, 2021), i.e., attachment to the local community, pride in cultural heritage, and a sense of responsibility for preservation.

(iii). Community embeddedness of residents: This component was measured using four items informed by Wang *et al.*'s (2024) study, addressing cognitive, relational, structural, and institutional dimensions of embeddedness.

(iv). Residents' behavioral intentions to engage in heritage tourism: Behavioral intentions were assessed with four items adapted from Shen & Shen (2021), focusing on resident's support for and willingness to participate in tourism development initiatives.

Responses were recorded on a five-point Likert scale ranging from 1 = "*strongly disagree*" to 5 = "*strongly agree*."

This methodological approach provides a thorough assessment of the diverse aspects affecting residents' attitudes and behaviors toward heritage tourism development in the Ming Tombs scenic area.

3.3. Data collection and analysis procedure

In late September 2019, a preliminary field survey was conducted in the vicinity of the Ming Tombs scenic area.

Table 1. Latent constructs and observed variables

Latent constructs	Observed variables
Community embeddedness	X_1: Cognitive embedding: I know basic information about the history, culture, and heritage sites of the village. X_2: Relational embedding: I have a close relationship with most of the residents in the village. X_3: Structural embedding: I actively participate in various activities in the village. X_4: Institutional embedding: There are many village rules and regulations that play a role in daily life in the village.
Value perception	X_5: Cultural value: Cultural heritage has a very important cultural value. X_6: Economic value: Cultural heritage can bring economic income from tourism and improve the standard of living. X_7: Social value: Cultural heritage can help to improve the humanistic qualities of society at large.
Local emotion	X_8: I am proud to live near a World Heritage Site. X_9: My village means a lot to me. X_{10}: I have a responsibility as a villager to protect the World Heritage Site.
Behavioral intention	Y_1: I support the development of tourism for the cultural heritage. Y_2: I would like to be a host for tourists. Y_3: I am willing to participate in tourism decisions or operations in my community. Y_4: I am willing to accept some inconvenience caused by tourism development.

A random sample of 12 participants was engaged to pilot test the questionnaire, leading to modifications to the wording of specific measuring items. In October 2019, a formal week-long field survey was conducted in Zhaoling village and Changling village, two localities adjacent to the accessible mausoleums. These villages, with a combined population of about 1,500, were selected as the research sites.

The survey was administered by three graduate students from Peking University, who had received prior training. The investigators explained the questionnaire to each participant to ensure that responses accurately reflected their thoughts. The questionnaires were completed and collected on-site through random household visits, achieving a 100% recovery rate. A total of 218 questionnaires were distributed, and after the exclusion of incomplete responses, 202 valid questionnaires were retained, yielding a response rate of 93%.

The sociodemographic characteristics of the respondents are presented in Table 2. Of the respondents, 109 were males (54%) and 93 were females (46%), with ages ranging from 20 to 75 years. Notably, 44% were aged 50 or older, and a substantial majority (82%) identified as native to the region. In addition, nearly one-third of the respondents identified themselves as descendants of the original mausoleum custodians.

Concerning the educational qualifications of the respondents, 10% hold a college degree or higher, while 29% have completed primary school or lower. Regarding income, 49% of respondents report monthly incomes between 1,000 and 3,000 Chinese yuan, while 27% earn <1,000 Chinese yuan/month. In terms of occupations, 48% are employed in tourism-related professions, while 37% work in fields unrelated to tourism. The predominance of lower educational attainment among respondents can be attributed to the significant percentage of older residents in the sample. Furthermore, female respondents have attained lower educational achievement relative to their male counterparts; specifically, 77% of female respondents have completed only junior high school or lower, in contrast to 55% of male respondents. A notable proportion of respondents were merchants of souvenirs and memorabilia or employees of agricultural tourism enterprises, encompassing both owners and staff. These enterprises engage in a wide range of operations aimed at attracting visitors by providing recreational, educational, and entertainment experiences, ultimately generating income.

Survey data indicate that residents in the Ming Tombs scenic area participate in the tourism sector and related commercial activities primarily through three avenues: (i) Employment within the Ming Tombs scenic area, (ii) hosting farm tours, and (iii) offering ancillary services such as mobile vending and private tour shuttles. The majority of the survey subjects comprised elderly, less educated, and low- to middle-income rural residents.

This study employs structural equation modeling to examine and interpret the data. Structural equation modeling is an advanced multivariate statistical method that integrates factor analysis for measurement and path analysis for regression modeling. It encompasses a variety of statistical methodologies, providing a robust framework for analyzing latent variables, such as psychological constructs and perceptions, which are often difficult to measure using conventional methods. The efficacy of structural equation modeling in evaluating these intangible variables has established it as a widely utilized tool in tourism research.

Table 2. Respondents' characteristics

Item	Option	Count	Percentage
Gender	Male	109	54
	Female	93	46
Age (years)	20 – 30	18	9
	30 – 40	35	17
	40 – 50	61	30
	50 – 60	44	22
	≥60	44	22
Education	Primary school and below	59	29
	Junior high school	73	36
	Senior high school/vocational education	50	25
	University diploma and above	20	10
Individual average monthly income (Chinese yuan)	<1,000	55	27
	1,000 – 3,000	99	49
	3,001 – 5,000	30	15
	5,001 – 10,000	14	7
	>10,000	4	2
Occupation	Agritainment business	19	9
	Employees of agricultural tourism attractions	20	10
	Souvenir vendor	40	20
	Passenger transport staff	10	5
	Scenic area staff	8	4
	Farmers	20	10
	Working at other places	13	6
	Others (working locally but in other professions, e.g., teacher and doctor)	41	21
	Retired or unemployed	31	15

The research hypotheses were evaluated through a three-step procedure. First, a reliability analysis was performed using SPSS version 26.0 to assess the reliability and internal consistency of the measurement items. Second, confirmatory factor analysis was performed using AMOS version 26 to validate the measurement model. Finally, four theoretical hypotheses derived from the model were tested.

4. Results

4.1. Analysis of reliability

The reliability of the data for the four dimensions – community embeddedness, value perception, local emotion, and behavioral intention – was evaluated using SPSS version 26.0 (Table 3). The Cronbach's alpha coefficients for these dimensions ranged from 0.715 to 0.768, all surpassing the threshold of 0.7. These results demonstrate substantial reliability and robust internal consistency. The composite Cronbach's alpha for the overall scale was 0.780.

The Kaiser–Meyer–Olkin measure of sampling adequacy was 0.813, surpassing the minimum criterion of 0.7, signifying that the dataset was suitable for factor analysis. Bartlett's test of sphericity yielded a Chi-square value of 2,607.201 at 496 degrees of freedom, significant at $p < 0.001$. These results confirm the presence of significant interrelationships among the items, validating the data's appropriateness for further analysis.

4.2. Results of structural equation modeling

The conceptual model's hypotheses were meticulously evaluated using AMOS version 26. During the analysis, the coefficient for Y4 – one of the four observed variables within the behavioral intention construct – fell below 0.2, suggesting statistical non-significance of the results. Consequently, this variable was excluded, and the model was re-evaluated.

The re-evaluated model's measurement results are presented in Table 4. The absolute fit indices showed a χ^2/df ratio of 2.376, below the criterion of 3. The root mean square error of approximation was 0.079, falling below the threshold of 0.08, and the goodness of fit index was 0.939, surpassing the criterion of 0.9. These values indicate an exemplary model fit.

In terms of fit indices, the incremental fit index was 0.912, and the comparative fit index was 0.907, both surpassing the required threshold of 0.9, signifying a favorable fit. The parsimony fit indices, including the Parsimonious goodness of fit index at 0.604 and the Parsimonious normed fit index at 0.597, also exceeded the minimum threshold of 0.5. Together, these results suggest that the model achieves a satisfactory overall fit, with logical structural relationships that support the validity of the evaluations.

Table 5 illustrates the standardized coefficient estimates and *t*-value test results for the relationships between the four structural variables and the observed variables. These results validate all four hypotheses.

4.3. Hypothesis testing and results interpretation

The results of testing the research hypotheses are presented in Figure 3.

H_1 is validated, indicating that the perception of heritage value significantly enhances residents' emotional attachment to their local community. Among the dimensions assessed, cultural and economic values of

Table 3. Results of the validity test

Dimension	Cronbach's alpha coefficient	Kaiser–Meyer–Olkin sampling adequacy	Bartlett's test of sphericity		
			Approximate Chi-square	Degrees of freedom	Significance test
Community embeddedness	0.739	0.735	561.825	45	0.000
Value perception	0.768	0.796	484.546	45	0.000
Local emotion	0.734	0.719	452.476	45	0.000
Behavioral intention	0.715	0.723	471.865	45	0.000
Population level	0.780	0.813	2,607.201	496	0.000

Table 4. Model fitting results

Indicator	Absolute fit indicator			Incremental fit index		Parsimonious fit index	
Specific classification	χ^2/df	RMSEA	GFI	IFI	CFI	PGFI	PNFI
Assessment criteria	<3	<0.08	>0.9	>0.9	>0.9	>0.5	>0.5
Fitting effect	2.267	0.079	0.939	0.912	0.907	0.604	0.597

Notes: CFI: Comparative fit index; GFI: Goodness-of-fit index; IFI: Incremental fit index; PGFI: Parsimonious goodness-of-fit index; PNFI: Parsimonious normed fit index; RMSEA: Root mean square error of approximation.

Table 5. Path analysis results

Path	Path coefficient	Standard error	Critical ratio	*p*-value
Community embeddedness→Value perception	0.526	0.138	3.804	<0.001
Behavioral intention→Local emotion	0.902	0.127	7.094	<0.001
Community embeddedness→Behavioral intention	0.606	0.134	4.507	<0.001
Local emotion→Behavioral intention	0.408	0.109	3.722	<0.001

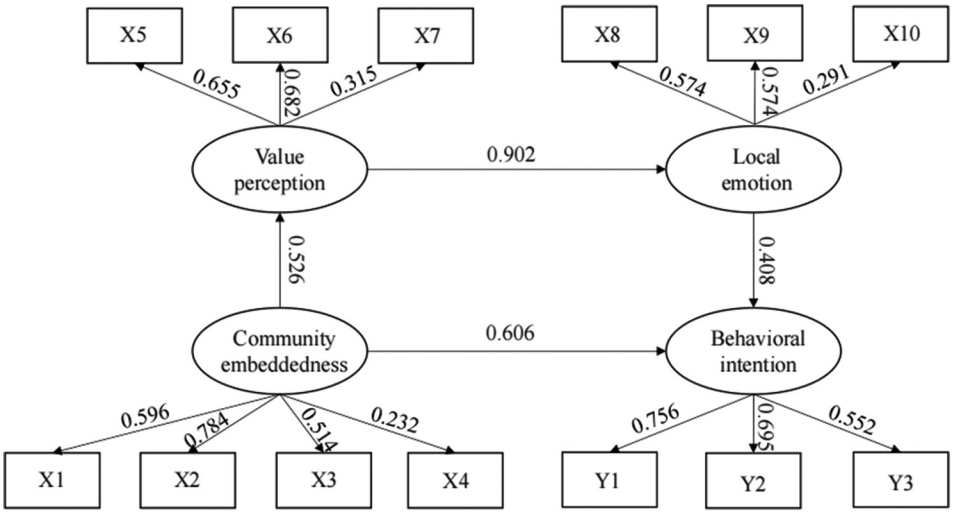

Figure 3. Structural equation modeling results. Source: Diagram by the authors.

cultural heritage had a more pronounced impact, with path coefficients of 0.655 and 0.682, respectively, compared to the coefficient of 0.315 for social values. These findings suggest that residents with a deeper comprehension of the cultural and economic values of heritage are more likely to develop a robust emotional connection to their community. This emotional attachment may stem from their deep-rooted connection to cultural heritage, recognized as a representation of communal identity and historical legacy.

H_2 is corroborated, demonstrating that residents' emotional attachment to their local area significantly and positively affects their behavioral intention to participate in cultural heritage tourism development. Notably, pride in their heritage and loyalty to their local community exerted the strongest influence, with a path coefficient of 0.574, surpassing the coefficient of 0.291 for a sense of responsibility toward heritage preservation. This impact suggests that residents with stronger emotional connections to their locality are more inclined to support and engage in tourism development efforts. While the impact of the sense of responsibility for heritage preservation was comparatively modest, the mean score of 3.86 reflects a general consensus among residents in favor of cultural heritage preservation. This sentiment likely arises from their awareness of the delicate equilibrium between safeguarding cultural heritage and fostering tourism development, as well as their evaluation of the intrinsic value and the extrinsic benefits associated with cultural heritage preservation.

H_3 is validated, confirming that place embeddedness significantly and positively influences residents' perception of heritage value. Residents with a deeper understanding of their village's history and culture displayed greater appreciation for the Ming Tombs as a cultural heritage. This appreciation suggests that cognitive embeddedness reflects how cultural heritage resources integrate into residents' value systems and belief structures. Furthermore, residents' active engagement in community events and close interactions with neighbors foster strong community ties and strengthen social cohesion. These connections, in turn, encourage greater participation in local cultural activities and practices, further amplifying their appreciation for cultural heritage. Conversely, village rules and regulations exert a relatively negligible influence on residents' perceptions of heritage value. Overall, the deeper the villagers' embeddedness within their community, the more pronounced their perception of cultural heritage value becomes.

H_4 is supported, indicating that local embeddedness has a substantial positive effect on residents' propensity to engage in tourism sectors, with a coefficient of 0.606. This finding suggests that increased integration within the local community is strongly associated with a higher likelihood of residents expressing favorable support and a willingness to participate in local tourism development. This phenomenon can be attributed to residents' emotional attachment to and identification with local cultural heritage, coupled with their optimistic anticipations for the prospective economic and social benefits of tourism development.

5. Discussion

The behavioral intentions of residents in tourist destinations have been a focal point in prior research, with most studies examining the influence of residents' perceptions of tourism impact on their behavioral intentions. Nonetheless, there has been limited attention to the possible impact of residents' views and emotions regarding tourism resources on these aspirations. This study addresses this gap by examining two villages within the Ming Tombs scenic area in suburban Beijing as case studies. It investigates how residents' perceptions and emotions shape their behavioral intentions, integrating the cognition–emotion–behavioral framework with community interaction dynamics and residents' behavioral actions. This study constructs a structural equation model by combining the cognitive–emotional–behavioral framework with elements of community interaction to evaluate the mechanisms influencing behavioral intentions toward tourism development in cultural heritage sites. This approach provides a nuanced understanding of the factors shaping residents' willingness to engage in tourism development.

Consistent with Prayag & Del Chiappa's (2023) findings, the cognitive–emotional–behavioral model offers a comprehensive explanation of the behavioral intentions of residents at cultural heritage sites regarding their participation in tourism activities. Cognitive factors significantly influence residents' emotions about their locality, with assessments of cultural and economic values exerting a notably positive impact on emotional responses. These cognitive factors are indicative of residents' awareness and appreciation of cultural heritage. Enhanced cognitive awareness fosters pride in heritage, loyalty to the local community, and a sense of responsibility for heritage preservation, all of which significantly influence attitudes toward the protection and utilization of cultural heritage. While some scholars have suggested that residents' perceptions of tourism resources directly influence their participation in tourism activities (Luo *et al.*, 2022), this study reveals a more complex mechanism. Specifically, the cognitive evaluation of cultural heritage value significantly influences residents' emotional responses, which, in turn, affect their willingness to engage in tourism development activities. This finding may be attributed to the historical ties between the villages established as settlements for mausoleum custodians and the mausoleums themselves. Village residents, especially the descendants of the original mausoleum custodians, maintain a profound and enduring bond with the cultural monument. Their emotional connection to the tomb region strongly affects their attitudes toward the tourism development related to the cultural monument.

This study diverges from previous research by recognizing that residents' sense of responsibility for cultural heritage preservation does not result in resistance or opposition to tourism development activities (Nunkoo & Gursoy, 2012). This finding is particularly pertinent to the Ming Tombs scenic area and its adjacent villages, which are in the early phases of tourism development. The tourism sector in this region remains underdeveloped, with most visitors being transient tourists en route to the Badaling Great Wall. These visitors' brief stays and limited spending generate only modest economic benefits for local residents (Karl *et al.*, 2020).

The potential adverse impacts of tourism development on cultural heritage sites have not been prominently highlighted in this region. Instead, the community's perception of cultural heritage predominantly centers on leveraging it for economic gains through tourism. The research revealed that the descendants of the mausoleum custodians maintain a familial sentiment toward the cultural heritage of the Ming Tombs, perceiving the protection of the emperors' tombs as a hereditary duty (Dragan *et al.*, 2024). However, they also aspire to derive economic benefits from tourism revenue while preserving their heritage. While some descendants have inherited their ancestors' roles as tomb inspectors and receive regular incomes, such positions are scarce, compelling the majority to seek alternative livelihoods.

Urbanization in Changping district, where the Ming Tombs scenic area is located, has further reduced the proportion of descendants among the local population. Many original residents have migrated to the urban areas, leasing their houses to others (Zang *et al.*, 2020). These newer residents, lacking the familial mission and historical inheritance, are primarily focused on the economic potential of the Ming Tombs as a World Heritage site. They advocate for increasing accessibility to additional mausoleums to attract more tourists and boost tourism-related income.

The research reveals significant community concerns regarding how government planning and policies shape the future of tourism development. In China, authorities responsible for cultural heritage conservation and urban planning are entrusted with developing comprehensive master plans, conservation strategies, and policies to manage the growth of historical sites such as the Ming Tombs. These regulations encompass architectural guidelines and landscape preservation measures aimed at safeguarding these sites while fostering sustainable tourism growth. However, some residents contend that the stringent regulations imposed by the National Cultural Relics Protection Department for the Ming Tombs, although crucial for preservation, restrict tourist access and subsequently hinder local tourism. Moreover, the villages surrounding these historical sites are also subject to conservation policies that affect their development. The master plan for the Ming Tombs scenic area imposes constraints on construction scale, architectural style, and color schemes within the settlements, thereby limiting local tourism development.

During fieldwork, the majority of residents expressed concerns that tourism development at the Ming Tombs lags behind other renowned attractions in Beijing. They advocate for enhanced governmental policies to support their communities in diversifying tourism offerings to attract more visitors. In addition, they seek monetary compensation from the government for the restrictions imposed by cultural heritage protection plans, which they perceive as limiting their rights to freely renovate and construct their properties.

This study found that, alongside cognitive and emotional factors, residents' relational embeddedness within the heritage site community significantly influences their value assessments and behavioral intent to engage in tourism development. Cognitive embeddedness, relational embeddedness, structural embeddedness, and institutional embeddedness emerged as pivotal predictors of residents' willingness to participate in tourism initiatives. These findings indicate that enhancing community activities and bolstering individuals' embeddedness within their communities can stimulate greater resident involvement in tourism development.

However, the study also observed that institutional embeddedness had a negligible impact in the study area. This is likely due to the urbanization process, which has contributed to the "aging" and "hollowing out" of villages in Beijing (Ren *et al.*, 2023). The outmigration of long-time residents has diminished the impact of institutional constraints within these villages. The two villages examined in this study exemplify this demographic transition: many younger residents have sought employment in nearby counties or urban centers or relocated their families to cities for better educational opportunities for their children. This demographic shift has reduced reliance on village collective economies and organizational structures, resulting in a decline in emotional attachment to and respect for traditional rural norms.

Relational embeddedness was found to have a more pronounced impact on residents' willingness to participate in tourism development compared to cognitive and structural embeddedness. This may stem from the study's rural context, defined as a cohesive "acquaintance society" (Zhang, 2022). In this setting, interactions among villagers

– many of whom are descendants of the mausoleum custodians – foster a shared understanding of the heritage. This contrasts with metropolitan communities, where neighbors often remain unfamiliar with one another. The close-knit relationships within the village amplify the significance of residents' perceptions of heritage tourism. Their deep-rooted connection to the heritage site enhances their appreciation of it, strengthens their emotional ties to the area, and heightens their willingness to participate in tourism development initiatives.

In light of the fact that the villages near the Ming Tombs still maintain a considerable resident population, the successful implementation of conservation measures requires the support and active involvement of these residents. Therefore, these interventions must also address villagers' livelihoods and economic needs. This underscores the necessity of integrating tourism development strategies that not only safeguard cultural assets but also meet the socio-economic aspirations of the local community.

6. Conclusion

Tourism development at cultural heritage sites, similar to other tourist destinations, depends heavily on the support of local residents. While previous research has concentrated on factors influencing residents' willingness to engage in tourism development initiatives, there remains a notable gap in studies that concurrently examine intra-individual motivators and social embeddedness in the context of resident involvement at heritage sites (Rasoolimanesh *et al.*, 2017). This study addresses this gap by integrating intra-individual drivers and social embeddedness factors into a structural equation modeling framework to clarify the causal links driven by their interaction. The proposed modeling approach is applicable not only to cultural heritage sites but also to other community-based tourism contexts. The findings demonstrate that the interplay between residents' individual motivations and social embeddedness elements positively influences their willingness to engage in tourism development activities. By expanding the scope of research on tourism development at heritage sites, this study deepens our understanding of the factors shaping residents' behavioral intentions toward tourism initiatives.

The conclusion provides practical recommendations for governments and managers of cultural heritage sites to optimize the use of heritage resources. Local governments and site managers must recognize the significant impact of residents' perceptions of cultural heritage value on their attitudes toward tourism development. Efforts should be intensified to enhance residents' awareness of the cultural, economic (Stone & Nyaupane, 2020), and social values of heritage through targeted publicity campaigns (Tosun, 2000). In practice, managers often prioritize the promotion of cultural treasures to tourists while neglecting local residents. This oversight is particularly apparent in rural heritage sites in China, where locals, owing to low literacy rates, frequently fail to fully appreciate the value of cultural heritage. This cognitive awareness deficit can adversely affect locals' emotional connections to history and heritage sites, ultimately hindering the development of local tourism activities.

The effective development of tourism activities at heritage sites requires consideration of both residents' personal emotions and the influence of informal community networks in promoting tourism growth. A variety of socio-economic factors can shape residents' behaviors in supporting or participating in tourism development initiatives. These factors include the management of community organizations, mechanisms for participation, and capacities for service provision, among others. Future research could explore the development of rational policy standards and management strategies for cultural heritage tourism, considering the diverse viewpoints of individual residents and community organizations. Enhancing residents' emotional attachment to their community may involve leveraging its historical significance and organizing diverse events to foster emotional engagement. This approach could entail revealing the community's historical narratives and creating opportunities for residents to connect with their collective heritage. Moreover, local authorities and community administrators could strengthen community embeddedness through incentives and subsidies, thereby fostering a supportive cultural environment. Such strategies could progressively assist communities in appreciating and leveraging their cultural heritage in accordance with the overarching objectives of sustainable tourism development.

Employing established and validated scales is essential to ensure the scientific validity of research findings. This study adapts, modifies, and supplements existing scales to more accurately assess residents' cognitive, emotional, and social embeddedness within the specific local context. Nonetheless, the universality and applicability of these scales in analogous domains necessitate additional empirical validation. Increasing sample size enhances the capacity to analyze social phenomena more effectively. This research includes 202 valid questionnaires and, after modeling and item refinement, yields 13 items, resulting in a sample size-to-item ratio of 15.5:1. This ratio adheres to the recommended standard of 15:1 and fulfills the basic

requirements for the study (Ramesh & Jaunky, 2021). Future research should incorporate supplementary sample surveys and conduct factor constancy assessments across diverse case sites to enhance the validation and stability of the structural equation model across a wider array of samples.

Furthermore, the cognition and emotions of residents in various tourist destinations can vary markedly due to geographical, ethnic, and life cycle differences unique to those areas. The degree of local governance also influences residents' community embeddedness. Consequently, conducting research across diverse tourist destinations and community contexts is imperative to identify and integrate patterns connecting residents' cognition, emotions, social embeddedness, and behaviors.

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Conflict of interest

The authors declare that they have no competing interests.

Author contributions

Conceptualization: Linlin Dai
Formal analysis: Yujie Fan
Investigation: All authors
Methodology: Linlin Dai
Writing – original draft: All authors
Writing – review & editing: Linlin Dai

Ethics approval and consent to participate

Our study did not require further ethics committee approval, as it did not involve animal or human clinical trials and was not unethical. Informed consent was obtained from all participants before their involvement. The anonymity and confidentiality of the participants were strictly guaranteed, and participation was entirely voluntary.

Consent for publication

Not applicable.

Availability of data

The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

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ORIGINAL ARTICLE

Urban features of Lingnan town analyzed using multi-source online image: A case study of 81 central towns in the Pearl River Delta, Guangdong, China

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Abstract

The advancement of digital technology has greatly improved the accessibility and convenience of public participation via the internet, enabling the quantitative evaluation of urban imagery. To quantitatively analyze urban features from an internet-based perspective, this study integrates image and text data from 81 central towns in the Pearl River Delta, Guangdong, China, selected based on their eligibility for image retrieval from search engines. By examining the relationships between image types, high-frequency words, and regional spatial patterns, the study identifies typological differences among the towns, aiming to systematically categorize and comprehensively evaluate their urban landscape characteristics. Building on Kevin Lynch's city image theory, this article presents a detailed exploration and empirical analysis of urban image, specifically focusing on small- and medium-sized towns in the Lingnan region.

Keywords: Town image; Central town; Pearl river delta; Types; Landscape characteristics

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1. Introduction

Since Kevin Lynch proposed the theory of city image in 1960 (Lynch, 1960), numerous scholars, including Donald Appleyard (1928 – 1982) (Appleyard, 1969), Donata Francescato (Francescato & Webane, 1973), Gary Evans (Evans *et al.*, 1982), Xun Li (Li and Xu, 1993), Fang Xu (Xu, 1983), Yulian Lin (Lin, 1999), and Chaolin Gu (Gu and Song, 2001), have used this theory to explore urban design and planning. Empirical studies have demonstrated city images for Milan, Rome, and Beijing, and the cognitive mapping approach central to Lynch's theory has become one of the most commonly used methods for analyzing social data related to urban environments (Lee & Schmidt, 1988).

Lynch argued that while city images are influenced by the culture and customs of a place, there are common perceptual features that allow urban researchers to systematically categorize these images. He likened this process to the work of an archeologist, extrapolating potential patterns from existing types (Lynch, 1960). This theory laid the foundation for the study of city imagery, spurring ongoing research and methodology development (Wu, 1988; Xu, 2012; Zhao *et al.*, 2015).

In the digital era, perceptions of cities are no longer solely dependent on direct physical interaction with urban environments (Negroponte, 1995). Instead, these perceptions are increasingly shaped by internet media and social media platforms (Zhao *et al.*, 2014). These platforms facilitate open public spaces for content creation and exchange (Yu & Chen, 2024), allowing them to play a significant role in "extensively participating in the generation of urban images" (Kong, 2020, p. 241). Scholars now employ Internet platform images and related technologies to identify and analyze city images. For example, Miao (2018) used street-view image data to assess the spatial quality of urban streets, while Zhao *et al.* (2015) analyzed Google images of 21 cities in Guangdong province, China, to compare urban imagery in cyberspace.

The advent of artificial intelligence (AI) and advancements in Internet technologies have expanded the tools available for such analyses. AI platforms such as ChatGPT and Tencent Cloud provide vast datasets (Zhou, 2024) and highly accurate semantic information (Li *et al.*, 2018). These technologies enable the visualization of urban spaces through social media feeds and AI-based recognition tools. For instance, Naik *et al.* (2014) utilized computer vision technology to analyze extensive street-view image datasets, demonstrating its potential for urban research. Subsequent studies have further explored this approach, refining methodologies and expanding applications (Han *et al.*, 2022; Naik *et al.*, 2016; Wei *et al.*, 2022; Yao *et al.*, 2019). Notably, Naik's work also focused on using computer vision techniques to predict the formation of "perceptual maps" (Naik *et al.*, 2014). Similarly, as highlighted by Xu (2013), LeCun employed neural networks to train models on large datasets, enabling machines to recognize and categorize images effectively.

Since the beginning of the 21st century, the rapid urbanization in China has led to the emergence of numerous central towns in the Pearl River Delta (PRD) region in Guangdong province, China. These towns, characterized by strong economic development and the early stages of small city formation, have become significant focal points for planning and control efforts (Tang *et al.*, 2020). However, the townscape often exhibits more "commonalities" than "differences," and most studies on the image have primarily focused on urban or rural levels (Lin, 1999; Liu,1994; Zhang,2013). Research specifically addressing the image of towns is limited, with existing studies predominantly concentrating on historical and tourist towns (He *et al.*, 2020).

To address this gap, this study explores the following research questions:

(i) How does the image of towns in the PRD distinguish it from the imagery of urban or rural areas?
(ii) What are the distinguishing and memorable characteristics of certain central towns in PRD?
(iii) How can town images, analyzed through new technologies and multi-source data, provide insights into the development level of small-town landscapes?

Based on these research questions, this study applies Lynch's city image theory to conduct an empirical analysis. Methods include image type classification, text-based word frequency analysis, and a comprehensive evaluation of the landscape in central towns of the PRD. Through this approach, the study aims to expand and adapt Lynch's image theory to better understand town-level landscapes.

2. Literature review

Research on city image and landscape in Western countries started earlier than that in China. Early studies primarily analyzed the imageability of urban elements and trajectories, while later research focused on calculating the spatial perception of Internet images. Psychologist Edward Tolman first proposed and generalized the concept of cognitive maps, describing them as comprehensive representations of local environments and spaces (Tolman, 1948). Lynch (2001) further explored city image through psychology and behavior, proposing five key elements of city image. Other studies derived perceptions of various image attributes using rigorous mathematical, statistical, and qualitative analyses (Cranshaw *et al.*, 2012; Hawelka *et al.*, 2014; Hillier, 1999; Hunter, 2008). As information technology has evolved, network media has emerged as a critical medium for comprehending the world, with representations of urban images increasingly shifting toward indirect dissemination and data-driven portrayals facilitated by digital platforms (McLuhan, 2000; Zhao & Liu, 2012; Zhao, 2012). For example, Salesses *et al.* (2013) explored urban space perception in terms of safety, hierarchy, and equity by analyzing visual representations of four internet-centric cities. Gavric *et al.* (2011) analyzed Berlin's tourism characteristics and tourist routes using Flickr data, while Kavaratzis and Ashworth (2005) linked urban spatial perception to the development of urban image.

In China, research on city image began later. Before the rise of social media, most studies relied on questionnaire surveys and cognitive maps to explore urban and rural landscape image perception. For example, Gu and Song (2011) emphasized the application of city image research in urban design and other fields. Shen (2004) reflected on Lynch's five elements, proposing that city image includes non-spatial elements, such as culture, alongside spatial elements. Liu and Li (2017) and Liu *et al.* (2018) applied urban landscape iconographic methods to summarize city

image structure. Liu (1994) identified iconic images of historical and cultural villages, including ancestral halls, towers, trees, squares, ponds, water bridges, roofs, and gables. Fan & Wang (2010) analyzed the rural landscape image of the PRD using questionnaire surveys and cognitive maps, emphasizing the importance of regional landscape characteristics for the reconstruction of rural images.

In recent years, the influence of mobile internet has transformed city image research. Perceiving subjects, objects, modes, presentations, and feedback mechanisms have evolved, reflecting tendencies toward planarization, symbolization, and digitalization (Wang & Zhen, 2015; Yu & Chen, 2024). Scholars have increasingly studied network-based imageability through street view analysis and public perception data derived from media platforms. For example, Zhou *et al.* (2014) used web image crawling to summarize city image types. Zhao *et al.* (2015) analyzed internet images of 21 cities retrieved from Google. Long & Zhou (2017) leveraged open internet data to evaluate urban images, proposing the concept of "picture urbanism." He & Li (2021) employed statistical methods, including principal component analysis and regression, to explore typological characteristics and relationships between image elements. Wang (2023) conducted a comparative study of internet images of Changsha from official websites and social networking platforms, exploring the metaphorical ideologies behind the images.

Despite advancements in urban image research, most studies focus on singular data types, such as cognitive maps, street view recognition, or internet texts. Such approaches risk incomplete or biased evaluations. As information technology continues to advance, integrating multiple data types is imperative for comprehensive analyses. In this study, we analyzed images and texts of central towns in the PRD retrieved from internet search engines. This approach highlights similarities and differences between small-town and city image elements. Our findings will provide valuable insights into perceptions of town landscape styles, identify landscape style types under network environments, explore the development potential of small towns, and contribute to establishing positive town images.

3. Overview of PRD areas and research methodology

3.1. Overview of central towns in the PRD

Central towns refer to towns within smaller settlements that possess advantageous locations and robust economic strength. These towns benefit from the economic and infrastructural influence of nearby large- and medium-sized cities while also playing a significant role in gathering resources and radiating development to surrounding rural areas and smaller townships (Li *et al.*, 2022). They serve as key nodes in China's township system, bridging the gap between small towns and larger urban centers (Dong & Gao, 2011).

In 2023, the urbanization rate of the PRD region reached 87.5%, making it the most densely populated and economically urbanized region in China (Office of the Seventh National Population Census Leadership Group of the State Council, 2022). The spatial quality of towns within the PRD significantly impacts the region's high-quality urban agglomeration development.

Over the years, the composition of central towns in the PRD has undergone notable changes. Compared to the list of central towns announced by the Guangdong Provincial Government in 2002, some towns have expanded into small cities, while others have lagged behind in development. This study identifies central towns with strong imageability in internet media, offering insights into the general developmental trends of central towns in the PRD.

3.2. Analytical framework and methodology

The readability of town images and texts serves as a foundation for understanding the spatial perception of towns. As American poet Ezra Pound observed, "Image is the complex of thoughts and feelings in a moment" (Pound, 1986, p. 152). To address the dynamic nature of urban images, which evolve over time and space, this study collected images and accompanying text content associated with town names from internet search engines over a single day in 2024. This approach aims to provide an objective basis for analyzing town images from an internet perspective.

This study seeks to construct a quantitative framework for analyzing network image features by evaluating their characteristics and commonalities. The methodology involves the following steps (Figure 1 for the network image feature quantification framework):

(i) Overall images and text recognition:
- A brightness histogram was utilized to analyze overall image brightness, reflecting disparities between urban and rural image content for each town.
- Semantic network analysis was utilized to analyze co-occurring word pairs associated with towns, highlighting public attention and focus areas.

(ii) Image type recognition:
- Images for each town were analyzed using Tencent Cloud AI image recognition (Figure 2).
- After manually categorizing and recording the semantic labels for each image, the top picture labels for each town were counted. Principal factor analysis, conducted using a statistical

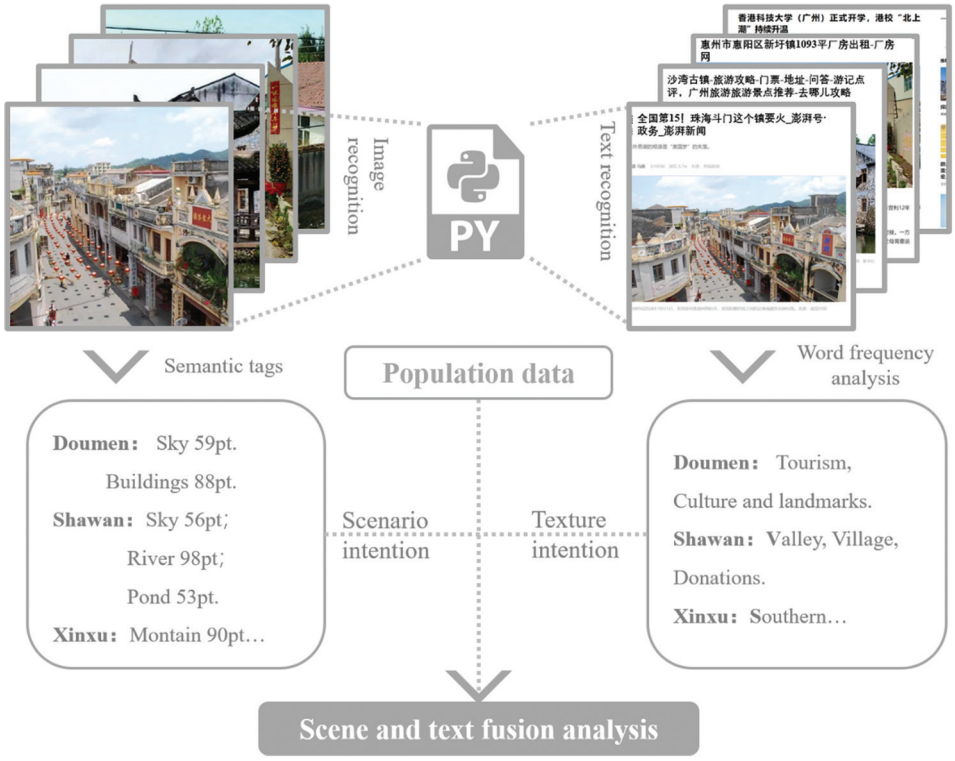

Figure 1. Network image feature quantification framework
Source: Diagram by the authors.

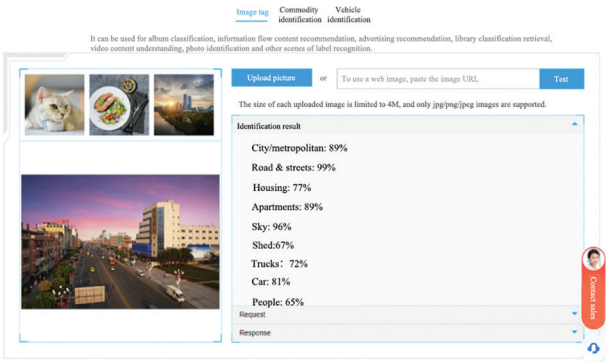

Figure 2. Example of Tencent Cloud artificial intelligence (AI) image identification results
Source: Tencent Cloud AI.

package for the social sciences (SPSS), was then applied to determine the types and spatial layout of primary image factors.

(iii) Text word frequency analysis:
- Textual comments and descriptions accompanying the images were analyzed using SPSS, ROSTCM6, and GIS software.
- The analysis focused on overall text word frequency, co-occurrence values, and top-ranked word frequencies based on standard deviation, intensity value, and typological generalization.

(iv) Image and text two-factor comprehensive analysis:
- By overlaying the first-label type of images with the word frequency types of texts, the study identified the spatial cumulative distribution of images.
- This method reflects the focal points and hotspots of the town image, offering insights into content emphasis and high-interest areas (Liang & Pan, 2015; Marine, 2017).

3.3. Data collection

The research data consists of two primary types: population data and internet data. The internet data were obtained from the Bing search engine, which offers higher image quality and less redundant information compared to other search engines available in China. The accompanying text information for the images was sourced from news websites, enterprise portals, and new media platforms such as Xiahongshu (小红书; translated as Little Red Book) and Weibo. Using the directory of central towns published by the Guangdong Provincial Government in 2002 as a reference, this study utilized Python programming to search for the names of central towns in the PRD through

the Bing search engine. Corresponding images and text titles associated with these towns were synchronously downloaded. During the data collection process, it was observed that the top 100 images of each central town, along with their associated text content, were sufficient to capture the imageability of the towns. Therefore, these top 100 images and their corresponding text were selected as the study's research materials.

However, some central towns had fewer than 100 images available for download, suggesting a lower level of public interest or search activity on the internet. These towns were excluded from the study. Ultimately, 81 central towns with more than downloadable images were included as the research objects of this study. The image sources included enterprise portals, such as the Paper (https://m.thepaper.cn/newsDetail_forward_7153747) and travel websites such as Qunar (https://travel.qunar.com/p-pl6077281). The accompanying text was extracted from the titles of the pages where the images were located.

After data cleaning, sorting, and storage, each central town's dataset consisted of the top 100 images and their corresponding texts. This step resulted in a total of 8,100 valid images and over 510,000 characters of segmented text. Using the Tencent Cloud AI image recognition model, which intelligently analyzes the content proportions within images, image labels for the research materials were obtained through Python-based API calls. The high-proportion image labels were organized, resulting in the identification of more than 20,000 image tags in total.

4. Empirical findings

4.1. Overall analysis of network image

4.1.1. Clarity analysis of overall images in each town

The present study distinguishes the overall imagery of each town by analyzing the brightness histograms of image matrices. The aim is to identify whether the images predominantly feature dark, urban landscapes dominated by dense buildings or light, rural landscapes characterized by open countryside.

To achieve this, town images were assembled into a 10×10 grid using Photoshop software, creating a set of images downloaded sequentially from a search engine (Figure 3). The brightness levels of each town's images were examined using Photoshop's histogram function, and the standard deviation of brightness values was calculated to compare the differences between urban and rural landscapes across towns (Table 1). By arranging the mean brightness values in descending order, it was found that the central towns of Huizhou, Zhaoqing, and Foshan ranked highest. These towns displayed brighter and lighter imagery, dominated by scenes featuring open skies and water, reflecting expansive and bright rural landscapes. Conversely, Guangzhou exhibited the lowest average brightness values, indicating a predominance of darker urban imagery.

The standard deviation analysis revealed that Dongguan and Huizhou had the highest values, both exceeding 5. This finding suggests significant variation between urban and rural landscapes in these areas, with each exhibiting distinctive representative scenes. The imagery strongly highlights the recognizability of both urban and rural environments. For instance, in Machong town of Dongguan city (Figure 2), the first 100 images collected featured not only densely constructed urban landscapes but also extensive farmlands and waterways, demonstrating a pronounced trend of urban–rural integration. In contrast, the spatial scenes of the central towns in five cities, including Zhaoqing and Guangzhou, exhibit characteristics of partial ruralization or partial urbanization.

4.1.2. Analysis of high-frequency words in texts associated with each town

By analyzing the present values of text word frequency, a public image network formed by high-frequency word pairs in central towns was constructed. The research first established a planning corpus focused on small towns.

Table 1. Average and standard deviation of image brightness for each town

City name	Central towns (*n*)	Minimum value	Maximum value	Average value	Standard deviation
Guangzhou	16	167.10	182.93	173.8163	4.50395
Zhuhai	4	176.16	185.78	180.4525	4.04679
Foshan	8	177.04	187.78	180.5938	4.13237
Huizhou	10	175.07	192.54	181.7170	5.66506
Dongguan	13	167.45	187.85	177.3708	5.70226
Zhongshan	3	176.67	182.84	179.2933	3.18695
Jiangmen	9	170.18	184.39	175.3044	4.44096
Zhaoqing	17	173.70	188.73	181.4753	4.59489

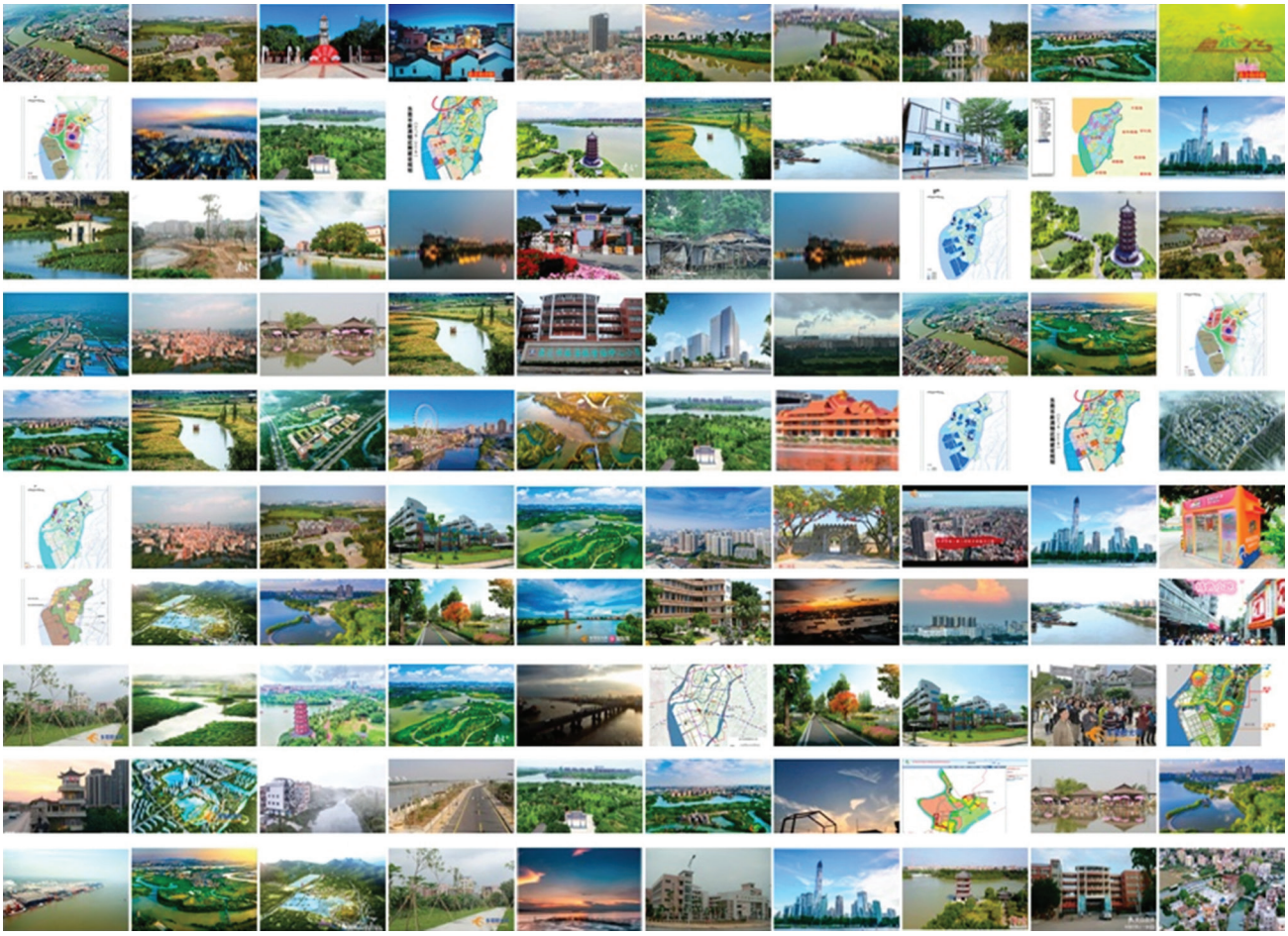

Figure 3. Image collection of Machong town, Dongguan city, Guangdong, China
Source: The Bing search engine.

After filtering out irrelevant factors such as place names, a semantic network analysis was conducted using ROSTCM6 software to calculate word frequency co-occurrence values among all word pairs associated with the towns. This process resulted in a co-occurrence matrix and a word list composed of high-frequency word pairs.

As shown in Table 2, to top five high-frequency word pairs included terms such as "rural revitalization," "tourist attractions," "valley planning," "portal website," and "district website." These findings indicate that central towns in the PRD primarily serve to promote rural revitalization and development in surrounding rural areas. They also act as key tourist destinations for visitors from large- and medium-sized cities.

Furthermore, the findings align with the objectives of the One Hundred Million Project in Guangdong province. Central towns, typically situated in valley plains, are planned and designed to integrate with their valley landforms. In addition, relevant information about these towns is disseminated through portal websites and local websites.

4.2. Typological characteristics of town image

4.2.1. High-frequency images

The research categorizes the five elements of city image and evaluates 100 images from each town according to these categories to determine the main content of public perception for each town. By refining the five elements of city image and applying AI semantic analysis, the study categorizes recognizable image content based on Lynch's theory of five elements (Table 3) and constructs a semantic recognition framework (Table 4). Using Tencent Cloud AI image recognition model to identify and label the image content, tags such as "mountains," "water," "buildings," and "traditional landscape towns" frequently appeared. Scoring the image labels revealed that boundary elements, including "mountains" and "rivers and lakes," accounted for 37% of the total. This was followed by node elements (14%) and district elements (11%), while paths and landmarks were the least frequent. These results indicate that public perception of central town images primarily focuses on

Table 2. Top five high-frequency word pairs based on co-occurrence values

Link	Vocabulary I	Vocabulary Type I	Vocabulary II	Vocabulary Type II	Word frequency co-present value
Link I	Villagers	Planning content	Re-energize	Planning content	278
Link II	Tourists	Planning content	Place of interest (tourism)	Planning content	277
Link III	Valleys	Planning content	Planning	Planning content	201
Link IV	Portal	Planning content	Websites	Media	178
Link V	The district	Planning content	Websites	Media	175

Table 3. Refinement of image tags based on the five elements of city image

City image	Town image tags
Landmark	Urban landmarks, business events
Node	Architecture, parks, squares, urban events, factories, agriculture
Path	Transportation facilities, roads, streets
District	Traditional landscape towns, urban landscapes, rural landscapes, historical culture and folklore, planning
Edge	Mountain, rivers and lakes, plant

Table 4. Semantic recognition framework for town image tagging

Category	Subcategory	Element
Ecological scene	Natural features	Mountain
		Rivers, lakes
		Plant
Living scene	History and humanity	Traditional landscape towns
		Historical culture and folklore
	Rural and urban landscape	Rural landscape
		Town landscape
		Urban landmarks
		Parks, squares, streets
		Architecture
Production scene	Road and transportation facilities	
	Industrial features	Agriculture
		Factories
		Business activities
		Urban events
		Planning

natural scenery, with urban architecture also receiving attention. This suggests that the rural characteristics of the towns are more likely to attract public interest.

To further analyze the typological characteristics of town images, principal factor analysis was carried out on the values of various elements corresponding to the semantic framework. The research employed SPSS for this analysis, yielding a Kaiser–Meyer–Olkin value of 0.654, indicating that the sampling adequacy passed. The significance test value was <0.001, confirming the success of Bartlett's sphericity test. The initial eigenvalue criterion was used to determine the number of principal factors, where factors with eigenvalues ≤1 were selected. A total of six principal factors were identified, with a cumulative contribution rate of 74.287%. Therefore, the research selected Components 1 – 6 as the initial factors (Table 5).

To better understand the significance of each factor, the factors were rotated and examined, resulting in a clearer differentiation of the six principal factors (Table 6):

(i) First factor: historical features of town concentration areas
- Larger loadings for "architecture," "road," "parks, squares, and streets," "traditional landscape towns," and "urban events" suggest a blend of historical and modern town features.
- This factor reflects the coexistence of historical and contemporary elements and is thus termed the "historical feature factor of town concentration areas."

(ii) Second factor: value landscape factor
- Larger loadings for "urban landscape," "transportation facilities," "mountain," and "rural landscape" highlight the typical landscape characteristics of valley towns.
- This factor is named the "valley landscape factor."

(iii) Third factor: cultural and production space
- Larger loadings for "historical culture and folklore," "factories," and "traditional landscape towns" indicate a close integration of cultural and production activities within traditional style areas.
- This factor reflects a mixed urban–rural production and living space and is termed the "cultural living and production space factor."

(iv) Fourth factor: industry and trade circulation
- Larger loadings for "factories," "business activities," and "transportation facilities" suggest

Table 5. Explanation of total variance of factors for scene features

Factor analysis metrics	Component	Total	Percentage of variance	Cumulative %
Initial eigenvalue	1	3.972	24.823	24.823
	2	2.570	16.064	40.887
	3	1.790	11.187	52.074
	4	1.311	8.194	60.268
	5	1.225	7.659	67.927
	6	1.018	6.360	74.287
	7	0.752	4.701	78.988
	8	0.663	4.143	83.131
	9	0.516	3.224	86.355
	10	0.485	3.031	89.386
	11	0.429	2.680	92.066
	12	0.401	2.505	94.570
	13	0.349	2.184	96.754
	14	0.225	1.409	98.163
	15	0.165	1.031	99.194
	16	0.129	0.806	100.000
Extract the sum of the squares of the loads	1	3.972	24.823	24.823
	2	2.570	16.064	40.887
	3	1.790	11.187	52.074
	4	1.311	8.194	60.268
	5	1.225	7.659	67.927
	6	1.018	6.360	74.287
Rotational load sum of squares	1	2.656	16.598	16.598
	2	1.997	12.478	29.076
	3	1.977	12.357	41.433
	4	1.926	12.036	53.469
	5	1.892	11.823	65.292
	6	1.439	8.995	74.287

Table 6. Factor-rotated component matrix of scene features

Element	Component					
	1	2	3	4	5	6
Architecture	0.851					
Road	0.729					0.406
Parks, squares, streets	0.713				0.377	
Traditional landscape towns	0.646		0.524	0.340		
Urban events	0.643		0.327			
Agriculture	0.524	−0.455	0.315			0.324
Rivers & lakes	−0.489		−0.362		0.371	0.439
Urban landscape		0.752				
Road and transportation facilities	0.447	0.663				
Mountain		0.574			0.488	0.357
Rural landscape		0.559		0.397	0.310	
Plant	0.448	0.467				0.402
Urban landmark		0.431	0.419		0.392	
History, culture, and folklore	0.481		0.566	0.461	0.334	
Factories		0.396	0.551	0.511		
Business activity	0.355		0.403	0.503		0.361

a focus on industrial and commercial functions.

- This factor is named the "industry and trade circulation factor."

(v) Fifth factor: rural cultural landscape

- Larger loading for "rural landscape," "mountains," and "historical culture and folklore" highlight the rural cultural aspects of the towns.
- This factor is termed the "rural cultural landscape factor."

(vi) Sixth factor: agricultural landscape

- Larger loadings for "rivers & lakes," "roads," "plants," "urban events," "mountains," and "agriculture" emphasize agricultural and natural landscape elements.
- This factor is referred to as the "agricultural landscape factor."

These six principal factors: – historical features, valley landscape, cultural and production space, industry and trade circulation, rural cultural landscape, and agricultural landscape, – together define the primary components of town images in the PRD. Compared with urban image factors (Zhao *et al.*, 2015), the landscape factors of the central towns in the PRD are richer in detail and content, encompassing both urban and rural elements.

The scatter plot of Components 1 – 6 visualizes the distribution of data in rotated space (Figure 4). The plot reveals that attributes such as transportation facilities, traditional landscape towns, and history, culture, and folklore are widely dispersed, indicating significant variation among these factors. Conversely, elements such as agriculture, mountains, transportation facilities, and architecture cluster under distinct factors, highlighting their specificity. This indicates that the 81 central towns, such as cities, exhibit diverse image factors. The traditional landscape town factor is weakly generalizable, while elements such as landscape, dominant town functions, and physical space exhibit clustered characteristics. These clusters reflect that the physical environment, including

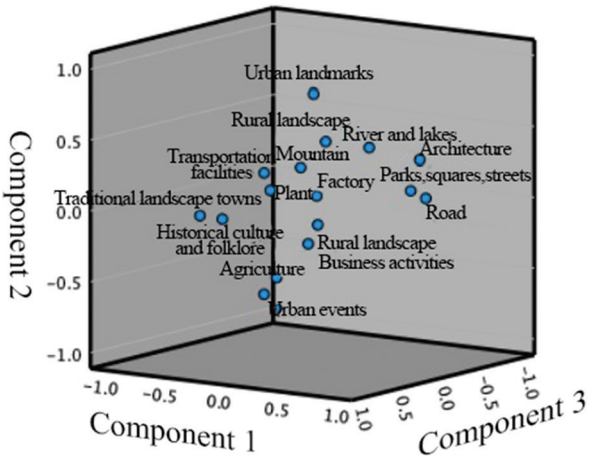

Figure 4. Town scene components in rotated space
Source: Graph by the authors.

living places, connectivity, and roadside landscapes, is central to the image expression of these towns in the networked space.

The locations of towns and their functional relationships with large- and medium-sized cities significantly shape their spatial scenes. The research statistically identifies the image labels of townscapes and countryside landscapes and categorizes them into three groups (Figure 5):

(i) Urban–rural integration category: Found mainly in Guangzhou and Dongguan, these central towns exhibit prominent natural characteristics, alongside diverse urban scenes, such as modern urbanization and local culture.
(ii) Rustic-dominated category: Towns in Huizhou, Jiangmen, and Zhaoqing are characterized by pronounced agricultural and rustic scene features.
(iii) Town-dominated category: Towns in Zhuhai, Zhongshan, and Foshan are primarily defined by townscapes featuring parks, squares, and urban landmarks.

The high degree of urbanization and the clear functional division in surrounding towns (Shen *et al.*, 2023) contribute to the diversity of image labels in central towns. In medium-urbanized areas, fewer central towns exist, but their image scenes are more prominently related to urban characteristics. Conversely, in less urbanized areas, there are more central towns, with scene characteristics predominantly shaped by agriculture and countryside features.

Overall, most town scenes align with public perceptions. Identifying towns that deviate from the dominant regional characteristics can further uncover unique development potential or heritage resources.

4.2.2. High-frequency texts

The frequency of text words reflects the main spatial carrier and media communication content in the presentation of town images. By analyzing the top-ranked high-frequency words in the texts associated with each town (Table 7), it is evident that the primary terms are "valley" (18.52%), "tourism" (12.35%), "countryside" (8.64%), and "urban areas/communities" (3.70%). The remaining words appear in <3% of the texts, indicating that public perception is strongly shaped by topography, behavior, and regional features. Among second-ranked high-frequency words, "culture," "park/tourism," and "landscape" are dominant, reflecting that the public's impressions of small towns are shaped by cultural communication and the visual image of towns conveyed through nodes of public open space.

The content and value of text word frequencies reflect public attention hotspots. By summing the frequency of the top three words in the text for each town and dividing the towns into five equal groups based on word frequency values (Figure 6), it becomes clear that towns recognized as famous tourist destinations in traditional public perception exhibit markedly higher word frequencies than industrial towns. Among famous tourist towns, Yuecheng town in Zhaoqing City, home to the renowned Dragon Mother Ancestral Temple, has a word frequency value more than double that of other towns. Other notable towns include:

- Lubao town in Foshan city, known for its hot springs resorts;
- Shawan historical town in Guangzhou city, a nationally recognized historical and cultural town;
- Siqian town in Jiangmen city, branded as the "Thousand-Year Old Town, Hundred-Year Dragon Boat;" and
- Xiaolan town in Zhongshan city, celebrated as the hometown of cultural and folk arts.

In contrast, industrial towns show a different focus. Examples include:

- Lecong town in Foshan city, a hub for traditional home furnishing;
- Xinxu town in Huizhou city, aiming to establish an industrial park with an output value exceeding 100 billion RMB by leveraging its proximity to Shenzhen; and
- Yangcun town in Huizhou city, featuring a provincial industrial transfer park and the Bodong Industrial Park agglomeration area.

These findings underscore the dual role of central towns in the PRD. While they serve as leisure and suburban tourism destinations for residents of large- and medium-sized cities, they also play a pivotal role in facilitating industrial

Figure 5. Scene diagram of three landscape types of central town images
Source: Photos by the authors (2024).

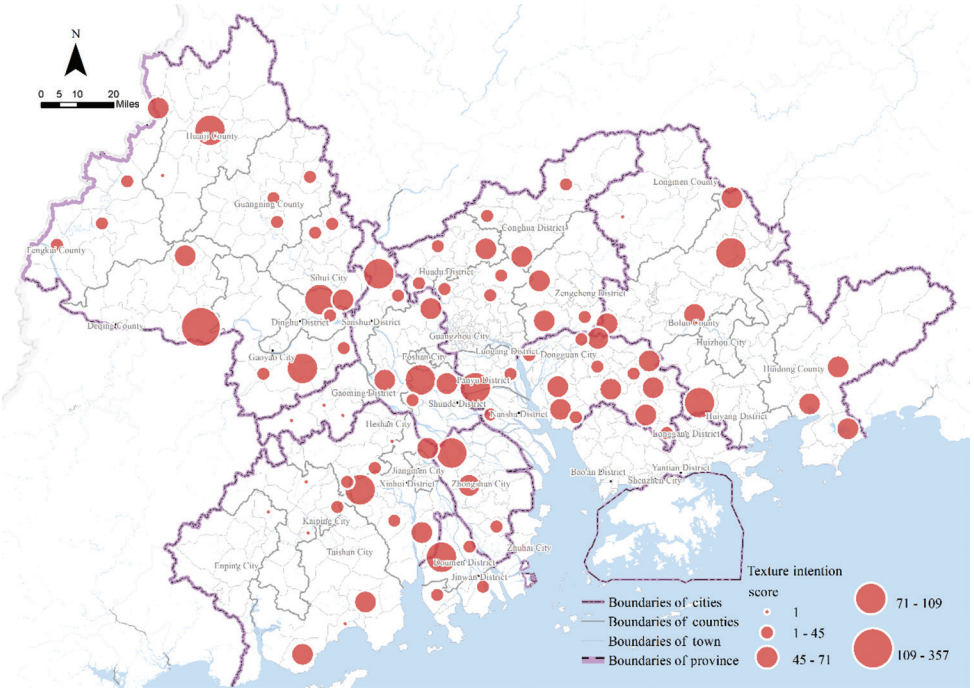

Figure 6. Spatial mapping of textual images associated with central towns in the Pearl River Delta based on the top three word frequencies
Source: Drawing by the authors.

transfers from core cities in the PRD and advancing the transformation and upgrading of traditional industries.

4.2.3. Overlay analysis of image tags and textual imagery

Overlay analysis of the first tag types from image recognition and textual imagery types helps identify towns and cities that are highly recognized by the online public and exhibit prominent features. Following classification and analysis, the first tag types for image recognition are categorized into four primary types: "architecture," "plants," "traditional town," and "urban events." Similarly, textual imagery types are summarized into seven categories of towns: ecological development type, agro-industrial development type, industrial development type, modern-style service type, rural culture and tourism type, history and culture and tourism type, and other types.

By establishing a GIS database and using an attribute selection tool to evaluate image- and text-related features simultaneously, the present study assesses central towns based on combinations of these prominent features (Table 8).

Table 7. Top ten and top three high-frequency words in texts associated with central towns in Guangzhou

Name	Top ten words (in order of frequency)	Top three word frequencies		
		1	2	3
Taihe town	Travel, specialty, culture, food, valley, farm, Baishan village, Dongpo, refreshing, original	16	14	14
Zhongluotan town	Valley, Longgang village, donation, energy, Chamber of Commerce, smooth, park, style, livelihood, home for the elderly	17	13	10
Jianggao town	South, park, countryside, culture, center, Hegang, base, development, old village, beautiful	22	13	10
Shilou town	Darling, elementary school, shrine, south, seagull, land, plant, area, school, history	14	14	10
Shawan town	Historical town, tourism, attractions, fulfillment, quality, photography department, scenery, Lingnan, travelogue, broadway	66	25	13
Huadong town	Landscape, region, landscape, town, Europe, photography department, landscape, resort, planning, mountain towns	25	17	16
Tanbu town	Village, garbage sorting, valley, south, beautiful, river and lake front, houses, subway, scenery, genealogy	16	15	10
Shiling town	Valley, Cangxi, leather, platform, transportation facilities, investment, leather, digitalization, tourism, parks	16	15	11
Wanqingsha town	Resettlement, scenery, action, new homes, amenities, environment, landscape, countryside, idyllic, mangroves	15	12	10
Dagang town	Countryside, science and technology, valley, beauty, history and culture, sports, facilities, springtime, scenery, Cantonese opera	13	10	10
Liangkou town	Ecology, prune, beautiful, tourists, hot springs, reservoir, environment, tourism, blue rivers and lakes, tongue	20	15	10
Taiping town	Tourism, attractions, tourists, Liuxi river, banks, parks, landscapes, valleys, historical towns, literature, and history	19	19	12
Aotou town	Valley, countryside, story, arts district, straw, agriculture, health, green, base, access	15	10	9
Xintang town	City, culture, valley, elementary school, family, historical and modern, promotional association, library, Ganquan Zhan, scenery	21	17	16
Shitan town	City, slate, upstream, community, folklore, transportation facilities, tourism, flatbed, elementary school, culture	22	8	6
Zhongxin town	Urban, rural, valley, center, campus, architecture, high school, culture, community, home buying	35	8	8

Only two towns – Doumen town in Zhuhai city and Yuezhen town in Zhaoqing city – are classified as "cultural tourism towns." These towns combine the textual imagery type "history, culture, and tourism" with the image recognition tag "traditional towns." This finding highlights their distinction compared to other traditional towns, with deeper impressions, more prominent cultural branding, and uniquely recognizable nodes.

Xiqiao Town in Foshan City stands out as the only "eco-town," with the image tag "plants" and the textual imagery type "eco-development." This suggests that Xiqiao mountain's countryside recreation function is more widely recognized by the public than similar landscape resources in other towns.

Furthermore, the overlay of the image tags "architecture" and "urban events" with the textual imagery type "comprehensive service" identifies 19 towns, including Xintang town in Guangzhou city. These "comprehensive service towns" demonstrate greater public recognition compared to other towns with similar landscape resources. They are characterized by their ability to receive significant urban influence, provide robust trade circulation, public services, and other functions, and exhibit a strong inclination toward urbanization. Spatially, these towns are predominantly located on the periphery of large- and medium-sized cities or counties (Figure 7).

5. Discussion: The internet-based image recognition method and its potential to shape town landscapes

Small towns serve as the initial stop for the urbanization of rural populations. As central towns have remained in a state of "semi-urbanization" for an extended period, their spatial characteristics often reflect a blend of urban and rural dichotomies. These towns retain the original rural settlement texture while undergoing transformation and reconstruction driven by urbanization. Small towns within the PRD urban agglomeration must navigate relationships with large- and medium-sized cities and megacities, tailoring their industries and development paths to their unique resource endowment and geographical locations (Luo, 2022).

Table 8. Central towns identified through overlay analysis of image tags and textual imagery

Image first tag	Text type	Comprehensive feature evaluation	Central towns
Plants, architecture	Agricultural innovation type	Agricultural innovation town	Changping town, Fenggang town, Taihe town, Xiaolan town, Lishui town, Hetang town, Mingcheng town, Nishan town, Yishan town, Baishao town, Mingcheng town
Plants, architecture	Rural cultural tourism type	Agriculture and tourism town	Duozhu town, Baitu town, Sanxiang town, Gonghe town, Shuikou town, Nanfeng town, Yuelao town, Jiangtun town, Jianggao town, Gangping town, Jilong town, Didou town, Mocun town
Plants	Eco-developmental	Eco-town	Xiqiao town, Hainan town
Architecture, urban events	Industrial development type	Industrial town	Xinwei town, Dalang town, Shiling town, Shijie town, Shilou town, Beijiao town, Jinli town, Shuangshui town, Lechong town, Yangcun town, Shiwan town
Architecture, urban events	Modern style service type	Modern-style service town	Xintang town, Chang'an town, Houjie town, Tangxia town, Zhongxin town, Zhangmutou town, Longjiang town, Shiwan town, Humen town, Zhonglutan town, Nanjie town, Luoyang town, Lianhua town, Jiangkou town, Pingsha town, Yong'an town, Xinqiao town, Leiping town, Gujing town
Traditional towns	Historical and cultural tourism type	Rural cultural and tourism town	Yuezhen town, Doumen town

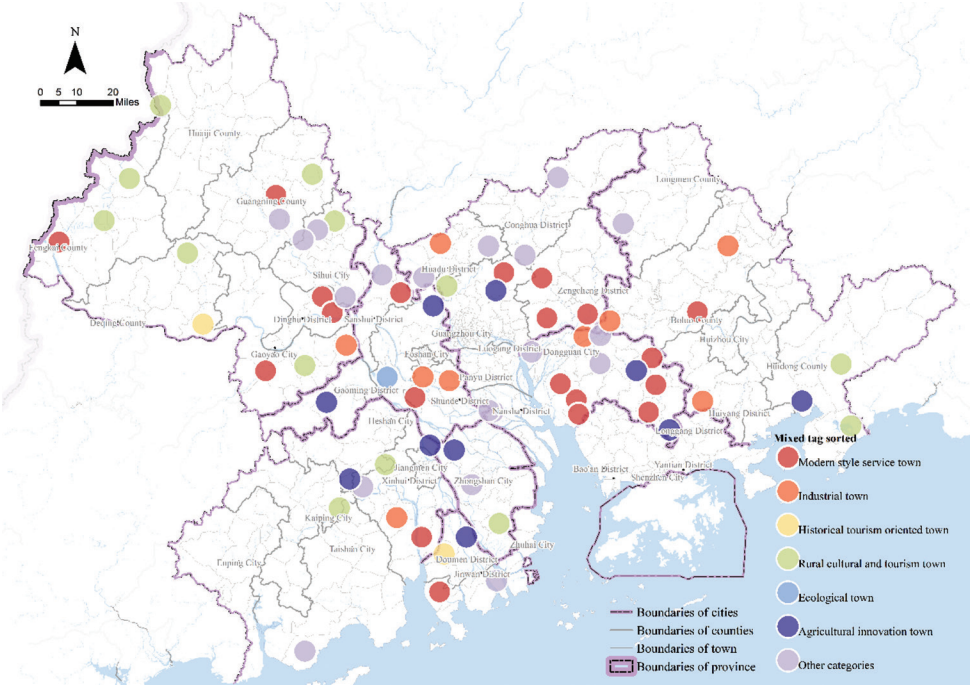

Figure 7. Spatial layout of the central town for the joint selection of images and textual image

This study introduces a novel approach to summarizing the components of town images using internet-based methodologies, thereby optimizing the research paradigm for town image analysis from an online perspective. The empirical results highlight the spatial morphological characteristics of urban images through integrated image and text analysis. These findings classify small towns into distinct developmental categories, scientifically identify towns with notable features, and provide a foundation for optimizing urban spatial design and formulating development countermeasures for small towns.

At present, the focus of city and town image research has gradually shifted from traditional media commentary to leveraging spatial representations derived from extensive

online data. However, this study mainly considers public contributions through photo uploads and does not fully address the perspectives of individuals who did not participate in this form of expression. A critical question for future research is: how can digital technology be employed to build a representative Lingnan town image network that incorporates both online and offline public participation?

In addition, future efforts should focus on constructing urban actor networks to assist in deconstructing traditional urban acquaintance networks and rewriting urban memory (Hu, 2014). This approach could significantly improve the spatial image of urban areas. With the advancement of informatization and digitalization, future studies may develop computational models of city images using semantic segmentation, data mining, and machine learning technologies (Filomena *et al.*, 2019). These tools could facilitate the integration of online and offline public participation. This article uncovers image-map features influenced by public preference and explores the formation mechanism of the digital sense of place (Yu & Chen, 2024). It also extends Lynch's urban image theory by predicting future images that integrate vision, imagination, and real spatial elements.

6. Conclusion: The unique imageability of towns in the Internet era

An urban image represents people's perception of physical space combined with their thoughts and emotions, making it an effective metric for assessing spatial quality (Tian, 2010). In contemporary settings, spatial media are closely connected to the production of everyday spatial knowledge. The interconnection of cyberspace and geospatial dimensions forms a hybrid cyberspace (Elwood & Leszczynski, 2013; Madge & Connor, 2005; Wang & Wang, 2020), which can be used to evaluate regional development (Chen *et al.*, 2022).

Based on empirical evidence, this study demonstrates the following key findings:

(i) Urban image is defined by a blend of urban and rural characteristics For example, the integration of historical features, the overlap of historical and production spaces, and the circulation of industry and commerce – identified through the principal component analysis of urban built-up areas – all highlight the merging of cities and towns within the framework of urban development. Simultaneously, the presence of rural folk customs and agricultural landscapes underscores the retention of certain rural attributes. Nevertheless, factor rankings reveal that the urban character dominates the town image, with rural landscapes playing a secondary role.

(ii) By applying the methods of image recognition and textual word frequency analysis, this study identifies the recognizable features of central towns in the PRD. These towns exhibit distinct themes and subtle variations that can guide their development. In formulating town development strategies, these features can be further explored and expanded to transform and optimize the town's characteristics, creating a compelling town image and brand.

(iii) Internet-based image evaluation functions as a form of "physical examination" for towns, conducted by the public. This approach assesses both the external image and internal experience of towns, mapping public perception of spatial quality, popular activities, and functional division.

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Conflict of interest

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Writing – review & editing: All authors

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Availability of data

The data are open-access, and relevant researchers are welcome to contact the authors to access the details.

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ORIGINAL ARTICLE

Reconstructing Minyue Kingdom's roads: A least-cost path approach to cultural heritage networks

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Abstract

This study utilizes high-resolution digital elevation models (DEM) and Landsat 8 remote sensing imagery to reconstruct the ancient road networks of the Minyue Kingdom in present-day Fujian province, China, focusing on the Qin dynasty (221 – 206 BCE) and Eastern Han dynasty (25 – 220). Using 12.5 m precision DEMs for elevation and Landsat 8 for land use and environmental data, a cost surface model was developed, leveraging the region's stable geographical environment. Least-cost path (LCP) analysis was applied to identify the most efficient travel routes, accounting for natural and human-made barriers. The findings highlight five key insights: (i) mapping over 10,000 km of ancient pathways, emphasizing their significance in military logistics, trade, and cultural exchanges; (ii) identification of critical nodes, such as forts and trading posts, that facilitated strategic control and economic development; (iii) the influence of Fujian's diverse topography on road network configurations; (iv) cultural narratives facilitated by these routes during the Minyue period (306 – 110 BCE); and (v) validation of LCP models in predicting undocumented routes and enhancing understanding of ancient transportation systems. This interdisciplinary approach integrates historical research, geographic information systems (GISs), and digital preservation, enriching archaeological knowledge and offering practical tools for cultural heritage management. The findings underscore the potential of GIS technologies in reconstructing historical landscapes and suggest broader applications for heritage preservation and education. The digital visualization of these networks provides a valuable resource for researchers and cultural heritage professionals worldwide.

Keywords: Minyue Kingdom; Ancient road networks; Geographic information system technology; Least-cost path analysis; Cultural heritage preservation

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1. Introduction

In the tapestry of linear cultural heritage (Cao *et al*., 2021; Chen & Sun, 2023; Choi *et al*., 2023; Kamran, 2022; Li *et al*., 2016), ancient roadways emerge as pivotal conduits within historical transportation networks (Crabtree *et al*., 2021; Güimil-Fariña & Parcero-Oubiña, 2015; Harrower & Dumitru, 2017). Amid the resurgence of international corridors such as the overland Silk Road and the Maritime Silk Road (Cinar *et al*., 2016; Feng, 2017; Liang & Guan, 2013; Shroder, 2014) under the aegis of Belt and Road

Initiative, these venerable pathways have gained renewed strategic significance (Xiao *et al*. 2023; Wang *et al*. 2023).

Situated as a key juncture on the ancient overland Silk Road and at the heart of the 21st Century Maritime Silk Road, Fujian province, China, is a testament to the ebb and flow of historical and cultural shifts, marked by a plethora of transportation-related cultural relics (Hong, 2016). The study of ancient roadways in Fujian dating back to the era of the Minyue Kingdom represents not only an academic pursuit but also a vital effort to illuminate the history of the Maritime Silk Road and foster its contemporary development (Kong, 2020; Sen, 2023; Xie *et al*., 2020).

The present study addresses a significant gap by leveraging the least-cost path (LCP) model to reconstruct and visualize the Minyue Kingdom's road networks, offering new insights into its socio-economic and military history. Conventionally, scholarly exploration of Fujian's ancient roads has been limited to the analysis of local chronicles, county records, and ancient manuscripts (Chen, 2018). These studies have mainly focused on translating texts, narrating historical events, and cataloging significant nodes along these ancient paths (Ding, 2006; Zhuang & Dong, 2017).

While traditional methods, such as the analysis of historical records and manual mapping of archaeological sites, have provided valuable insights, they often fall short in precision and comprehensiveness. This limitation is particularly evident in regions such as the Minyue Kingdom, where historical documentation is sparse. To overcome these challenges, this study innovatively applies the LCP model combined with modern geographic information system (GIS) technology, enabling a digital reconstruction of ancient routes that incorporate the region's topography and geographic characteristics. Unlike previous studies, which often relied on isolated textual interpretations and focused on single nodes such as postal stations or fortresses, this study seeks to create a holistic digital model of interconnected transportation networks from the Minyue period (306 – 110 BCE). By integrating environmental context and archaeological findings, it reveals a more cohesive understanding of how ancient travelers navigated the Fujian landscape.

A distinctive contribution of this research lies in its use of modern remote sensing data, facilitated by the stability of Fujian's geographic environment. The region's largely unchanged topographical features provide the foundation for constructing a reliable cost surface model to simulate ancient travel routes. This approach addresses a crucial gap in the digital representation of ancient transportation systems, as prior studies often lacked a comprehensive methodology combining environmental context with archaeological findings. By leveraging stable terrain data and advanced modeling tools, we reconstructed these pathways with a level of precision previously unattainable.

Beyond offering insights into the socio-economic and military history of the Minyue Kingdom, this study also highlights the importance of digital heritage preservation. This digital reconstruction represents an innovative step forward in cultural heritage studies, allowing researchers and policymakers alike to visualize the dynamics of historical networks and better understand the spatial logic of ancient roadways. Moreover, by reconstructing these paths, the study sheds light on the socio-economic conditions of the time and explores the role these routes played in shaping interactions among diverse communities within and beyond the region.

Overall, this research transcends traditional historical investigation, emphasizing the transformative value of digital reconstruction in heritage preservation. By developing a systematic digital representation of the ancient transportation networks in Fujian, the study not only contributes to the academic understanding of the region's history but also offers a foundational model for the preservation and adaptive management of cultural landscapes. Bridging historical scholarship with innovative technology, this study seeks to inspire further explorations into the intricate connections between cultural heritage and modern geographical science.

2. Review of existing research on transportation restoration

In the field of cultural heritage restoration, transportation networks occupy a unique position as both historical artifacts and functional components of modern infrastructure (Li *et al*., 2021; Lim *et al*., 2023; Ruiz *et al*., 2017). This review delves into the myriad approaches adopted for restoring transportation systems, emphasizing the delicate balance between preserving historical integrity and addressing contemporary functional needs. Recent advancements in technology and methodology have significantly transformed this landscape, offering novel perspectives and solutions to long-standing challenges.

2.1. Concept of transportation line heritage

The concept of "heritage of transportation lines" emerges from the broader framework of "cultural lines," a term ratified by the International Council on Monuments and Sites in the 2008 Charter of Cultural Lines (Lewis, 2023; Wang & Ruan, 2009). According to this charter, cultural lines depend on transportation networks that

span extensive historical and spatial dimensions (van den Dries, 2016). Three key elements define cultural lines: transportation routes, their specific uses, and the distinctive historical phenomena they encapsulate (Van Tan, 1995). Transportation line heritage, particularly ancient roadways, represents a confluence of natural and cultural landscapes formed through the interplay of human, economic, and cultural histories (Li *et al*., 2021; He *et al*., 2023). These routes are characterized by spatial flexibility and temporal fluidity, making them significant not only for historical and scientific inquiry but also for their cultural and touristic appeals (Huo *et al*., 2018; Jiang *et al*., 2023).

The term "ancient transportation routes" encompasses both tangible and intangible cultural heritage within a specific temporal and spatial context, including their surrounding natural and cultural environments (Tan *et al*., 2021). This study focuses on the tangible aspects, particularly ancient roadways and their associated relic sites, to provide insights into the intricate web of historical transportation networks and their enduring legacy.

Ancient transportation networks are functionally categorized into three types: military routes, cultural trade routes, and ancient postal paths (Wei, 2015). During the Minyue Kingdom, the establishment of ancient roadways within present-day Fujian province was primarily driven by military needs (Li, 2021). Traditional research has focused on textual analysis and manual mapping of archaeological sites, often limited to single nodes such as postal stations or fortresses. While being foundational, these studies lack systematic analyses of interrelated nodes and broader transportation networks.

To address these gaps, this study combines fieldwork with digital methodologies, applying the LCP model to reconstruct the Minyue Kingdom's transportation system. This approach integrates environmental context with archeological data, offering a comprehensive view of Fujian's historical pathways and advancing digital heritage preservation.

2.2. Restoration methods for transportation lines

The LCP model in GIS is frequently utilized in research across various fields, such as geography (Tang & Dou, 2023), environmental science (Bagli *et al*., 2011), archaeology (Hardt *et al*., 2023), and urban planning (Balbi *et al*., 2021). These studies address diverse topics, including terrain analysis, natural resource management, transportation planning, environmental conservation, and hazard risk assessment (Murekatete & Shirabe, 2021; Savary *et al*., 2022; Yu *et al*., 2003). For example, Boroujerdi and Uhlmann (1998) demonstrated that paths generated using the LCP model based on the Dijkstra algorithm significantly outperformed those generated with the O(EV) algorithm. Cohen *et al*. (2009) utilized the LCP model to delineate Metropolitan Margins Green Corridors, demonstrating the influence of distance on the LCP. Rees (2004) utilized the LCP model to design a road network and conducted a comparative analysis with pre-existing footpaths in the mountainous regions of Wales, with a focus on route optimization. During the Minyue Kingdom period, Fujian province was predominantly mountainous, with some coastal plains. These topographical features significantly influenced transportation, agriculture, and settlement patterns. Given that Fujian's geographical environment has remained relatively stable over time, modern remote sensing imagery can be reliably employed to construct a cost surface model for reconstructing the ancient pathways of the Minyue Kingdom. Numerous architectural and archaeological discoveries from this period, including postal stations, passes, fortresses, ports, docks, bridges, and other critical nodes, have been documented (Wu, 2020). These important nodes can serve as "sources" in the LCP model (Li, 2023), allowing for the generation of optimal paths to reconstruct the ancient road networks of the Minyue Kingdom.

The innovation in this study lies in applying the LCP model not merely for path optimization but as a tool for historical reconstruction. Given that many ancient routes in Fujian are poorly recorded or entirely undocumented, this study identifies roads lacking historical records, those with limited information, and those thoroughly documented but amenable to further refinement through spatial analysis. By doing so, the study reveals previously unknown pathways and enhances understanding of ancient routes, providing specific data on locations, lengths, and connectivity that were previously unmapped or insufficiently analyzed. For ancient routes still in use today, the study offers a comparative analysis of historical and contemporary pathways, highlighting the resilience and longevity of Fujian's transportation networks and adding layers of historical context to current infrastructure.

This approach not only brings new clarity to the Minyue Kingdom's transportation network but also demonstrates the value of digital tools in heritage preservation. It contributes both a digital representation and a robust framework for assessing the evolution of historical routes. By addressing historical gaps through rigorous GIS analysis, this study highlights the significant role of spatial modeling in advancing the understanding of cultural landscapes and supporting heritage preservation efforts in ways traditional research methods have yet to achieve.

3. Restoring Minyue Kingdom's road networks

3.1. Survey site and research period

Drawing on historical atlases and relevant documents, the Minyue Kingdom is identified as a regional power that emerged during the Western Han dynasty (202 BCE – 8 CE), centered in what is now Fujian province in southeastern China. The temporal scope of this study spans the Qin dynasty (221 – 206 BCE) to the Eastern Han dynasty (25 – 220), delineating the chronological boundaries of the Minyue Kingdom.

Ancient cartographic evidence (Figure 1) indicates that during the Qin dynasty, particularly the period when the area was known as the Minzhong county, and throughout the Minyue Kingdom period, the administrative domain extended beyond the current borders of Fujian province to include parts of Zhejiang province. However, this research focuses on the modern administrative boundaries of Fujian province (Figure 2) to investigate its historical context within the Minyue Kingdom.

Regarded as the "Southeast Mountain Kingdom," Fujian province stands as a geographically distinct region within China. Its terrain, defined by prominent water ridges, divides the province into unique physiognomic and hydrological units, with the exception of the Ting river. Notably, all rivers in Fujian originate within its borders and flow toward the sea along the provincial shoreline. The region's tallest ridge, the highest in southeastern mainland China, forms a natural barrier that shields Fujian from northern cold fronts, contributing to its unique climatic traits.

The intricate relationship between Fujian's landforms, water systems, and climate has profoundly influenced its soil types and vegetation distribution. This environmental cohesion and relative geographic stability have simultaneously limited and fostered Fujian's historical development. While the challenging terrain restricted

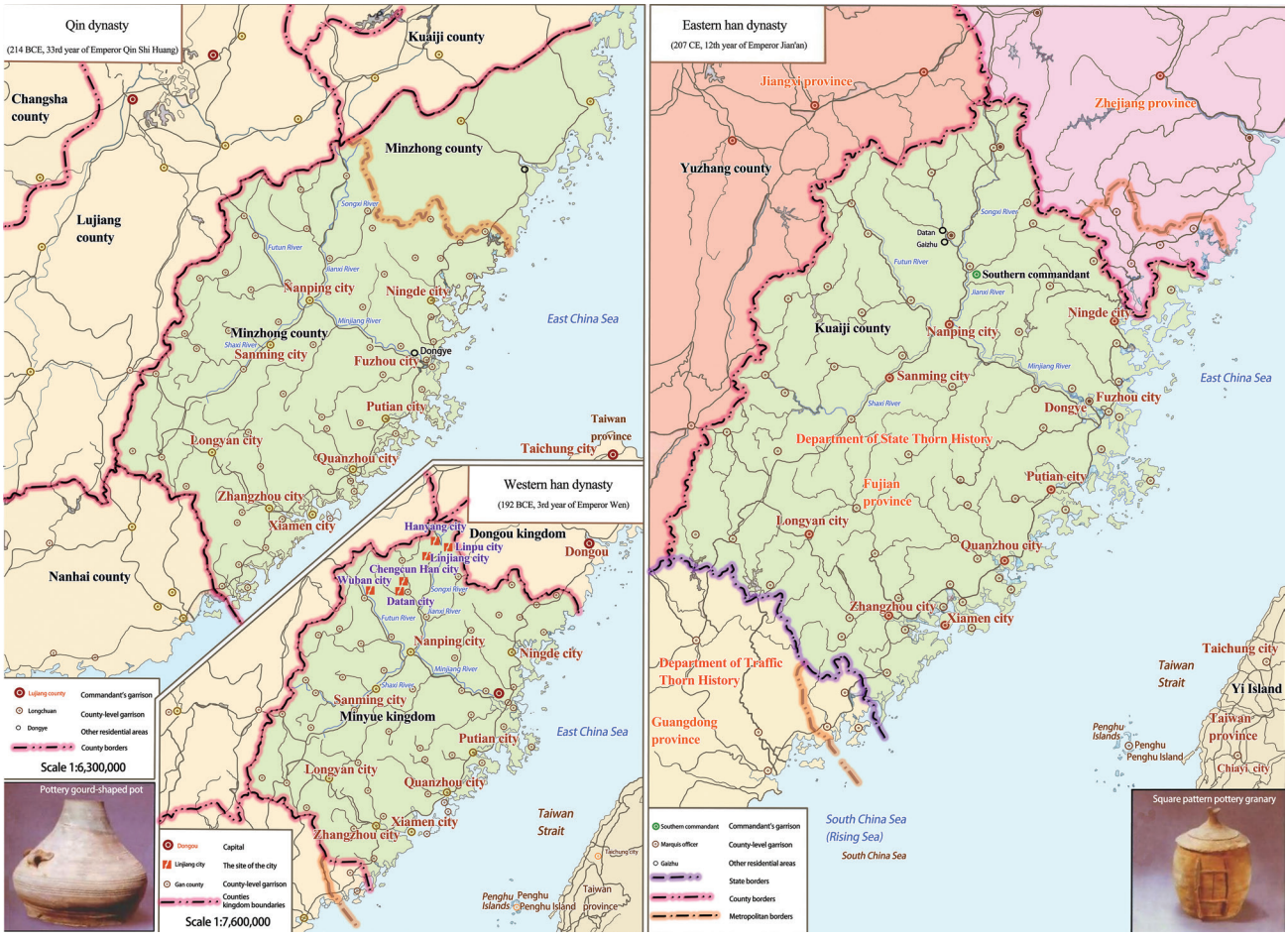

Figure 1. The geographical extent of the Minyue Kingdom
Source: Modified historical map by the authors, originally from State Cultural Relics Bureau (2009), Atlas of Chinese Cultural Relics, Fujian Rite.

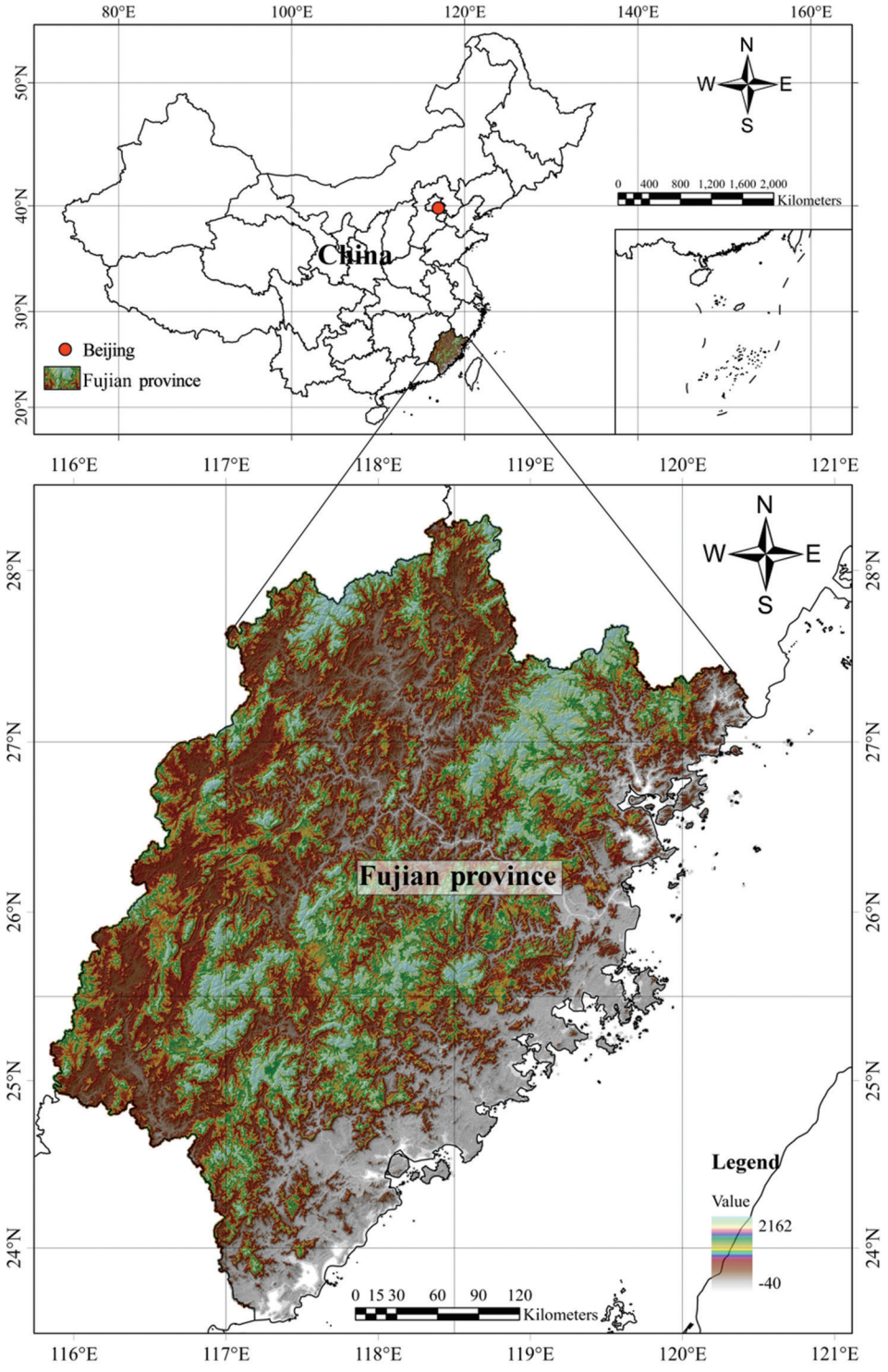

Figure 2. Survey region: Fujian province, China
Source: Drawing by the authors using digital elevation model from https://www.gscloud.cn.

economic and cultural exchanges with the Central Plains, it also encouraged vibrant local economic growth and contributed to Fujian's unique social and historical identity.

Since Fujian's physical landscape has remained largely unchanged over time, current remote sensing imagery provides a reliable basis for constructing cost surface

models, making the reconstruction of the ancient paths of the Minyue Kingdom feasible.

3.2. Data sources

This study harnesses a diverse array of data sources to reconstruct the ancient road transportation networks of Fujian province, including:

(i) High-resolution digital elevation model (DEM) data:

A 12.5-m precision DEM dataset provides detailed topographical information for the study area (Source: https://www.gscloud.cn/).

(ii) Landset 8 remote sensing imagery:

Imagery with a 30-m resolution and <1% cloud cover was used to extract geographic cost data for the route (Source: Geospatial Data Cloud).

(iii) Key points database for the ancient Minyue Kingdom roads:

This database was developed using two primary data sources:

- The Atlas of Chinese Cultural Relics: Fujian Branch (State Cultural Relics Bureau, 2009): This atlas compiles results from the first and second cultural relic surveys conducted in Fujian province. While the atlas includes locational information on nodes related to ancient pathways, it lacks precise coordinates, which are an invaluable form of metadata (Gregory & Ell, 2007). Therefore, geographic rectification methods were employed in GIS to align the atlas with actual geographic locations, allowing for the determination of coordinates for these sites.
- The Third National Cultural Relics Census: Additional data on less-documented ancient pathway sites were sourced from the List of Immovable Cultural Relics provided by the county and municipal cultural heritage authorities in Fujian province. This dataset includes key sites such as corridor bridges, fortresses, mountain passes, and postal stations relevant to the Minyue Kingdom's road networks.

Since many of these sites lack precise geographic coordinates and rely solely on descriptive address information, Gregory & Ell's (2007) methodology for digitizing historical geographic locations was employed. Using this approach, all ancient pathway sites were georeferenced in a GIS environment, generating latitude and longitude coordinates. This process significantly enriched the database of ancient pathway sites from the Minyue Kingdom era, providing a more accurate and comprehensive spatial representation of these historical routes.

3.3. Research methodology

3.3.1. Technical route

This study employs an integrated methodology combining various software tools and data analyses to reconstruct the ancient road network system during the Minyue Kingdom period.

- Data collection: Microsoft Excel was used to aggregate pertinent historical data.
- Database construction: ArcGIS Pro was employed to construct a database encompassing nodes related to the ancient roads.
- Data analysis: DEM data of Fujian province (focusing on slope and aspect) and Envi5.3 remote sensing data were used for analytical purposes. This analysis facilitated the comprehensive formation of resistance values for geospatial elements across Fujian province.
- Network system restoration: By integrating key points data from the ancient roads, a cost-distance analysis tool was applied to reconstruct the ancient road network system of the Minyue Kingdom (refer to Figure 3 for the technical route).

The core of the research methodology is centered on collecting key nodes from the ancient roads of the Minyue Kingdom era, identified as the "source" in this study. Subsequent steps involve determining the resistance values that shaped the formation of these ancient roads, culminating in the restoration of the network system.

3.3.2. Minimum cumulative resistance (MCR) model

In this study, the MCR was used to generate LCP, which represents the minimum-cost path across the landscape, conceptualized as an ancient pathway. The MCR model is a pivotal tool for computing the landscape cost associated with varying resistance levels originating from a defined "source." This model quantifies the effort required to overcome such resistance (Hardt *et al.*, 2023; Knaapen *et al.*, 1992). Integrating the cost-distance concept commonly employed in GIS, the MCR model incorporates three critical components: the "source" of the ancient road, the route itself, and the resistance base surface. The foundational formula for the MCR model, reflecting these considerations, is as follows:

$$R_{MCR} = f\sum_{j=n}^{i=m} D_{ij} \times R_{imin} \quad \text{(I)}$$

In Equation I, f is a positive, unknown function encapsulating the minimal resistance relationship of any given point on the ancient road. This function takes into account both the spatial proximity to ancient road-related

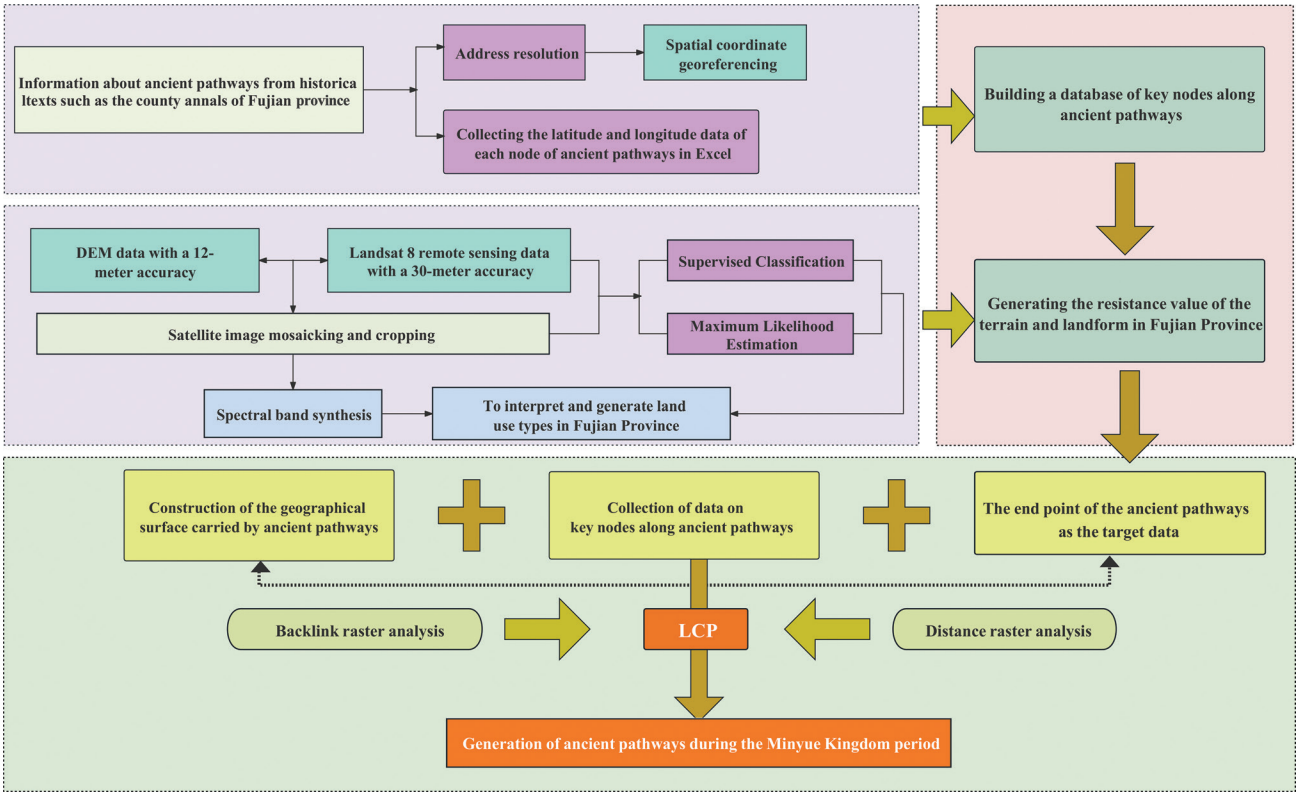

Figure 3. Technical route for the restoration of the Minyue Kingdom
Source: Drawing by the authors.
Abbreviation: LCP: Least-cost path.

site points and the attributes of the resistance base surface. D_{ij} represents the spatial distance traversed by an ancient road site across a geographical base surface i from the starting point j to a specific point in space, while Ri is the resistance coefficient.

The implementation of the MCR model was carried out using the Cost Path tool in ArcGIS Pro 3.2 software. The MCR model prioritizes the environmental and geomorphological characteristics of ancient roads, incorporating multiple cost weights into the computation to generate an optimal path. This approach is particularly effective for spatial analysis in areas with complex topographical features. As a result, it provides robust technical support for analyzing the ancient roads of Fujian province during the Minyue Kingdom era, taking into account a range of influencing factors.

3.4. Restoration procedure

3.4.1. Envi5.3 interpretation of remote sensing images

Utilizing Envi5.3, Landsat 8 remote sensing data (2014 – 2018) with a resolution of 30 m and cloud cover <1% were accessed for the summer season. The data underwent a radiometric calibration process to modify the spectral characteristics of land boundary classes, enhancing the interpretative quality. Subsequent atmospheric correction was applied to remove radiative distortions caused by atmospheric conditions, thereby retrieving accurate surface reflectance of terrestrial objects. The strategic combination of different bands was employed to facilitate the extraction of vegetation and land use classifications.

For the classification of land types, a non-parametric method coupled with an unsupervised approach was selected. Considering the extensive area of the study, land use in Fujian province was categorized into four classes based on the land use status classification standard (GB/T21010-2017): vegetation, water bodies, constructed land, and unused land. These classifications are visually represented in Figure 4 and detailed in Table 1.

3.4.2. Generation of comprehensive resistance value

The delineation of ancient road routes is intricately linked to the geographical environment. To simulate the ancient terrain, archaeologists and scientists often utilize modern landform data. In determining the resistance factors

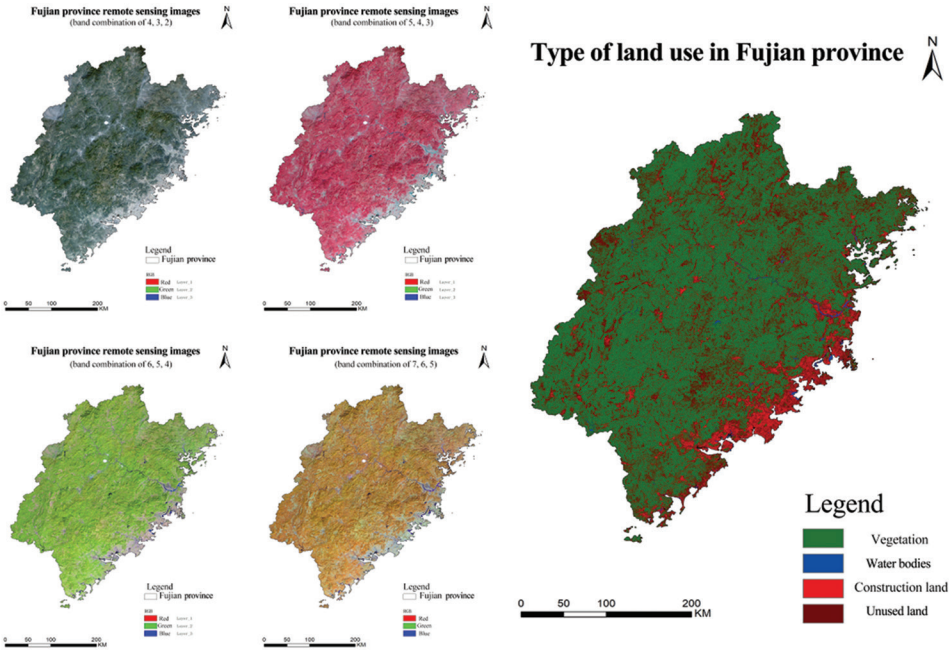

Figure 4. Interpretation of remote sensing images in Fujian province, China
Source: Drawing by the authors using remote sensing images from https://www.gscloud.cn/.

Table 1. Land use classification in Fujian province, China, by remote sensing interpretation

Name	Area (sq km)	Percentage of total area
Vegetation	90,579.65	73.05
Waterbody	22,844.53	18.42
Construction land	6,836.8	5.51
Unused land	1,215.78	0.98
Total area	124,000	100.00

pertinent to ancient roads, this study was motivated by the research of Beyin *et al.* (2019), San *et al.* (2013), and Chinese scholars such as Zhao *et al.* (2013) and Hu *et al.* (2020). Acknowledging the distinctive natural and geographical context of Fujian province, the analytic hierarchy process was employed to select land use type, elevation, and slope as key factors for weight value allocation (as detailed in Table 2).

The resistance values related to elevation and slope, derived from DEM data, in conjunction with land use type resistance values obtained from remote sensing interpretations (Section 3.4.1), were computed using the "Raster Calculator" tool in ArcGIS Pro. This process culminated in the formation of a raster surface representing the cost associated with the ancient roads, as illustrated in Figure 5.

3.4.3. Database construction of key nodes of the ancient road

Table 2. Resistance factor and weight value of ancient roads

Resistance factor	Resistance classification	Resistance value (0 – 100)	Weight value
Land use categories	Waterbody	10	0.533
	Vegetation	20	
	Construction land	30	
	Unused land	100	
Elevation	0 – 200 m	10	0.214
	200 – 500 m	30	
	500 – 800 m	50	
	800 – 1200 m	70	
	>1200 m	100	
Slope	Slowly inclined slope (0° – 3°)	5	0.253
	Equal slope (3° – 8°)	10	
	Slope (8° – 15°)	30	
	Sharp slope (>25°)	100	

The Minyue ancient roads comprise pivotal nodes, including various traffic heritage sites such as passes and fortresses. Notable among these are the Wuyi Mountain Water Pass in Northern Fujian, the Ziling Pass in Pucheng of Western Fujian, and the Pukui Pass in Zhangpu, all of which continue to serve vital transportation roles to this day. In addition, significant fortresses include nine key

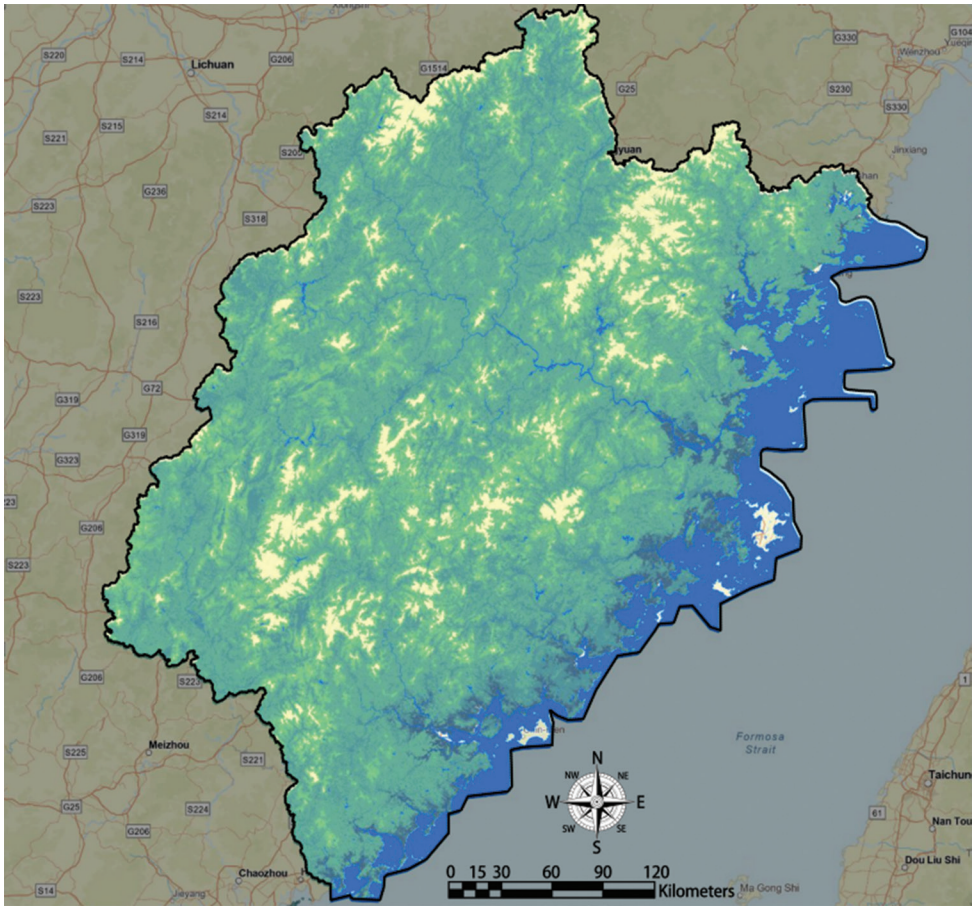

Figure 5. Cost grid surface of ancient roads
Source: Drawing by the authors.

Table 3. Important passes of the Minyue Kingdom

No.	Name	Longitude	Latitude	Location
1.	Wuyi Mountain Water Pass	117.837738	27.936084	Wuyishan, Nanping city, Fujian province
2.	Ziling Pass in Pucheng	118.626321	28.236052	Pucheng county, Nanping city, Fujian province
3.	Pukui Pass in Zhangpu	117.460064	24.059252	Zhangpu county, Zhangzhou city, Fujian province

city sites, such as Fuzhou Yecheng, Wuyishan Chengcun, Hancheng, and Jianyang Datancheng, along with seven critical ancient roads.

Nine principal starting points were meticulously cataloged using county records. Advanced geospatial technologies, including API and Xgeocoding (which were used to decode ancient geographic names and determine their precise longitude and latitude), were employed. This process led to the creation of a comprehensive database (as detailed in Tables 3-5), laying the foundational groundwork for reconstructing the network of the Minyue ancient roads.

3.4.4. Restoration of ancient road transportation lines

To reconstruct the ancient road transportation lines, the "Cost Weighted Distance" function was deployed in the final phase of the study. This involved utilizing the key nodes of the ancient roads identified earlier as the foundational source data. The analysis integrated the "Cost Path" tool within ArcGIS Pro 3.2, leveraging the point database established in Section 3.4.3. In addition, the "cost backtracking link" and "cost distance" outputs derived from Section 3.4.2 were incorporated. The combined application of these tools and data culminated in the generation of the ancient road lines that once traversed the Minyue Kingdom occupying present-day Fujian province.

Table 4. Important fortresses in the Minyue Kingdom

No.	Name	Longitude	Latitude	Location
1.	Fuzhou Yecheng	119.292904	26.095606	Gulou district, Fuzhou city, Fujian province
2.	Wuyishancheng Cunhancheng	118.045281	27.555698	Wuyishan city, Nanping city
3.	Datancheng of Jianyang	118.11386	27.327846	Jianyang Datan Mountain, southeast of the stream
4.	Pucheng Linpucheng	118.526995	27.919668	Shuinan road, Pucheng county, Nanping city, Fujian province
5.	Pucheng Hanyang Chen	118.531596	28.068851	Pucheng county, Nanping city
6.	Pucheng Linjiangcheng	118.466624	27.806233	Pucheng county, Nanping city
7.	Shaowu Wushancheng	117.513624	27.337211	Nanping Shaowu city
8.	Putian Yuewangtai	118.991063	25.612922	HanJiang district
9.	Xianyou Jizicheng	118.731129	25.392553	Xianyou county, Putian city
10.	Xianyou Shewancheng	118.807183	25.517773	Xianyou county, Putian city
11.	Xianyou Longchuancheng	118.813416	25.688141	Xianyou county, Putian city

Table 5. Starting points of ancient roads of the Minyue Kingdom

No.	Name	Longitude	Latitude	Location
1.	(Minyue capital city) Xindian ancient city ruins (from)	119.292904	26.095606	Gulou district, Fuzhou city, Fujian province
2.	Jian'ou (from)	118.045281	27.555698	Wuyishan city, Nanping city
3.	Nanping (from)	118.11386	27.327846	Jianyang Datan Mountain, southeast of the stream
4.	West Fujian Yongding (from)	118.526995	27.919668	Shuinan road, Pucheng county, Nanping city, Fujian province
5.	Shun Chang (from)	118.531596	28.068851	Pucheng county, Nanping city
6.	Ninghua (from)	118.466624	27.806233	Pucheng county, Nanping city
7.	Mount Wuyi, Minyue Kingdom (from)	117.513624	27.337211	Nanping Shaowu city

4. Results

The application of the LCP model in reconstructing the ancient roads of the Minyue Kingdom yielded results that align remarkably with historical records, thereby validating the LCP's efficacy in ancient road restoration studies. Our research identified 13 principal ancient roads dating back to the Minyue period, encompassing a total distance of over 10,000 km. These include (Figure 6):

(i) Pre-Qin Minyue Kingdom's riverine ancient pathways,
(ii) Han army's route of attack against the Minyue Kingdom,
(iii) Minyue's ancient pathway to Jianhua (now Ningdu) in Jiangxi province, China,
(iv) Minyue's route for military expeditions toward Nanyue,
(v) Branch route of Minyue's military expedition toward Dongou,
(vi) Minyue's military expedition route toward Dongou,
(vii) Branch route of Minyue's pathway to Poyang Lake in Jiangxi province, China,
(viii) Minyue's pathway to Poyang Lake in Jiangxi province, China,
(ix) Minyue Kingdom's riverine ancient pathways,
(x) Yu Shan's anti-Han military routes,
(xi) Ancient pathways along Futun Creek and Jian Creek,
(xii) Minyue's pathway to Guangchang in Jiangxi province, China,
(xiii) Chanting ancient pathway to Ruijin in Jiangxi province, China.

These extensive networks of land and water transportation routes not only facilitated socio-cultural exchanges within Fujian, Zhejiang, Jiangxi, and Guangdong provinces in China but also played a critical role during military confrontations with the Han rulers. The ancient road network established during the Minyue Kingdom era is pivotal, as it forms the genesis of the modern provincial traffic framework. Consequently, understanding these ancient pathways is instrumental for contemporary inter-provincial tourism planning in Fujian, offering invaluable insights into the region's historical transportation dynamics.

The application of the LCP model, underpinned by high-resolution DEM and Landsat 8 imagery, has yielded precise reconstructions of the ancient road networks of

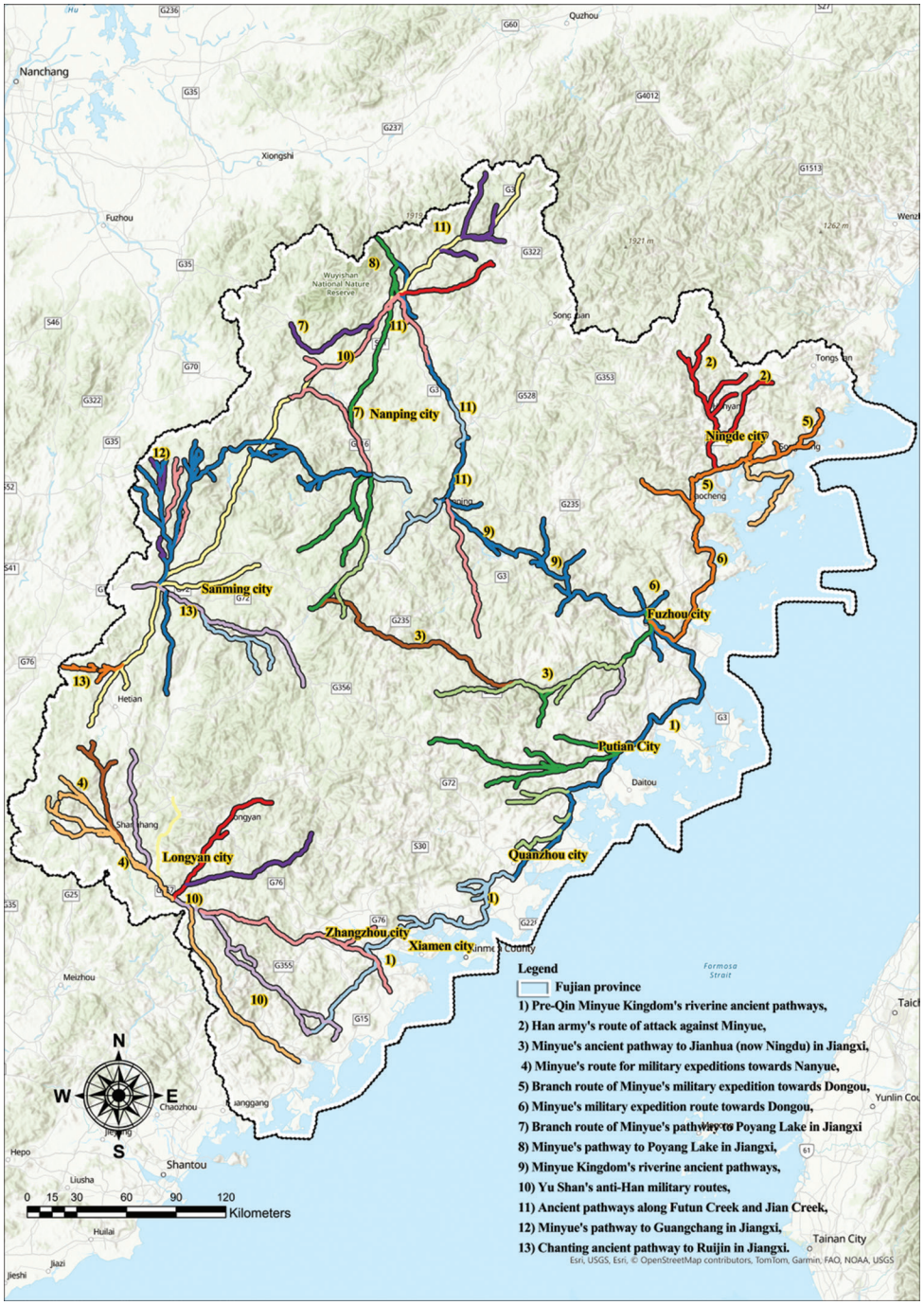

Figure 6. Reconstruction results of ancient roads during the Minyue Kingdom period in the present-day Fujian province, China
Source: Drawing by the authors.

the Minyue Kingdom. Our results identified several key routes that played significant roles during the Minyue era, facilitating various aspects of military logistics, economic trade, and cultural exchange.

(i) Spatial analysis and road reconstruction: The integration of GIS technologies allowed for the detailed mapping of ancient pathways, revealing a network spanning over 10,000 km. Key military routes comprised a significant portion of these pathways, utilized during confrontations with neighboring regions. In addition, the network supported economic activities such as trade and agriculture.

(ii) Identification of key nodes: This analysis involved pinpointing several critical nodes along the roads,

such as forts, trading posts, and settlement areas. These nodes were essential for the strategic control and economic development of the Minyue Kingdom. The nodes not only served logistical purposes but also facilitated cultural interactions and the spread of goods and ideas across the region.

(iii) Topographical and geographical impacts: Fujian's diverse topography significantly influenced the development of road networks. The rugged terrain dictated the placement and structure of roads, shaping the economic and military strategies of the Minyue Kingdom. The roads adapted to mountains, valleys, and waterways, illustrating an intricate understanding of landscape utilization and management.

(iv) Cultural and historical insights: The reconstruction of the road networks offered deeper insights into the social and cultural dynamics of the Minyue period. The roads were more than mere conduits for travel; they were lifelines that carried cultural narratives, artisanal knowledge, and religious practices. They facilitated the spread of Buddhism and other cultural elements from South to East Asia, enriching the cultural fabric of the region.

(v) Technological validation: Our use of the LCP model validated its effectiveness in archaeological and historical studies. The model not only accurately mapped known roads but also predicted previously undocumented routes based on geographical and topographical data. This capability underscores the potential of GIS and remote sensing technologies in uncovering and preserving unseen aspects of human history.

These results collectively contribute to a nuanced understanding of the Minyue Kingdom's transportation infrastructure and its broader socio-economic and cultural contexts. The successful mapping and analysis of these ancient roads open new avenues for the exploration of historical interactions across Asia, providing a valuable framework for future archaeological investigations and heritage conservation efforts.

5. Discussion

This study leverages GIS and the LCP model to reconstruct and analyze the ancient transportation networks of the Minyue Kingdom, providing critical insights that enhance the understanding of early Chinese civilization's logistical, economic, and cultural practices. As illustrated in Figure 6, particularly, the key findings highlight 13 principal routes that constituted the backbone of the Minyue Kingdom's transportation network. These included essential military and trade pathways, such as the riverine routes, connections between Minyue and Jiangxi province, and military expedition routes toward Nanyue and Dongou. Collectively, these routes spanned over 10,000 km, connecting a vast area encompassing present-day Fujian, Zhejiang, Jiangxi, and Guangdong provinces, in China.

The identification of these routes, along with previously undocumented branches, underscores the adaptability and strategic design employed by ancient societies in navigating challenging terrain. This extensive network facilitated not only inter-regional economic activities but also social, cultural, and religious exchanges, suggesting the existence of a sophisticated infrastructure essential to the socio-political development of the Minyue Kingdom.

The application of the LCP model allowed for precise mapping of these pathways, offering new historical insights and a validated approach for reconstructing ancient road networks. By pinpointing specific route nodes, such as trading posts and forts, our analysis provides valuable data on the spatial distribution of strategic points that significantly influenced the kingdom's economic and cultural landscape. These findings have broad implications, contributing not only to archaeological research on the Minyue Kingdom but also providing a foundation for future studies in other historically rich, yet geographically complex regions.

In summary, this study demonstrates the profound utility of GIS technology in archaeological and historical research, paving the way for innovative preservation strategies and enhancing the understanding of ancient civilizations. The methodology established here serves as a replicable model for similar analyses worldwide, reinforcing the significance of integrating technological tools in exploring and safeguarding cultural heritage.

6. Conclusion

The findings of this study provide valuable insights into the ancient road networks of the Minyue Kingdom. To ensure the validity of our propositions, we employed a multi-faceted validation approach. Specifically, our results were cross-referenced with existing archaeological evidence, including artifacts and historical records, where available. In addition, we conducted a sensitivity analysis to assess the impact of variations in model parameters, thereby reinforcing the robustness of our findings. This methodological rigor underscores the credibility of our study.

In discussing our results, we acknowledge the importance of contextualizing them within the existing body of research. While limited studies specifically address the ancient road networks of the Minyue Kingdom, we

highlight relevant literature on ancient transportation systems in similar geographical contexts. Furthermore, historical documents and records referencing ancient routes are noted as potential avenues for future research, which could enrich the understanding of the Minyue period.

Regarding the use of modern Landsat 8 remote sensing imagery, we recognize the significance of this choice in our analysis. It is essential to note that the geographical features of Fujian province have remained relatively stable over the centuries due to its enclosed geographical location. This stability allows contemporary DEM and Landsat 8 imagery to be effectively utilized in studying the ancient road networks of the Minyue Kingdom. While urbanization and land-use changes have altered specific areas, the overall topographical context remains consistent, ensuring the relevance and applicability of our findings to the historical landscape.

In conclusion, the integration of modern technologies with historical analysis facilitates a deeper understanding of ancient transportation networks. Our study not only contributes to the archaeological record of the Minyue Kingdom, but also highlights the need for further exploration of historical documents to enhance future investigations into ancient road systems.

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Conflict of interest

The authors declare that they have no competing interests.

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Availability of data

Data will be made available from the corresponding author on reasonable request.

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VIEWPOINT

Mitigating risks of natural and human-made disasters caused by excessive urbanization

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Abstract

Urbanization, a significant outcome of the Industrial Revolution, has led to the excessive concentration of industries and populations in geologically vulnerable areas, such as low-lying coastal and riverside zones. This geographic clustering amplifies the risk of disasters, such as floods. Geological and archeological evidence highlights a long history of natural disasters, such as severe flooding often associated with earthquakes and other geological events. To address these risks, governments must reassess the vulnerability of densely populated areas and prioritize the implementation of risk reduction and mitigation measures. One potential strategy involves relocating key industries to safer locations, such as higher elevations less prone to flooding, while simultaneously developing measures to protect urban populations from natural disasters.

Keywords: Urbanization; Climate change; Natural disasters; Social development; Welfare policy

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1. Introduction

Urbanization has been an important driving force for economic and social development, playing a particularly significant role in regional economic growth (Cai *et al*., 2019). The concentration of population in urban areas has facilitated the development of industrial agglomerations, leveraging the synergy between industries and the employment opportunities created by a large urban population. This synergy fosters the development of economies of scale and enhances human well-being by improving access to jobs, medical services, and education, thereby advancing both economic productivity and the quality of life for urban residents (da Silva *et al*., 2017). Consequently, urbanization has attracted extensive attention in global planning initiatives, such as the United Nations' 2030 Agenda for Sustainable Development (https://sdgs.un.org/2030agenda) and various international collaborative efforts (Elmqvist *et al*., 2019). However, the rapid and often uncontrolled expansion of urban areas has brought significant challenges, such as environmental degradation and ecological imbalances, which have emerged as pressing global challenges (Bloomberg, 2015; Uttara *et al*., 2012). As a result, identifying pathways to safer and more sustainable urbanization has become an urgent imperative.

According to the United Nations' World Population Prospects 2024 (https://population.un.org/wpp/), while the world's population is projected to peak within this century, one-quarter of the global population already resides in countries and

regions where population levels have peaked. In addition, the proportion of people living in urban areas is expected to rise to 70% by 2050 (Cai *et al.*, 2019). Urban agglomeration appears to be an inevitable outcome of human civilization's evolution, and urbanization is now an unstoppable global trend.

This urban expansion has clear economic advantages. For instance, in China, every 1% increase in the urbanization rate is estimated to contribute approximately 1.5% to GDP growth (National Development and Reform Commission of China, 2016). Accordingly, China's urbanization rate has rapidly surged from 17.9% in 1978 to 64.7% in 2021, driven by both economic benefits and policy guidance (National Bureau of Statistics of China, 1979 – 2021). This shift represents perhaps the largest population migration in human history. However, despite its undeniable economic benefits, this rapid urbanization has also exacerbated obstacles to sustainable development by concentrating human activity and its environmental impacts into increasingly dense urban areas.

Cities contribute about 70% of the global GDP and serve as the core of the global economy (Kosovac *et al.*, 2020). The rapid development of global trade has further accelerated the migration of the world's economic centers and inland populations toward coastal and riverside areas, exacerbating regional development imbalances in inland regions. This pattern of urban growth increasingly appears unsustainable, contributing to significant ecosystem degradation and other adverse effects (Nguyen *et al.*, 2019). At the same time, beneficial but inequitable policies that favor urban residents over rural residents – such as price controls on agricultural products, preferential access to welfare and social services, and tax incentives for exporters (Cao *et al.*, 2009) – have further intensified the overdevelopment of urban and coastal regions, deepening the divide between urban and rural areas. These inequitable government actions and market behaviors collectively distort a country's social and economic development, while the associated environmental risks remain insufficiently addressed by economists and governors.

The consequences of unsustainable urbanization are reflected in the decline of ecosystem service values (Basu & Das, 2021; Mitchell *et al.*, 2015). More critically, the concentration of population in low-lying coastal areas and seismically active fault zones significantly increases the risk to human lives and infrastructure. Historical examples reveal that cities can collapse under the pressures of disasters, particularly when they exceed their maximum sustainable scale (Seto *et al.*, 2010).

To achieve safe and sustainable social and economic development, governments must look beyond purely economic development strategies. A more balanced regional approach is essential, one that accounts for the growing risks posed by concentrated human population in cities.

2. Causes of excessive urbanization

Humans, along with our crops and animals, require continuous access to freshwater resources. Consequently, most villages and cities have historically been established on low-lying riverbanks or near coastal areas to facilitate trade through ports, despite the increased risk of natural disasters such as floods and tsunamis (Chen and Cao, 2013). Rivers offer significant advantages for agricultural and logistical activities, such as providing nutrient-rich soil for crop cultivation, improving irrigation conditions, and enabling lower costs for accessing freshwater resources. In addition, lakes and seas support inexpensive transportation of large cargoes between coastal cities, making these areas highly favorable for human settlements.

However, these low-lying areas – particularly in the lower reaches of rivers and along the shores of lakes and oceans – are highly vulnerable to water-related natural disasters. Runoff from heavy rainfall or snowmelt at higher elevations can lead to excessive water accumulation and fast-moving flow, significantly increasing the risk of waterlogging and flooding (Esfandeh *et al.*, 2022; Grimmond, 2007).

In addition to water access, the search for rare mineral resources has also driven urbanization. Mining activities often lead to the establishment of cities and mine ores around geological fault zones and volcanoes, particularly when these areas are near important water sources that can support a large population and water-intensive industries. Unfortunately, the scarcity of suitable land often forces people to cluster in low-lying areas or on steep slopes, areas that are highly prone to flash flooding and landslides (Deacon & Samways, 2021). These risks are further exacerbated by land degradation (e.g., deforestation, which reduces the interception and retention of rainfall and meltwater), along with increased precipitation driven by the interplay of topography and climate change. Earthquake-prone regions add yet another layer of vulnerability for these communities.

Another advantage of urbanization is its ability to reduce transportation costs and improve the efficiency of commodity and information exchange. To capitalize on these benefits, humans have increasingly migrated to cities. Between 2000 and 2018, the number of cities with a population exceeding 500,000 grew at an average annual rate of 2.4%. By 2018, there were 548 cities worldwide with a population of at least 1 million, a significant increase

from 371 in 2000. This number is projected to rise to 706 by 2030 (United Nations, 2018). However, despite these economic benefits, urban concentration carries significant risks that are often underestimated. One such risk is the heightened damage from natural hazards, such as hurricanes, earthquakes, floods, and fires, because the extent of damage tends to increase rapidly with population density (Zhang *et al*., 2007).

Furthermore, agricultural subsidies implemented by most industrialized countries, alongside price controls on agricultural products for urban residents, have contributed to lower urban food prices (Zhao *et al*., 2014). Combined with additional subsidies for medical care, education, and insurance, urban life has become increasingly attractive (Cao *et al*., 2009). This attractiveness is further reinforced by the misconception that urbanization equates to modernization, driving excessive urbanization and the development of megacities. Modern cities are characterized by high population density and heavy reliance on resource imports for their continued functioning. This dependency makes them increasingly vulnerable to both natural and human-made disasters that disrupt resource supply chains (Rebelo *et al*., 2011). Global warming has further exacerbated this issue, as rising sea levels pose an escalating risk to people settled in low-lying coastal areas.

3. Risks created by excessive urbanization

From a historical perspective, while excessive population concentration may yield short-term economic benefits, it often exacerbates long-term risks of natural disasters. Large cities are increasingly facing environmental hazards. When the population size exceeds sustainable limits, cities may become vulnerable to collapse (Odum & Odum, 2001; Seto *et al*., 2010). Rapidly expanding cities often extend urban areas into flood-prone zones in an attempt to alleviate congestion, inadvertently increasing their exposure to natural disasters. Between 1985 and 2015, the global area covered by cities expanded by an average of 85%, while the area of settlements located in regions facing the highest flood risk increased by 122% (Rentschler *et al*., 2023). At present, more than 100 million people around the world live in coastal areas at serious risk of flooding, with elevations of < 1 m above sea level (Seto *et al*., 2010).

Global trade has accelerated the pace of coastal development, coinciding with global sea level rise (Pilkey & Cooper, 2004). This combination makes coastal cities increasingly vulnerable to tsunamis. In addition, global climate change has amplified the frequency and intensity of hurricanes, even for inland cities not directly threatened by rising sea levels. For example, the tsunami that struck Indonesia on December 26, 2004, resulted in at least 170,000 deaths, while the 2011 Fukushima earthquake and the subsequent tsunami caused 15,878 deaths, with 2,713 people reported missing and more than 340,000 displaced (Wang *et al*., 2016).

As urbanization increases, disease outbreaks have become an escalating concern. Densely packed human population significantly increases the spread of communicable diseases, particularly waterborne illnesses, in developing countries. For example, multiple cholera outbreaks in African cities such as Lomé and Tamatave suggest that reported epidemics in densely populated urban areas are often associated with low-lying land, where the incidence of cholera is notably higher (Zerbo *et al*., 2020). However, even developed countries are not immune to the increased risk of disease epidemics, as exemplified by the global COVID-19 pandemic that began in 2020.

Natural disasters also pose a substantial threat to urban residents, often resulting in a devastating loss of life. For example, the magnitude 7.8 earthquake in Tangshan, Hebei, China, on July 28, 1976, caused approximately 240,000 deaths, while the magnitude 8.3 earthquake in Xi'an, Shaanxi, China, on January 23, 1556, led to an unprecedented 830,000 deaths. Calculating the economic return of urbanization using only simple market prices, without accounting for the impacts of environmental degradation, natural disasters, and other hidden costs, can dangerously overlook these additional hazards of urbanization.

Historically, natural disasters have always posed existential threats to human societies. In China, for example, the relatively advanced *Liangzhu* culture (3300 – 2300 BCE) in present-day northern Zhejiang and the *Longshan* culture (3000 – 1900 BCE) in northeastern China both were abruptly extinguished due to seawater intrusion caused by a massive tsunami, which flooded extensive low-lying areas. Archaeological evidence suggests a significant regression of these cultures, even though some people survived the disasters (Yu, 1997). Further archeological findings indicate that rising sea levels inundated China's eastern coast during two distinct periods: 2 – 57 CE and 465 – 527 CE. Evidence shows a near absence of human activity in areas below 4 m above sea level along the eastern coast during 1 – 600 CE (Yu, 1995).

As sea levels rise, coastal low-lying areas become increasingly vulnerable to tsunamis, particularly in tectonically active regions, such as the Pacific "Ring of Fire." Therefore, it is necessary to implement proactive measures to mitigate such risks before they escalate into disasters. For example, residents in flood-prone areas should be encouraged to relocate from low-lying, highly developed areas to higher elevations. While this movement

may be costly, it is far easier – and likely less expensive – than rebuilding after a catastrophic event.

Natural disasters are often closely accompanied by social crises, as illustrated by the collapse of China's *Liangzhu* and *Longshan* cultures. Large-scale natural disasters can trigger severe social upheavals, such as the collapse of political power, wars, dramatic population decline, and associated consequences. For example, the Bohai tsunamis that struck China approximately 2,000 years ago coincided with the collapse of the Western Han dynasty (202 BCE – 8 CE) and contributed to the onset of the most chaotic and violent period in Chinese history: the Northern and Southern dynasties (420 – 589). During this period, farmers were often slaughtered as soldiers sought to seize their food supplies. The turmoil persisted until 589 CE when emperor Yang Jian of the Sui dynasty (541 – 604) reunified China and restored order.

In modern times, global economic activity, including in China, is heavily concentrated in low-elevation coastal areas. Disaster mitigation and response strategies in these regions often rely on standard models developed based on the frequency of return of a disaster (e.g., a "100-year flood"). However, such models fail to adequately account for the larger, less frequent disasters that have occurred throughout history, as well as the increasing frequency and severity of disasters driven by global climate change.

The world's rapidly growing population continues to place immense pressure on the environment and the infrastructure essential for supporting life in large modern cities (e.g., water supply, drainage, and waste disposal systems). Repeated episodes of urban flooding have sounded the alarm regarding both inundation risks and associated urban epidemics (Sun *et al.*, 2020). For example, the July 20, 2021, heavy rainstorm in Zhengzhou resulted in 398 deaths, affected nearly 15 million people, and caused economic losses of 53.2 billion Chinese yuan (Figure 1). Unfortunately, this event is not an isolated case but rather an inevitable consequence of urban expansion and the evolution of large cities. Most urban infrastructure, such as streets and roads, is impermeable, preventing rainwater infiltration. Consequently, stormwater runoff concentrates, exacerbating urban flood hazards, which increasingly resemble flash floods observed in some natural ecosystems (Zhang *et al.*, 2021). In recent years, the uncontrolled expansion of Chinese cities has made flood disasters increasingly common – so much so that many Chinese citizens humorously remark online about "going to an inland city in the summer to see the sea."

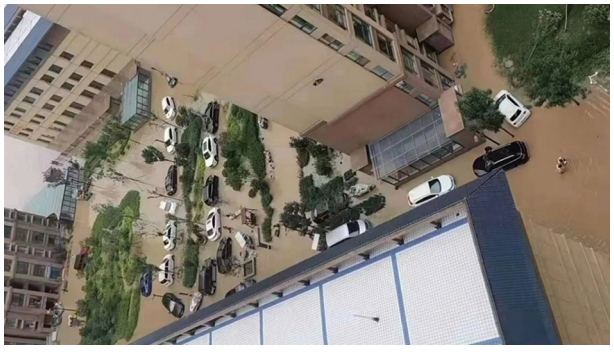

Figure 1. The extraordinarily heavy rainfall on July 21, 2021, in Zhengzhou, China, resulted in 380 deaths and caused billions of Chinese Yuan in economic damage. Source: Photo by the authors

4. Mitigation strategies

The development of human society increasingly depends on knowledge-based industries, which do not require proximity to ports and reliance on water transportation to distribute services. Unlike sectors focused on physical products, knowledge-based economies depend on engineering and technical personnel who produce software and intellectual resources. This sector's flexibility allows for relocation to safer areas that are more distant from the coast and situated at higher elevations.

However, coastal areas remain critical for importing and exporting essential inputs (e.g., industrial chemicals, fuels, and metals) that sustain cities and the industries they support. The coastal areas naturally evolve into hubs of industrial activity and dense population centers. If disasters such as coastal flooding strike these areas, the consequences are far-reaching. As demonstrated by the COVID-19 pandemic, the human costs – both locally and at the ends of global supply chains – can be severe and, in many cases, exceed the economic damage.

To mitigate these problems, governments must reconsider the subsidies that encourage migration to coastal cities. In some cases, it may be more practical to incentivize migration to inland cities beyond the reach of floodwaters. This initiative can be achieved by investing in efficient, inexpensive railway transport that connects inland cities to coastal hubs for overseas shipping. Large national programs, such as the China Railway Express, a key component of the national "Belt and Road" strategy aimed at increasing trade with Europe, could play an important role in providing this alternative to coastal ports (Gao, 2022). However, these railway links often run through areas prone to rainfall-induced landslides or structural damage to critical infrastructures, such as bridges. As a result, planners and managers must carefully consider the risk posed by extreme events, such as "thousand-year floods," and implement measures to reduce risk and mitigate the severity of potential disasters.

Advanced technology will be essential in addressing these risks. Big data analysis can be powered by networks of sensors to monitor geological and climatic changes and identify related hazards. Artificial intelligence technologies can build risk assessment models, improve the accuracy of early warnings, simulate disaster scenarios to support the development of response plans, and provide predictive data for urban planning and emergency preparedness. In addition, satellite systems enable rapid, cost-effective monitoring of large areas and facilitate the smooth dissemination of information during disasters.

In many industries, particularly in computer and knowledge-based sectors, transportation costs are minimal or negligible. As a result, these industries do not require proximity to coastal areas. Instead, they can be relocated to less-populated inland cities that are safer from natural disasters, such as tsunamis. This relocation not only promotes development in inland cities but also reduces the risk of disruption to these industries caused by catastrophic events. For example, Guizhou, in western China, is well suited for large-scale data-storage systems due to its favorable climate.

However, it remains challenging to convey both the severity of these risks and the potential mitigation strategies to governments and industrial investors. The Chinese government, for example, has not prioritized shifting its regional economic development plans to safer inland areas, such as western China's Tibetan Plateau. Instead, in 2019, it reaffirmed its focus on developing Guangdong, Hong Kong, and Macau – coastal cities at low elevations – as key economic regions, with plans to expand even larger urban agglomerations in the future.

The ongoing expansion of coastal cities must account for the potential threat posed by natural disasters, such as tsunamis and hurricanes. To address these risks, comprehensive risk assessments should be carried out during the early stages of urban planning to identify high-risk areas. The primary goal of this analysis is to avoid constructing critical infrastructure and major residential development in areas vulnerable to disasters. At the same time, governments must establish and enforce strict building standards and codes to ensure that new development projects are adequately resistant to earthquakes and tsunamis. Key measures include: (i) raising the 1st floor of buildings above anticipated flood levels; (ii) using earthquake-resistant materials and designs; and (iii) designing structures that facilitate rapid evacuation in emergencies. In addition, it is crucial to establish an efficient and reliable tsunami early warning system. This system should incorporate seismic monitoring stations and sea-level monitoring equipment to detect early signs of a tsunami. Immediate dissemination of warnings to the public will help minimize casualties and property damage by enabling timely evacuations.

5. Conclusion

A global view of Earth from orbit reveals dense clusters of city lights concentrated in coastal areas and along rivers. These illuminated regions symbolize economic development, but they also highlight areas of extreme vulnerability to natural disasters. Disasters in such areas extend far beyond economic and environmental damage. They impose an enormous human cost through immediate impacts, followed by secondary crises such as disease and famine. These cascading consequences often heighten tensions among people and even between nations, further exacerbating the disaster's aftermath. To mitigate these risks and reduce the severity of disasters, all nations with extensive and densely populated coastal areas – as well as those located near tectonically active zones – must act swiftly. This proactive approach involves: (i) identifying areas at greatest risk; (ii) developing risk reduction and mitigation measures; and (iii) implementing these measures without delay. This is particularly urgent given the escalating and unpredictable consequences of global warming.

Reducing the risks of urbanization requires the dispersal of the urban population, as densely populated areas face the highest potential loss of life when disasters strike. It is also essential to disperse economic centers of gravity to prevent the devastation of an entire industrial sector by a single disaster. Governments should discourage or prohibit development in areas prone to tsunamis and earthquakes.

The urban component of long-term government planning should increasingly shift economic focus to inland areas located in tectonically stable zones to reduce the dependence on ports. By controlling population density in high-risk coastal areas, distributing residential, commercial, and industrial centers to more suitable locations, and encouraging migration to inland areas, mitigation measures can become both easier to implement and more effective. These measures include:

- Optimizing transport network to provide multiple rapid evacuation routes
- Investing in efficient, high-capacity flood control and drainage systems to improve a city's ability to withstand floods; and
- Restoring and protecting natural ecosystems, such as mangroves and wetlands that function as natural breakwaters, and forests on sloping land that reduce the risks of landslides and flash floods.

Governments and industries must adopt a holistic approach that considers multiple interconnected factors to design safer, more resilient cities.

Furthermore, the aftermath of tsunamis presents an additional risk: low-lying land often becomes salinized by seawater pushed inland, resulting in severe damage to arable land and, in some cases, rendering it unsuitable for crop cultivation. This can lead to temporary or long-term famine, social unrest, political instability, and other cascading social crises.

To address this, governments must urgently protect essential agricultural land from conversion to other uses, particularly in higher-elevation areas that are less vulnerable to salinization, and increase food reserves by storing grain and other crops in dry, tectonically stable areas where they will remain safe from flooding damage.

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Conflict of interest

The authors declare that they have no competing interests. The opinions expressed here are those of the authors and do not necessarily reflect the position of the Government of China or of any other organization.

Author contributions

Conceptualization: Shixiong Cao
Writing – original draft: All authors
Writing – review & editing: All authors

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Availability of data

The data discussed in this article were obtained from published sources (Cai *et al.* [2019], Pilkey & Cooper [2004], Seto *et al.* [2010], Wang *et al.* [2016], Yu [1995], Yu [1997], Zhang *et al.* [2007]). A summary of the data is available from the authors upon request, as cited in the references.

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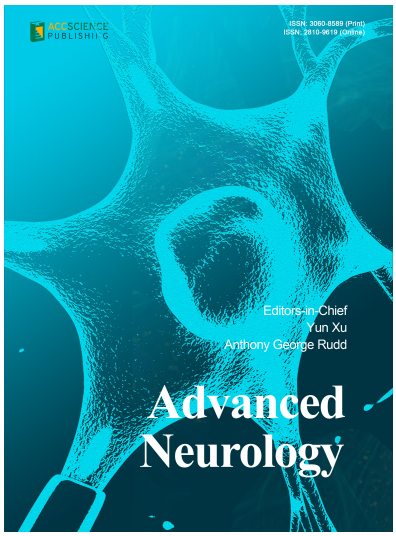

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