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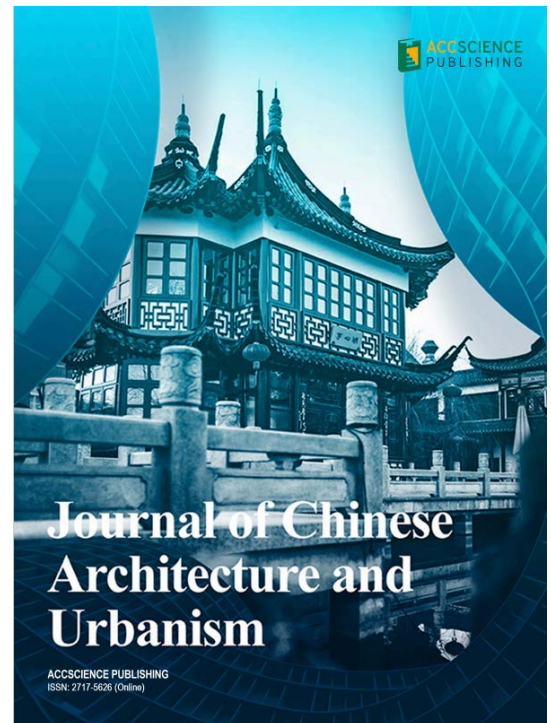


# Journal of Chinese Architecture and Urbanism

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# Journal of Chinese Architecture and Urbanism

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# Journal of Chinese Architecture and Urbanism

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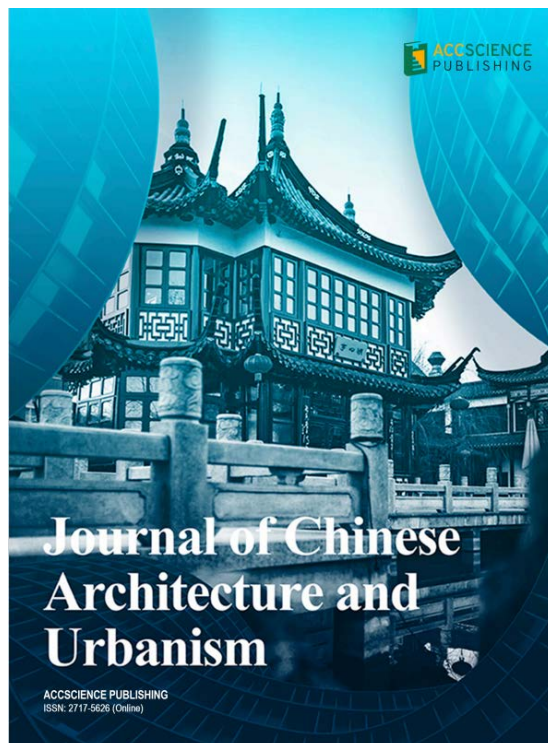
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A typical Chinese-styled building

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## EDITORIAL

Cultural characteristics and application of  
adaptive inheritance technology to traditional  
Chinese rural areasCheng Wei<sup>1,2†</sup>  and Xiaoxiang Tang<sup>2,3†\*</sup> <sup>1</sup>Department of Urban Planning, School of Architecture, South China University of Technology, Guangzhou, Guangdong, China<sup>2</sup>National Key Laboratory of Subtropical Architecture and Urban Science, South China University of Technology, Guangzhou, Guangdong, China<sup>3</sup>Department of Landscape Architecture, School of Architecture, South China University of Technology, Guangzhou, Guangdong, China

(This article belongs to the *Special Issue: Cultural Characteristics and Application of Adaptive Inheritance Technology to Traditional Chinese Rural Areas*)

China's traditional rural areas harbor some of the world's most extensive and representative cultural heritage, characterized by a wealth of regional history, folklore, and art. However, recent years have witnessed a rapid surge in urbanization and rural construction driven by the push for rural revitalization, significantly impacting the protection and inheritance of traditional rural culture. The evident disparities across China's rural areas necessitate tailored approaches to cultural protection and inheritance, accommodating diverse lifestyles and spatial utilization patterns in different regions. Addressing how to develop regionally adapted conservation and utilization techniques aligned with the unique rural cultural characteristics and development needs is an urgent issue facing the inheritance of traditional rural regional culture in China.

In response to this imperative, this Special Issue focuses on exploring the regional cultural characteristics of Chinese villages and their applications in conservation and inheritance technologies. It encompasses a range of topics, including the regional adaptive protection methods of typical regional traditional villages, the combination of regional culture and modern rural green building technology, the regional adaptive construction methods of new rural buildings, and the adaptation relationship between the indoor physical environment of traditional folk houses and regional climate characteristics. These discussions provide valuable references for the scientific recognition of rural cultural values, as well as for the implementation of adaptive protection and utilization techniques.

In the first article, Wei *et al.* (2023) used Jiangbian Village in Dongguan City, a rapidly urbanizing area, as a case study. They explored the cultural heritage value and location characteristics of the village and proposed a strategy that integrates traditional village elements with the surrounding urbanization development trend. Their approach involves fostering cross-regional integrated development by leveraging surrounding resources. They advocate for the utilization of idle spaces within Jiangbian Village, integrating urban functions and public service facilities. By aligning these efforts with the overall regional development pattern, they aim to foster the coordinated development of both villages and cities. Ultimately, their goal is to realize dynamic protection and utilization of traditional villages amidst rapid urbanization.

<sup>†</sup>These authors are the guest editors for this Special Issue.

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In the second article, Bai *et al.* (2023) developed a comprehensive technical system for the green transformation of rural buildings, integrating them into the regional culture. They approached this task from five key aspects: regional characteristic building, outdoor environment improvement, envelope performance optimization, indoor environmental quality improvement, and renewable energy utilization. Grounded in the theoretical tools of cultural regionality, they explored strategies to achieve green and sustainable development of rural buildings in the Guangfu area of Lingnan. To illustrate their approach, they examined the renovation of Nanping Village settlements in Conghua City, Guangzhou.

The escalating demands brought about by rapid urbanization and population growth are impacting the built environment, quality of life, and energy consumption. In the third article, Liu *et al.* (2023) examined the indoor solar and thermal environment, as well as energy consumption, in traditional Miao dwellings within Xiangxi Tujia and Miao Autonomous Prefecture, Hunan province, China. Through monitoring and simulation, they delve into the compatibility between Miao dwellings and their surrounding environment. Their study reveals the efficacy of traditional Miao dwellings in adapting to local climatic conditions and summarizes the advantages and disadvantages of their indoor light and heat environment in western Hunan province. Furthermore, they evaluated the adaptability of local dwellings to regional geography and climate.

“Grotto-Heavens and Blissful Lands” (*Dongtianfudi*, 洞天福地), originating from Daoist philosophy, originally denoted sacred mountain retreats where deity resided. Today, it symbolizes places of scenic beauty. In the fourth article, Wang *et al.* (2023) summarize the esthetic characteristics of Jingfu Mountain, drawing from three dimensions rooted in the theory of culture and regional character within landscape architecture esthetics. Taking Jingfu Mountain in the Lingnan region as an example, they explore its regional and technical characteristics of adaptation to local conditions, as well as its social significance. Through this analysis, they highlight the milieu of landscape architecture esthetics, emphasizing the pursuit of inner pleasure and the integration of diverse cultures. They also examine the artistic and human qualities exhibited by Jingfu Mountain, including clarity, quiescence, exquisiteness, elegance, morality, and righteousness. This research provides valuable research support for the regional protection and living inheritance of the Daoist “Grotto-Heavens and Blissful Lands” cultural landscape.

Chinese villages stand as the most widely distributed traditional settlements and repositories of vernacular

architecture in China. They embody rich regional culture and ecological construction wisdom, holding significant regional historical, folk, and artistic value. Given the close relationship between traditional settlements, vernacular architecture, and the geographical environment, as well as natural and geographical conditions, substantial variations exist among settlements and vernacular constructions across different regions. In this Special Issue, the four papers aim to summarize the characteristics of rural regional culture and the application of protection and inheritance technologies in various regions of China. They consider the geographical environment and locational conditions of the empirical objects. However, these four articles provide only a glimpse into the broader picture. We hope for further academic research to offer more detailed insights into the preservation and inheritance of traditional Chinese settlements and vernacular architecture – a task of utmost importance.

As China’s urban-rural development has gradually entered a transition period of focusing on stock transformation and quality improvement, the role of culture has become increasingly prominent in the current phase of comprehensive and high-quality urbanization development. On September 3, 2021, China issued the Opinions on Strengthening the Protection and Inheritance of Historical and Cultural Heritage in Urban and Rural Construction. These opinions underscore the necessity of establishing a system for the protection and inheritance of urban and rural culture characterized by scientific classification, robust protection, and effective management. They emphasize the need to coordinate the protection and utilization of cultural heritage, aiming for comprehensive spatial coverage and inclusivity of all elements. This indicates that cultural protection and inheritance serve as an important orientation for China’s urban and rural construction in the New Era. Strengthening historical cultural protection and inheritance has become an inevitable choice for China to achieve high-quality development, with far-reaching implications for shaping a new urban and rural development pattern and promoting the high-quality development of China’s living environment.

This initiative has injected a boost to the protection and utilization of rural cultural heritage, which was previously widely neglected. It calls for fully exploring scattered and remote rural historical cultural resources in a timely and effective manner, clarifying protection requirements, addressing the shortcomings of supporting infrastructure and public service facilities, improving disaster prevention, mitigation, and relief capabilities, enhancing the living environment, maximizing the value of rural cultural

resources, facilitating rural revitalization, and playing its due role in promoting the high-quality development of China's urban and rural human settlements.

## Funding

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## Conflict of interest

The authors declare that they have no competing interests.

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## REVIEW ARTICLE

## Progress, limitations, and prospects for improvement in understanding the impact of urban built environment on residents' leisure-time physical activity in China: A systematic review

Fan Yang<sup>1</sup>, Chao Ge<sup>2,3\*</sup>, and Jiayin Wang<sup>1</sup><sup>1</sup>Department of Urban Planning, College of Architecture and Urban Planning, Tongji University, Shanghai, China<sup>2</sup>Faculty of Innovation and Design, City University of Macau, Macau, China<sup>3</sup>The Second School of Clinical Medical, Guangdong Medical University, Dongguan, Guangdong, China

## Abstract

Leisure-time physical activities (LTPAs) play a crucial role in improving health. Likewise, improving certain aspects of the built environment is essential for promoting residents to engage in LTPA. However, the impact of urban built environment characteristics on residents' levels of LTPA and its underlying mechanism remain unclear. To address this gap, we conducted a systematic literature review in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analysis guidelines. In 2022, we searched eight databases and identified 453 relevant publications. The selected literature had to meet specific inclusion criteria: (i) the sample targeted Chinese adults ( $\geq 18$  years), and (ii) it quantified the effect of urban built environment characteristics on residents' levels of LTPA. Out of the initial pool, 18 articles met our inclusion criteria. Our findings indicate that although previous studies have revealed that esthetic perception and road safety can facilitate residents' participation in LTPA, there is a lack of methods for identifying built environment characteristics and analyzing the psychosocial mediation mechanism between the built environment and LTPA in specific populations. Improving the robustness of research conclusions is an important research direction that will yield solid evidence of the impact of the urban environment on human health. Limited evidence exists regarding the association between urban built environment characteristics in China and residents' LTPA levels. However, advancements in remote sensing images, computer vision in artificial intelligence, and machine learning technologies offer innovative avenues for modeling built environments and land use functions. Developing an impact mechanism model of the built environment and LTPA using individual perceptions and social psychological factors as mediating mechanisms is imperative. This approach will serve as a reference for urban spatial optimization and the development of spatial planning intervention tools.

**Keywords:** Leisure-time physical activity; Built environment; Mediating effects; Space optimization; Chinese cities

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## 1. Introduction

Urbanization often brings about heightened economic efficiency, bolstering human productivity, health, and overall well-being. However, when urbanization occurs too rapidly and without proper planning, it can yield numerous negative effects on both the environment and human health (Organization, 2021). The 2023 Chinese Statistical Bulletin reports that 65.2% of Chinese citizens already live in urban areas (China, 2023). Despite the economic benefits, urbanization has also led to an alarming prevalence of chronic diseases among the Chinese population, with rates soaring as high as 81.1% (Su *et al.*, 2023). The rapid expansion of urban areas often results in the depletion of green spaces and public areas due to high-density settlement patterns. This lack of accessible green and public spaces has contributed to a decline in physical activity levels among residents, thereby exacerbating the incidence of chronic diseases and premature mortality (Nieuwenhuijsen, 2016; 2020).

An increasing number of studies have focused on the association between the built environment (BE) and residents' physical activity levels. The 5D elements, namely, density, diversity, design, destination accessibility, and distance to transit, represent initial efforts in characterizing the BE and have been validated as key factors that influence residents' physical activities (Sallis *et al.*, 2020). According to the World Health Organization (WHO), physical activity encompasses any bodily movement driven by skeletal muscles that require energy expenditure, occurring across four domains: leisure time, occupation, household, and transportation. Research has underscored the benefits of leisure-time physical activities (LTPAs) for both physical and mental health, surpassing those of other forms of physical activity such as transportation, occupational, and household activities (Wens & Hansen, 2017). Elevated levels of LTPA have demonstrated a significant effect on suppressing increases in waist circumference as well as blood triglyceride and glucose levels (Fong, 2021). However, the considerable heterogeneity in personal and BE characteristics has clouded our understanding of the impacts and mechanisms underlying the relationship between LTPA and urban BE characteristics (Kärmeniemi *et al.*, 2018). It remains uncertain whether the above-mentioned effects of the five BE characteristics on physical activity are equally applicable to LTPA (Booth *et al.*, 2009; Cervero & Kockelman, 1997; Ewing & Cervero, 2010). Furthermore, the majority of relevant empirical studies have predominantly focused on developed countries, such as the United States, Canada, and various regions in Europe (Ding & Gebel, 2012; Van Dyck *et al.*, 2013), raising questions regarding the generalizability of these findings to other regions. Significant disparities exist between urban BE characteristics in developed and

developing countries (Sallis *et al.*, 2020), further emphasizing the need for comprehensive investigations across diverse geographical and socioeconomic contexts.

China's urbanization rate represents a unique phenomenon globally, marked by complex heterogeneity across multiple developmental stages. Therefore, we aim to conduct a systematic review of international literature to answer the following research questions: "Have Chinese academic circles found solid evidence regarding the impact mechanism of urban BE on residents' LTPA in Chinese cities?" and "Do previous studies reveal specific BE elements that play an important role in improving LTPA among distinct resident demographics?"

## 2. Methods

In this systematic review, we followed the criteria outlined in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Li *et al.*, 2023; Page *et al.*, 2021). Before commencing the literature search, we developed and registered the systematic review protocol with PROSPERO (PROSPERO ID: CRD42023457679).

### 2.1. Search terms and search strategy

In December 2022, we meticulously conducted a thorough search across eight databases, namely, PubMed, ProQuest, the Cumulative Index to Nursing and Allied Health Literature (CINAHL) Plus, PsycNet, SPORTDiscus, the Cochrane Library, Web of Science, and the China National Knowledge Infrastructure (CNKI). Given that terms associated with BE and LTPA may include medical terminology, we identified search terms collaboratively from both the Medical Subject Headings (MeSH) and Chinese Medical Subject Headings (CMeSH) databases. In addition, we searched synonyms related to BE and LTPA to ensure a comprehensive search (Peters *et al.*, 2020). Our search strategy adhered to the combined Boolean search strategy commonly used in systematic evaluation articles (Van Cauwenberg *et al.*, 2011). To ensure the inclusivity of the latest studies, we updated our search in June 2023. Detailed tables outlining our comprehensive and refined search strategies are available from the authors through reasonable request.

### 2.2. Inclusion and exclusion criteria for selecting articles

Eligible articles had to meet six inclusion criteria: (i) participants were aged  $\geq 18$  years, (ii) at least one urban BE characteristic was examined, (iii) primary or secondary LTPA outcomes were reported, and (iv) studies included leisure-time walking or other forms of LTPA. We excluded articles that did not focus specifically on LTPA or a particular type of LTPA, even if physical activity was included as a

dependent variable. Cross-national comparative studies, research protocols, books or book chapters, dissertations, reviews, editorials, and systematic reviews were also excluded from the study. Subsequently, one of the authors reviewed the abstracts of the selected articles, while another author with expertise in the subject area randomly reviewed abstracts to verify inclusion criteria. After these steps were completed, the three authors reached a consensus on the final list of literature and jointly reviewed the full articles. [Table 1](#) provides a compilation of included articles.

### 2.3. Extraction of study characteristics from the included articles

At least, two of the three authors examined the key details of the included articles, including the first author's name, year of publication, study design, city, sample characteristics, methods for measuring the BE and LTPA characteristics, BE characteristic extraction, LTPA measures, covariates, and other influencing factors. [Table 1](#) displays the comprehensive details of the extracted study characteristics. In cases of disagreement between the two authors, the third author was consulted. This process continued until all three authors reached a consensus.

### 2.4. Type classification of urban built environment characteristics

Due to variations in the definitions and measurements of urban BE characteristics among the included articles, the extracted data on urban BE characteristics differed significantly and were not amenable to direct quantitative analysis. To address this limitation, we categorized different urban BE characteristics and explored their associations with residents' LTPA levels using a framework of eight BE categories proposed by existing studies (Giles-Corti *et al.*, 2022; Giles-Corti *et al.*, 2016). These categories include design, density, distance, destination accessibility, diversity, desirability, distribution, and demand management. However, we replaced the expression "demand management" with "composite or other" in our classification. [Table 2](#) details these classifications of the types of BE characteristics. The term "demand management" specifically refers to traffic management measures and is not directly related to urban BE characteristics associated with residents' LTPA levels. Moreover, existing studies usually combine several urban BE characteristics into a single index for comparative analysis among cities. For example, the "community walkability index" assesses the extent to which an area is designed to support walking through urban design and is calculated based on the measurement of several characteristics, such as density, diversity, design, destination accessibility, and distance to transit (Rundle *et al.*, 2019). Additionally, we considered the possibility that

other urban BE characteristics not explicitly categorized might impact LTPA levels, hence the inclusion of the term "other" to emphasize the potential diversity of influencing characteristics. In addition, urban BE characteristics related to "distribution" were not found in the included articles and were consequently excluded from our analysis.

### 2.5. Coding evidence on the association between urban built environment characteristics and residents' leisure-time physical activity levels

To analyze and compare the evidence of associations between the seven urban BE characteristic categories mentioned in the previous subsection and residents' LTPA levels, we coded the association evidence using statistical criteria from previous systematic reviews (Ding *et al.*, 2011; Van Holle *et al.*, 2012; Wendel-Vos *et al.*, 2007; Zapata-Diomedes & Veerman, 2016). Specifically, we coded the number of associations with the urban BE characteristic category that was significantly associated with residents' LTPA levels as a ratio of the number of positive, negative, and non-significant associations with each characteristic category. [Figure 1](#) and [Table 3](#) present the flowchart illustrating the association encoding process and the corresponding coding standards, respectively. First, an urban BE characteristic category was considered to have convincing evidence if more than 50% of the evidence showed the same association with residents' LTPA levels. Positive associations were coded as "+," while negative associations were coded as "-." Second, when the evidence for the same association between an urban BE characteristic category and residents' LTPA levels ranged 40–50%, it was considered probable. A probable positive association was coded as "(+)," and a probable negative association was coded as "(-)." Third, if the proportion of evidence for the same association was less than 40%, or if a negative association was found in at least 25% of the 40–50% evidence range, the association was considered to have "no evidence" and was coded as "0." Conclusive testing required at least three articles. If this requirement was not met, the association was classified as "not applicable" and coded as "N/A."

### 2.6. Determination of the quality of a study

We developed our own criteria to assess the quality of the literature for this study, drawing commonly used literature assessment tools in systematic reviews (Barnett *et al.*, 2017; Cerin *et al.*, 2017; Ewing & Cervero, 2010; Forsén *et al.*, 2010; Grasser *et al.*, 2013), in combination with the Effective Public Health Practice Project (EPHPP) tool for assessing the quality of quantitative research (Gebel *et al.*, 2015; Peters *et al.*, 2020; Zapata-Diomedes & Veerman, 2016). [Table 4](#) furnishes a comprehensive overview of the quality assessment criteria applied to the included articles. Our inclusion criteria were as follows: (i) achieving a

Table 1. Summary of study characteristics for each included article (N=18)

First author, year	Study	City	Sample (n)	Age range (years)	Sociodemographic or other factors	Built environment: assessment, factors	LTPA outcomes: assessment, condition studied	Psychosocial factors
Guo <i>et al.</i> , 2021	Cross-sectional	Beijing	2061	≥65	Self-reported; age, gender, educational level, previous occupation, living situation, and physical functioning	(i) Self-report through questionnaire (ii) Overall satisfaction, satisfaction with neighborhood path/road/street condition, satisfaction with neighborhood recreational resources (iii) Objective through Walk Score and POI (iv) Objective neighborhood walkability, objective neighborhood accessibility of recreational resources	Self-report through questionnaire; LTPA	
Su <i>et al.</i> , 2014	Cross-sectional	Hangzhou	1434	25 – 59	Self-reported; age, height, weight, waist circumference, BMI, education beyond middle school, unemployment, per capita disposal annual income, and per capita living space	(i) Self-report through NEWS-A (ii) Residential density, access to commercial and physical activity destinations, access to public services, street connectivity, sidewalk and bike lane quality, esthetic quality, safety from traffic and crime objective through environmental audit, China Urban Built Environment Scan Tool (CUBEST) (iii) Access to commercial destinations, access to physical activity destinations, street connectivity, sidewalk quality, bike lane quality, esthetic quality, and safety from traffic.	Self-report through IPAQ-long; LTW and LTPA	
Yu <i>et al.</i> , 2021	Cross-sectional	Shenzhen	986	18 – 69	Self-reported; sex, age, education level, occupation, marital status, and the length of residency and body mass index	(i) Self-report through ANEWS (ii) Facilities availability, road condition, neighborhood esthetic, traffic condition, and safety	Self-report through IPAQ-long; LTW and LTMVPA	
Cerin <i>et al.</i> , 2013	Cross-sectional	Hongkong	484	≥65	Self-reported; gender, age, educational attainment, and other significant environmental predictors	(i) Self-report through NEWS-CS and NWQ-CS (ii) Residential density, land use mix, proximity of recreational destinations, street connectivity,	Self-report through IPAQ-long; LTW	

(Cont'd...)

Table 1. (Continued)

First author, year	Study	City	Sample (n)	Age range (years)	Sociodemographic or other factors	Built environment: assessment, factors	LTPA outcomes: assessment, condition studied	Psychosocial factors
						infrastructure for walking, indoor places for walking, esthetics, presence of people, crowdedness, traffic and road hazards, traffic speed, social disorder/littering, crime, fence separating sidewalks from traffic, bridge/overpass connecting to services, easy access of residential entrance, and sitting facilities		
Yu <i>et al.</i> , 2021	Cross-sectional	Jinhua	240	≥60	Self-reported; age, education level, income, travel mode choice, and whether having motion sickness	(i) Self-report through NEWS-A; (ii) Residential density, land use mix diversity, access to services, street connectivity, walking and cycling facilities, esthetics, traffic safety, and crime safety	Self-report through IPAQ -short; LTPA	
Yu <i>et al.</i> , 2021	Cross-sectional	Yiwu	252	≥60	Self-reported; age, gender, education level, income situation, travel mode choice, and whether having motion sickness	(i) Self-report through NEWS-A; (ii) Residential density, land use mix diversity, access to services, street connectivity, walking and cycling facilities, esthetics, traffic safety, and crime safety	self-report through IPAQ -short; LTW and LTPA	
Gao <i>et al.</i> , 2022	Cross-sectional	Ningbo	312	≥60	Self-reported; age, education level, income situation, travel mode choice, motion sickness	(i) Self-report through NEWS-A; (ii) Residential density, land use mix diversity, access to services, street connectivity, walking and cycling facilities, esthetics, traffic safety and crime safety	Self-report through IPAQ -short; LTW and LTPA	
Yu <i>et al.</i> , 2020	Cross-sectional	Hangzhou, Wenzhou	308, 304	≥65, ≥65	Self-reported; sex, age, education level, income situation, travel mode choice, occupational status, and whether having motion sickness	(i) Self-report through NEWS-A; (ii) Residential density, land use mix diversity, access to services, street connectivity, walking and cycling facilities, esthetics, traffic safety, and crime safety	Self-report through IPAQ -short; LTPA	
Sun <i>et al.</i> , 2020	Cross-sectional	Xian	728	≥18	Self-reported; sex, age, work status, ethnic groups, number of family members, and marital status	(i) Self-report through NEWS-A; (ii) Residential density, land use mix diversity, access to services, street connectivity, walking	Self-report through IPAQ-long; LTPA	

(Cont'd...)

Table 1. (Continued)

First author, year	Study	City	Sample (n)	Age range (years)	Sociodemographic or other factors	Built environment: assessment, factors	LTPA outcomes: assessment, condition studied	Psychosocial factors
						and cycling facilities, esthetics, traffic safety, and crime safety		
Wu <i>et al.</i> , 2019	Cross-sectional	Nanjing	399	≥60	Self-reported; gender, age, highest educational level, average monthly income, chronic disease, self-assessment of health, and living situation	(i) Self-report through NEWS; (ii) Access to facilities, community safety, esthetics, residential suitability, and traffic safety	Self-report through the Physical Activity Scale for the Elderly (PASE) questionnaire; recreational physical activity	
Li <i>et al.</i> , 2022	Cross-sectional	Tianjin	851	18 – 65	Self-reported; gender, age, education level, income situation, marital status, health status, psychological stress, organizational influence, and activity accompaniment	(i) Objective through GIS; (ii) Road connectivity, facility convenience (iii) Perceived through HRNet; (iv) Environmental comfort, environmental safety	Self-report through IPAQ-long; LTW and OLTPA	
Zhu <i>et al.</i> , 2022	Cross-sectional	Guangzhou	991	≥18	Self-reported; gender, age, education level, income situation, marital status, occupation, and social support	(i) Objective through GIS; (ii) Greening rate, distance to the nearest park square, park square coverage, and number of fitness facilities	Self-report through IPAQ; LTPA	Self-reported; social support
Yin-Juan <i>et al.</i> , 2020	Cross-sectional	Qingdao, Hangzhou, Suzhou, Chengdu	3789	25 – 65	Self-reported; gender, age, education level, income situation, occupation, marital status, per capita living space, per capita disposal annual income, number of family members, and cities	(i) Self-report through NEWS-A; (ii) Residential density, land use mix diversity, access to commercial places, physical activity places and public services, street connectivity, walking and cycling facilities, esthetics, traffic safety, and crime safety	Self-report through IPAQ-long; LTW and LTPA	
Dai <i>et al.</i> , 2019	Cross-sectional	Guangzhou	776	≥18	Self-reported; gender, age, education level, income situation, occupation, and community type	(i) Objective through GIS; (ii) Community greening coverage, neighborhood green coverage, distance to the nearest park square, and number of fitness facilities	Self-report through IPAQ-long; LTPA	
Fu <i>et al.</i> , 2018	Cross-sectional	Shenzhen	986	18 – 69	Self-reported; gender, age, education level, and occupation	(i) Self-report through NEWS-A; (ii) Supporting facilities, road conditions, environmental beautification, traffic conditions, access to exercise facilities, and security situation	Self-report through IPAQ-long; LTW and OLTPA	

(Cont'd...)

Table 1. (Continued)

First author, year	Study	City	Sample (n)	Age range (years)	Sociodemographic or other factors	Built environment: assessment, factors	LTPA outcomes: assessment, condition studied	Psychosocial factors
Liu <i>et al.</i> , 2018	Cross-sectional	Dalian	316	≥60	Self-reported; gender, age, income level, household composition, episode participation occasion variables (activity time, trip purpose, activity duration, activity companion), and walking location choices	(i) Objective through GIS; (ii) Distance to the nearest park (iii) Self-report via a five-point Likert scale; accessibility to local shops, footpath conditions, neighborhood esthetics, and traffic safety	Self-report through questionnaires; LTW	
Cerin <i>et al.</i> , 2013	Cross-sectional	Hongkong	484	≥65	Self-reported; gender, age, educational attainment, and other significant environmental predictors	Objective through the Environment in Asia Scan Tool-Hong Kong version; Presence of recreational and commercial facilities, safety, infrastructure, and esthetics and cleanliness, including perceptible pollution	Self-reported through IPAQ; recreational walking and OLTPA	
Lyu <i>et al.</i> , 2022	Cross-sectional	Harbin	367	≥18	Self-reported; gender, age, educational attainment, income, and occupational status	Self-report through a five-point Likert scale; Environmental quality, traffic walkability, and facility accessibility	Self-reported through IPAQ; LTPA	Self-reported; psychological willingness; family and social impact

Abbreviations: GIS: Geographic information system; IPAQ: International Physical Activity Questionnaire; LTPA: Leisure-time physical activity; LTW: Leisure-time walking; NEWS: Neighborhood Environmental Walkability Scale; OLTPA: Other forms of leisure-time physical activity.

Table 2. Type classification of urban built environment characteristics in the included articles

Category	Meaning	Examples
Design	The urban design creates walkable catchments around activity centers and incorporates accessible public open space	Walking/cycling space, coverage of neighborhood green, indoor places for walking, and recreation facilities
Density	The variable of residential per unit of area	Residential density
Distance	LTPA locations located within short walking distances from home	Distance to the nearest park and square, proximity to recreational facilities
Destination accessibility	LTPA locations are conveniently accessible by public transport or on foot	Accessibility to commercial destinations, accessibility to recreation, and physical activities facilities
Diversity	Residential areas built with different types of housing mixed with commercial, public, and recreational opportunities	The diversity of land use functions
Desirability	Neighborhoods designed to be safe, attractive, and accessible; LTPA locations that are convenient, affordable, frequent, safe, and comfortable	Esthetics and cleanliness-related characteristics, street pavement slope, pollution/stray animals/signs of crime/disorder, social disorder/littering, and traffic safety
Composite or other	Combining multiple urban BE characteristics into one indicator and the potential diversity of other influencing characteristics	Neighborhood walkability

Abbreviations: BE: Built environment; LTPA: Leisure-time physical activity.

sufficiently large participant response rate; (ii) controlling for sociodemographic variables (e.g., age, gender, and socioeconomic status) or stratifying participants based on at least one key urban BE characteristic (e.g., sampling

participants separately in areas with high or low walkability at the time of recruitment); (iii) using clearly described or validated measures to assess urban BE characteristics and LTPA levels; and (iv) accurately presenting the results (e.g.,

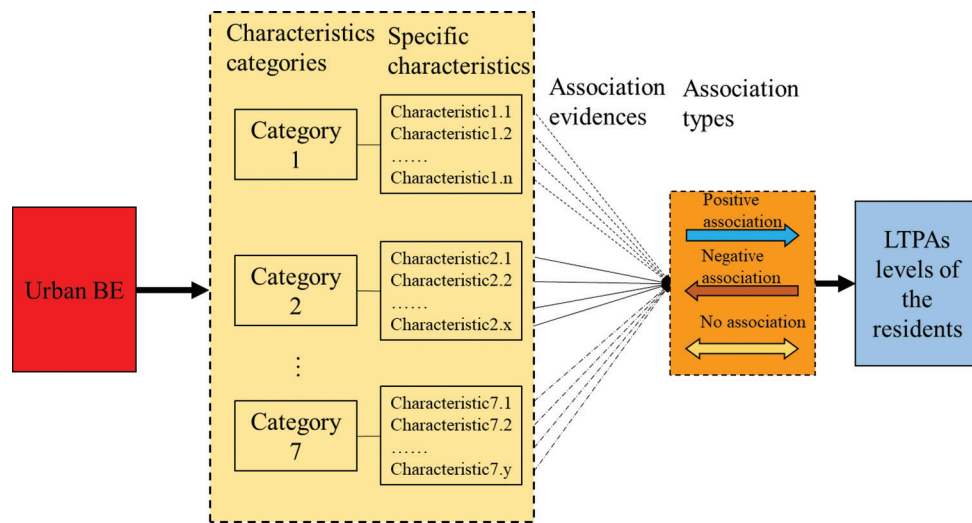


Figure 1. Association encoding logic diagram. Source: Illustration by the authors  
Abbreviations: BE: Built environment; LTPA: Leisure-time physical activity.

Table 3. Associated coding standards

Percentages of records supporting association	Summary code	Description
0 – 39% associated	0	Evidence unrelated
40 – 50% associated in one direction and ≥25% in the opposite	0	Evidence unrelated
40 – 50% associated in one direction and <25% in the opposite	(+); (-)	Possible evidence for a positive/negative association
51 – 100% associated in one direction and ≥25% in the opposite	(+); (-)	Possible evidence for a positive/negative association
51 – 100% associated in one direction and <25% in the opposite	+; -	Convincing evidence for a positive/negative association

Note: (i) Only valid when the association was investigated in at least three independent samples; otherwise, evidence was regarded as “not applicable” (coded as “N/A”). (ii) Double -signed summary codes are applied when convincing positive “+,” convincing negative “-,” possible positive “(+),” possible negative “(-),” or no associations “0” were present in at least three independent studies.

Table 4. Quality assessment of the included articles

<sup>a</sup> Representativeness	<sup>b</sup> Confounder		<sup>c</sup> Data collection		<sup>d</sup> Results
Response rate	Individual level	BE level	BE measures	LTPA measures	Analytical Approach
2: “≥60%”; 1: “41–60%”; 0: “≤40% or not known”	2: “individual attributes”; 0: “not met or not known”	2: “Participants recruitment stratified by environmental attributes”; 0: “not met or not known”	2: “validated questionnaire or clearly described objective measures”; 1: “self-reported or not yet validated or established in the field”; 0: “not met or not known”	2: “validated questionnaire or clearly described objective measures”; 1: “self-reported or not yet validated or established in the field”; 0: “not met or not known”	2: “Analyses conducted and presented correctly”; 1: “not yet validated or established in the field”; 0: “not met or not known”

Note 1: Criteria (a) What is the response rate?; (b) Were confounders controlled?; (c) Are valid, reliable, or standardized measures used for the outcome measure?; (d) Were the included studies analyzed and presented correctly (e.g., confidence intervals, p-values indicated)?

Note 2: Rating: “2”: strong; “1”: moderate; “0”: weak. Global rating: “Good”: no weak ratings; “Fair”: 1 weak rating; “Poor”: 2 or more weak ratings.

indicating confidence intervals and *p*-values). Next, we categorized the quality of the studies as “good,” “fair,” or “poor” based on the number of articles that met the above criteria. Specifically, articles that did not receive a “weak” rating were classified as good quality. Those receiving one “weak” rating were categorized as fair quality, while articles with two or more “weak” scores were classified as poor quality.

### 3. Results

#### 3.1. Study description

##### 3.1.1. Article selection results

As of June 2023, we retrieved 486 subject-related publications. After removing duplicates and filtering articles based on title and abstract, 81 studies remained.

On thorough reviewing of the literature, we excluded publications that involved participants under 18 years of age or non-Chinese participants ( $n = 13$ ), those not focusing on LTPA or a particular type of LTPA ( $n = 38$ ), those related to cross-national comparative studies ( $n = 8$ ), as well as research protocols, books or book chapters, dissertations, reviews, and editorials or systematic reviews ( $n = 12$ ). In addition, publications on experimental design errors were excluded ( $n = 10$ ). Ultimately, 18 articles that met the inclusion criteria were included for further screening. Figure 2 illustrates the PRISMA screening process and presents the results in a flowchart format.

### 3.1.2. Sample characteristics of the included articles

Over the 10-year period from 2013 to 2022, 18 articles that met the inclusion criteria were published, all employing a cross-sectional study design. Sample sizes varied, ranging

from 240 (Yu *et al.*, 2021) to 3789 (Yin-Juan *et al.*, 2020). Notably, more than half of the articles ( $n = 9$ ) focused specifically on the elderly population aged 60 years and older (Cerin *et al.*, 2013a; Cerin *et al.*, 2013b; Fu *et al.*, 2018; Gao *et al.*, 2022; Liu *et al.*, 2020; Wu *et al.*, 2019; Yu *et al.*, 2020; Yu *et al.*, 2021). With the aging population, understanding the health behaviors of older adults becomes increasingly critical (Watts *et al.*, 2022). These studies provide valuable insights into addressing the specific health challenges faced by China's aging population. Furthermore, a majority of the sample groups included in the study were located in megacities ( $n = 15$ ). In China, cities with a resident population of 5 million or more are classified as megacities. Therefore, the characteristics of these sample groups provide a reference for exploring the influence of the BE characteristics of cities on residents' LTPA levels in densely populated urban areas.

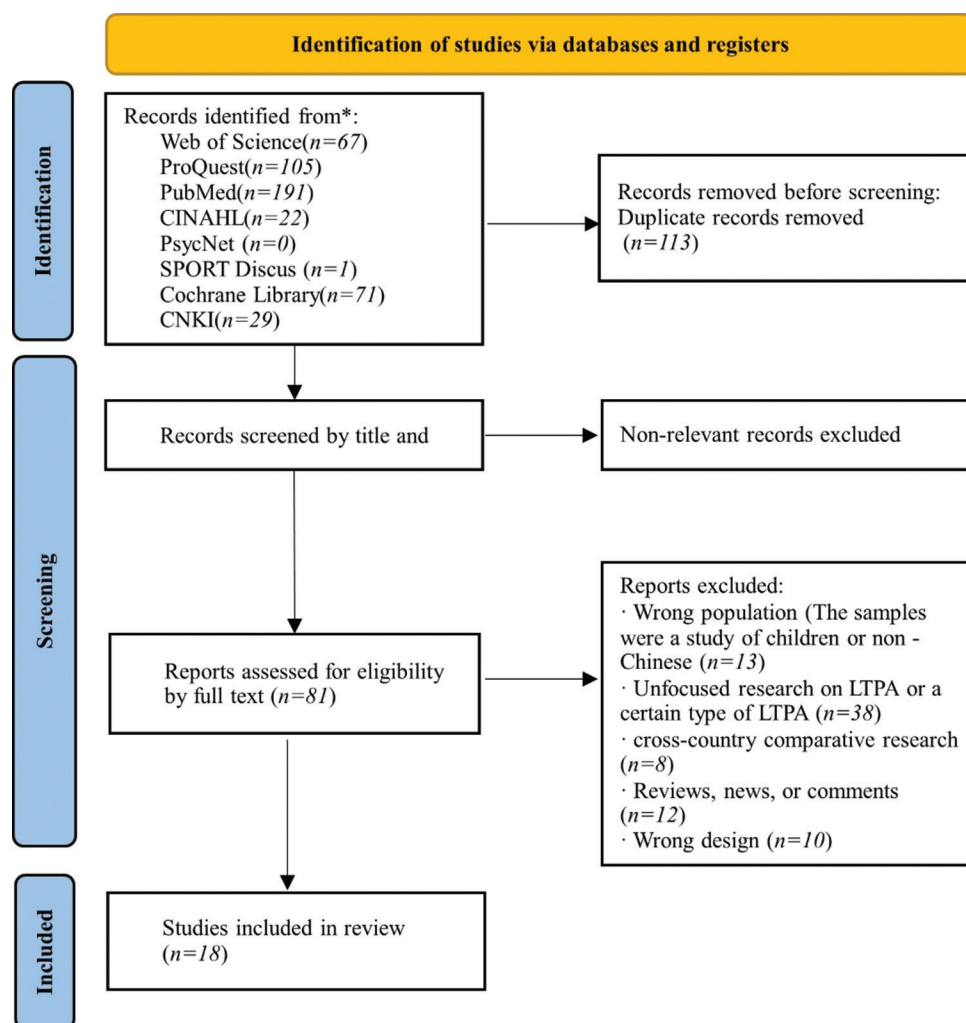


Figure 2. PRISMA flow chart of the screening process and results. Source: Illustrated by the author

### 3.1.3. Measurement method for the base data

There are two main types of measures used to assess urban BE characteristics, namely, perceptual and objective measures. Figure 3 provides a summary of the measurement methods employed for the base data. Among those employing perceptual measures, the majority ( $n = 11$ ) used the Neighborhood Environmental Walkability Scale (NEWS) and its revisions (ANEWS, NEWS-CS, and NEWS-A) to gather data. These measures facilitate data acquisition based on seven urban BE characteristics, enabling assessment of neighborhood walking environments and analysis of factors influencing LTPA. In addition, certain studies utilized an environmental audit instrument (e.g., China Urban Built Environment Scanning Tool and Asia Environmental Scanning Tool - Hong Kong version) (Cerin *et al.*, 2013a; Su *et al.*, 2014) and a five-point Likert scale technique (Fei *et al.*, 2022; Liu *et al.*, 2020) to capture respondents' subjective perceptions of the urban BE. However, one article employed a self-developed scale and did not provide clear descriptions of the perceptual measures used (Guo *et al.*, 2021).

In studies adopting objective measures, geographic information system platforms (Dai *et al.*, 2019; Li & Zhao, 2022; Liu *et al.*, 2020; Zhu *et al.*, 2022) were commonly used to collect, organize, and analyze spatial data related to urban BE. Furthermore, one article used a high-resolution network semantic segmentation model to quantitatively measure complex factors in the BE, such as visible greenery, open sky, enclosure, and surveillance, to assess the comfort and safety of the environment (Li & Zhao, 2022). This method offers more detailed, objective, and accurate data on the characteristics of urban BE compared to traditional manual measurements or subjective assessment methods.

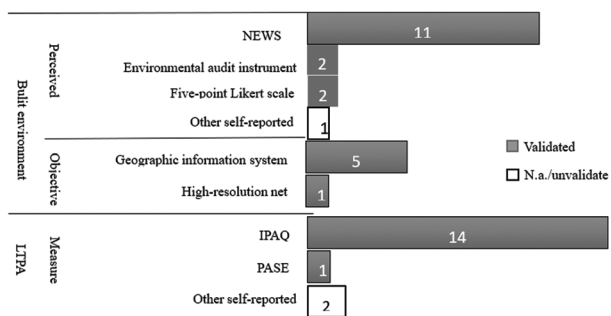
Most studies used scales or sociological research methods to measure residents' LTPA levels. Among the included

studies, 15 initially measured the frequency and duration of walking, moderate-, and higher-intensity physical activity for leisure purposes within the preceding 7 days using the International Physical Activity Questionnaire. Subsequently, these data were converted into metabolic equivalent scores, following the questionnaire's established scoring procedure (Craig *et al.*, 2003). Individual residents' weekly LTPA levels were then calculated by multiplying the duration of their LTPA by the respective score. In addition, studies focusing on older adults used the Physical Activity Inventory (PPAI) for the Elderly to measure LTPA levels within this demographic (Wu *et al.*, 2019). However, some articles lacked effective descriptions of the self-report methods employed (Guo *et al.*, 2021; Liu *et al.*, 2020).

### 3.1.4. Evaluation of the research quality of articles

Of the 18 articles included in the study, six were rated as good quality (33.3%), six were rated as fair quality (33.3%), and six were rated as poor quality (33.3%). Table 5 summarizes the results of the research quality assessment. Consequently, a majority of the articles exhibited fair or poor quality. The reasons for these results are elaborated here.

First, the sample response rate (which is calculated as the ratio of the number of valid samples for which data are available to the total sample size) was generally low in the included articles. A low sample response rate for a study makes it impossible to determine whether the sample used in the article was representative. Seven articles had sample response rates of less than 40% or did not provide information on the sample response rate. Second, the method of stratified sampling based on key urban BE characteristics was not commonly adopted. The key urban BE characteristics identified by these studies included the degree of land use mix, commercial and public service allocation (Su *et al.*, 2014), geographic location (Wu *et al.*, 2019), residential area renovation (Fei *et al.*, 2022), housing type (commercial housing, subsidized housing, historic districts, and urban villages) (Zhu *et al.*, 2022), pedestrian friendliness (Cerin, *et al.*, 2013), and public space characteristics (street, squares, and parks) (Liu *et al.*, 2020). Third, the accuracy and validity of the perceptual measures used in the included articles were insufficient. Moreover, many articles did not adequately describe the measurement methods or used unvalidated methods ( $n = 9$ ). Finally, the articles included in the study failed to present the findings correctly or clearly ( $n = 4$ ), and the actual  $p$ -values derived from individual studies did not match the conclusions ( $n = 1$ ).



**Figure 3.** Summary of the measurement methods used for the base data. Source: Illustration by the authors  
Abbreviations: IPAQ: International Physical Activity Questionnaire; LTPA: Leisure-time physical activity; n.a.: Not available; NEWS: Neighborhood Environmental Walkability Scale; PASE: Physical Activity Scale for the Elderly.

### 3.2. Status of the evidence presented in the article

#### 3.2.1. Association between urban built environment characteristics and residents' leisure-time walking

Leisure-time walking (LTW) is a major form of residents' LTPA, making evidence of LTW valuable for revealing

Table 5. Results of the research quality assessment of the included articles

Author, year	Representativeness	Confounder		Data collection		Results	#Global rating
	<sup>a</sup> Response rate	<sup>b</sup> Individual level	<sup>c</sup> BE level	<sup>d</sup> Perceived BE measures	<sup>e</sup> LTPA measures	<sup>f</sup> Analytical approach	
Guo <i>et al.</i> , 2021	0	2	0	1	0	2	0
Su <i>et al.</i> , 2014	1	2	2	2	2	2	2
Yu <i>et al.</i> , 2021	2	2	0	2	2	2	1
Cerin <i>et al.</i> , 2013	2	2	2	2	2	2	2
Yu <i>et al.</i> , 2021	0	2	0	1	2	1	0
Yu <i>et al.</i> , 2021	0	2	0	1	2	1	0
Gao, 2022	0	2	0	1	2	0	0
Yu <i>et al.</i> , 2020	0	2	0	1	2	1	0
Sun <i>et al.</i> , 2020	0	2	0	2	2	2	0
Wu <i>et al.</i> , 2019	2	2	2	1	2	2	2
Li <i>et al.</i> , 2022	2	2	0	2	2	2	1
Zhu <i>et al.</i> , 2022	0	2	2	2	2	2	1
Duan <i>et al.</i> , 2020	2	2	0	2	2	2	1
Dai <i>et al.</i> , 2019	2	2	2	2	2	2	2
Fu <i>et al.</i> , 2018	2	2	0	1	2	2	1
Liu <i>et al.</i> , 2020	2	2	2	2	0	2	1
Cerin <i>et al.</i> , 2013	2	2	2	1	2	2	2
Lyu <i>et al.</i> , 2022	2	2	2	1	2	2	2

Notes: (a) 2: “>60%”; 1: “41-60%”; 0: “<40% or not known”; (b) 2: “individual attributes”; 0: “not met or not known”; (c) 2: “Participants recruitment stratified by environmental attributes”; 0: “not met or not known”; (d) 2: “validated questionnaire or clearly described objective measures”; 1: “self-reported or not yet validated or established in the field”; 0: “not met or not known”; (e) 2: “validated questionnaire or clearly described objective measures”; 1: “self-reported or not yet validated or established in the field”; 0: “not met or not known” (f) 2: “Analyses conducted and presented correctly”; 1: “not yet validated or established in the field”; 0: “not met or not known”; (g) 2: “no weak ratings”; 1: “one weak rating”; 0: “two or more weak ratings”.

Abbreviations: BE: Built environment; LTPA: Leisure-time physical activity.

LTPA patterns. Figure 4 illustrates the evidence of the association between urban BE characteristics and residents’ LTW levels across ten articles, while Figure 5 depicts the proportion of significant associations observed in these articles. When calculating the amount of evidence of a significant association between each urban BE characteristic category and residents’ LTW levels as a proportion of the total number of analyses for that association, none of the ten articles demonstrate a statistically significant association. Specifically, the proportion of the included articles reporting significant associations between urban BE characteristic categories such as design, destination accessibility, and desirability, and residents’ LTW, accounted for less than 40% of the total evidence. Moreover, fewer than three articles examined the association between the remaining urban BE characteristic categories and residents’ LTW levels, rendering clear conclusions difficult to draw. Therefore, these were marked as N/A (not applicable) or 0 (insufficient evidence).

Focusing on the percentage of associations verified in the articles with good and fair research quality, a potential positive correlation (41.5%) emerged between desirable elements of the urban BE and residents’ LTW, marked as “(+)” Further, categorical analysis of desirability revealed that six articles with good and fair research quality agreed that esthetic perception exerted a significant positive effect on residents’ LTW levels (Cerin *et al.*, 2013a; Fu *et al.*, 2018; Li & Zhao, 2022; Liu *et al.*, 2020; Su *et al.*, 2014; J. Yu *et al.*, 2021). In addition, five of these six articles highlighted the important contribution of road safety to residents’ LTW levels (Cerin *et al.*, 2013; Fu *et al.*, 2018; Li & Zhao, 2022; Liu *et al.*, 2020; T. Yu *et al.*, 2021).

### 3.2.2. Association between urban built environment characteristics and residents’ other forms of leisure-time physical activity in addition to leisure-time walking

In addition to LTW, examining other forms of LTPA (OLTPA) is also beneficial for understanding overall physical activity levels. Figure 6 illustrates the evidence



Figure 4. Evidence on the associations between urban built environment characteristics and the residents' leisure-time walking levels in the ten articles. Source: Illustration by the authors

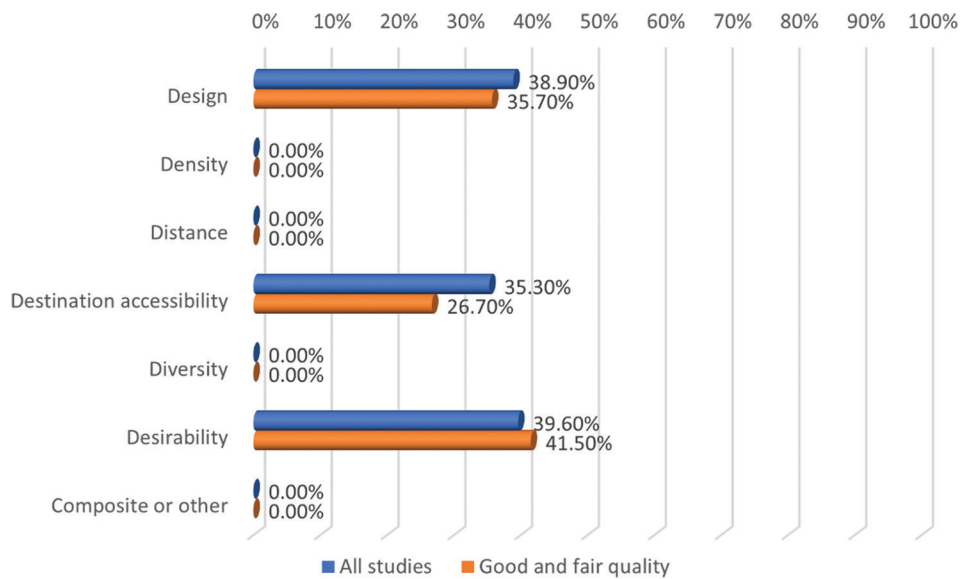


Figure 5. The proportion of significant associations between urban built environment characteristics and residents' leisure-time walking levels in the ten articles. Source: Illustration by the authors

of the association between urban BE characteristics and residents' OLTPA levels across four articles, while Figure 7 depicts the proportion of significant associations observed in these articles. Notably, the four articles examining the association between urban BE and residents' OLTPA were of fair and good quality. When assessing the proportion of evidence indicating a significant association between BE characteristic categories and residents' OLTPA levels in each city study, a robust positive association was identified between destination accessibility within the category of urban BE characteristics and residents' OLTPA levels (80% of the evidence). This finding suggests that improved accessibility to recreational facilities such as green spaces and parks positively influences residents' OLTPA levels (Cerin *et al.*, 2013a; Fu *et al.*, 2018). Furthermore, these four articles revealed a potential positive correlation between desirability and residents' OLTPA levels (40.9% of the evidence). On further analysis of the desirability classification, three out of the four articles concluded that esthetic perception (Cerin *et al.*, 2013a; Fu *et al.*, 2018; T. Yu *et al.*, 2021) and road safety (Cerin *et al.*, 2013a; Li & Zhao, 2022; T. Yu *et al.*, 2021) significantly impacted residents' OLTPA levels. The remaining urban BE characteristic categories were marked as "N/A."

### 3.2.3. Association between the urban built environment characteristics and residents' leisure-time physical activity levels

Twelve articles did not distinguish between specific types of LTPA in their primary outcomes. Figure 8 illustrates the evidence of the association between urban BE characteristics and residents' LTPA levels across 12 articles, while Figure 9 depicts the proportion of significant associations observed in these articles. When calculating the proportion of the evidence of a significant association between BE characteristic categories and residents' LTPA levels in each city relative to the total number in the association analysis, this study revealed a significant positive association between the urban BE category design and desirability and the LTPA levels of residents (52.4% and 43.8% of the evidence, respectively). If only the proportion of associated evidence in the three articles of good and fair quality is calculated, there is compelling evidence of an association between design and the LTPA levels of residents, with a significant association reaching 60%. Further, analysis of the design classification revealed that two of the four articles provided evidence of a positive association between greenness and residents' LTPA levels (Dai *et al.*, 2019; Zhu *et al.*, 2022), while the remaining two articles provided evidence of a positive association between street connectivity and residents' LTPA levels (Fei *et al.*, 2022; Wu *et al.*, 2019).

## 4. Discussion

### 4.1. Discussion of the main ideas

At present, there is limited evidence regarding the association between urban BE and residents' LTPA. First, the response rate is a key factor in determining the quality of a study. A high sample response rate reflects a more representative sample and reduces the likelihood of non-response bias (Meterko *et al.*, 2015). Conversely, low response rates or significant differences between respondents and non-respondents can introduce statistical bias, undermining result validity (Sivo *et al.*, 2006).

Second, confounding factors at different levels can influence the association between urban BE and residents' LTPA levels (Glanz *et al.*, 2008). At the individual level, the dependence of individuals' physical activity on certain characteristics of the urban BE intensifies as their activity capacity declines with age (Ribeiro *et al.*, 2013). Moreover, women may be more susceptible to certain urban BE characteristics influence on LTPA compared to men (Kavanagh *et al.*, 2006). At the social and environmental levels, well-connected bicycle lanes, walkable streets, ample green spaces, and accessible recreational facilities positively impact on attracting individuals and promoting higher LTPA levels (Wang *et al.*, 2016).

Third, the influence of urban BE characteristics on residents' LTPA levels often reflects socioecological connotations (Sallis *et al.*, 2015). Specifically, psychosocial factors play a crucial role in moderating individuals' behavior and motivation to participate in LTPA (Bauman *et al.*, 2012). Among the psychosocial factors, "self-efficacy" (Bergström *et al.*, 2015), "beliefs" about the benefits of physical activity (Stehr *et al.*, 2021), and "social support networks" (Kim *et al.*, 2020) have been identified.

Finally, the measurement methods for urban BE and residents' LTPA levels significantly impact on revealing their association mechanisms. Quantitative measurements may overlook individuals' subjective factors, leading to biased conclusions (Peters *et al.*, 2020). The same physical environment may elicit different LTPA levels among individuals (McCormack *et al.*, 2008). Therefore, relying solely on objective or perceptual measures can yield limited conclusions (Weden *et al.*, 2008). Similarly, exclusive reliance on self-reports often leads to overestimations of LTPA levels (Zhu *et al.*, 2022).

### 4.2. The urgent need to explore the impact mechanism of the urban built environment

Rapid urbanization in China has led to an enormous spatial gap related to physical activity, both within and between cities. At the national level, the per capita green

	Positive	Negative	No association	All studies	Good and fair quality
Design	11	11	11 15 15	N/A	N/A
Density				N/A	N/A
Distance				N/A	N/A
Destination accessibility	15 4 4 4		3	+	+
Diversity				N/A	N/A
Desirability	3 3 4 4 4 4 4		3 3 4 4 4 4 4	(+)	(+)
	11 15		11 11 11 15 15 15		
Distributed				N/A	N/A
Composite or other	4 4 4 4		4 4 4 4 4 4 4	N/A	N/A

**Figure Legend**

Color of bar:

- Good quality
- Fair quality
- Poor quality

Bar number and study ID:

- 3. J. Yu *et al.*, 2021
- 4. Cerin *et al.*, 2013
- 11. Li *et al.*, 2022
- 15. Fu *et al.*, 2018

Figure 6. Evidence on the associations between urban built environment characteristics and residents’ other forms of leisure-time physical activity levels in the four articles. Source: Illustration by the authors

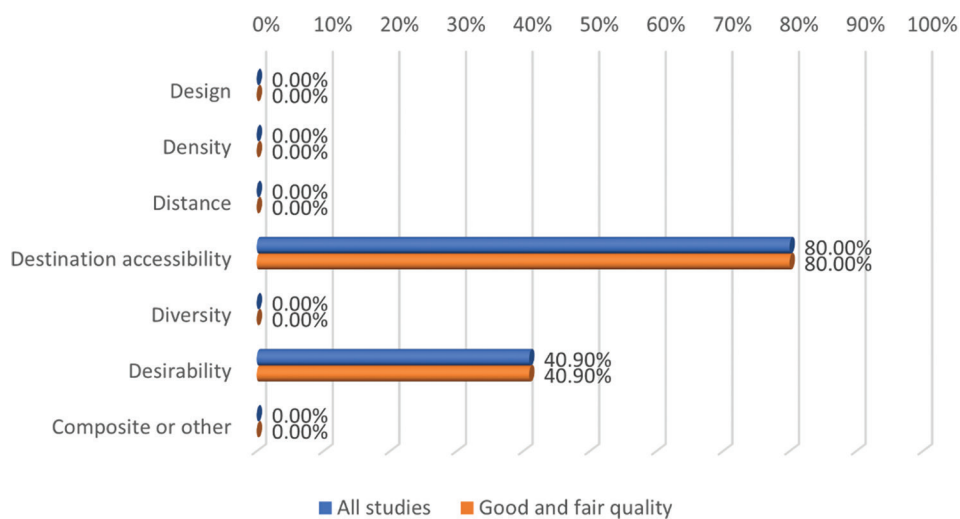


Figure 7. The proportion of significant associations between urban built environment characteristics and residents’ other forms of leisure-time physical activity levels in the four articles. Source: Illustration by the authors

space in Chinese cities is approximately 14.87 m<sup>2</sup>, falling below international standards (China, 2021). Moreover,

the availability of sports facility sites per capita in Chinese cities lags far behind neighboring countries such as Japan

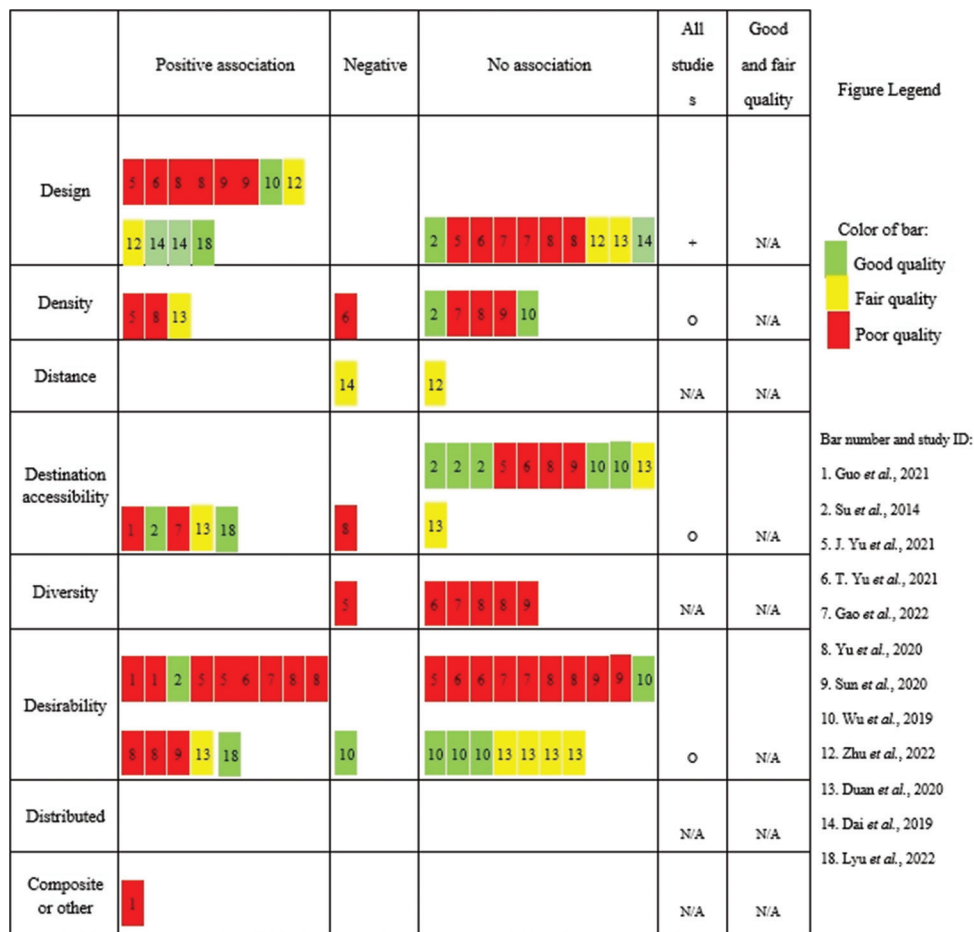


Figure 8. Evidence on the associations between urban built environment characteristics and residents' leisure-time physical activity levels in the 12 articles. Source: Illustration by the authors

and South Korea (China, 2021). However, Chinese cities vary greatly in size, ranging from small urban centers inhabited by tens of thousands of people to megacities with tens of millions of inhabitants. Addressing the spatial shortage and misalignment of physical activity facilities cannot be accomplished through the introduction of a “one-size-fits-all” spatial allocation policy.

Second, there are significant differences in the characteristics of demand for physical activity spaces among cities with distinct geographical and developmental socioeconomic characteristics. Given the diverse employment demographics and industrial landscapes across cities, identifying and extracting BE characteristics necessitates consideration of both urban population dynamics and industrial attributes. This calls for a comprehensive approach to measuring residents' LTPA through empirical studies that capture the diversity and typicality of urban contexts, rather than focusing solely on megacities (Cui *et al.*, 2023; Sudmant *et al.*, 2020).

Third, Chinese-style urbanization policies, which emphasize population mobility, pose challenges in aligning physical activity spaces with residents' evolving needs (Liu *et al.*, 2019; Liu *et al.*, 2021). Achieving an effective match between physical activity spaces and demand groups requires careful consideration, not only of spatial and temporal factors but also of population mobility dynamics and the static nature of spatial facilities.

In addition, the “old residential area” housing policy (China, 2021) targets low- and middle-income individuals, the elderly, and numerous tenants seeking proximity to their workplaces within China. In contrast to commercial housing, these residential areas generally exhibit spatial constraints and shortcomings in the configuration of service facilities.

### 4.3. Ideas for enhancing future research

This systematic review offers valuable insights into future research directions in the field. First, there is a need to

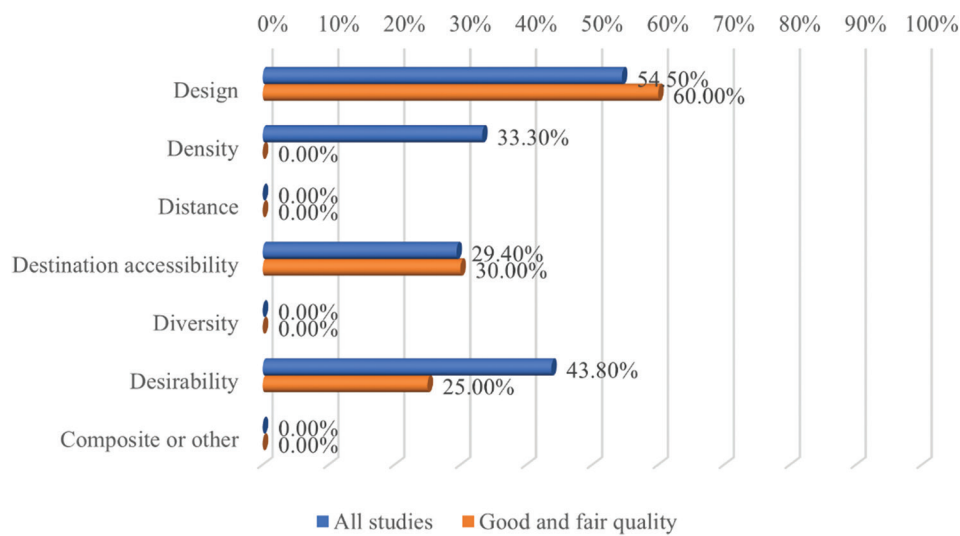


Figure 9. The proportion of significant associations between urban built environment characteristics and residents' LTPA levels in the 12 articles. Source: Illustrated by the author

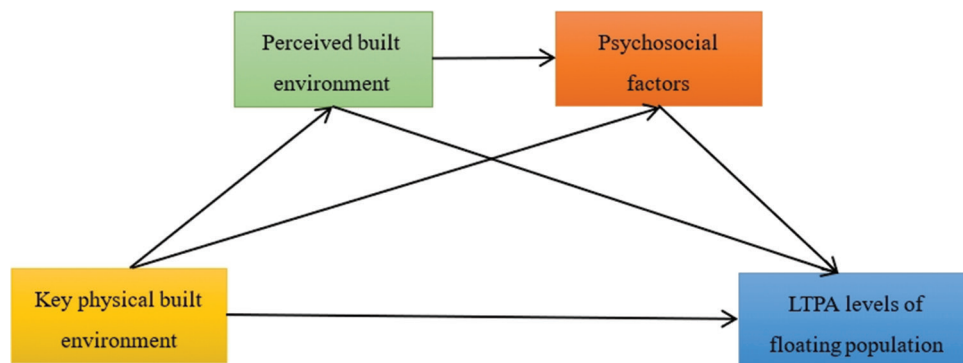


Figure 10. Innovation model of the association between urban built environment characteristics and floating population's leisure-time physical activity (LTPA) levels in the future. Source: Illustration by the authors

enhance the accuracy of characteristic identification and element extraction for urban BE. Utilizing computer vision and machine learning technologies (Ibrahim *et al.*, 2020) within the artificial intelligence context can enable the acquisition of data with subjective intentions such as place perception, emotions, and impressions. Combining this data with high-resolution remote sensing image data (Wen *et al.*, 2021) can facilitate the extraction of additional features suitable for the BE in Chinese cities. These features play crucial roles in land use modeling and understanding and shaping the spatial organization of human activities.

Second, improving methods for measuring LTPA levels in the population is imperative. Building on traditional measurement methods such as the International Physical Activity Scale, the utilization of emerging low-cost sensors and wearable devices allows for the application of accelerometer and global positioning system data

acquisition methods tailored to specific demographic groups.

Third, follow-up studies should prioritize investigating the health effects of physical activity in urban-specific populations, such as the floating population supporting labor-intensive industries. Given that China hosts the world's largest floating population (Fan & Li, 2020), addressing their health vulnerabilities due to poor working and living environment, and the lack of social security and support in places of immigration is crucial. The floating population is extremely vulnerable to health risks such as infectious diseases, occupational diseases, and poor reproductive and mental health (Wu *et al.*, 2021). Improving key built-environment elements and creating living environments conducive to good health are important measures for achieving overall health goals for this vulnerable population.

Finally, the mediating effect of urban BE on residents' LTPA levels should be evaluated. We propose the concept of the perceived BE of cities in relation to the physical BE characteristics of cities. This concept acknowledges that individuals' behavior forms "social perceptions" through social networks, which influence the behavior of a larger population (Nasar, 2008). Therefore, the empirical study envisages the existence of two pathways: direct and indirect. The direct influence is moderated by individuals' psychosocial factors and perceived BE, resulting in an indirect influence path. Figure 10 displays the innovation model, elucidating the interrelationships among individual factors, social relationship factors, and physical environment factors.

## 5. Conclusion

This article presents a systematic review of the associations between BE characteristics and residents' LTPA levels in Chinese cities. However, several limitations need to be acknowledged. First, we did not explicitly search for the effects of specific urban BE characteristics (e.g., green spaces and recreational facilities) on residents' LTPA levels. Second, our synthesis of the study data was based on the eight characteristics categories in the health promotion framework. However, the actual effects of the urban BE on residents' LTPA are often more subtle, and established classifications of BE characteristics may fail to accurately describe the mechanisms of these associations. Future research should consider exploring the impact of a more accurate classification of urban BE characteristics. Third, we applied a quantitative research quality assessment tool to assess study quality, which may oversimplify the assessment process and overlook nuances in study quality. Future research should adopt research quality assessment tools to enhance the understanding of the literature. Finally, our attempt to examine the evidence provided by the literature using meta-analysis methods was hindered by the large variation in data and study methods among the included studies. This variability made it difficult to combine statistical results effectively. Therefore, more appropriate research methods for literature analysis need to be further explored.

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## Conflict of interest

The authors declare no conflicts of interest.

## Author contributions

*Conceptualization:* Fan Yang

*Data curation:* Chao Ge

*Formal analysis:* All authors

*Funding acquisition:* Fan Yang

*Investigation:* Fan Yang

*Methodology:* Fan Yang, Chao Ge

*Project administration:* Fan Yang

*Resources:* Fan Yang

*Supervision:* Fan Yang

*Validation:* Fan Yang

*Writing – original draft:* Fan Yang, Chao Ge

*Writing – review & editing:* All authors

## Ethics approval and consent to participate

Not applicable.

## Consent for publication

Not applicable.

## Availability of data

The datasets used and/or analyzed during the present study are available on reasonable request from the authors.

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## ORIGINAL ARTICLE

## Regenerating tradition: Empowering rural revitalization through Li culture and green infrastructure in a design case study of Yulong village, Hainan, China

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Green infrastructure is an approach to land planning that aims to restore and manage the natural environment within human contexts. Its widespread use in post-industrial urban and peri-urban settings recognizes the need to reconcile environmental issues and regenerate social and cultural connections with the natural landscape. However, green infrastructure is seldom discussed in rural contexts, where efficient production practices increasingly dominate agriculture, invariably overwhelming cultural associations with land and its environmental qualities. In China, a government policy has been introduced to revitalize rural areas in response to the deleterious environmental effects of industrialized agriculture. Green infrastructure, in this context, offers the potential to usher in a new transformation toward more ecologically sustainable rural environments that embrace environmental, social, and cultural connections. This research considers the role of traditional rural cultures in facilitating this transformation. Through a case study of Yulong Village and its agricultural fields in the middle reaches of the Changhua River in Hainan, this paper maps the modernization of the traditional Li family's agrarian culture and its legacy of ecological dilemmas. In projecting forward, this article describes a design research process that deploys new and established cartographies and speculates on the role of landscape design in integrating ancient cultural traditions with modern agriculture. The findings suggest a path for the realization of the goal of rural revitalization, emphasizing the importance of recognizing the relationship between ecological, economic, cultural, and social values.

**Keywords:** Landscape architecture; Eco-cultural tourism; Eco-agriculture; Traditional knowledge; Community-led change

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**1. Introduction**

Over the past century, rapid urbanization and modernization on a global scale have caused tremendous disturbances to the natural environment and its ecosystems. While

material living standards have substantially improved for significant portions of the world's population, ecological problems have emerged as a serious threat to humanity's continued survival.

Since entering the academic and professional lexicon in the United States in the 1990s (Seiwert & Rößler, 2020), the concept of green infrastructure has found wide application in urban planning, urban forestry, and urban greening efforts in both the United States and Europe. Grabowski *et al.* define green infrastructure as “a system of interconnected ecosystems, ecological-technological hybrids, and built infrastructures that provide contextual social, environmental, and technological functions and benefits” (Grabowski *et al.*, 2022, p. 158). It now underpins many government planning policies worldwide. While its original focus was primarily on the protection, enhancement, and management of stormwater and river systems, ecological services, and biodiversity conservation (Ying *et al.*, 2022), it is increasingly called on to reconcile the trade-offs between ecological function and human land use demands, particularly in the face of climate change. As a planning concept, green infrastructure “brings attention to how diverse types of urban ecosystems and built infrastructures function in relation to one another to meet socially negotiated goals.” (Grabowski *et al.*, 2022, p. 158).

More recently, the community and cultural value of green infrastructure has become a subject of extensive debate in academic literature. Kati and Jari (2015), for example, emphasize the importance of the multiple meanings and values generated by community interests in green infrastructural design, advocating for the integration of locally derived values as part of the techno-economic planning strategy for urban ecosystems. Orantes *et al.* (2017), in their study of Yesan County's green infrastructure program in South Korea, highlight the increasingly important role of cultural heritage and religious values in the green infrastructure planning process. Razzaghi Asl and Pearsall (2022) conclude that green infrastructure has the potential to integrate small-scale design with local governance models. These studies suggest that green infrastructure can be interpreted in various ways to support diverse sociocultural contexts, although the current debate remains primarily centered around urbanism.

The recent rapid urbanization in China has provided a rich testing ground for green infrastructure research through urban case studies. However, there is a notable gap in research concerning innovation in green infrastructure design methods suitable for rural settings and environments in the countryside (Shao *et al.*, 2023; Yang *et al.*, 2023; Ni *et al.*, 2023). This article seeks to contribute to this developing area of research.

After more than 70 years of “rural reorganization” and “opening up” in China, the economic livelihoods and living conditions of rural inhabitants have prospered. However, the abandonment of traditional agricultural practices in favor of modern industrialized agricultural processes has led to the erosion of intangible cultural heritages among rural ethnic minorities and the degradation of the broad-scale environment. This development prompted a reframing of modernization in 2022. The 20<sup>th</sup> National Congress of the Communist Party of China proposed a “rural revitalization” with a new form of common prosperity, which acknowledges the harmonious coexistence of humans and nature. This proposal builds on various suggestions by Chinese scholars, advocating for the development of high ecological service value in ecoagriculture, rural cultural tourism, ecological capital deepening, and agricultural finance innovation, among other options. These are considered key initiatives to re-establish the cultural landscape of the countryside (Tong, 2023; Liu, 2023; Zhang, 2021; Wen and Lu, 2021; Xiang, 2023). The government's 2023 “No.1 Document on Rural Revitalization” recognizes the benefit of “in-depth farming culture inheritance and protection projects, and strengthening the protection and utilization of important agricultural cultural heritage.” However, implementation of these measures will not be easy. The loss of cultural traditions in the earlier periods of “rural reorganization” has already generated a lack of knowledge and authenticity in many expressions of rural culture (Liu & Xu, 2022).

Using Li Yulong Village in the middle reaches of the Changhua River of Hainan Island as a case study, this research investigates how the integration of modern green infrastructure methods with traditional agricultural practices might promote rural revitalization and enhance the future development of rural villages in China. Some scholars have already explored the human-ecological connections embedded in the traditional practices of the Li family (Chang, 2012), suggesting that Li family's farming culture demonstrates profound human-environment relations in both Li villages and farmlands (Qi *et al.*, 2022). However, a gap still exists in current research regarding the regeneration of ecological landscapes based on Li family's traditional farming culture. In this respect, green infrastructure holds the potential to leverage Li family's traditional knowledge and generate community-based practices suited to rural revitalization in Yulong Village, effectively integrating sustainable ecology, culture, and economy.

In this article, we first analyze the ecological and economic predicament of Yulong through historical materials, documentation, field investigation, and satellite imagery. Second, by examining historical paintings and

existing anthropological and ethnographic research about the Li family, we interpret the Li family's beliefs and the value of traditional agricultural practices in modern rural life. Then, employing a design research methodology that utilizes advanced technologies, we elucidate the potential for locally and culturally informed green infrastructure interventions in Yulong Village. This approach enriches the study of green infrastructure by intertwining it with traditional culture and provides a potential prototype for the revitalization of the Li villages in Hainan.

## 2. Methods

### 2.1. The study site

#### 2.1.1. Modernization of the Yulong village

At the time of the founding of New China, the Li villages in Hainan were in a state of poverty. In the 1950s, the Chinese government reformed the organization of these villages and funded the introduction of modernization in agriculture. The Hainan government established rural production cooperatives, allocated collective land to all Li farmers on the island, and introduced modern farming tools and high-quality rice cultivars, all of which greatly improved agricultural productivity (Li *et al.*, 2009). However, rural labor and agricultural production were priced at a low rate due to the state's need to accumulate its economic foundation through the surplus value of rural agricultural production. The limited income of farmers resulted in an increase in cultivation areas, including reclaimed forests and other unfarmed land (Wen *et al.*, 2018). The Reform and Opening Up in the 1980s, further, increased the commercialization of agricultural production and led to the extensive introduction of tropical cash crops in Hainan. During this period, agricultural reforms were accompanied by the household responsibility system, which encouraged increased entrepreneurial activity among Li villagers, who thereby accrued substantial increases in economic income (Figure 1).

However, the transformation adversely affected the natural landscape and ecological environment of the Li villages. Large areas of mountain forest and riverside wetlands were cleared to make way for cash crops such as mango, betel nut, and rubber. In the new landscape dominated by cash crops, the extensive use of pesticides accelerated the acidification of the soil. In the old-growth forests, rosewood was harvested on a hitherto unseen scale to service the demands of the international furniture market. Much of it is now depleted, along with many natural habitats and a significant portion of native fauna. The decimated populations of frogs, birds, and other ecologically important animals have led to locust infestations along the riverbanks, in the villages, and in the

rice paddies. To compound these problems, the absence of vegetative cover has accelerated runoff, which has initiated perennial flooding in the villages and fields (Figure 2). In response to these challenges, the Daguangba Reservoir was built in the late 1970s in the middle reaches of the Changhua River to regulate floodwaters (Figure 3) and to meet the increased demand for water in urban expansion and for farm irrigation. Unfortunately, historic and satellite images from the late 1990s to the present reveal that the reservoir has adversely affected the alignment and flow of the river. The construction of the reservoir has resulted in changes to the natural hydrology, gradual loss of the original floodplain, and shrinkage of the village's farmland. Many Li villages were abandoned, and the government consolidated some of the low-lying villages, like the Yulong Village, into new settlements along the new edge of the reservoir (Figure 4). In doing so, the villagers lost the physical qualities and the spaces where they once practiced some of their centuries-old traditions of sustainable farming.

#### 2.1.2. The Li family's tradition of sustainable farming

The ancestors of Hainan's Li family were part of the ancient Hundred Yue tribes in the present-day Guangdong and Guangxi regions of China, who migrated to Hainan Island. They formed tribes with different dialects and made a living through fishing and hunting in the coastal areas. From the Han dynasty (206 BCE-220 CE) onward, following maneuvering and friction between the Li minority and representatives of imperial powers and Han Chinese settlers, the Li family gradually migrated to the western interior of Hainan Island, settling in the upper and middle reaches of the Changhua River basin (Figure 5) of Hainan Island (Wang and Jiang, 2004). The terrain along the Changhua River is mountainous in the southeast and low flatlands in the northwest. The mountainous areas feature steep slopes and rapid water level changes, while the lower reaches have a wide riverbed and smooth water discharge (Stubel, 1937).

Long-term interaction with the Changhua River and their acute understanding of the landscape have gradually led the Li people to habitually reside close to water. This is evident in the Qing dynasty painting depicting Li family's traditional customs, showcasing their cultural techniques for managing and engineering water resources. In the mountainous areas, where the Changhua River served as an important transportation route, the ancient Li family developed rafts capable of transporting materials even in places with fast water currents (Figure 6A). Qing dynasty paintings (Fu, 2007) illustrate how the Li people built stone barriers at the rapids of rivers and streams, filling them with aquatic plants to trap fish. Beneath waterfalls, they created small ditches with a narrow water source,

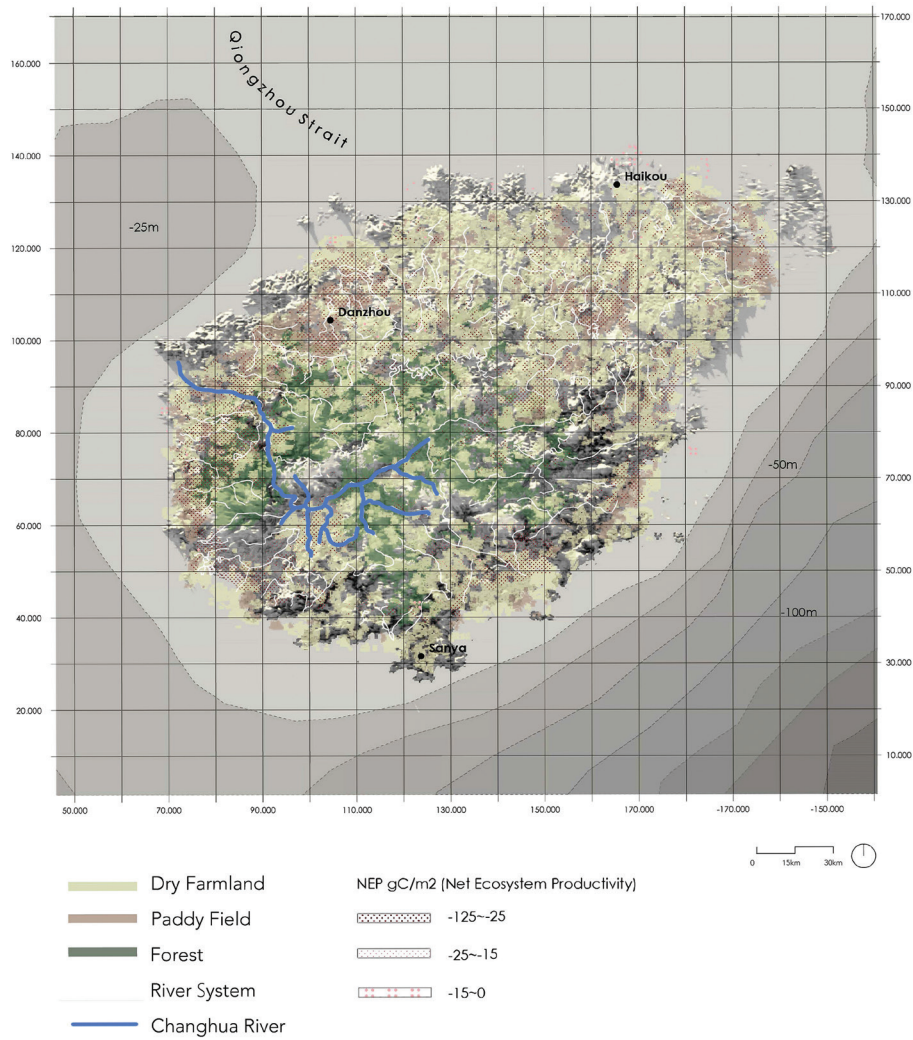


Figure 1. Map of Hainan Island. Source: Drawing by the authors



Figure 2. Images of Yulong Village. Source: Photos by the authors

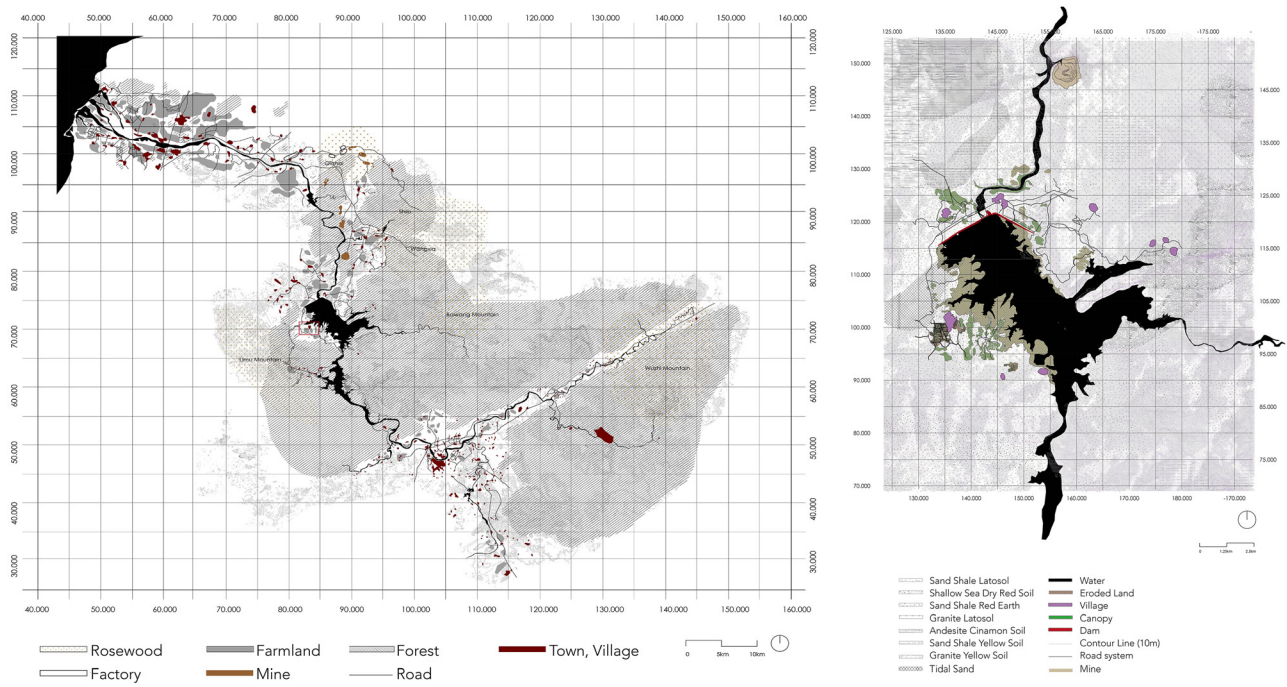


Figure 3. The maps of Changhua River and Daguangba Reservoir. Source: Drawings by the authors

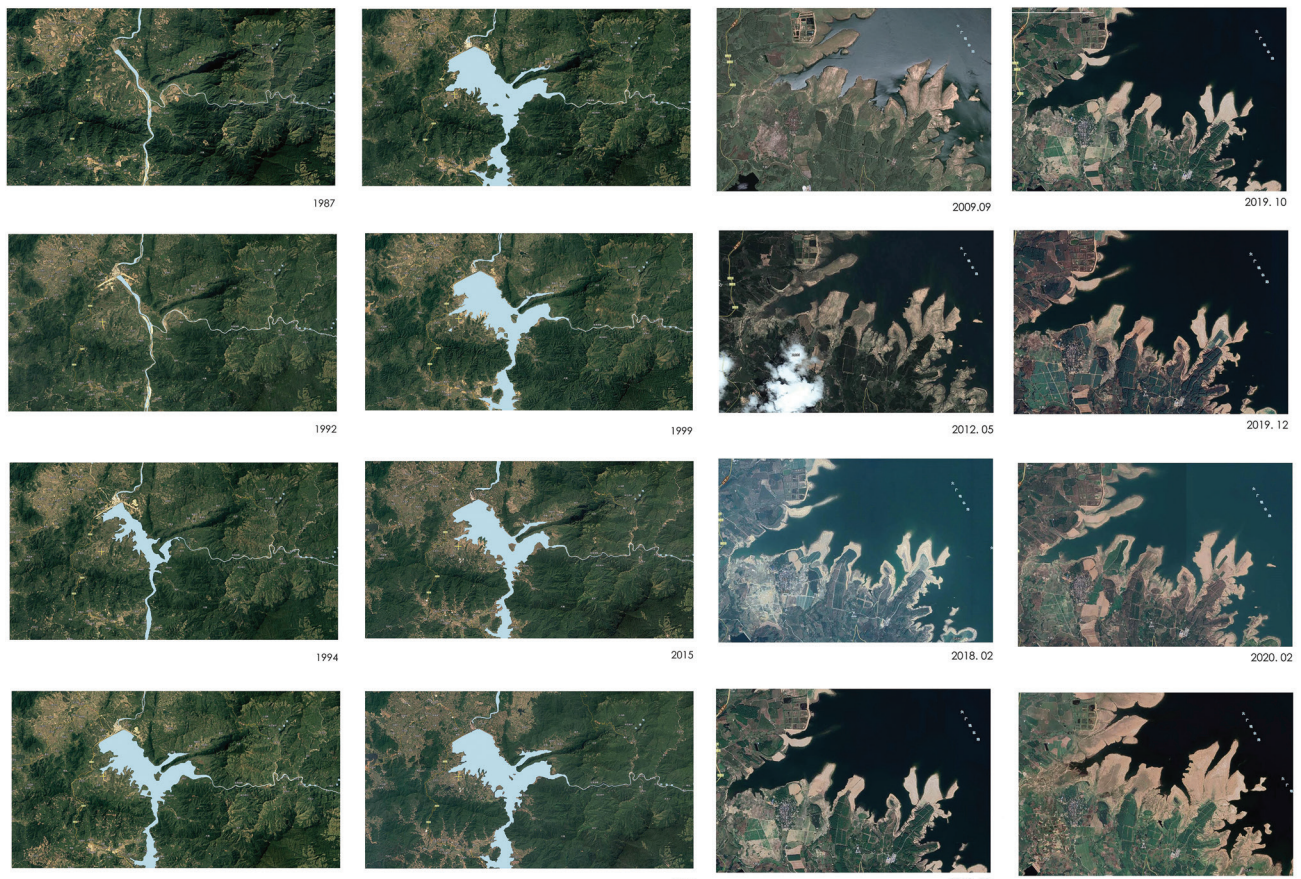


Figure 4. Satellite image of the Daguangba Reservoir and its edges. Source: Photos by the authors

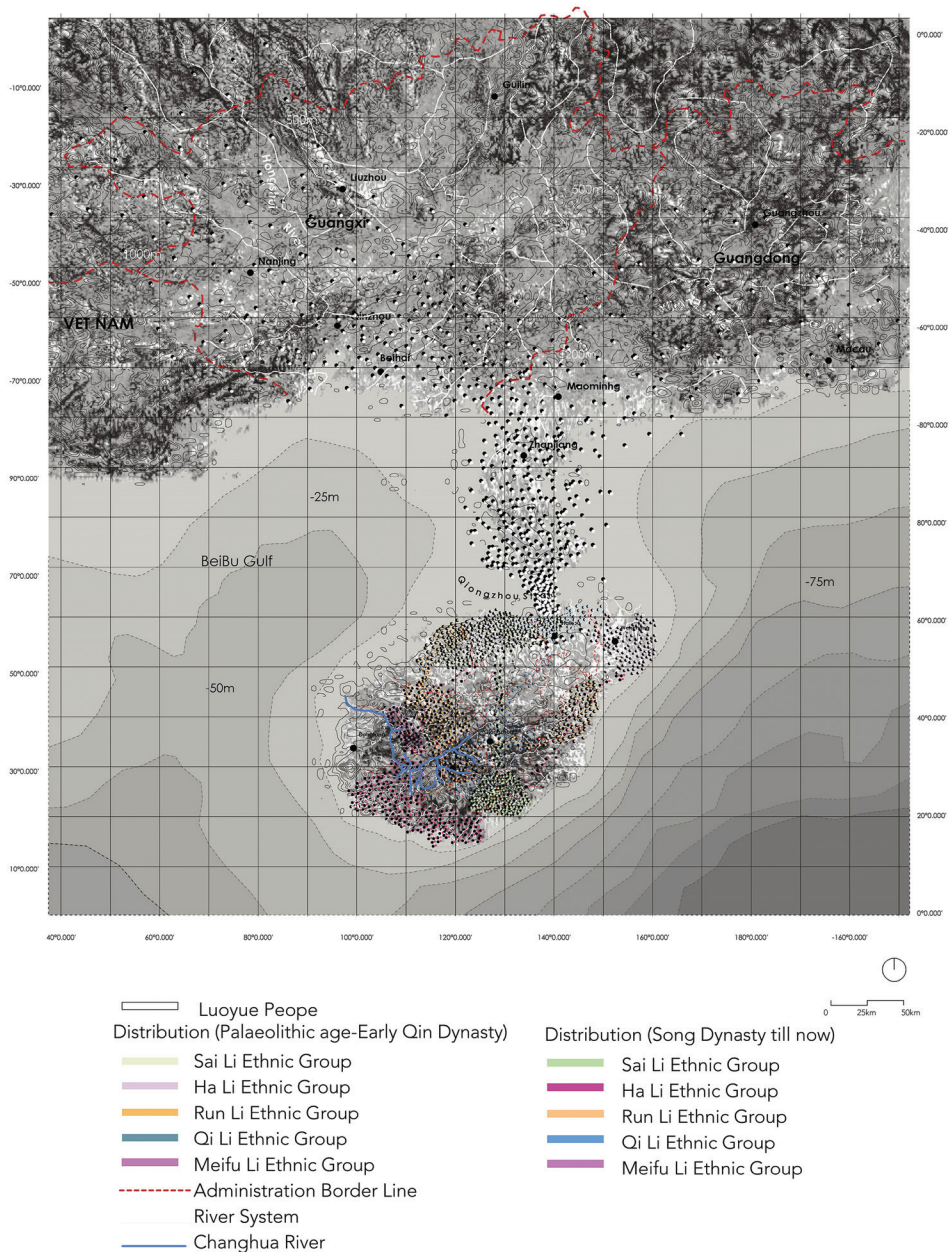


Figure 5. Li anthropology mapping. Source: Drawing by the authors

closing them off to net fish (Wen & Wen, 2012). In the lower catchment wetlands and low-lying areas near rivers, the Li family built open canals in their paddy fields and cofferdams in the rivers. These dams, constructed with stones or soil, would block one-third or even half of the river, creating a water diversion. This diversion allowed water to flow into the open canals irrigating the fields until filled, at which point the cofferdam would be removed. In areas with varying levels of rice fields, the Li family managed rainwater by diverting it through ditches

and then, using a hollowed-out log, diverting the water between the fields.

Knowledge of natural resources also enabled the ancient Li family to accumulate rich practical knowledge in adapted agricultural production, fostering a self-sufficient small-farming economy. They employed cows to break up the soil and provide natural fertilizer. Chickens freely foraged in village streets. In the fields, the Li family practiced crop rotation to restore soil fertility and planted crops such as



Figure 6. (A) Li traditional water management. (B) Li traditional farm activity. (C) Li traditional plant use. Source: Scans from *Li nationality's custom pictures of Qing dynasty*

sweet potatoes, mung beans, and peas to increase leaf area and ground cover, improving biological nitrogen fixation and reducing soil erosion. Through their cultivation practices, the Li family developed Shanlan rice, a grain unique to the Li village areas of Hainan (Figure 6B). This rice variety is well-suited to the seasonally dry slopes with low soil nutrients (Wang and Jiang, 2004). Unlike modern cultivars, it grows without the need for extensive pesticides or chemical fertilizers. Due to the low population density and large forest area in the Changhua River basin before the modern era, the cultivation activity of “Kanshanlan” increased the grain productivity of the ancient Li people, enabling them to maintain self-sufficiency. In addition, it was distilled to produce local rice wine.

Evidence from paintings from the Qing dynasty (Fu, 2007), demonstrates the distinctive self-sufficiency of the ancient Li family in the use of local plants for clothing, food, housing, and transportation realms (Figure 6C). Wild hemp, herbs, and bark were used for weaving and dyeing. Rattan and bamboo were used in building traditional Li family’s boat-shaped dwellings, weaving baskets, traps, rice sieves, and dustpans, and crafting bamboo rafts. Local herbs and bark were soaked and heated to create natural dyes, while various plants served medicinal purposes. This culture, developed in homes, by the river, and in the fields, illustrates that the Li family’s sustainable farming practices were rooted in their profound knowledge of natural resources.

The conscious knowledge of plants and animals in promoting healthy land and people perpetuates a spiritual attachment and belief system for traditional Li family. They believe that elements of the natural world serve as a medium that connects the divine realm with the everyday world. Different gods and ghosts govern the natural environments, and humans must take care not to offend

these entities through reckless or disrespectful behavior toward nature (Wen & Wen, 2012). Fearing punishment for disturbing the ghosts of the earth during planting activities, Li family’s farming traditions impose restrictions on the extent of agricultural planting. Not surprisingly, they view planting rice for food as a gift from the earthly god. During the pre-modern period, before planting each year, Li elders performed rituals in the mountains to pray to the mountain god for their blessings on agricultural production. They maintained a worship of Shanlan rice and pray to it after the harvest, holding a “Shanlan Festival” (Wang *et al.*, 2004). In addition, they had an attachment and affection for cows beyond their utilitarian value. Every year, on the eighth day of the 3<sup>rd</sup> month of the lunar calendar, Li farmers celebrated the Cow Festival by releasing their cows from daily toil in the fields and serving them glutinous rice wine to express gratitude for their hard work throughout the year (Wang & Jiang, 2004). Beside their villages, each family maintained a section of virgin forest as a cemetery, where human souls return to nature to rest in peace. Plants in these cemetery forest patches cannot be willfully cleared (Wang & Jiang, 2004). However, chickens, considered intrinsic to nature, are permitted to forage without it being considered an offense to their ancestors. This spiritual and material connectivity with animals is manifested in their special gratitude and goodwill for animal totems that they worship, considering the totems sacred and inviolable and forbidding hunting or eating them. Thus, the pre-modern Li family’s reverential admiration for nature fostered care and maintenance of sustainable production methods and daily life, intertwining nature and humans in enduring culture and traditions.

Today, traditional Li family’s agricultural practices and beliefs continue to influence the daily life of Yulong

Village residents. The people of Yulong Village maintain their worship and reverence for the mountains, forests, rivers, and land. In front of every house, there is a small shrine where the Li family make offerings to mountain god, earthly god, and other deities. Shanlan rice is still venerated; at the borders of some uncultivated mountains and paddy fields, the Li people continue to plant Shanlan rice and other local crops in small areas, preserving other traditions of crop planting and rotation (Figure 7). Shanlan wine, made from Shanlan rice, is still served at family gatherings and banquets. Even though the current residents of Yulong Village have been relocated at some distance from the ancestral forest cemeteries, modern Li family have adapted forest areas near where their relocated village meets their agricultural fields as a new cemetery, maintaining trees and plants in that area as lush as possible. While Yulong villagers no longer build boat-shaped houses, they still use local bamboo, rattan, hemp, and grass plants to build fences, barriers, and storage shelters. They also maintain traditions of gathering plants for weaving and dyeing cloth. Li women from all generations in the village often gather in their yards or in front of their neighbors' houses to practice and pass on traditional weaving techniques. In the yards, areas for storing modern agricultural machinery coexist with spaces reserved for growing local plants for home consumption and medicinal purposes. On the riverbanks, Li residents of Yulong Village still spontaneously gather to dig their own ditches, guided by the topography and the direction of water flow to secure water for irrigation. Every year, during the rise in water levels that floods the riverbanks, village children play in the shallows and fish from the shore. Older Li teenagers in the village are proficient swimmers and skilled in rowing boats, which villagers still use to transport tools, materials, and agricultural commodities (Figure 8).



**Figure 7.** Li traditional farm practice in Yulong village. Source: On-site photos by the authors

However, the dominant trend in modern agricultural development, primarily focused on quantitative growth, has largely eroded the beliefs and traditional farming practices of the Li family. With the damming of the Changhua River, uncontrolled development of land resources, modernized agriculture emphasizing cash crops, near-total abandonment of the “Kanshanlan” cultivation, large-scale deforestation of mountain forests, and the loss of animal habitats, the spatial opportunities for Yulong Village residents to maintain their traditional activities and associations with flora and fauna are becoming insignificant. Yet their knowledge systems may prove beneficial as global climates warm and biodiversity loss affects sustainability.

## 2.2. Green infrastructure design tools for Yulong Village

While the current environmental degradation is widespread, the future impact of intensified rainstorms and typhoons resulting from climate change poses an additional threat to the lives and landscapes of Yulong Village residents. This scenario anticipates an increase in flooding, landslides, and crop damage. Considering that the Li people have navigated changes and natural events for nearly 2000 years, there is likely value in exploring how to cultivate the regeneration of ecology – a green infrastructure based on Li family’s agricultural values.

Accordingly, we undertook a design research investigation of green infrastructure in the environment of Yulong Village. The aim of the green infrastructure design is to spatialize the potential for ecological adaptability to extreme weather, improve ecosystem health, restore species diversity, and continue traditional Li family’s agricultural autonomy. In regional settings in China, green infrastructure is primarily based on morphological spatial pattern analysis and multivariate curve resolution analysis tools. However, the limited accuracy of available data and the broad acreage of Yulong Village’s fields make these tools inadequate for coping with design at a relatively detailed scale. To address this, our project used other tools to elucidate on morphological possibilities of beneficial hydrology, community, and vegetation systems. Hence, our approach integrated existing satellite images, field surveys, Rhino 3D modeling, and McHarg’s “layer-cake” land suitability analysis.

We imported the topographic features of the site, recording them during the field survey and utilizing the clipped digital elevation modeling grid files. Subsequently, we used Rhino 3D modeling to depict the topography of the site and Grasshopper’s Stormwater Runoff Analysis

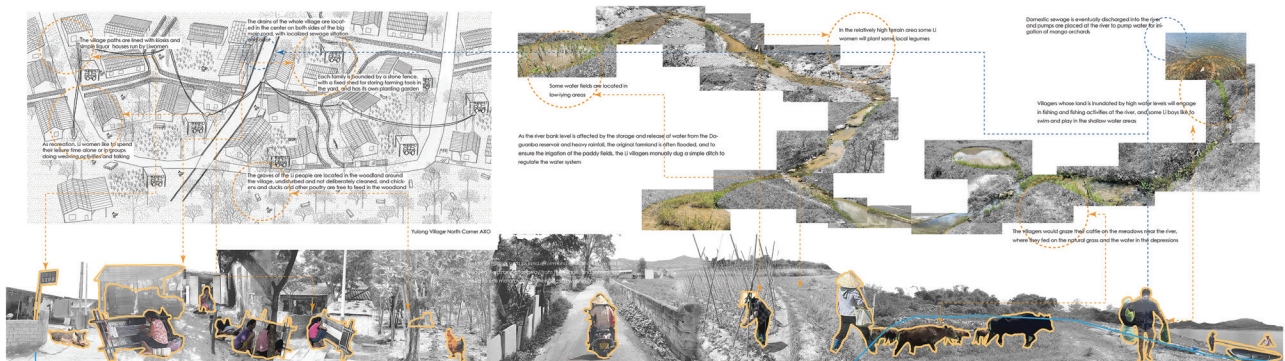


Figure 8. Vernacular life in Yulong Village. Source: Drawing by the authors

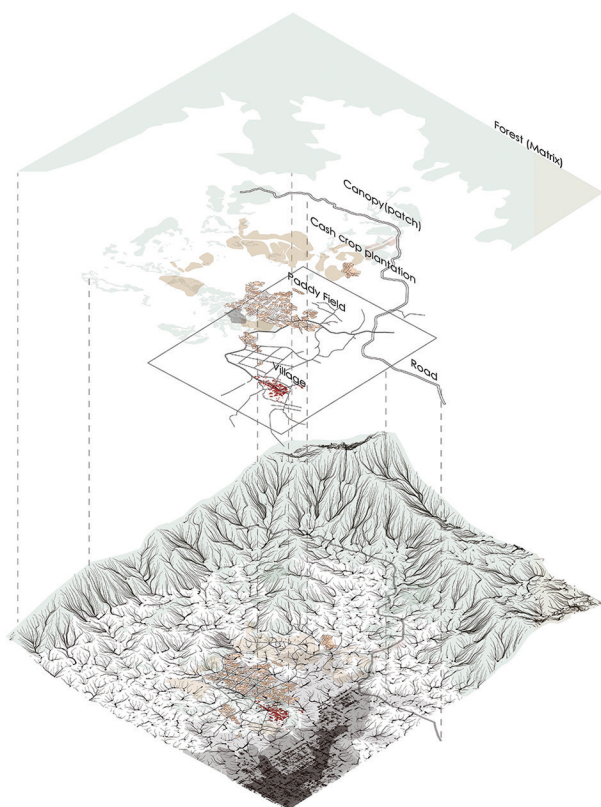


Figure 9. Runoff analysis. Source: Drawing by the authors

plug-in to identify potential depressions. Results propose a system of water corridors connecting these depressions in both the mountainous cash crop area and the lowland agricultural fields (Figure 9). This proposal catalyzed the exploration of design options for the riverbanks, where erosion problems are escalating due to frequent annual water-level changes.

We speculated on a series of riparian wetlands by simulating the submerged areas caused by rainfall and the rising of the reservoir’s water level. Superimposing the

water corridor system’s morphology through topographic modeling revealed potential benefits. These tools for hydrological modifications could project a succession ecology, with native mangroves eventually mitigating riparian erosion. Li family’s ecological knowledge, together with modern tools, could enable multifunctional benefits: the water corridor system brings sediment to the riverbank edge, shaping the riparian wetland, enhancing mangroves, restoring soil nutrients, and reducing flooding impacts on higher ground.

Our field surveys uncovered the narrative of Li family’s agriculture, encompassing abstract beliefs and concrete practices. This approach allows a deeper understanding of the spiritual core of Li family’s culture, even for those unfamiliar with Li family backgrounds. Despite the lacking of a written language, Li family’s farming traditions are usually kept alive by word of mouth between generations of the Li family clans and by subtle influences in daily life. In Li family’s farming traditions, the language of landscape and its flux has a strong vitality. Although modernization has greatly interfered with the communication of Li family traditions and, to some extent, diminished their carriers of language, the spiritual core of Li family traditions persists in the collective subconsciousness of Li descendants. This influence shapes the lives and behaviors of the current Li family members, enabling them to find a relatively comfortable way of life in the ever-changing environment. Protecting and enabling these oral traditions are crucial for the realization of rural revitalization. For this research, uncovering the remnants of living Li family traditions in text-based research posed a challenge. Mapping from field surveys proved more effective in understanding the Li people’s culture and agricultural sensitivity. Consequently, the research introduces a cartographic technique that may supplement the oral narrative, contributing to the revitalization of the diminishing Li family’s farming culture.

Guided by field surveys and an understanding of the significance of oral narratives, the design mapped the daily circulation pathways of the local Li people and analyzed the spatial expression of Li family's traditional belief systems. Leveraging satellite images to discern patterns of forest and shrub vegetation in the mountains, farmland, and village surroundings, we proposed vegetation corridors. These mappings were then superimposed onto the general shaping of water corridors to ensure that the morphology of the vegetation corridors fully covered the existing daily collection and ritual activities of the Yulong Village residents (Figure 10). To respect the living traditions of Yulong Villagers and avoid unnecessary disturbances, the fieldwork extended green infrastructure to a detailed scale within the village. Utilizing humble concrete drainage channels, the design incorporated a landscape strip of graminoid plants to facilitate rainwater infiltration and minimize the impact on village life. This approach in design research combined site-based interpretations with modern cartographic technologies, seamlessly integrating broader vegetation patches and field hydrology corridors into the village life.

### 3. Results

#### 3.1. Empowering Li family's agriculture through green infrastructure in Yulong Village

The proposed green infrastructure network, consisting of water corridor and vegetation corridor systems, aims to improve the resilience of Yulong Village to weather extremes, will reshape residents' ability to connect with nature, and provide space for the revitalization of traditional Li family's agricultural activities. The design research shows how these goals can be achieved (Figure 11).

The Li village-based water corridor system in the mountain would serve to divert runoff from the slopes during heavy rains, preventing flood damage to the village and fields. In addition, it would collect rainwater during the dry season, providing irrigation for planting and sustaining the organisms in the vegetation corridors. Within the native amphibian-populated vegetation corridor system, species such as frogs and birds would contribute to controlling locusts (Figure 12).

Along the river's edge, mangrove shallows would provide a habitat for birds and amphibians, such as the Hainan

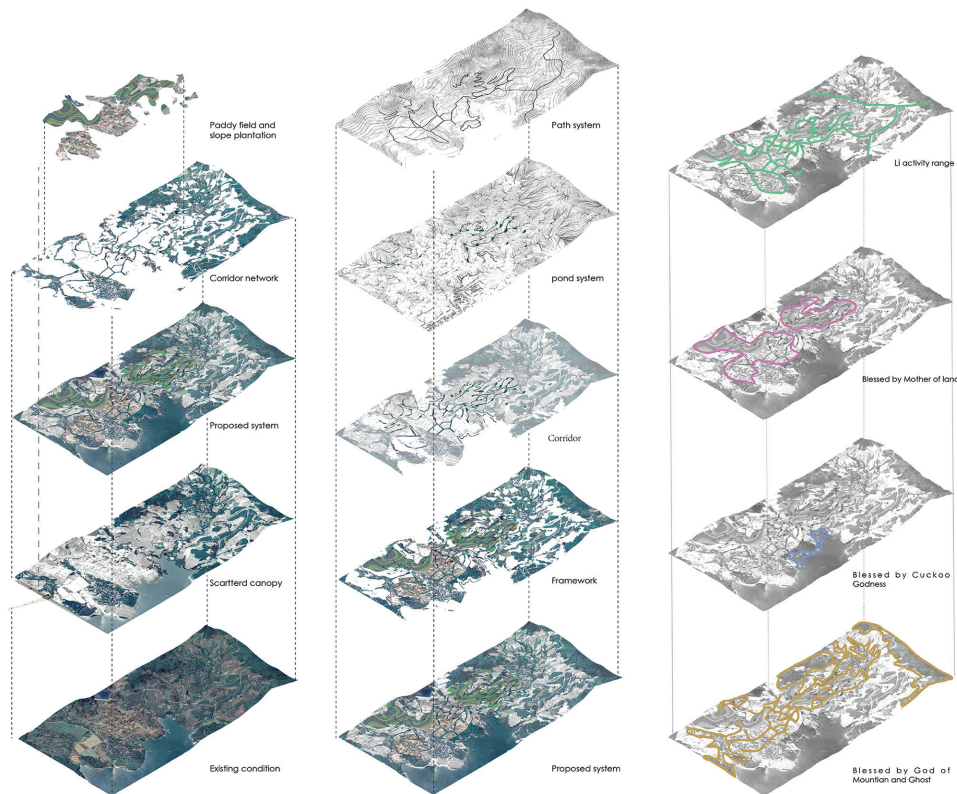


Figure 10. Green infrastructure morphology design. Source: Drawings by the authors

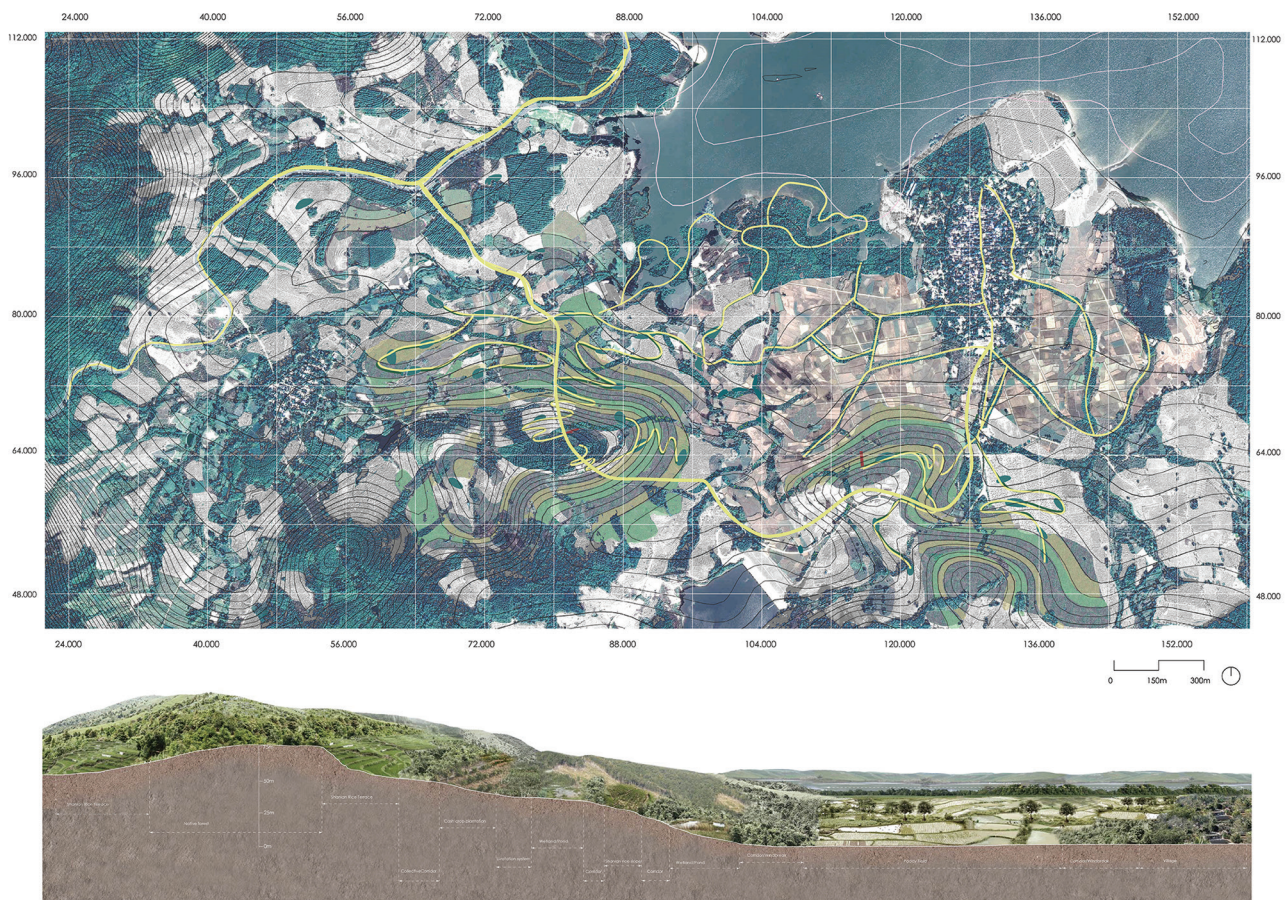


Figure 11. Yulong Village master plan and perspective section. Source: Drawings by the authors

black-faced spoonbill, which, in turn, help ameliorate locust infestation. The spoonbill, like many other native animals, holds significance as an object of totem worship for the Li people, and their return is important for the continuity of Li family's agriculture. A healthy riverbank space surrounded by mangrove shallows would also provide a safe environment for local activities such as fishing and children's water games.

Similarly, the green drainage canals in the village would function as miniature ecological corridors, attracting local insects and birds. These canals could become potential play spaces for Li children and foraging spaces for the poultry that roam the streets of Yulong Village. These localized vegetation systems, coupled with a broader vegetation corridor running through the entire production and living space of Yulong Village, would provide sufficient space for local animals to move and migrate. This setup ensures sufficient plant resources for traditional Li villagers gathering activities and offers context for Li elders to teach their children the skills of identifying and utilizing local plants, thus preserving and passing down traditions to newer generations.

With the integration of traditional water and vegetation systems, there is an opportunity to expand the cultivation of Li family's Shanlan rice and implement a crop rotation system on the slopes of Yulong Village. This approach aims to compensate for the constraints posed by recurrent flooding in lowlands and the extensive cultivation of tropical cash crops in mountainous areas. Traditional Shanlan rice cultivation practices, facilitated by the establishment of terraces for improved accessibility and safety on the slopes, can contribute to soil restoration. In addition, the traditional crop rotation and planting practices hold potential value in restoring and protecting the soil in Yulong Village. After a few rounds of Shanlan rice planting and traditional crop rotation, a healthy soil profile would enable the diversification of agricultural products, including the rotation with some tropical crops. This diversified approach aims to make land resources as sustainable as possible. By working in tandem with cash crops, these traditional agricultural systems can ensure both the ecological security of the sloping plantation area in Yulong Village and the economic security of the villagers (Figure 13).

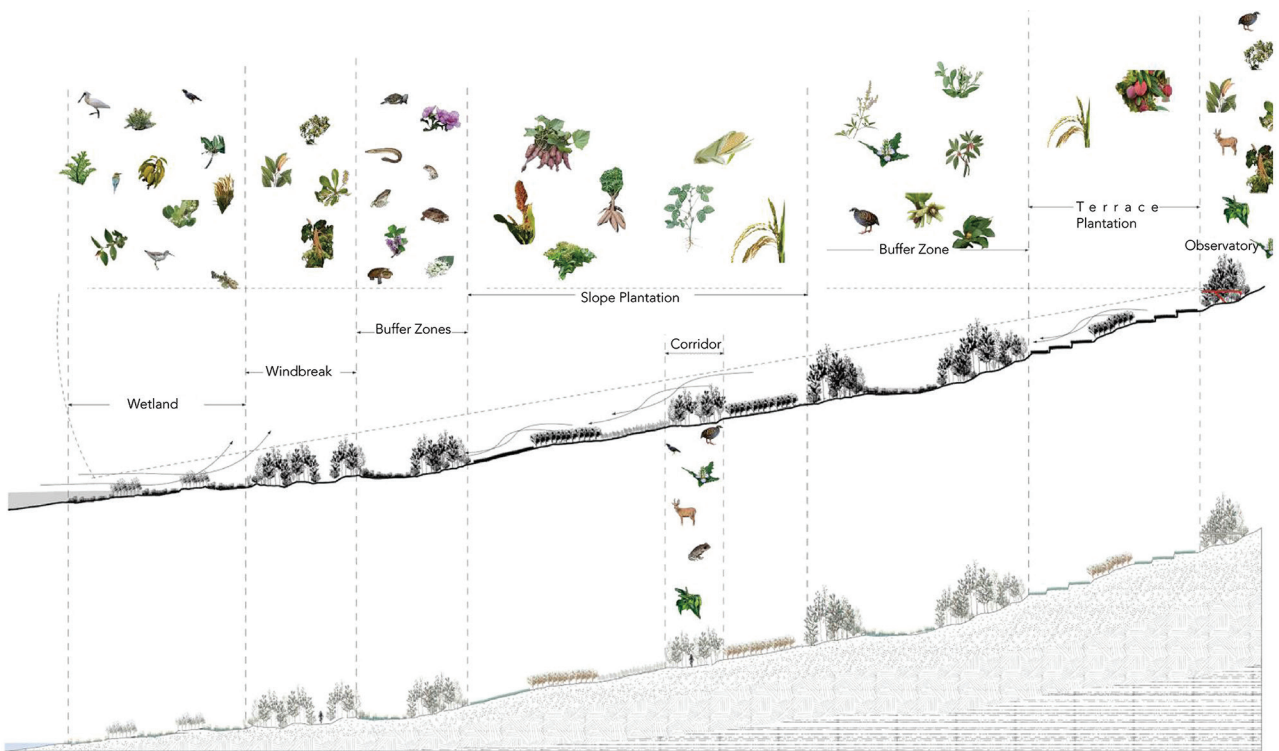


Figure 12. Plant corridor that protects the biodiversity of Yulong village. Source: Drawing by the authors

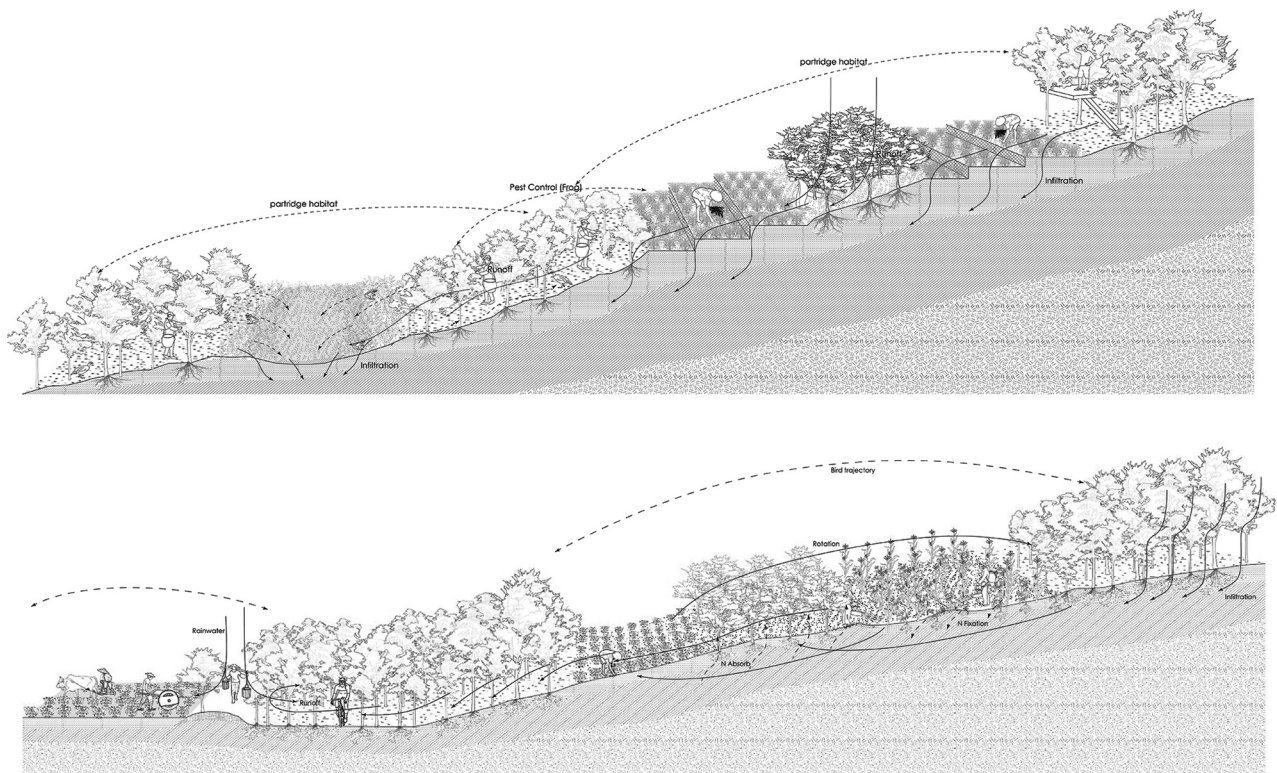


Figure 13. Proposed slope area section. Source: Drawings by the authors



Figure 14. The participation of villagers in constructing the wetland area. (A) Rain season. (B) Dry season. Source: Photo combinations by the authors

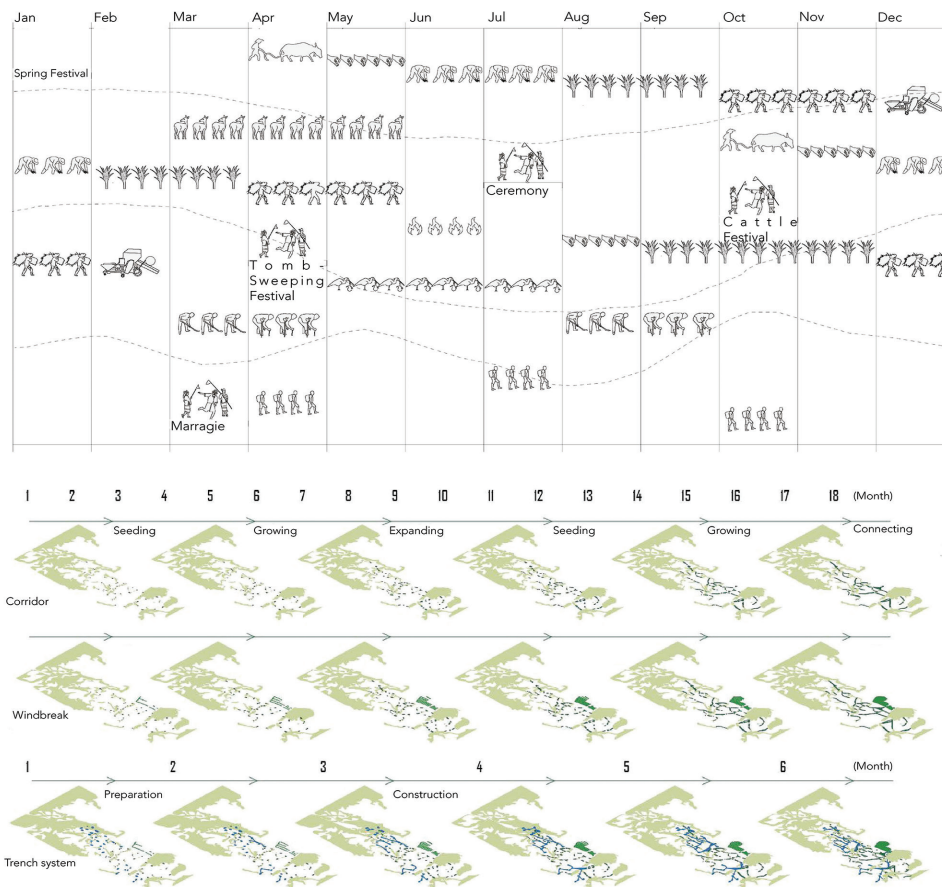


Figure 15. Proposed construction schedule of green infrastructure. Source: Drawings by the authors

The outcomes of the design research, relying on low-funded community involvement, would be implemented incrementally. The first phase begins by delineating the extent of the potential ecological corridor’s ribbon area. These ribbon spaces allow villagers to plant at intervals to

form clusters of small patches, which become habitats for native animals. Native animals forage for food in the patches and spread plant seeds through feces to the space beyond the patches, realizing the gradual expansion of the patches and connecting them to each other to form the corridor

space. Species in the patches and corridors compete freely to improve and stabilize the ecosystem. The ecological ribbons also leverage residents' traditional knowledge of plant use and experience in ditch construction. The mountain soil excavated for the ditch system and the agricultural straw produced by regular farming during this phase could be temporarily stockpiled to be used as raw materials for the second phase of implementation.

The next phase focuses on creating mangrove ecosystems along the riverbanks. By this point, the density of vegetation in the ditches and corridors has increased through the autonomous spread of plants and animals. Mountain soils, agricultural residues, sediments carried by the ditch system, and materials hoarded and decomposed in the first phase become the raw material for shaping the topography of the riparian wetland system and serve as fertilizer for soil restoration. This phase also provides additional work opportunities for villagers during their agricultural downtime (Figure 14).

The staged construction approach allows the ecosystem of the entire area sufficient time for viability and self-improvement, minimizing the loss in the income stream of the residents throughout the implementation cycle. The incremental phasing would closely reintegrate the daily activities and labor of local residents with the natural environment, revitalizing the traditionally close relationship between Li family's agriculture and local ecosystems. By participating in the process of ecosystem creation, the often-overlooked value of the villagers' traditional agricultural beliefs and practices is effectively realized. This model reduces the costs and total carbon emissions of the implementation process and allows for the recycling of agricultural resources (Figure 15).

### 3.2. Economic possibilities arising from a revitalized Li family's agriculture

The design of green infrastructure that incorporates traditional Li family's agricultural practices offers possibilities for eco-agriculture, eco-finance, and cultural tourism in Yulong Village. Once the ecological network of the entire Yulong Village has been virtually completed and the new rural green infrastructure landscape is essentially in place, tourist and visitor infrastructure could be added. Cycling routes within the existing road network could be installed. The topography affords places for viewing platforms, offering excellent outlooks of the landscape without disturbing the everyday lives and production activities of the villagers. On the cycling route, tourists could observe the landscape during the Li villagers' harvest season, watch cattle treading and aerating the fields, witness harvest-gathering activities, and experience other traditional Li family's agricultural activities. At different viewing platforms, tourists will have the opportunity to enjoy the landscape beauty of Yulong Village's sloping Shanlan rice terraces and smell the unique aroma emitted from the mountain orchid rice. Walking through the streets of Yulong Village, visitors can encounter Li women weaving in front of their houses and courtyards, wander among the poultry and animals walking along the streets, and hear the chirping of birds and insects attracted by the green infrastructure system. In such a landscape space, the residents of Yulong Village themselves are a living embodiment of the continued vitality of traditional Li family's agriculture and engage in its active dissemination through acts of sharing rather than performance. Tourists visiting Yulong Village would gain a better insight into authentic Li family's traditional culture compared to tourist attractions that rely on



Figure 16. Tourism experience in Yulong village. Source: Photo combinations by the authors

artificial reconstructions and performances created exclusively for tourist entertainment.

The outputs from the ecocultural systems offer additional economic possibilities. Although the cultivation of Shanlan rice on the slopes will be limited, it offers unique food and wine production. Compared to mass-produced commodities, these products might become high-value-added ecoagricultural items. The vegetation corridor system will also provide sufficient raw materials for the traditional textile and tie-dyeing crafts of the Li people, offering potential sales for handmade fabric and clothing products crafted from natural and ecological sources. Sustainably harvested rosewood in the vegetation corridor not only can provide value to the ecosystem but could also be harvested sustainably to generate additional profits for the residents of Yulong Village. The economic diversification brought about by green infrastructure improves the ecological security of Yulong Village. The residents' agricultural production activities may become less precarious, and they may remain stable sources of income, reducing the incentives to over-exploit land resources for short-term gains (Figure 16).

## 4. Discussion

The study found that in contrast to modern worldviews founded on Enlightenment humanism and Western scientific processes, the Li family's farming tradition in Hainan, China derives knowledge from perceptual understanding and reverence for their natural environment. This knowledge, characterized by a conscious nature-based practicum and spiritual mystique, has given rise to traditional values emphasizing the conservation of natural resources and a labor ethic of moderation. These values have enabled the Li people of Yulong to foster a long-term and stable coexistence with their landscape. However, these ideas, often absent in modern societies focused on productivity and wealth, have been transformed by industrial agriculture in the Li village environment. While new agricultural technologies bring beneficial efficiencies, they also leave a legacy of ecological and environmental erosion. Only a few remnants of vernacular life in Yulong Village and its agricultural fields have remained.

This design research has explored Li family's farming traditions and applied the theory and practices of green infrastructure – a greening paradigm usually deployed in cities and parklands – to discover potential avenues for restoring ecological vitality and human connectivity to the environment of Yulong Village. Drawing inspirations from urban models of green infrastructural practices, this research highlights the potential of implementing nature-based solutions, such as systematic water management

and diversified plant corridors, within and between areas of industrialized agricultural production. This approach aims not only to retain agricultural efficiencies but also to contribute greatly to the preservation of the Li family's farming culture. Green infrastructural practices in cities demonstrate that it is neither possible nor necessary to fully restore the landscape to its pre-modern state or return people to pre-modern ways of production and living. Similarly, in the Li villages' rural environment, green infrastructure landscape design could underpin the ecologically and economically sustainable development of Yulong Village. Green infrastructure has the potential to realize the mutual support and promotion of ecological security, cultural heritage, and economic development in Li villages. The projection is that this implementation will re-establish the traditional cultural space of the Li people, thereby reinforcing the connection between people and landscape.

Fundamental to our study on new approaches to green infrastructure design and the communication of tradition through new cartographies is the integration of morphological landscape design processes and field studies. MacHarg's layering design method, combined with other advanced cartographic technologies, spatializes a top-down view of the restoration. Field study mapping captures the narrative of village residents' culture. Instead of relying on a government edict, the society's active involvement in the implementation process of a bottom-up green infrastructure strategy would be essential to empower villagers to participate in the design and creation of green infrastructure. This approach will not only meet the actual needs of the Li residents but also leverage their practical knowledge of plant collection, soil care, Shanlan rice cultivation, and water management to inform this rural green infrastructure.

While this approach to green infrastructure design appears to be a potential method for rural revitalization, it must be acknowledged that rural revitalization is still in the exploratory stage. In reality, it faces challenges such as the ambiguous definition of stakeholders' rights and insufficient financial subsidies from local governments due to the uncertainty of relevant policies and legislation. In addition, there is still a considerable amount of traditional Li family's farming culture that deserves further study, such as Li family legends, stories, and music, which have the potential to provide important references and inspirations for the design of green infrastructure in the Li villages. More accurate geographic information collection of the Li villages and more in-depth sociological surveys could improve the precision of the morphology design of the Li family's green infrastructure. Establishing a more effective consultation and communication platform with the Li residents to realize a more sophisticated participatory

design and construction model will also be an important direction for future research. To be consistent with the holistic nature of Li family's farming traditions, the upgrading of the existing residential facilities in the Li villages should also be included in the design of future green infrastructural network. While this research offers promising conclusions for the longevity of Li family's agricultural tradition and a more sustainable environment in Hainan, future landscape design for rural revitalization needs to conduct in-depth interdisciplinary research with related disciplines, such as law, economics, and politics. Such exploration will contribute to the improvement of China's rural revitalization policies and legislation, providing a top-down assurance for the on-ground practice of green infrastructure.

## 5. Conclusion

After nearly a century of modernization, China has indeed achieved remarkable success in eradicating rural poverty. However, it now confronts the even more arduous task of transforming its ecological civilization and revitalizing the countryside. This endeavor entails not only the need to apply more scientific and efficient modern approaches to rural governance but also the need to infuse new connotations into China's ancient agrarian civilization, thereby nurturing China's spiritual civilization. Li family's agriculture is an important part of China's farming culture, serving as a crystallization of wisdom passed down from generation to generation by the Li people. The significance of Li family's traditional farming culture and vernacular culture, therefore, extends far beyond their immediate context, bearing extraordinary significance in the construction of China's ecological theory and the discourse of China's ecological civilization. The practice of green infrastructure will play a key role in reshaping the implementation of ecological civilization. In conclusion, we assert that Chinese landscape architects have an obligation to help protect and promote traditional Chinese culture in the process of global cultural integration and impact. They play a key role in building up cultural self-confidence for the Chinese people and conveying to the world a different story of modernization.

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## Conflict of interest

The authors declare that they have no competing interests.

## Author contributions

*Conceptualization:* Keshen Wu

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*Writing – review & editing:* Andrew Toland, Martin Bryant, Yong He, Bo Chen

## Ethics approval and consent to participate

Not applicable.

## Consent for publication

Not applicable.

## Availability of data

The data that support the findings of this study are available on request from the author Keshen Wu on reasonable request.

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## ORIGINAL ARTICLE

From burrow to bungalow: The role of  
storytelling in regenerative architectureRolf Hughes\*

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(This article belongs to the *Special Issue: Regenerative Architecture*)**Abstract**

Regenerative architecture requires interdisciplinary knowledge instruments to help us reconceive research from post-anthropocene perspectives, initiating new conversations about how we creatively engage our world. In this paper, the author — a writer, prose poet, and professor of artistic research — explores the contribution of storytelling as a practice within artistic research to regenerative architecture, a form of architecture for which the ecological and ethical implications of each design decision are foremost. It argues, through a reading of Kafka's last short story, *The Burrow*, that the current focus on maintenance and sustainability may be insufficient; we need, like Jack in the tale "Jack and the Beanstalk," to explore the problem of survival on a higher level. Artistic research can help us navigate uncertainty, develop toolsets, integrate practices, and extend the concept of experiment. Artistic researchers develop knowledge-making through unconventional concepts, creative methodologies, and alternative practices that accompany and engender unique sensibilities, patterns of thought, and knowledge formats. Bringing established knowledge practices into dialog with non-conventional perspectives, such research provokes new mode(l)s of knowledge that serve regenerative architecture's need for "worlding" narratives. Inviting us to think anew through remaking the world materially and relationally, the paper argues that storytelling allows us to mediate emergent encounters and alternative epistemologies. It summarizes the salient elements of narrative craft, provides examples of regenerative themes in different cultural narratives, including two Chinese folk tales, offers a reading of Franz Kafka's *The Burrow* from a regenerative architecture perspective, and adapts Kafka's story into a contemporary setting through an original short story — a fable for the consequences of ignoring ongoing signs of crisis. The paper, which is illustrated by the author's original artistic images throughout, is a contribution from a foremost proponent of language-based artistic research, a practice that combines creative and critical writing. By enfolding creative and critical approaches to regenerative architecture, the paper demonstrates how stories can provide compelling models of ethical and political complexities that engage interdependencies within the ecological realm.

**Keywords:** Creative and critical writing; Artistic research; Storytelling; Speculative fiction**\*Corresponding author:**Rolf Hughes  
(rolf.hughes@gmail.com)**Citation:** Hughes, R. (2024). From burrow to bungalow: The role of storytelling in regenerative architecture. *Journal of Chinese Architecture and Urbanism*, 6(2), 1335. <https://doi.org/10.36922/jcau.1335>**Received:** July 19, 2023**Accepted:** August 29, 2023**Published Online:** March 13, 2024**Copyright:** © 2024 Author(s). This is an open-access article distributed under the terms of the Creative Commons Attribution-Non-Commercial 4.0 International (CC BY-NC 4.0), which permits all non-commercial use, distribution, and reproduction in any medium, provided the original work is properly cited.**Publisher's Note:** AccScience Publishing remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Note: All images by the author (Figures 1–9) are intended to evoke the setting and atmosphere of the short story *The Bungalow*, published at the end of the article. As such they do not illustrate specific arguments in the text.

## 1. Introduction

“[...] we watch the landscape for signs that might tell us something more of the something less we sense inside.”

- *The Transformation of Nature* by George B. Moore (Poetry Magazine, May 1992, p.88)



Figure 1. Bungalow I. Source: Original work by the author

Regenerative architecture has been defined as “the practice of engaging the natural world as the medium for and generator of architecture. Living systems on the site become the building blocks of the structure, built in harmony with the overall ecosystem” (Gattupalli, 2023). It aims to design sustainable, resilient, and regenerative built environments that enhance and restore ecological systems. Its ambitions are essentially restorative — seeking to temper the material excesses of extractive construction by making more environmentally-conscious choices, leading to results that are not only more “sustainable” but also work to regenerate surrounding ecosystems. In this emerging field, there are a growing number of formal educational programs focused specifically on regenerative architecture. The Experimental Architecture Group (EAG), founded in 2016 by Rachel Armstrong at Newcastle University, has developed regenerative architecture research from its inception, disseminating

its findings in galleries, biennales, and triennials internationally and across a range of publications and media outlets.<sup>1</sup> This paper is authored by one of the original members of EAG, who brought expertise in creative and critical writing,<sup>2</sup> dramaturgy, and sound art to the group’s design research, helping create an interdisciplinary blend of science, design, pedagogy, art, poetry, audio-visual media, and performance. The European Union-funded research project *Living Architecture* was highly praised by evaluators for repeatedly reaching out to wider audiences by presenting its findings in cultural venues.<sup>3</sup> More recently, *Xenomorph Energy: Necromantic Orchid*

<sup>1</sup> For an overview of recent Experimental Architecture group outputs, see Armstrong, R., Hughes, R., & Ferracina, S. *Monsterring: a transdisciplinary method for an unstable world*. *Palgrave Commun* 6, 60 (2020). <https://doi.org/10.1057/s41599-020-0426-3>

<sup>2</sup> See, for example, my entry in Cocker, E. *et al Practice Sharing II* (2023) <https://www.researchcatalogue.net/view/1538250/2166723/8701> (accessed 9 January 2024)

<sup>3</sup> The *Living Architecture (LIAR)* project ran from April 2016 to April 2019. Funded (€3.2 million) by the Horizon 2020 Research and Innovation Program under EU Grant Agreement no. 686585, the project brought together experts from the University of Newcastle, UK; the West of England (UWE Bristol); Trento, Italy; the Spanish National Research Council in Madrid; LIQUIFER Systems Group, Vienna, Austria; and Explora Biotech, Venice, Italy. *Living Architecture* proposes a new infrastructure for buildings — our homes and workspaces — that uses “living” technologies to replace some of the tasks currently performed by machines, such as electricity production. The aim is to reduce, and eventually eliminate, our dependency on fossil fuel-based systems, particularly as the built environment is currently responsible for 40% of our total carbon emissions. Not only do these “living technologies” generate useful “housework” but they also reduce and ultimately eliminate household waste, using our discards and excrements as “fuels” to feed the incredible organic processes of microorganisms that can transform them into useful substances. The *LIAR* infrastructure is a strategically coordinated system of microbes that are housed in specific bioreactors. It takes the form of a freestanding, next-generation, selectively programmable bioreactor complex composed of microbe-specific building blocks (microbial fuel cell, algae bioreactor, and a genetically modified processor). Each of these bioreactor types possesses a specific “metabolism,” or the capacity to transform one set of substrates into another. When they are sequenced spatially, the waste products of one system can become the starting point for another. Through the configuration of both microbial “programs” (wild type and “synthetic” organisms) and bioreactor sequencing, particular kinds of work can be carried out (Armstrong & Hughes, 2022). Using our own metabolic activities as a starting point (consuming resources, producing waste matter, and moving around), the bioreactor complex transforms our liquid wastes (urine, grey water) into useful products (cleaned water, electricity, and biomolecules) while also removing pollutants (nitrous gases).

(XENO) (Armstrong *et al.*, 2023a) was exhibited from October 13, 2023, to March 17, 2024, as a commissioned artwork for the POWER exhibition at the leading architectural venue CIVA Gallery in Brussels.<sup>4</sup>

Design involves storytelling, yet designers rarely put much thought into crafting their narratives. As a result, presentations and pitches are often a chronology of interests, intentions, and compromises, accompanied by images of work-in-progress. This represents an account of the architectural process and production told from a narrow, human perspective, one that legitimizes its aims by excluding other points of view, perspectives, and interests (see, for example, Crutzen & Stoermer, 2000).

This paper argues that storytelling should have a central role in regenerative architecture due to its unique capacity to model the complexities of relations between humans, the built environment, and the natural world. Narrative helps us envision a more sustainable and resilient future; yet, its potential remains under-explored. My written, spoken, and performed narratives create structures through which multiple worlds and values are navigated. These are not didactic but seek to provide tools for uncovering latent micro-stories, thereby creating multiple, decolonializing perspectives, voices, and relations to complex events and situations. In my artistic and research practices, I explore an extended notion of writing — creative and critical forms alike — to address the wider concept of exposition in artistic

and interdisciplinary research. This incorporates expressive objects such as experiential artifacts and performative practices. I have taught Master's and Ph.D. courses in creative and critical writing across art, architecture, and design practices, covering themes such as art writing; architecture and/as storytelling (and vice versa); critical “voice(s)”; materiality and genre; site-specific writing; sound art; the prose poem and the boundaries of genre; the philosophical dialogue; ekphrasis; and the role of language in conceptual art. I have led workshops that investigate how the characteristics of literary, critical, and philosophical genres of inquiry shape relationships to spatial, (im)material, and experiential practices through materialized descriptions, installations, performances, philosophical dialogues, and critical poetics. This helps us rethink the relationship between critical and creative practice through a close engagement with genre and style and related questions of voice, subjectivity, point-of-view, spatiality, perspective, embodiment, and materiality.<sup>5</sup> Over the past 5 years, I have been developing the potential of (written, spoken, video, and performative) narrative to address the challenges of living on a damaged planet and have published several speculative fictions on this theme (Hughes, 2018; 2023).

Citing examples of relevant narratives from a range of regions and cultures, the paper provides a reading of Kafka's last story, *The Burrow*, from a regenerative architecture perspective. To demonstrate that stories have always developed through re-telling other stories (part of the regenerative characteristic of narrative itself), the paper additionally makes a strategic switch to “showing rather than telling” by offering a contemporary adaptation of Kafka's story through an original story written by the author for this special issue of the *Journal of Chinese Architecture and Urbanism* (JCAU), titled *The Bungalow*.

## 2. Why storytelling?

Storytelling has been used throughout history to express wonder, share information, affirm or question values, and give voice to doubts and beliefs. It can help communicate the goals, values, and vision of an architectural project to a wider audience, inspiring and engaging people, building community, and fostering a sense of connection to the natural world. Storytelling can model desirable (or undesirable) futures and facilitate discussions among its listeners or readers about its interpretation. In this way, the values of a community are celebrated, configured, or contested.

<sup>4</sup> XENO is an installation featuring a chimeric plant hybrid composed of mechanical and animal parts, drawing energy from silts and mosquitoes that feed on human blood. This challenges our understanding of natural energy, emphasizing that it is a precious exchange between living bodies, not a value-free resource. Natural energy involves constant negotiation between living organisms, operating through metabolism — essentially a continuous transfer of electrons between different bodies. In the modern world, energy has been commodified, stripped of its inherent complexity. Industrial society's use of fossil fuels transforms long-deceased organic matter into seemingly limitless power, elevating humans to quasi-divine status by animating machines. However, this process severely depletes natural resources, endangering our future. XENO's intricate energy exchange not only animates the plant but also implicates us in the ethical dilemmas and processes of (re)vitalization within an “alien” energy ecosystem (Armstrong *et al.*, 2023b). Additional information about the exhibition is available at <https://civa.brussels/en/exhibitions-events/power> (accessed on January 9, 2024). In addition to codeveloping the concept, I authored Xeno's Song and, in collaboration with Rachel Armstrong, the story Xeno: The Tale of a Misfit. The narratives were recorded and embedded in the sound design, which is audible through headphones at the gallery. Access to the texts is provided here: <https://xenoenergy.wixsite.com/xeno>

<sup>5</sup> Eminent researchers such as Jane Rendell, Katja Grillner, and Sepideh Karami have developed parallel initiatives through site specific writing, dialogic architectural theory, writing practices, and critical fiction as political practices of making architectural spaces.

Furthermore, storytelling enables the teller to weave together the different elements of an architectural project into a cohesive and compelling narrative. Narrative elements from an architectural perspective might include the site, building, materials, technologies, geo-political context, the people involved in or affected by the project, and its impact on the environment. By telling the story of how these different elements are interconnected, architects can design what they might consider an appropriate reception of the project. We might characterize this pedagogic type of storytelling as one of instruction or persuasion.

In regenerative architecture, storytelling can also foreground the importance of nature and the natural systems that support life on Earth. By telling stories about the ecological systems on a site, how they have been disrupted by human activity, and how they might be restored and enhanced through regenerative design practices, architects and designers can help raise awareness about the importance of protecting and restoring the natural world. We might characterize this ethical/political type of storytelling as one of (re)configuring values.

Regenerative architecture is frequently conceived as a practice of compensation, mitigation, or restoration. Students often unwittingly deploy the tropes of fall and redemption as the mythical archetypes underpinning regenerative architecture.<sup>6</sup> These tropes imply a certain narrative arc: (i) Once upon a time, Nature flourished (Paradise existed)...(ii) ... until one day, sadly, it became despoiled by industry (the Fall); (iii) regenerative design must restore what has been exhausted and depleted (desire for redemption); (iv) after some struggles, ecological restoration is achieved (resolution/Paradise is — partly — restored, albeit modified).<sup>7</sup>

Such a narrative might seed a script development workshop for the likes of Pixar or Disney, but it is hardly a compelling narrative to inspire the sustained work of design. For this, we need to think beyond easy oppositions between nature as the site of eco-purity confronting industrial capitalism as the agent of despoilation. We have become far too entangled for such consoling simplifications.

Storytelling can help us explore complexities and contradictions in the communities that will inhabit a building or space, the cultural traditions and values they bring with them, and the ways in which the built

environment can support and enhance these traditions and values. We might characterize this type of storytelling, which draws on multidisciplinary perspectives, as one of methodological pluralism.

In my practice, storytelling unfolds in a similar way to sketching. A detail is set down, implying a development. In both cases, we take a line for a walk. Decisions are made, and a nascent pattern emerges. Knowledge is explored, tested, and expressed. We let ourselves be led by the inner logic of the story/sketch. Both sketching and storytelling thus serve as complementary design tools in regenerative architecture. The aim is simultaneously to follow and subvert the logic of the line, thereby creating artistic, critical, and epistemological tension and dynamism.

Using stories and narrative principles to guide the design process, architects can create buildings and spaces that are more responsive to the needs of the people and communities they serve. “Participative design” is one practice in which storytelling clearly facilitates the exchange of expectations and experiences between stakeholders. In telling the story of how an urban intervention might support the activities and aspirations of a neighborhood, architects, and residents can co-create spaces that are better adapted to local needs. We might characterize this type of storytelling as one of aspiration or even worlding.

It is through storytelling that an architect communicates the vision, values, and goals of a site or architectural intervention, seeking to inspire and engage people, build community, foster a sense of connection to the natural world, and support social and cultural differences. These forms of storytelling rely on a didactic or mimetic logic, whereby the explanatory/illustrative arguments operate to transmit understanding or soft persuasion.

As architects work to create more complex, sustainable, and resilient built environments, storytelling will become an increasingly important tool for acknowledging the complexities, contradictions, and uncertainties of projects. This is not the linear logic of problem-solving; it calls for a more sophisticated concept of storytelling than the merely “illustrative” dimensions that I have outlined above.

### 3. Elements of storytelling

Covering the elements of storytelling in sufficient detail would require a longer paper, one encompassing a broad range of considerations such as narration, setting, mood, atmosphere, plot, exposition, structure, weather, metaphor, conflict, crisis, resolution, recognition, characterization, point-of-view, voice, speech, dialogue, time, genre, and more. For the purposes of the present focus on regenerative architecture, I identify the following elements as deserving of particular attention:

<sup>6</sup> From 2022–2023 I was course director for the Academic Design Office and Master dissertation studio *Architecture for Living on a Damaged Planet* at the Faculty of Architecture, KU Leuven.

<sup>7</sup> The (Judeo-Christian) story of the Garden of Eden portrays a world in which humans lived in harmony with nature, without causing harm or destruction, before the fall.

### 3.1. Site and setting

The history (or future) of an architectural site can inspire a regenerative design intervention. For example, a site that was once a polluted industrial wasteland but has since had its soil remediated and restored to what approximates its natural state can inspire the continued use of sustainable materials and programs in the design of buildings, gardens, and parks on that site. A site that was the setting for a traumatic episode in history (a massacre, for example, or enduring contamination by pollution) will be haunted by its own scars, silences, and ghosts (Armstrong, 2023).

The setting involves the context that shapes us, including place, values, traditions, climate, and the conditions of survival or thriving. It includes atmosphere (narrative tone/mood), time of day, and weather. Questions of harmony or disharmony between character and setting raise the possibility of wider conflict. It may draw on (or subvert) the familiar symbolism associated with a place (Paris, for example, has its own established romantic clichés that largely ignore the realities of life in the Parisian banlieues).<sup>8</sup>

These are not separate considerations but are subtly intertwined, as Burroway (2019, p. 171) comments:

“Our relation to time, place, and weather, like our relation to clothes and other objects, is charged with emotion, more or less subtle, more or less profound. It is filled with judgment, mellow or harsh. And it alters according to what happens to us. In some rooms, you are trapped; you enter them with a grim purpose and escape them as soon as you can. Others invite you to settle in, to nestle or carouse. Some landscapes lift your spirits, others depress you. Cold weather gives you energy or bounce, or else it clogs your head and makes you huddle, struggling. You describe yourself as a ‘night person’ or a ‘morning person.’ The house you loved as a child now makes you, precisely because you were once happy there, think of loss and death.”

Others (e.g., Morley, 2007, p. 173) stress the “intangible” aspects of the place:

“Place is more than location; it is mood, history, and other people’s lives. A recognizable cityscape is something a reader understands; gaining their trust, they move towards your story. You may then choose to make that city a place of strangeness or to allow it to offer your story local color.

<sup>8</sup> This discussion is indebted to Janet Burroway (10<sup>th</sup> edition, 2019), *Writing Fiction: A Guide to Narrative Craft* (Chicago and London, University of Chicago Press).

A carefully observed and vivid natural landscape carries its own precise connotations, edges for wildness, and the unpredictable.”

The story of a building connects it to the site and its surroundings. For instance, a building designed to house a nature education center might aim to blend with a natural feature such as a rock outcropping or a tree, intending to engage with the surrounding environment in its presence. However, there is a risk of succumbing to a form of literalism that inspires neither on an aesthetic nor a metaphorical level. Conversely, a building that has failed in its original conception may gain greater resonance in fictional terms. Furthermore, many buildings undergo repurposing over time, and incongruities between a building’s contemporary function and its original purpose may eventually become a source of irony.

### 3.2. Materials

The materials used in a regenerative architecture project also relate to the site and the overall narrative of the project. For example, the use of locally sourced materials such as wood, stone, and clay can tell a larger story of the site’s natural resources and the local communities that have historically relied on them. Materials may be thought of as an aspect of the “characterization” of a site. Materials are not necessarily fixed categories, as they can also be hybrid or “inauthentic” assemblages (think of a magpie’s nest that incorporates anti-bird spikes from the surrounding environment, for example,<sup>9</sup> or a home constructed from the detritus of a garbage dump that yet expresses a sense of belonging, pride, and design expertise).

### 3.3. Technologies

The technologies used in a regenerative architecture project can be an important expression of the overall narrative. For example, the use of passive solar design and rainwater harvesting systems can tell the story of a building conceived to work in harmony with its natural surroundings, implying a particular set of ethical and even esthetic values among the communities that benefit from the building. However, these utopian impulses may be challenged by conflicts over power and/or resources or turned toward dystopian purposes, such as weaponry and war.

<sup>9</sup> Ian Sample, “Crows and magpies using anti-bird spikes to build nests, researchers find,” *The Guardian* (July 11, 2023). Available from: <https://www.theguardian.com/science/2023/jul/11/crows-and-magpies-show-their-metal-by-using-anti-bird-spikes-to-build-nests#:~:text=The%20crows%20used%20the%20anti,including%20other%20birds%20and%20weasels.> [Last accessed 2023 July 12]

## 3.4. Community

A regenerative architecture project may aim to connect local communities to the project and each other, arguing that a community coming together to build a sustainable community center may experience a stronger, more durable sense of connection and belonging. However, a community may be split between those desiring to protect the environment and those seeking to profit from the project, irrespective of environmental consequences. Examples in literature and film include “Silent Spring” (Carson, 1962), Rachel Carson’s ground-breaking book exposing the detrimental effects of pesticides on the environment; “Chinatown” (1974), Roman Polanski’s neo-noir film set in 1930s Los Angeles uncovering a conspiracy related to water rights and environmental exploitation; “The Lorax” (1971), Dr. Seuss’ book later adapted into an animated film in 2012, telling the story of the Lorax who speaks for the trees and warns against environmental destruction driven by greed; “There Will Be Blood” (Anderson, 2007), Paul Thomas Anderson’s film focusing on an oil prospector in the early 20<sup>th</sup> century disregarding environmental or social consequences while pursuing wealth; “The Cove” (2009), Louie Psihoyos’ documentary exposing the annual dolphin hunt in Taiji, Japan, highlighting the conflict between profit-driven industries and marine conservation; “Promised Land” (2012), Gus Van Sant’s film exploring the contentious practice of fracking and the opposition it faces from a concerned rural community.



Figure 2. Bungalow II. Source: Original work by the author

## 4. A sea of stories

### 4.1. Genre and its discontents

This is not a story<sup>10</sup> but an essay (of sorts).<sup>11</sup> To write creatively about regenerative principles perhaps requires less the red thread of linear exposition than an unfurling weave of interdisciplinary entanglements.

### 4.2. Tales of regeneration

We have said that regenerative architecture is an approach to building design that seeks to create structures that are not only sustainable but also restorative, supporting the natural environment and contributing to the health and well-being of the people who use them. Across different cultures, we find many stories that illuminate aspects of regenerative architecture. In Aboriginal culture, for example, there has long been a concern with issues of regeneration and sustainability. The Aboriginal Dreamtime story of the Rainbow Serpent is a creation myth that explains how the world and all its creatures were formed by the actions of the Rainbow Serpent. Emerging from the depths of the earth to create mountains, rivers, and valleys, the Rainbow Serpent also created plants and animals, including humans. The Rainbow Serpent is seen as a powerful and benevolent force that controls the elements and brings life to the natural world, possessing an intelligence and agency of its own. For Aboriginal people, this story provides a powerful framework for understanding the importance of maintaining a harmonious relationship with the environment. The Rainbow Serpent is an active participant in the ongoing cycle of growth, decay, and renewal that characterizes the natural world, serving as a symbol of the interconnectedness of all living things, a reminder that humans must act responsibly to safeguard the ongoing health and vitality of the natural world.<sup>12</sup>

<sup>10</sup> *This Is Not A Story* is the title of a play that I wrote about the life and thought of Denis Diderot. It was performed by The Great Escape Theatre Company at the Royal Dramatic Studio Theatre, Stockholm, in August 1995, and published in *Hybrid Thought* (Hughes & Monk, 2003). It is also, paradoxically, the title of a story by Denis Diderot published in 1772. Each story develops from other stories and is entwined and entangled with multiple pre- and retellings, making storytelling more naturally organic and emergent (“regenerative”) than reified in print. Diderot was also (after Laurence Sterne) the connoisseur of digression. Sterne’s *Tristram Shandy* inspired Diderot’s *Jacques le Fataliste*, which inspired in turn Milan Kundera’s play *Jacques and His Master*.

<sup>11</sup> The patient reader will be rewarded with a story shortly.

<sup>12</sup> Many cultures have stories in which a great flood devastates the world, yet a few individuals survive by

The Chinese folk tale titled “*The Three Sisters Who Harvested the Moon*” (三姐妹摘月亮) tells the story of three sisters who see the moon shining brightly in the sky and decide they want to bring it down to Earth. They try to climb a tall tree to reach the moon, but it remains beyond their reach. They decided to build a tower using bricks made of rice flour and mortar made of sticky rice. With each layer of the tower, they climb higher, closer to the moon. Finally, they reach the moon and bring it down to Earth, where it becomes a source of light and beauty for all. A reading of this folk tale through the interpretative lens of regenerative architecture might note approvingly the use of locally sourced, renewable materials. The tower, adaptable and resilient (the sisters add layers to the tower as they climb higher, allowing it to grow and evolve over time), can be seen as an example of regenerative thinking. Flexibility and adaptability are key principles of regenerative architecture, creating buildings that can evolve over time. The story emphasizes the importance of working together and using community resources to achieve a common goal. The sisters bring the moon down to earth only through cooperation and collaboration, highlighting the importance of building community connections and engaging with local resources. By emphasizing the use of sustainable materials, designing for adaptability and resilience, and building community connections, the traditional Chinese folk tale “*The Three Sisters Who Harvested the Moon*” highlights several key principles of regenerative architecture.

Of particular interest is the Chinese folk tale “*The Magic Gourd*” (神奇的葫芦), in which a young boy named Wang Bao discovers a magical gourd that can apparently yield unlimited amounts of food and water. With the help of the gourd, Wang Bao can feed and provide for his entire village. However, as more and more people come to rely on the gourd, it begins to lose its magical power. Wang Bao realizes that he needs to find a way to regenerate the gourd’s power, so he takes it to a wise old man who advises him to bury the gourd in the ground and let it rest. Here, we have an allegory of regenerative relations between fallow and fertile resources. In time, the gourd regains its power and is able to produce food and water once again. The story illustrates several themes relevant to regenerative architecture: the idea of using natural resources to provide for the community, the importance of regeneration and renewal, balance, and sustainability. Magic needs to be

building boats or climbing to high ground. The English folk tale of the *Three Little Pigs* may be used to illustrate the importance of building with strong, resilient materials that can withstand natural disasters such as high winds, floods, and earthquakes. In regenerative architecture, designing buildings that are resilient to flooding, and creating infrastructure that can manage water sustainably and withstand natural disasters, is critical, especially in the face of the current climate crisis.

tempered to be meaningful.<sup>13</sup> As more and more people come to rely on the gourd, it loses its power and needs to be regenerated, highlighting the importance of balancing human needs with the needs of the natural environment by designing sustainably, that is, in balance with nature’s cycles. As discussed earlier, regeneration and renewal are key concepts in the ambition to create “restorative” buildings and spaces that contribute to the health and well-being of their inhabitants and the natural environment.

From Chinese philosophy, regenerative architecture can learn from the importance of balancing human needs with the needs of the natural environment. In many traditional Chinese philosophies, such as Daoism, there is an emphasis on living in harmony with nature and on designing buildings and spaces that are in balance with the natural world. This concept means designing buildings and spaces that are not only functional and aesthetically pleasing but also promote environmental sustainability, ecological health, and responsiveness to the natural environment. Daoism is a philosophical and spiritual tradition that emphasizes the importance of harmony with nature, simplicity, and living in the present moment. The concept of *Wuwei* (无为) in Daoism translates to “inaction” or “effortless action”—the idea that we should allow things to unfold naturally without trying to force or control them. Yin and Yang are complementary forces present in all things and must be in balance for harmony to be achieved. In the context of architecture, *Wuwei* and Yin-Yang may be interpreted as designing buildings and spaces that are in harmony with the natural environment, allowing nature to take its course, balancing the needs of people with the needs of the natural environment, and promoting harmony and balance.

There are numerous stories, folk tales, and mythologies from diverse cultures that can illuminate regenerative architectural strategies for living on a damaged planet, narratives that prioritize harmony with the natural world, environmental sustainability, balance, resilience, and adaptability.<sup>14</sup> Regenerative architects should prioritize the use of sustainable building materials that are renewable, non-toxic, and have a low environmental impact. This includes materials such as bamboo, recycled steel, and low-carbon concrete. Buildings and spaces should be energy-efficient, using strategies such as passive solar heating and cooling, natural ventilation, and low-energy

<sup>13</sup> The Fairy Godmother’s intervention in Cinderella’s story, for example, is tempered by the constraint that Cinderella must be home from the Prince’s ball by midnight, for reasons that are never explained (except, implicitly, by the narrative need to temper magic by constraint).

<sup>14</sup> Examples include the Mayan myth of the Maize God, the Hopi creation myth, the Yoruba creation myth, and the Inuit story of Sedna.

lighting systems. Renewable energy sources such as solar, wind, and geothermal power should be favored to reduce our dependence on fossil fuels. In addition, buildings and spaces should prioritize water conservation, employing strategies such as rainwater harvesting, greywater recycling, and low-flow plumbing fixtures. Green roofs and walls should be incorporated where possible into building design, helping to reduce energy consumption, improve air quality, and provide habitat for wildlife. Buildings and spaces that are resilient to the impacts of climate change, including rising sea levels, extreme weather events, and natural disasters, should be favored. This implies strategies such as elevating buildings above flood zones, using hurricane-resistant materials, and designing buildings to withstand earthquakes. Cultural heritage prioritizes the adaptive reuse of existing buildings and spaces to reduce the environmental impact of new construction and preserve historic and cultural resources. While these principles are becoming widely accepted to varying degrees in different building cultures, communicating their significance and potential requires finding ways to embed their beneficial qualities in a compelling story.

A compelling story possesses the ability to inspire us, forge emotional connections with others and the natural world, and challenge our beliefs and values. It aids in cultivating empathy for other living beings, urging us to perceive the world through their eyes. Through narratives that illuminate the beauty and awe of the natural world, along with the destructive impact of human activities such as pollution and deforestation, we can engage people's hearts and minds in a way that statistics and data cannot. Stories about individuals and communities taking steps to reduce environmental impact or advocating for policies that protect the natural world can motivate others to take similar action. Narratives emphasizing the interconnectedness of all living beings and the significance of safeguarding biodiversity and ecosystem health challenge the notion of humans being separate from nature, fostering a more holistic and sustainable worldview. Stories with animals, plants, and other non-human entities as main characters encourage different generations to view them not merely as resources or commodities but as valuable and unique entities in their own right. This concept is explored in our latest project, *XENO*, an installation featuring a chimeric plant hybrid composed of mechanical and animal parts. This hybrid draws energy from silts and mosquitoes that feed on human blood, challenging our understanding of natural energy and reframing it as a precious exchange between living bodies rather than a value-free resource. Natural energy involves a constant negotiation between living organisms operating through metabolism. In its simplest form, metabolism can be considered as a continuous

transfer of electrons between different bodies. However, in the modern world, energy has been commodified and stripped of inherent complexity. Industrial society's use of fossil fuels transforms long-deceased organic matter into seemingly limitless power, elevating humans to quasi-divine status by animating machines. This process, however, has severely depleted natural resources, endangering our future. *XENO*'s intricate energy exchange both animates the plant and implicates us in the ethical dilemmas and processes of (re)vitalization within an "alien" energy ecosystem.<sup>15</sup> A comparison can be made to the fate of the creature in Kafka's story *The Burrow*, discussed below.

In essence, a compelling story has the power to move, inspire, challenge, and cultivate empathy for the natural world. Stories, as I have argued, are crucial tools for devising, understanding, and communicating regenerative architecture by establishing connections between folk tales, mythologies, and core principles of regenerative architecture. I have aimed to advance these claims in accessible language, providing a basic toolkit that others can develop and apply while acknowledging the inconvenient truth that powerful stories in fiction rarely affirm a single idea but tend to be complex, contradictory, and ambiguous, drawing on the resources of paradox and uncertainty. Over time, they solidify into gourds that might somehow yield provisional cartographies, imaginary choreographies, and slippery epistemologies.

Which brings us to Kafka.

## 5. *The Burrow* by Franz Kafka

Kafka's final short story, *The Burrow*, can be read as a powerful allegory of regenerative architecture. In this narrative, we encounter a creature meticulously residing in a self-made burrow, obsessively preoccupied with its security and maintenance. The story unfolds with numerous architectural dimensions, highlighting the choices involved in constructing and sustaining the burrow. In the narrator's voice, we hear something of the neurotic solipsism of the ill-prepared architect confronting the current environmental crisis.

The creature devotes its time to building and maintaining its underground burrow, which largely delineates the horizon of its thought. The obsessive attention to construction details consumes endless hours, involving tasks such as reinforcing walls, digging new tunnels, and fortifying the home against potential invaders: external threats and the possibility of unseen creatures advancing through the soil demand

<sup>15</sup> *XENO* is exhibited at the CIVA museum in Brussels as part of the POWER Expo until March 17, 2024. The cyborg hydroponic plant is also described in the story (Armstrong & Hughes, 2023) *Xeno: The Tale of a Misfit*.

constant vigilance. The entrances and exits of the burrow evoke perpetual anxiety, with fake entrances considered as decoys to mislead predators. The burrow ingeniously incorporates elements from other creatures, such as forest voles. It is described as an engineering marvel featuring intricate tunnels, chambers, defenses, and a central citadel — a grotesque abattoir or proto-shopping mall:

“When I’m standing in the citadel, surrounded by my towering stocks of meat, facing the ten exits that radiate from there, each one fulfilling its role in the overall plan, going up or down, straight or curved, widening or narrowing, and all equally silent and empty and ready, each one after its fashion all set, to lead me on to the numerous plazas, and these too all of them empty and silent — then I have little thought of security, then I know exactly that this is my castle, which I carved out of the recalcitrant earth by scratching and biting, stamping and butting, my castle that can never belong to another in any way, that is so much mine that in the end I can take the mortal wound from my foe quite calmly, because my blood will drain away into my soil, and will not go to waste.” - Kafka, 2017, p. 217-8

For this creature, ventilation and silence are sources of satisfaction. While aware that ventures outside the burrow increase vulnerability, such excursions are necessary for hunting and replenishing food supplies. Despite the careful design aimed at protecting and sustaining the creature’s life, the burrow fails to eliminate anxiety and fear. The creature remains acutely conscious of the possibility of intrusion over its borders and tirelessly works to maintain defenses against collapse or potential threats. The obsessive building and maintenance work accumulate into a form of imprisonment for the creature, which yearns for an ally but concedes that trusting another creature is impossible, given that the burrow was created for its builder alone.

In *The Burrow*, the creature’s fixation on security and control serves as a reminder that an exclusive focus on creating secure environments risks losing sight of the larger systems and processes that sustain life. It underscores the intricate relationships between buildings and structures and their impact on the environment and, reciprocally, how the environment impacts us. The creature’s perpetual awareness of the need for burrow maintenance, adaptation

to environmental changes, and resource management depicts the burrow as a living system in a constant state of regeneration and adaptation to new conditions.



Figure 3. Burrow. Source: Original work by the author

Kafka’s fiction burrows through language, constructing and collapsing its own narratives, gnawing at its own epistemological craft and structures. To read *The Burrow* instrumentally, merely as a straightforward allegory for the challenges and opportunities of regenerative architecture, would overlook the story’s intricate craftsmanship, which robustly resists interpretative closure.

My intention here, therefore, is to explore a line of reading that might yield insights for our present purposes. Such a reading serves as a reminder that sustainable design goes beyond sketching physical structures; it involves creating living systems that adapt and regenerate over time. It prompts us to consider how our buildings and structures impact the environment, urging us to work towards a more harmonious and sustainable future—one in which humans and the natural world can coexist in balance, avoiding the trap in which the solitary creature in Kafka’s story has been ensnared.

Temporal logics of progress, causality, and decline — or the notions of fall and redemption — are not in play here. Instead, the story’s abrupt ending (“—but everything went on unchanged”) locates the story, as so often in Kafka, in the infinite uncertainty of ritual. Whether this applies to our current trajectory of ecological collapse remains a question contingent on one’s relationship to optimism.

## 6. The Bungalow

“The greatest hazard of all, losing one’s self, can occur very quietly in the world, as if it were nothing at all. No other loss can occur so quietly; any other loss — an arm, a leg, five dollars, a wife, etc. — is sure to be noticed.” - Søren Kierkegaard, *The Sickness Unto Death*, p. 165.



Figure 4. Bungalow III. Source: Original work by the author

My days were once marked by clarity and purpose. I attribute this to a training that imparted discipline, rigour attention to detail. The pavement I traversed always seemed firm. As I set about gathering, sorting, ordering resources, partners, and offspring, securing home and hearth with a modest but sustainable salary, I led my brood at a stately pace towards a destination envisaged as a brightly illuminated portal to another world. In short, everything I did before things fell apart was, once upon a time, a real life.

In my 55<sup>th</sup> year, with the country self-destructing and the nest newly emptied, I staggered like a drunk toward a place of sanctuary, a refuge against the rising tides of stupidity threatening to engulf the land. I wandered the length of the east coast of England to study the ruins of Second World War defence posts before returning to North Norfolk, its desolate mud flats seeming to best mirror the flatness of my spirit. Spurred by the twin demands of alimony and the recent collapse of my modest stock portfolio, I contemplated the restoration of the bungalow that I had inherited from my mother, who had been gifted it in turn by a bachelor uncle.

Once upon a time, the bungalow had been a popular seaside getaway for my young family but had long since

fallen into disrepair. The coastal climate had chewed the building’s fabric over successive seasons, and damp had seeped into its foundations. However, I had a plan to fix it up. I used to manage an insurance brokerage, employing upwards of a dozen clerks. Renovating this old place would be a piece of cake by comparison.

The grounds surrounding the bungalow were spacious. As I walked through the overgrown pathways that crisscrossed the property, a sense of determination took hold. I paid close attention to every detail. Those neglected pathways once cleared and repaired, would become vital connections to the sea and, with it, conversation and companionship.

The eroding coastline certainly posed challenges, but I believed that just as the waves shape the shore, the bungalow’s restoration would help it adapt. It would become part of its changing surroundings, flexing and adjusting to the squalls and tides, embracing the soft sand to secure its own future.

Each night, I contemplated the transformative journey that lay ahead. My breath as I slept seemed slowly to breathe life back into the structure. The weathered walls would become resilient, and the unstable foundations would become sturdy and strong! Each generation is a mere custodian of place, so we must bestow care and attention during our brief lifetime to secure its persistence for many years to come. I was convinced that the bungalow was destined to survive and thrive, its rooms to be filled once again with the human sounds of cutlery and chatter.

On waking, I plunged headfirst into an exhaustive cleaning routine, transforming my quaint abode into a fortress against decay, implementing a meticulous series of measures to combat the insidious intrusion of moisture and mould. My first line of defense involved the strategic placement of dehumidifiers throughout the corridors and bedrooms, their low hum creating the ambient soundtrack of my quest for a dry haven. In the kitchen and bathroom, I installed extractor fans, their whirring blades singing of banished humidity. I hung mothballs and uprooted the creeping moss that threatened to invade every nook and cranny. Tirelessly, I scrubbed the bathroom counters, the shower door, and every inch of the bathroom walls and floor, eradicating any trace of encroaching moisture. I wielded brooms and mops against the kitchen floor, while glass surfaces and mirrors bore witness to my incessant wiping, an effort to stave off the tenacious moisture that clings to reflective surfaces. Carpets and rugs were subjected to a vigilant vacuuming routine, and tiles yielded to my disinfecting spray that left no corner untouched.

However, my duties were not limited to the visible spaces. I reached into the cold recesses of appliances — the refrigerator became a sterile haven as I meticulously disinfected its

every compartment; under the bathroom counter became a pristine, germ-free surface; the toilet gleamed as a beacon of cleanliness in my war against encroaching filth. Bleach flowed liberally, a powerful elixir in my gloved hands. Each swipe of the disinfectant-soaked cloth became a battle won, a step closer to triumph over the incursion of the forces that threatened to consume my cherished abode.



Figure 5. Bungalow IV. Source: Original work by the author

I stored my books and papers within airtight plastic containers, their protection sealed and secured in the attic. On shelves, these containers stood like wan sentinels, guarding my records and memories against the invisible enemies threatening to consume them.

The exterior of my fortress was not overlooked. Armed with wooden ladders, I scaled heights to clear gutters and pipes of organic debris, leaving no avenue for nature's invasion. Leaks in the roof and cracks in the walls were not spared my scrutiny as I patched and sealed, intent on fortifying the very structure of my haven.

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There is a saying in insurance: "you cannot clean parts of your world without making other parts of it dirty."

In the hushed hours of the night, I found myself drawn to the edge of contemplation, scanning the vast horizon through the lens of an antique telescope. The sea, an eternal canvas of undulating waves, whispered secrets of our collective history. These lessons, elusive and opaque, were hidden in plain sight, teasingly concealed beneath the rhythmic dance of the ocean. Each wave held the potential to unlock answers to questions I had yet to formulate, mysteries waiting to be unraveled.

A conviction began to burgeon within me — an unshakable belief that the sea transcended its physical boundaries, transforming into a metaphysical repository of solutions. What if, I mused, a new currency could somehow tap into the vast power of the ocean? This notion became a beacon of inspiration, guiding me through the shifting currents of my musings.

Armed with a laptop that I had liberated from a dozing passenger aboard the Poppy Line between Sheringham and Holt, I embarked on a clandestine journey into the digital realm. Within encrypted folders, I forged the symbols and exchange logic of a currency that transcended the comprehension of even the most skilled and tenacious codebreakers. The stolen laptop, its light casting an ethereal ambiance in the dim shadows of my secret work, became a conduit to unseen possibilities.

As my fingers danced across its keys, weaving intricate patterns of cryptographic symbols, I became increasingly ensnared in the allure of my creation. The belief in the potency of my newly minted symbolic currency intoxicated my senses, infusing me with a glow of self-assurance. In those stolen hours, salvation seemed to manifest within the complex depths of my creation — an otherworldly solution to the very real threats posed by the wind, the rain, and the advancing tides.

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The gulls scavenged on the beach. The clouds slowly tumbled by.

I was relatively warm and had money for food. The mortgage on the property was paid. Punctually, I sent my children postcards on their birthdays. It was a happy time. My bare feet passed from rug to sand. I listened to birdsong while painting the exterior facade. There was a hole in the gable where the starlings nest. I decided against filling it. To do so would imply, to passing eyes, that the attic contained valuables. In this exposed location, I would not wish to encourage an opportunistic burglar. Caution is second nature to the insurance rep.

At a hundred or so steps from the bungalow, there was a ramshackle wooden gate that gave out onto a footpath traversing the edge of the seafront cliff. The wicker fence on either side of the gate had surrendered to sea gales and squalls, but the gate remained as a reminder of the boundaries of the property. Locals reminisced about when the clifftop footpath was an inland bridleway. They went on about when the sea was a faint whiff of salt air rather than a menacing presence before accepting with a shrug that the erosion of the coast was gathering pace, and Sten — our last, semi-retired council worker — seemed to have no idea how to halt the progress of the incoming waves.



Figure 6. Bungalow V. Source: Original work by the author

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In winter, the bungalow started howling like a drain. I was reluctantly obliged to abandon my encryption work, having failed to establish a protocol between digital code and seawater. Every day, we need to secure energy to power our routines. Every lamp, every heater, every fan, every meal draws on reserves that cannot be guaranteed.

Everything I did before was once upon a time real life.

I was free to set my own hours as, after the last pandemic, reps were permitted to work from home. Entire days passed keeping watch over an inbox filling with spam. Here is a representative example:

Subject: Memo: Opportunities and Threats of Ecosystem Collapse

On February 13, our corporate vision of catastrophic incidents leading to major global collapse was confirmed. Our mission is that a combination of factors, including climate change, pollution, habitat destruction, and overexploitation of natural resources, will result in widespread damage to ecosystems around the world, necessitating a significant influx of investments in insurance.

Our assessment indicates that this collapse will have major impacts on biodiversity, natural resources, and the livelihoods of communities around the world. Species extinction rates will increase exponentially. The loss of natural habitats will result in less fresh water, food, timber, etc. This is part of a larger pattern of environmental degradation. The failure to address these issues

has led to a critical tipping point, wherein the global ecosystem is no longer able to sustain itself. This represents a golden opportunity for the industry.

Governments, corporations, and individuals should immediately take out policies to insure against the consequences of this collapse. New insurance products can target, for example, the failure of carbon emission reductions, conservation efforts, and sustainable resource management practices.

Traditional policies will not fully cover damage resulting from ecosystem collapse. We, therefore, recommend developing specialized coverage options to address such risks. Property owners and corporations must also purchase such policies as a form of risk management.

In conclusion, while the collapse of the global ecosystem represents a significant threat to the long-term sustainability of life on earth, it also presents stakeholders with an unprecedented opportunity to proactively make products that address these risks and minimize the financial impact of future environmental catastrophes.

I marked most as junk or blocked them, yet they kept morphing and reappearing with red exclamation marks denoting a desire to escalate on the part of the sender.

\*

One evening, I saw three elderly men on the beach. They were on their knees, each bent over on the sand, their yellow sou'westers pulled over their heads, seemingly making themselves as inhuman as possible. From this distance, the effect was of three dying tulips in the sand. One of them seemed to be weeping. He brought a white handkerchief to his eyes, only to press his face close to the sand again a moment later. A little dog trotted indifferently past the strange gathering. With the light fading, a second man started shaking rapidly. I stepped back from the cliff.

\*

On the days when I could see myself clearly outlined in space, I would celebrate by planting seeds around the property – more through habit than in the expectation of being self-sufficient within a few seasons. In such sandy soil, little can be expected to survive.

One morning I became aware of a stranger watching me from the gate. It was a woman in her fifties, curls of grey hair escaping a peaked cap, her fists planted on her hips as if my modest gardening in sandy soil was a source of great amusement to her. She snotted onto the sand, then reached into her pocket. “These seeds for that telescope!”

she shouted, holding out a small paper bag. I waved away the bad trade, but she persisted, claiming hers were magical seeds that would bring me good fortune, which I clearly needed. “If you call it with the right word, by the right name, then it comes,” she said. “That is the essence of magic. It does not create but calls.” The power to say no, this most natural expression of refusal, is something that we believe we always have, but not always the courage. Living is saying no, which means saying no is also saying yes. Confronted by this ridiculous woman standing before me like a rag-and-bone crone, with nothing needing my attention despite the renovation being far from finished, I was struck by how incomplete each moment of human life is.

I fetched the telescope and made the exchange. She admired it briefly, slipped it into her coat pocket, and said, “Put your damned house in order!” before setting off along the cliff path once again. I split the bag, tossed her seeds among the seeds already sown, and thought no more about it. I had neglected to keep records of what was planted where, believing that the garden should offer me a respite from book-keeping. Besides, spring would eventually reveal any riches, irrespective of whether their names were entered in a ledger.



Figure 7. Bungalow VI. Source: Original work by the author

\*

Standing on my head with my legs against the wall, the outside plants seemed perverted. I envisaged a new movement, one of landownership rooted in verticality rather than the contested dirt on the ground.

Not infrequently, I would hear a scratching of a nail against the wall. I would right myself and burst into a bright room, only to find myself recoiling from a sudden shadow or the buzzing of a fly.

\*

One night, while I slept, somebody (or something) burned three words into my lawn. I thought about reporting it, but the words seemed harmless enough.

The sea rolled in. The waves continued to chew the coastline, undermining the foundations of the hamlet. Neighbors and dog walkers began to disappear from the skyline. Time itself was becoming an oscillation between darkness and light.

When the snow thawed, I emerged momentarily into the weak spring sunlight. My senses were agitated at the first tremor from the computer, which I could sense even from the doorway, drawing me immediately back inside and shutting the outer door behind me with a click. When I blew off the dust and opened the lid, I discovered that the incoming spam had continued unabated:

Subject: Accident Assessment Report - Norfolk Coastal Region Collapse

On March 23, we received a report of a catastrophic incident along the coast of North Norfolk. Our investigation revealed that a significant portion of the coastal road has collapsed into the sea, resulting in extensive damage to both property and infrastructure. Our assessment indicates that the primary cause of this collapse is the impact of rising sea levels due to climate change. The gradual erosion of the coastline, coupled with extreme weather events and storm surges, has weakened the foundation of the land, leading to the eventual collapse.

We also note that this incident is not an isolated event but rather part of a larger pattern of climate-related damage occurring in coastal regions worldwide. In addition, the collapse has had a significant impact on the local community, including the loss of property and displacement of residents.

Based on our assessment, we recommend that property owners in coastal regions take immediate action to assess and mitigate the risks associated with climate change and rising sea levels. This may include implementing measures such as shoreline restoration, elevating buildings, and developing contingency plans for extreme weather events.

In terms of insurance coverage, we note that many traditional policies may not fully cover damage resulting from climate-related events. This is why we recommend that property owners review their

existing policies and consider purchasing additional coverage specifically designed to address these risks. In conclusion, the collapse of the Norfolk coastal region represents a significant and ongoing threat to property and infrastructure in coastal regions worldwide. As such, we urge all property owners and insurers to take proactive measures to assess and mitigate these risks to minimize the financial impact of future climate-related incidents.

As spring turned to early summer, the letters in my lawn slowly healed. I noticed that my garden shrubs were taking on the form of adjacent plants. I received a chatty postcard from one of my sons. As a postscript he wrote in his still immature handwriting, “Out of a handful of sand, you will make the beginning of a magical garden.”

A horse galloped past outside, its heavy hooves whirling up dust from the path, darkening the skies.

The days began to shorten. I read that it takes about three years to settle after a traumatic event. The waters continued to rise. I felt I could weather any storm.

\*

The bungalow seemed to be inching towards the edge of the cliff. Soon, no doubt, it would succumb to gravity. I moved into the attic, carrying up possessions from the ground floor in airtight plastic boxes, mindful of my increasingly sodden front lawn. The wooden gate had fallen into the sea.

My Inbox contained 33718 unread messages. I selected one at random.

“On 20 October, we received a report of an incident involving an animal that had constructed an underground burrow on a piece of seafront property in Happisburgh. Our investigation revealed that the animal had been living in the burrow for an unknown period of time, during which it had evidently taken great care to create an elaborate system of tunnels and chambers.

The incident occurred when the animal, most likely a mole, experienced a collapse in one of the tunnels. This collapse caused a significant amount of damage to the burrow and also resulted in injuries to the animal.

Upon further inspection, we found that the cause of the collapse was likely due to a combination of natural erosion and wear and tear on the walls of the tunnel. We also noted that the animal had been making ongoing repairs and maintenance to the burrow, indicating a high level of awareness and concern for the safety and stability of its living space.

Based on our assessment, we conclude that the animal had taken reasonable measures to ensure the safety and stability of its burrow but was ultimately unable to fully mitigate the risks associated with living in an underground environment. We recommend that property owners in the area take precautions to monitor and assess the stability of the soil and rock formations on their land to prevent similar incidents in the future.

In conclusion, while the incident involving the animal’s burrow was unfortunate, we have determined that it was not the result of any negligent actions on the part of the party concerned. We, therefore, recommend that any damages or injuries resulting from this incident be covered by the appropriate insurance policies pertaining to neighboring homeowners.”

The rainfall created pools at the base of the utilities in my abandoned kitchen, causing electricity fuses to pop in the circuit board. I clutched the attic ladder and peered down. The furniture was twisting and bobbing in the greywater. The solar panels had long fallen from the roof. I would fish for one whenever it floated within reach, then hang it until I received some sort of signal. As long as there is a signal, a window to the world, there is hope. Power calls the fly from the flytrap.

\*



Figure 8. Bungalow VII. Source: Original work by the author

I drifted from a dream of a placid lake at dawn. I have come home. I am walking along a corridor, looking around

me. My parents are waiting at the top of the stairs. There is a puddle on the hallway carpet. A dog slinks out of the front door. Unfamiliar shadows are dancing through my consciousness. Mist is rolling in from the sea. I am surrounded by seawater. Far below me, I can just discern the pale flesh of a body in the water. My cold arms are gripping a stalk. I close my eyes and whisper, “At a morning hour yet to be determined; I am witnessing a body whose identity remains unknown in a submerged state within the surrounding waters. This I observe from an elevated position overlooking the scene.” My teeth begin chattering from the cold, but I am determined to continue. “The body’s complexion appears notably pale, possibly due to restricted oxygen supply and submersion in the water. This characteristic pallor aligns with the natural effects of reduced blood circulation and oxygenation during submersion incidents.”

I look down again, summoning every moment of my training. “The head and upper body are partially visible above the water’s surface, indicating that the corpse is either bobbing or in a state of semi-submersion. The hair floats on the water, moving in synchrony with the undulating current. This observation is consistent with the buoyancy of hair strands in an aquatic environment, as influenced by the laws of physics.”

My arms slip on the greasy beanstalk. I slide closer to the water.

“The observation is being made from an aerial viewpoint, allowing for a fairly comprehensive view of the incident scene. No additional details regarding the circumstances leading to the body’s submersion, nor of any potential rescue efforts, can be discerned from this perspective.”

My feet are now just above the floating body. My mouth is too cold to form words. What I want to say is that further investigation by appropriate authorities is to be recommended. Further investigation by appropriate authorities is to be recommended to ascertain the exact cause and sequence of events. The exact cause and sequence of events—



Figure 9. Caged bird. Source: Original work by the author

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## ORIGINAL ARTICLE

A practice of unitary community renewal led  
by cultural regeneration: The case of Dongba  
Township in Beijing

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**Abstract**

For communities, culture is not only a natural product of long-standing daily life but also a binding force that interconnects the interpersonal relationships among the community's inhabitants. This is particularly evident in centralized unitary communities where work and life are seamlessly integrated. However, with economic development and the transformation of the social structure, the unitary community model no longer aligns with the evolving needs of social development. As a result, it must undergo a transformation into a modern community that meets multiple needs. During the regeneration process, there has been a notable focus on the creation of space within the community, often at the expense of its cultural values. In this context, we have chosen six unitary communities in Beijing's Dongba Township as a sample. Drawing from cultural regeneration theory, our approach revolves around recreating space with community culture as its core. This approach involves not only integrating culture into the physical space but also reshaping the interpersonal network of the community through culture. Finally, we propose four regeneration models, namely, "Spatial Regeneration – Recreating the Spirit of Place," "Community Renewal – Diverse Expressions of Community Culture," "Vitality Regeneration – Enhancing the Cultural Supply," and "Social Regeneration – Reshaping the Social Network." These models aim to contribute to the rejuvenation of the community and provide references for the regeneration of old urban neighborhoods.

**Keywords:** Regeneration of old neighborhoods; Unitary communities; Community culture; Cultural regeneration

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**1. Introduction**

The unitary community is a unique and typical type of community in China, distinguished by its centralization and closed nature, particularly in comparison with other communities (Song, 2010). With the ongoing economic transition and social transformation, the unitary community has lost its original living environment, and its traditional form of organization has fallen apart. However, despite the disintegration of its system, the community itself has not abruptly disappeared. Instead, it endures as a basic unit of social life within the city, undergoing inner changes (Mao *et al.*, 2019). In the face of modern community development, the unitary community finds itself unable to meet the evolving needs of its inhabitants. It is now characterized by a "double decay"

affecting both its physical and social environment (Song, 2013), compelling it to urgently seek a transformation as the main model for rejuvenating old urban neighborhoods.

The unitary community is a rich social resource that combines business and local ties and creates a deep sense of mutual trust among residents, distinguishing it from commodity-based and combined unitary communities. This unique sense of community identity, formed by the same production and lifestyle, is often referred to as collective memory (Yu *et al.*, 2007). The concept of collective memory, defined as “the process and outcome of sharing past events among members of a particular social group” (Rouso, 1991, p. 169), aligns with Vygotsky (1997)’s perspective that human memory must be understood within the context of social, community, and cultural concepts. Over the years, symbolic tools aiding memory are invented one after another as the years go by Vygotsky (1997). From a cultural point of view, collective memory emerges from the combination of local identity and the spirit of place. It serves as the point of origin for groups with a specific history and culture to recall the past, perpetuated through cultural entrenchment (Zhu, 2006). Recent scholarly attention has focused on the role of collective memory continuity in planning. Yan *et al.* (2022), for instance, evaluated renovations based on a collective memory perspective for old industrial parks, while Lv & Wu (2018) incorporated collective memory in the renewal of historical relics, exemplified in the “156” projects in Harbin. In addition, collective memory is widely applied in community building. Zeng (2017) used the theme of collective memory to explore the construction of community contextual spaces associated with memory. In the case of the unitary community, the residents’ past social experiences and the unity of their social identity within a common living environment leave a more profound imprint of collective memory compared to other communities. These memories serve as the soul and roots that sustain the grassroots governance of the unitary community.

Beijing’s old neighborhoods, mainly comprised of unitary communities, are numerous and widely distributed, playing an important role in urban spatial governance. In recent years, the ongoing renovation of Beijing’s old neighborhoods has shown significant progress. However, the primary focus has been on the transformation of architectural spaces and the optimization of public service facilities, with an excess emphasis on improving the quality of life of community residents. Unfortunately, this focus has often led to neglecting the preservation and innovation of community cultural characteristics and emotional memories. As a result, many communities have become “materialistic but not spiritual,” featuring one-sided

cultural construction and an outdated style of memory space creation. To address this, it is essential to shift our focus not only toward preserving memories but also toward innovating and integrating them, seeking symbols that fit the modern community as a bridge of identity for residents.

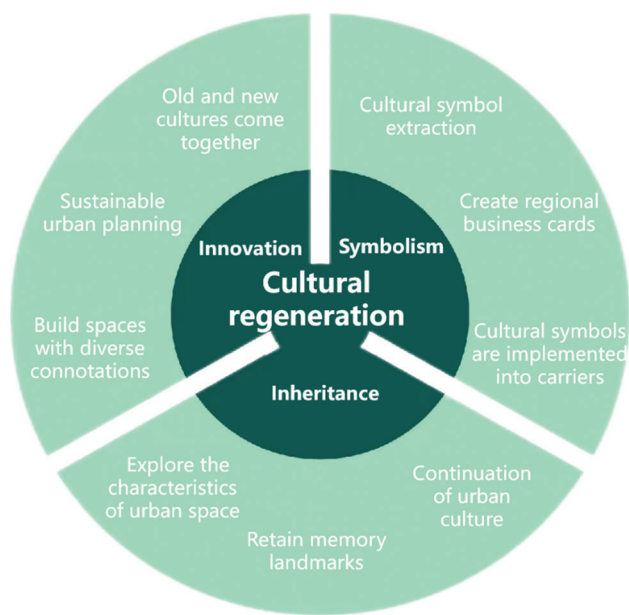
This paper, guided by cultural regeneration theory and adopting a community culture perspective, advocates the transformation of old neighborhoods into emerging modern communities characterized by resident-friendliness, sustainable landscapes, and technological innovations. Achieving this transformation involves public participation, spatial creation, landscape reshaping, and technological dissemination. Our findings underscore that culture serves not only as an important means to revitalize the physical space of a community but also as a spiritual bond that reshapes the interpersonal relationships within the community. Building on this insight, we explore a renewal strategy centered on regenerating old neighborhoods through culture. This exploration provides valuable references for the development of high-quality and high-vitality old neighborhoods.

## 2. Methods

### 2.1. Unitary community renewal based on cultural regeneration theory

#### 2.1.1. Applied research in cultural regeneration theory

Over time, a new thing eventually becomes old and obsolete, only to be discarded; it gains what is often referred to as historical value when it undergoes a process of rebirth (Vygotsky, 1997). The theory of “cultural reproduction” is derived from the sociological concept developed by Bourdieu (1971), encompassing three basic elements: “cultural capital,” “habitus,” and “symbolic violence.” Initially applied in pedagogy, this theory critiqued education as a system of inequality in which the elite perpetuated their status by eliminating opportunities for the children of lower classes and consolidating the position of the ruling class. This theory asserts that culture is a constantly evolving concept – a dynamic process of growth and decline. It suggests that one of the driving forces behind the functioning of contemporary society is cultural practices and their constant development (Zeng, 2009). At the planning and design level, the theory of “cultural regeneration” places a greater emphasis on the inheritance, innovation, and symbolism of culture (Figure 1). The “symbol” is no longer just a class form; it now serves as a representation of the spirit of place integrated into spatial design. Combined with theories of place, local culture, and related theoretical ideas, this approach improves the value of using culture in urban space. Jiang (2022) applied cultural regeneration to the renewal of urban landscape



**Figure 1.** Cultural regeneration theory applying properties and applications. Source: Drawing by the authors

scenes, and Xu & Li (2022) constructed a cultural image based on an examination of traditional village culture to achieve cultural connotation regeneration.

Building on the above understanding, this paper uses the concept of “cultural regeneration” in community planning to renew and revitalize old communities. Rather than simply replicating a certain spatial landscape, the emphasis is on embodying the cultural values of the community and re-creating cultural spaces. This approach emphasizes cultural inheritance and innovation, meeting the residents’ needs at a spiritual level and effectively integrating culture with the community.

**2.1.2. A theoretical framework for the application of cultural regeneration in the creation of community spaces**

In community regeneration, the designer not only needs to design a single community space but also has to address the complex and diverse subjects involved in the community. This requirement involves coordinating the interests of various stakeholders in the community transformation. However, differences in individual interests often lead to conflicts among the actors involved in the regeneration process. This conflict can result in a lack of motivation among residents to participate in public activities and a tendency toward an indifferent and negative atmosphere in the community. Therefore, there is an urgent need to use culture to create value for community participation.

In cultural sociology, culture plays a significant role in shaping human behavior. The influence on people’s

daily activities extends beyond their social status; it is also profoundly affected by the cultural context in which they live. Consequently, the thoughts and actions of a group are determined by the culture within that group (Mead, 1938). Culture serves not only as a symbol to express historical memory but also as a spiritual bond that maintains the pluralistic subjects within the community. By placing culture at the center, we construct the framework of community renewal based on the theory of cultural regeneration. In Figure 2, the interaction among residents, the community, and the space is explained. Figure 2 delineates that the ways culture is used for dynamic development and the associated values. Building on this basis, we propose a community space transformation strategy centered around the theme of cultural regeneration. The ultimate goal is to realize the community’s vision of “revitalization,” encompassing cultural space construction, normative governance within the community, and the reconstruction of social networks.

**2.2. Cultural regeneration theory for unitary community renewal practice**

**2.2.1. Project overview**

Located in the north-east part of Chaoyang District of Beijing, Dongba is only 10 – 15 km from the Central Business District, the Capital International Airport, the Ministry of Foreign Affairs, and the embassy district. It is expected to become a large-scale center for international exchange, catering to leisure, office, communication, and residential activities, with a focus on the international market. During the 1980s and 1990s, Dongba, like other suburbs of Beijing, was regarded as one of the “warehouses” of the city’s industrial system. Numerous state-owned enterprises (SOEs), such as the Beijing Textile Factory and the Beijing First Machine Tool Factory, established factories in the area, leading to a significant influx of employees. To support work and life, these enterprises created residential areas for their employees in the vicinity of the factories, thus forming a unit-based community system centered around units and unitary compounds. To date, most of the unit-based communities in the Dongba area remain, mainly in old neighborhoods located in the south-west part of Dongba. These neighborhoods are inhabited mostly by retired elderly individuals who worked in the neighborhood during its industrial heyday. This ongoing renovation project is located in the southern part of the Dongba area (Figure 3), encompassing six blocks with 18 buildings, primarily brick-concrete multi-story residential buildings constructed around the 1990s. Many of these buildings (Table 1) do not meet today’s living standards. Despite this, within the historical context of corporate

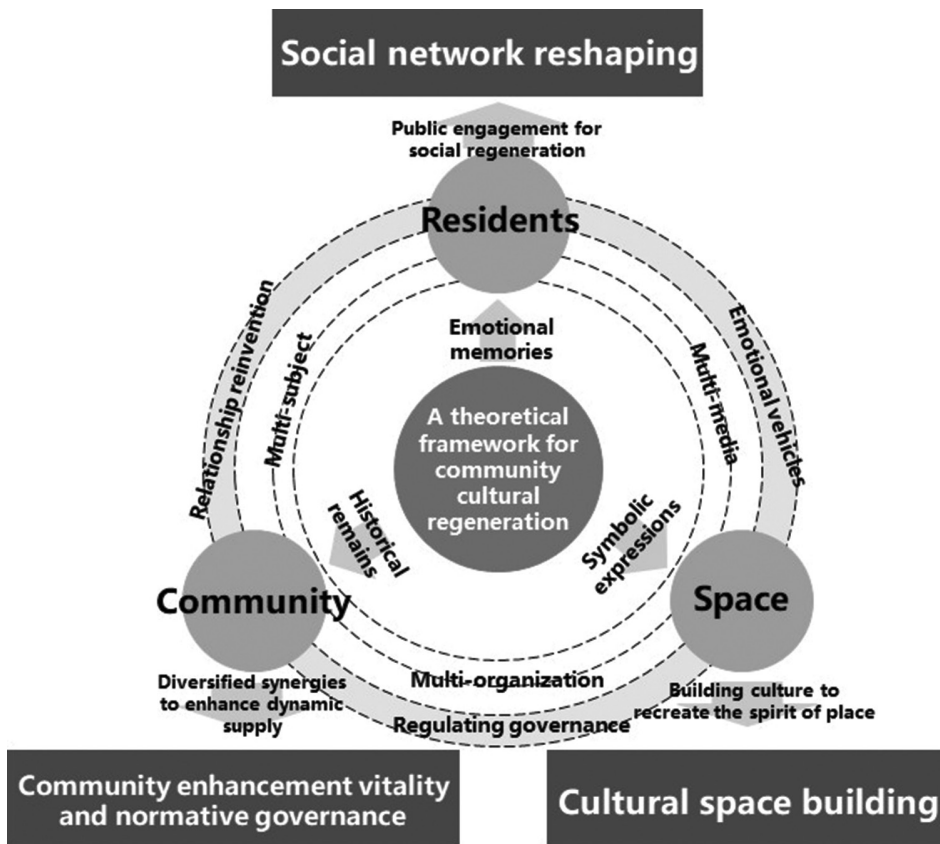


Figure 2. A framework for community transformation under cultural regeneration theory. Source: Drawing by the authors

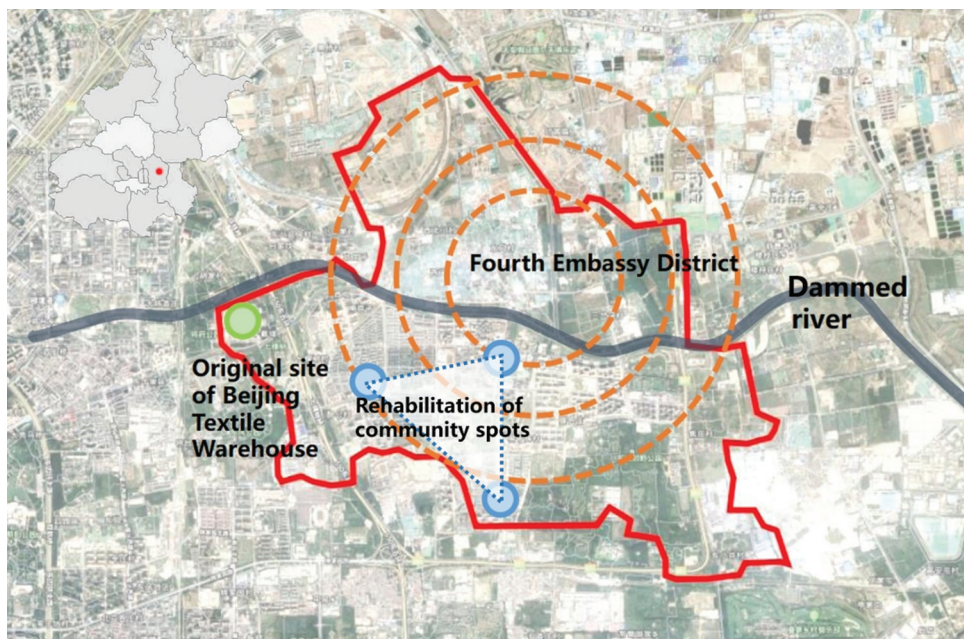


Figure 3. Location map of the Dongba area. Source: Drawing by the authors

housing allocation, the fixed lifestyle and long-term interpersonal interactions have given rise to a unique

local community culture, representative of a typical type of unitary community.

**Table 1. Information on the old neighborhoods in the Dongba area**

No.	Subdivision name	Total population/ household	Floor space (m <sup>2</sup> )	Number of buildings/ community	Completion time (year)
1.	Red Pine Garden Food Court Community	324	20820.8	6	1986
2.	Surveyor's Block	109	3117.56	2	1987
3.	Credit Union Building Block	30	2448	1	1995
4.	Teachers' House Community	48	2972	1	1995
5.	Gao Yang Shu Nan Li District	240	12052.5	5	1983
6.	Shandian Brickworks Community	206	13100	4	1980
Total		957	54510.86	19	

### 2.2.2. Current issues

#### (a) Underneath the quality of the spatial environment

We conducted two interviews to capture residents' wishes and organized two opinion solicitation sessions in six neighborhoods, with a total of 51 participants (11 from Red Pine Garden Food Court Community, 10 from Gao Yang Shu Nan Li District, 11 from Shandian Brickworks Community, five from Surveyor's Block, six from Credit Union Building Block, and eight from Teachers' House Community). Through field research and interviews with residents in these neighborhoods, we identified and diagnosed current problems in each neighborhood. Although each neighborhood presents different problems, the general direction for renewal and transformation is relatively similar. Therefore, the team summarized four common problems and combined them with specific individual needs to refine the neighborhoods based on this general direction (Table 2).

#### (b) Insufficient endogenous dynamics of community governance

##### (i) Unclear ownership of community governance

At the most fundamental level of governance, the community functions as a "mini" urban unit. The repair of complicated infrastructure and the resolution of daily problems within the community necessitate the allocation of responsibilities to various departments, forming a fine-grained community governance system. However, in older neighborhoods, historical disputes and ambiguous boundaries often result in community issues falling through governance loopholes. These issues are shuffled between departments, becoming a hidden source of obstructing collective community action and undermining collective community identity. In the Red Pine Garden area, trees and branches extend into residents' windows and doors, significantly disrupting their daily lives. However, due to the absence of a specific department responsible for this issue in the governance system, residents struggle to voice their concerns, leading to the question of "who is responsible." While it may seem like a consequence of the

lack of a professional property management model in the unitary community, the underlying cause lies in the unclear relationship between responsibility and rights resulting from the lack of clear property rights and the absence of an owner's authority structure in the unitary community. This ambiguity creates a reluctance among individuals to take responsibility for the maintenance of the community.

##### (ii) Lack of restraint in spontaneous construction of spaces by residents


Spontaneous spaces possess both a rational generative logic and a specific meaning in residents' lives, serving as the most direct reflection of their vision (Wang *et al.*, 2018). The majority of residents in the unitary community are long-term workers who reside here, gathering spontaneously for activities in the existing community space. Over time, these community spaces have evolved into a fixed public place. In the Red Pine Garden area, residents have built a shed for communal activities such as chatting and playing chess during the day, repurposed at night for parking electric cars. In addition, residents have planted greenery to add vibrancy to the community space (Figure 4). These places are not organized from the top down but are purely individual initiatives, often located in hidden courtyards or certain neglected spaces; yet, they remain the most vibrant locations in the community. The communal nature of diverse spaces brings vibrancy to the community, but it also brings problems of poor community appearance, clutter, and private divisions of ownership. Spontaneous spaces should not be outlawed but rather controlled and restrained, preserving space to meet the needs of residents while improving the environment and appearance.

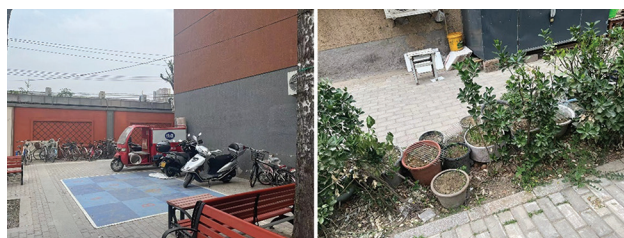
### 2.2.3. Community cultural regeneration practice

#### (a) Diversified participation: Finding memory resonance through culture and facilitating residents' interaction to create a highly autonomous community

With the restructuring of SOEs, the once vibrant scenes of life in the unitary communities have gradually fallen silent. The

**Table 2. The top four issues identified regarding the community environment. Source: Photos by the authors**

No.	Current issues	Detailed questions	Photo examples
1.	Insufficient motor vehicle parking spaces	The existing parking spaces in the old district cannot meet the demand of the residents for parking, and the spontaneous parking has greatly crowded the few free spaces left in the district.	
2.	Road system disorders	Most of the roads in the neighborhood are narrow in space, and the road surface is in a serious state of disrepair. Non-motorized parking sheds are under-utilized, and lighting and security systems are missing. Some roads are not reserved for fire escapes, and there are problems with road drainage wells, resulting in water on the roads.	
3.	Lack of recreational spaces	The existing space is under-utilized due to the accumulation of debris and randomly parked vehicles by residents, which seriously occupy the community space. Most of the vacant plots are hard-paved and cannot be used for recreational activities. There is a lack of shared spaces for introducing the history and culture of the area and for sharing emotional memories, which makes the residents' lives lack communication and unitized and closed.	
4.	Inadequate greenery and landscaping	Most of the districts have a single landscape vegetation, monotonous landscape colors, and no obvious seasonal changes. The landscape vignette is too small, and residents lack interaction. There is no green space in some of the plots and there is a phenomenon of residents spontaneously circling vegetable plots and planting plants, and the landscape appearance is not uniform.	



**Figure 4.** Spontaneous behavior and utilization of space among community residents. Source: Photos by the authors

proud sense of identity and pride that once filled the hearts of the local people is diminishing. However, this does not imply that the collective memory of the community has completely disappeared; instead, it remains a historical product lingering in the hearts of the residents. To evoke emotions in the community, we focused on residents and led the public to participate through various channels. We uncovered unique historical memories through numerous interviews. At the same time, to motivate residents to participate in the transformation of the community, the team actively planned activities, guiding residents in the construction process. These activities, including the mural painting titled “Big

Hands Pulling Small Hands,” collection of old objects, and other initiatives, served as implicit means to rediscover the dusty community memories accumulated over many years.

Diverse public participation reveals that community residents who lived through the era of SOEs feel nostalgic for the heydays when they worked, produced, lived, and enjoyed life together. They take pride in the work they accomplished in their youth, reminiscing about the past and acknowledging the impact of the changing times on them. Through this emotional resonance, a community culture inventory (Table 3) was compiled to distill the community spirit, unite residents’ consciousness, and provide a cultural basis for spatial creation.

At the same time, long-term active participation in community public activities, coupled with the emotional resonance of related cultural memories, can assist in the gradual formation of a friendly living atmosphere among the residents. Engaging in these activities not only fosters a sense of community but also boosts residents’ enthusiasm for community management. Building on this foundation, the community management department establishes an effective self-governance mechanism, allowing residents to

become integral members of the community management team. Residents transition from mere “users” to “managers” of the community, effectively addressing problems related to ambiguous community responsibilities and the lack of constraints on spontaneous space.

(b) Space creation: Creating culturally sustainable communities by reinventing friendly relationships through culture and reinventing community contexts

In the field of design, designers usually use the power of symbols and images to convey design concepts, facilitating mutual understanding across various contexts. However, relying solely on symbolic expressions can be too one-dimensional, hindering public perception. Therefore, we used culture as a medium and community space and activities as carriers, adopting the theme “Beautiful Dongba, Colorful Homeland” (Figure 5). Leveraging the spatial governance project, we integrated cultural symbols into the environment, shaping a distinctive sense of place. This approach allows residents to intuitively connect with the cultural characteristics embedded in their living scenes, reshaping the context of the place for the long-term preservation of community culture and the creation of a culturally sustainable community (Table 4).

(i) Cultural symbols decorating small and micro spaces to stimulate community vitality

The community’s unique historical memory is emphasized through the use of infrastructure such as cultural walls, cultural landscapes, and small spaces, creating a showcase of the community’s landscape. At the same time, cultural statues, historical photos, old objects, biographies, and stories are used to perpetuate the historical lineage and highlight the cultural characteristics of the community. In the area of Red Pine Garden Food Courtyard, a distinctive cultural belt has been established, using the boundary wall to showcase the historical development of the area, the lives of residents, and the stories of people through a walking trail. In the area of Teachers’ House Community, the theme of “Bamboo Scrolls” has been used to craft a vertical landscape wall, enriching the spiritual life of residents and elevating the cultural construction of the area, starting from the professional characteristics of teaching and educating people. The initiative enhances the level of cultural construction in the district (Figure 6).

(ii) Cultural symbols integrating into the spatial scene to sustain the spirit of friendship and neighborhood

Table 3. Community culture inventory

Name	Unitary community culture		Living community culture		Regional culture
	Work unit	Feelings	Activities	Sites	
Hong Song Yuan	Deputy food factory	Gastronomy	Playing chess; sunbathing	Community garden in front of the building	Dam River Culture, Canal, Folk Flower Festival, Golden Ancestors, etc.
Gao Yang Shu	Window and door factory	Reminiscence	Playing mahjong; playing sport	Entrance in front of the building	
Dan Dian	Brickworks	Enjoy	Sunbathing; chatting	Corridor	
Teachers’ House Community	School	Busy	Chatting	In front of the building	
Credit Union Block	Exploration institute	Pride	Playing chess	In front of the building	
Surveyor’s Block	Cooperatives	Busy	Chatting	In front of the building	

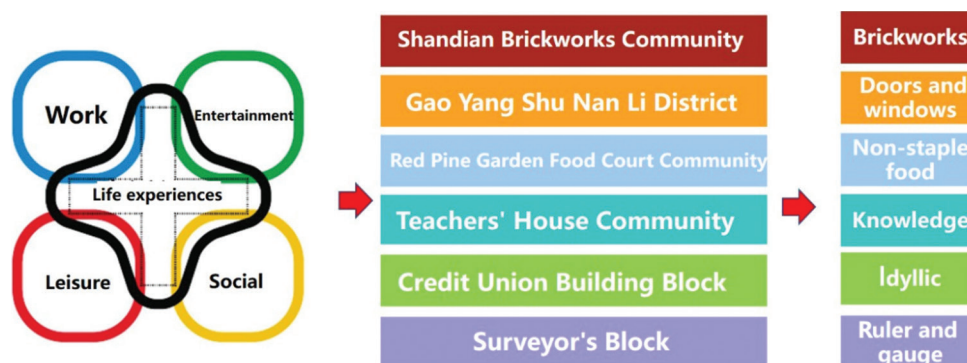


Figure 5. Six old neighborhood color cards

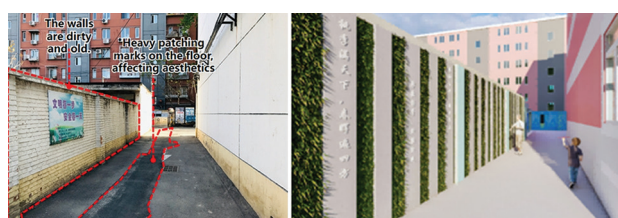
**Table 4. Exploring the cultural features of the areas**

No.	Name	Culture	Symbols	Design concept
1.	Hong Song Yuan	Deputy food factory	Colorful sweets	With the theme of “colorful sweets,” the landscape features such as “cute circles” and “stained glass” add interest to the public space and create a harmonious community for all age groups.
2.	Gao Yang Shu	Window and door factory	Doorway	The concept of the “doorway” is used to define the public space with a turning corridor, turning the corner space into a recreational space.
3.	Dan Dian	Brickworks	Red brick	The aim is to highlight the cultural characteristics of the brickworks and to create a walking trail using the red brick color to link the three “red brick” spaces.
4.	Teachers’ House Community	School	Bamboo scrolls	The bamboo scrolls are used as a model to create a cultural wall of poetry, highlighting the cultural characteristics.
5.	Credit Union Block	Exploration Institute	Greenfields	Due to the small size of the site, the main focus is on the renovation of facilities, with the theme of “greenfields” adding green facilities to create an idyllic life.
6.	Surveyor’s Block	Cooperatives	Ruler and gauge	The “ruler” element is incorporated into the wall design, and signage and interesting rulers are added to enhance the interactivity of the space.

Our main approach is to improve public space through “acupuncture” renewal, integrating cultural symbols into the spatial scene to recreate emotional memories. In the area of Red Pine Garden Food Courtyard, we used the “candy” symbol to craft a vibrant leisure space. Colorful sunshades serve as the roof of the veranda, casting a lively play of light and shadow in the sunlight. The original neighborhood garden is transformed into a community leisure and entertainment square, complete with play facilities to cater to children’s play needs. This transformation provides a pleasant environment for residents to interact with each other (Figure 7). In the Gao Yang Shu Nan Li district, we employ the “doorway” feature to create a shared cultural space for the community. Landscape nodes, such as vine planters, leisure green corridors, and sun gardens, are strategically placed to create a well-organized space for residents’ spontaneous planting behavior. Instead of merely serving as a feature, it acts as a bridge to reshape friendly neighborhoods and stimulate community vitality (Figure 8).

### (c) Media communication: Strengthening cultural adhesion through technology

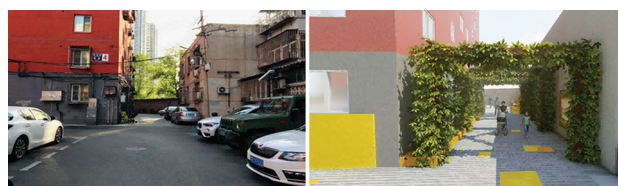
With the relocation of the original residents and the inflow of foreigners, the demographic structure of the old neighborhoods has changed considerably, with young people as the main wage earners becoming an important component of these neighborhoods. However, the young people have not experienced the traditional unitary system of earlier life, lacking a deep understanding of the history and culture of the community. Their busy schedules also prevent them from actively participating in community affairs. Cultural dissemination channels, primarily reliant on the spontaneous dissemination of the community’s older residents, struggle to capture the interest of the younger residents. This lack of enthusiasm poses a significant obstacle to the community’s comprehensive development of a distinctive culture.



**Figure 6.** The comparison of before and after the cultural wall construction in the Teachers’ House Community block. Source: Photos by the authors



**Figure 7.** Effect of the colorful corridor in the secondary food court area. Source: Photos by the authors



**Figure 8.** Effect of the characteristic doorway of the Gao Yang Shu Nan Li district. Source: Photos by the authors

To overcome limitations, we established an online community co-creation culture platform with the help of new media mediums, such as mobile apps and WeChat applets, systematically organizing community history, culture, district culture, and party-building culture through graphic content, video, and voice formats, marking them on an electronic map. Meanwhile, offline efforts involved installing QR code signs and signage for the platform,

enabling residents to engage with cultural awareness anytime and anywhere in their daily lives. The introduction of community electronic bulletin boards transformed the content and form of cultural communication through real-time cultural data statistics (Figure 9). By realizing culture and interactive experiences through technology, we increased residents' engagement with community culture services. Even those with initially limited interest were able to change from passively accepting community culture to actively understanding it. Residents could now use their fragmented time to actively participate in online community discussions. Accelerating the construction of community culture and improving the quality of cultural dissemination aims to enhance the cultural influence and cohesiveness of the community, thereby strengthening the cultural confidence of the residents.

## 3. Results

### 3.1. Strategies for the regeneration of unitary communities led by cultural regeneration

#### 3.1.1. Spatial regeneration: Recreating the spirit of place

The spirit of place encompasses the sense of belonging and identity that emerges from people's participation in a place. The sense of identity is shaped by various expressions such as the scale of space, environment, and light source, fulfilling people's imagination of space. Simultaneously, the sense of belonging is based on the sense of identity and the emotional resonance generated through frequent interaction between space and individuals (Ye *et al.*, 2018). Spatial re-creation, therefore, signifies a departure from an illusory concept of the spirit of place. Instead, it presents visually in material form, actively interacting with people and subtly influencing their lives and ideologies. The space created by the spirit of place must not only improve the surrounding environment but must also be built on the core of the local spirit, serving as the root and soul of the culture. In community regeneration, the spirit of place is recreated through the "renovation" of existing resources rather than the "creation" of new ones. Community culture serves as the source, community space as the medium, and the improvement of public activities and services in the community as the goal. This approach



**Figure 9.** Media communication empowering community culture. Source: Drawings by the authors

aims not only to fulfill the needs of local residents but also to solidify community culture within the physical space. It accumulates through different forms of expression, forming a unique community fabric.

#### 3.1.2. Community Renewal: Diverse Expressions of Community Culture

Community culture is expressed in a variety of ways, fully reflected in the forms of cultural existence, mapping subjects, and service objects. Different communities hold different understandings of the expression of community culture, and a single culture can take on numerous forms. In unit-type communities, using memory associated with the unit to create a distinctive neighborhood culture can not only preserve the historical lineage of the community and uphold humanistic values such as diversity, inclusiveness, and uniqueness through cultural means but can also foster a neighborhood interactive space themed on recreational activities, cultural performances, parent-child interactions, and more. This initiative aims to create a vibrant neighborhood cultural scene, promoting neighborhood exchanges. Consequently, it contributes to the regulation of the community governance system and improves the mode of operation of the community.

In the process of creating community culture, cultural application often takes the form of abstract and concrete applications, embodying culture in different cultural scenes. The application of culture in the design of community space can involve comprehensive landscape transformation, the creation of space with distinct cultural characteristics, the promotion of space-intensive usage and functional integration, and the creation of future community scenes in which art and landscape intertwine. While reflecting a "people-centered" approach and meeting the practical needs of urban development, it is essential to consider the sustainable development of the community.

#### 3.1.3. Vibrant regeneration: Enhancing cultural provision

If public space serves as a place for expressing culture, then community activities and projects represent a continuation of culture. Throughout the renewal process, whether through offline interviews with local residents or the organization of cultural activities aimed at environmental improvement, one consistent outcome is the stimulation of interest in conversation and interaction. This outcome, in turn, enhances residents' sense of belonging, identity, and recognition. This observation highlights that the original culture of the community has never disappeared but has accumulated dust over time. Cultural activities serve as an avenue for residents to share their stories, breaking the closed nature of a city life. Moreover, the constant exchange and integration of the



Figure 10. Diverse spaces generating diverse interactions and reshaping social networks. Source: Drawings by the authors

old unitary culture with the emerging community culture contribute to the formation of a new culture. In essence, cultural events open new avenues for community cultural expression and maximize the vitality of the community.

### 3.1.4. Social regeneration: Reshaping social networks

Traditional Chinese neighborhoods are characterized by a strong sense of individual belonging and collective identity, a characteristic even more pronounced in unitary communities with their concentrated nature. However, as urbanization and population mobility accelerate, the once harmonious neighborly relationships are gradually fading, and the relatively closed living style resembles a “transparent wall” within the community (Wang & Gao, 2021). The social network built on trust is gradually disintegrating, leading to an increased likelihood of conflicts arising from conflicting interests. To address this challenge, a consensus is required to guide people toward voluntary cooperation and harmonious coexistence. While each individual has a unique family and personality, their life trajectories converge here, with local community culture serving as the greatest common denominator among residents. Engaging residents in social activities through public participation harnesses the power of culture and spirituality to unite people, fostering the creation of new neighborhoods with each exchange. This gradual process contributes to reshaping a harmonious and congenial social network (Figure 10).

## 4. Discussion

Spaces undergo instantaneous changes; yet, the impact that spatial transformations have on human relations and behavior is profound. Culture, beyond being a product of history and civilization, stands as a valuable resource. This article, rooted in the theory of cultural regeneration, leverages community-specific culture to remodel the landscape and create public space in the unitary system of the old Dongba Town neighborhood in Beijing. The study explores the impact and interaction of cultural space regeneration on the social networks of community residents. Findings from the remodeling process lead to the conclusion that in the search for community regeneration, culture serves not merely as

an element of spatial remodeling but also as an endogenous driving force to activate the community and reshape the social network of residents. Using cultural memory as a guiding principle encourages residents to reflect on past years and promotes emotional exchanges. Employing cultural symbols as carriers reshapes the community context and invigorates public space. Utilizing cultural activities as connectors strengthens identity and builds a social network. Applying cultural forms as methods enriches cultural expression, ensuring the sustainable development of the community.

## 5. Conclusion

The renewal of unitary communities can use unitary culture as a medium to establish a grassroots governance system for residents through collective memory and the spirit of place. This process involves reconstructing both the material and spiritual spaces of the old community, transforming it from a mere collection of individual dwellings into a diversified and sustainable community capable of accommodating residents’ interactions, sports, recreation, and leisure activities. In projects focused on renovating similar types of communities, the designer’s task extends beyond expressing cultural symbols at the spatial or landscape level. More importantly, the designer must use culture as a link to connect with the emotional memory of the community residents in the preliminary research. This connection is instrumental in repairing the long-sealed, harmonious neighborhood relationships between residents during the renovation process. For subsequent research, exploring the combination of the varied spatial and temporal behaviors of community residents allows for a deeper understanding of the multiple functions of community cultural space. Such insights may provide valuable support for the dynamic transformation of community spaces.

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## Conflict of interest

The authors declare they have no competing interests

## Author contributions

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*Investigation:* Shurui Yin, Jing Li  
*Methodology:* Shurui Yin  
*Writing – original draft:* Shurui Yin  
*Writing – review & editing:* Shurui Yin

## Ethics approval and consent to participate

Not applicable.

## Consent for publication

Not applicable.

## Availability of data

Data are available upon reasonable request from the authors.

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## ORIGINAL ARTICLE

Design and implementation of the Beijing Road  
Traffic Environmental Monitoring Information  
Platform: A stakeholder's perspectiveXu Zhao<sup>1,2</sup>, Ning Lyu<sup>1\*</sup>, Mengqiu Cao<sup>3</sup>, Wenbo Guo<sup>4</sup>, and Ruonan Wang<sup>1</sup><sup>1</sup>School of Tourism Sciences, Beijing International Studies University, Beijing, China<sup>2</sup>Social Sciences Academic Press (CHINA), Beijing, China<sup>3</sup>School of Architecture and Cities, University of Westminster, London, United Kingdom<sup>4</sup>Transport Studies Unit, School of Geography and the Environment, University of Oxford, Oxford, United Kingdom(This article belongs to the *Special Issue: Advances of Data Analysis in Urban Planning*)**Abstract**

The process of urbanization continues to accelerate, placing an increasing burden on the urban environment through the transportation sector. To address this challenge, the Beijing Municipal Transportation Bureau has introduced the Traffic Transport Environment Monitoring Information Platform, which aims to strengthen the monitoring and management of the transportation environment by facilitating flexible management and control of the transportation planning and implementation process through timely diagnostics and dynamic feedback. It represents a technologically innovative measure designed toward establishing and improving the dynamic predictive power of transport planning and monitoring in Beijing. This study thoroughly examines the design and implementation of the platform, providing detailed insights into its overall framework, data collection, and processing mechanisms, as well as strategies for data sharing and utilization. Through an analysis grounded in stakeholder theory, the study demonstrates the effectiveness and practicability of the platform. By prioritizing stakeholder demands, the study not only contributes to transportation planning technology theory but also holds pioneering significance for the practical implementation of transport environment monitoring information platforms in cities across China.

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**1. Introduction**

Transport planning is an industry that has embraced big data technology in its early stages. The continuous iteration of new technologies, such as big data and artificial intelligence, provides a foundation for obtaining more refined data and new analytical methods within the field (Mehmood *et al.*, 2017; Wong, 2022). Traditional methods used in transport planning, such as traffic planning models, have played a crucial role in the design of transportation systems in mega-cities (Amekudzi *et al.*, 2007). However, these

methods primarily rely on manual inspection (Ozbay *et al.*, 2009), basic data (Milne & Watling, 2019), and model systems (Lay, 2005), while the related parameters often lack standardized criteria (Zito & Salvo, 2011), resulting in limitations in scope, missing values (Sharma *et al.*, 2004), an inability to comprehensively perceive critical aspects of transportation dynamics (Beukers *et al.*, 2012), and a lack of coordination (Du *et al.*, 2022; Wachs, 1999). In recent years, there has been a growing trend toward the rapid development of urban digitalization (Hashem *et al.*, 2016). Not only has significant progress been made at a technological level, but digitization is also having a profound impact on urban life, governance models, and economic development (Bai *et al.*, 2023). There is a growing awareness across all sectors of society of the significance of digitalization in urban construction (Hashem *et al.*, 2016), which is the main driving force for urban transformation and upgrading, and plays a key role in enhancing urban competitiveness. It is an inevitable requirement for the modernization of governance systems and capabilities in mega-cities (Van der Ploeg & Poellhekke, 2008), such as Beijing.

Currently, Beijing is actively developing its digital economy, primarily focusing on constructing a new digital landscape to ensure the secure and compliant flow of data, facilitate orderly data sharing, and integrate elements such as data infrastructure, digital transactions, digital platforms, and other digital scenarios (Sun *et al.*, 2022; Hansen, 2019). The digital economy, characterized by billions of daily online connections of people, businesses, devices, data, and processes, comprises the economic activity resulting from the widespread adoption of information and communication technologies across all business sectors to boost productivity. Therefore, it is essential to integrate digital transformation within the transportation sector by leveraging traffic models and big data analytics technology to create a digital application platform for transport planning. This integration will establish a new model for incorporating the digital industry within the transport sector. In the post-pandemic era, the digital economy has become a new focus and breakthrough point for China's economic growth (Wang *et al.*, 2022). The digital transformation of transportation systems aligns with this growing trend, with current efforts focusing on the digitization of construction. This digital transformation includes the utilization of smart transportation systems and traffic operation management platforms designed to enhance urban transportation operations. However, digital platforms intended to aid decision-making in relation to urban transport planning are still in the exploratory stage.

The implementation plan launched at the 2021 Global Digital Economy Conference clearly defines the overall requirements for urban digital transformation in Beijing. These requirements are designed to position the city as a national capital with a focus on constructing a secure and compliant digital economy. The process involves six key aspects, namely optimizing the urban structure, fostering international data hubs, incubating emerging digital industries, driving global technology innovation, enhancing digital governance using Chinese context-specific solutions, and promoting international cooperation within the digital economy. Beijing has set goals and specific paths for the digital transformation of planning resources, leveraging its foundational and leading role in fine-grained urban management. These goals include the use of big data and advanced analytics for energy optimization and digital R&D tools to expand the scope of digital technology applications. It is within this context that the Beijing Road Traffic Environmental Monitoring Information Platform (BRTEMIP) has been constructed. This platform integrates an information system with data from diverse sources to enable real-time monitoring, data analysis, and predictions about the urban transportation environment. It also facilitates the assessment and optimization of relevant policies and measures. By integrating data from various sources, such as the composition of motor vehicle types and the level of traffic activity, and by refining current accounting methods and other technologies, the platform provides technical support for scenarios such as setting quantitative targets for urban transport pollutants and evaluating the potential of different measures to reduce carbon emissions. In addition, it enables real-time collection, processing, analysis, and application of big data to save energy and reduce emissions within the transportation sector. The design of this platform is a crucial driver for the transformation of the transportation industry. It enhances the accuracy and efficiency of traditional traffic planning models, simplifies operations, and leads to more effective decision-making in the context of urban transport planning.

This paper aims to explore the design and implementation of the BRTEMIP in-depth, providing a comprehensive exploration of its overall framework, data collection and processing methods, and data sharing and utilization. The objective is to offer insights and guidance for the monitoring and management of urban transportation environments. The significance of this research is threefold. First, it presents effective methods for monitoring and managing urban transportation environments. The design and implementation of the BRTEMIP exemplify a scientific, accurate, and rapid approach to monitoring and managing urban transportation environments, offering a scientific

basis and technological support for the development of urban transportation and promoting the application of information technology in this domain. Second, the design and implementation of the BRTEMIP involve various areas such as sensor technology, data processing, and data mining. The application of these technologies will further drive the utilization of information technology in monitoring and managing urban transportation environments. Third, it offers insights into urban transportation environmental protection and sustainable development. As urbanization accelerates, the impact of transportation environments on their urban surroundings increases, making it increasingly urgent to protect urban transportation environments and ensure sustainable development. The design and implementation of the BRTEMIP offer crucial technological support and insights for these areas.

The paper is structured into six sections. Section 1 serves as the introduction, while Section 2 comprises the literature review. Section 3 explains the research framework and outlines the research design, and Section 4 presents the results. Following this, Section 5 offers a discussion of the key findings, and Section 6 provides conclusions.

## 2. Literature review

In recent years, significant progress has been made in researching and applying road traffic environmental monitoring information platforms (Wang *et al.*, 2023). For instance, traffic management centers in the United States use advanced sensor technology and real-time data processing algorithms to carry out operations such as traffic flow monitoring, congestion prediction, and intelligent traffic management (Iyer, 2021). Similarly, in European countries, extensive research has been conducted on traffic road environmental monitoring information platforms, aiming for effective monitoring and management of urban traffic through the integration of sensor networks, geographic information systems, and big data analytics (Garau *et al.*, 2020). Beyond traffic management applications, research has also explored the application of traffic road environmental monitoring information platforms in other areas. For example, some studies have focused on road traffic safety, using real-time monitoring and early warnings of traffic accidents by integrating monitoring data with statistics on traffic accidents. Simultaneously, other studies have addressed the issues of environmental protection and sustainable transportation development, providing a basis for decision-makers to formulate environmental protection policies and promote green travel by monitoring traffic emissions and environmental pollution indicators (Bibri *et al.*, 2020; Khan *et al.*, 2019).

In China, significant progress has been made in researching traffic road environmental monitoring information platforms (Jin *et al.*, 2021). Domestically, research on road traffic environmental detection has primarily focused on the impact of environment-related pollutant monitoring technology on green and sustainable development. The aim is to create a healthier, greener environment for people through timely monitoring of air pollutants (Qin *et al.*, 2019). However, there is currently a lack of technological innovation in regard to the monitoring of ambient air quality on urban traffic roads in China. Consequently, monitoring efforts in this area remain unregulated, impeding assistance for the management of motor vehicles, urban traffic roads, and urban ambient air quality (Liang *et al.*, 2019; Anderson *et al.*, 2010). To fully support the benign and effective operation of urban transportation, addressing these shortcomings is essential. Thus, it is worthwhile to present and examine the demands of different stakeholders and establish communication and connections among multiple subjects centered on the traffic road environmental monitoring information platform.

With regard to the implementation of technological applications, traffic management departments in major cities have actively promoted the construction of these platforms. Cities such as Beijing, Shanghai, Guangzhou, and Shenzhen have conducted in-depth research on traffic congestion monitoring, traffic signal optimization, and traffic event management (Wei *et al.*, 2022). In addition, some high-tech enterprises have innovatively researched traffic road environmental monitoring information platforms, developing sensor equipment and data processing algorithms with independent intellectual property rights, thus providing new solutions for urban traffic management.

Overall, research indicates that traffic road environmental monitoring information platforms play an important role and possess enormous potential for optimizing urban traffic management. Real-time monitoring and analysis of key information such as traffic flow, road conditions, and environmental pollution enable traffic management authorities to quickly grasp the urban traffic situation and formulate corresponding management strategies and emergency measures. However, challenges and unexplored areas remain, particularly concerning technology usage. Issues associated with data sharing could pose threats to the platform's main users, while data quality and privacy protection require further investigation and resolution (Imprialou & Quddus, 2019). In terms of research content, few studies have examined the design and implementation of the platform from a stakeholder's perspective, despite

stakeholders' significant influence on the complex relationship among policy and regulation formulation, transportation planning, and economic and industrial development. Therefore, this paper aims to thoroughly examine the role and value of the traffic road environmental monitoring information platform from a stakeholder's perspective. It intends to propose corresponding suggestions for improvements and applications to promote the optimal development of urban traffic management.

Previous studies have predominantly focused on three key areas within technology: sensor technology, data processing algorithms, and system integration. Advancements in sensor technology have enabled more accurate data collection for road traffic environmental monitoring, encompassing metrics such as traffic flow, vehicle speed, and air quality (Chung & Kim, 2020). The development of data processing algorithms has improved real-time data processing, rendering it more reliable, efficient, and capable of analyzing large-scale datasets. In addition, research on system integration has focused on the integration of multiple subsystems to promote data sharing and collaborative work, thereby enhancing the comprehensive performance of monitoring platforms.

Despite these advancements, several challenges and blind spots remain. First, ensuring data quality and consistency is paramount, as accurate and reliable data collection is essential for effective monitoring and analysis (Aad *et al.*, 2020). Second, prioritizing privacy protection and data security is crucial, necessitating careful consideration of user privacy and information security in platform design and data processing (Yang *et al.*, 2020). In addition, further research is warranted to address the scalability and adaptability of the platform to meet the dynamic demands of urban traffic management (Lana *et al.*, 2021).

Recent research indicates that traffic road environmental monitoring information platforms hold significant potential for broad applications, including optimizing urban traffic management, enhancing traffic safety, and promoting environmental protection. Despite notable achievements in technology application and platform design, further breakthroughs and innovations are necessary. In addition, further guidance and practical suggestions based on theory are required to ensure these platforms effectively address transportation challenges stemming from unpredictable environments. Therefore, this paper explores the role and value of the traffic road environmental monitoring information platform from a stakeholder's perspective. By doing so, it seeks to provide valuable insights and suggestions for optimizing urban transportation management.

## 3. Methods

### 3.1. Research framework

The design of the BRTEMIP encompasses the development of three subsystems and equipment integration. The aim is to establish an information platform capable of carrying out functions such as comprehensive statistical query analysis of collected environmental information. The implementation involves three main stakeholders with a vested interest, namely the municipal government and development institutions, service providers, and travelers/users. The main business processes involved in the platform design and implementation are illustrated in [Figure 1](#).

### 3.2. Research design

#### 3.2.1. Research objectives

To comprehensively assess the role and value of BRTEMIP, this paper focuses on two objectives, namely, the monitoring objects involved in the platform design and the stakeholders with a vested interest in its implementation.

The principle guiding the selection of monitoring objects for the platform is to be consistent with the layout of Beijing's transportation infrastructure. Following this principle ensures that the selected objects fully reflect the city's actual traffic situation, providing a reliable basis for traffic management and planning. In addition, the selection of monitoring objects is consistent with the goals of human settlement and ecological environmental protection, focusing on the selection of transportation infrastructure and emission sources that significantly impact residents' lives and environmental quality. This approach ensures the accuracy and pertinence of monitoring data, providing strong support for the formulation of appropriate, scientifically-based environmental protection policies. In addition, the selection of monitoring objects is coordinated with Beijing's Municipal Environmental Protection Department's existing environmental monitoring network. Following this coordination maximizes resource utilization, minimizes construction duplication, and ensures the comparability and compatibility of monitoring data.

The monitoring objects can be categorized into three types:

- (i) Conventional environmental quality monitoring objects: These objects monitor the impact of transportation-related sources of pollution on environmental quality, focusing primarily on ambient air quality and noise. They are strategically placed along roads and adjacent areas, integrated into Beijing's environmental protection monitoring system, and contribute to the assessment of urban environmental quality.

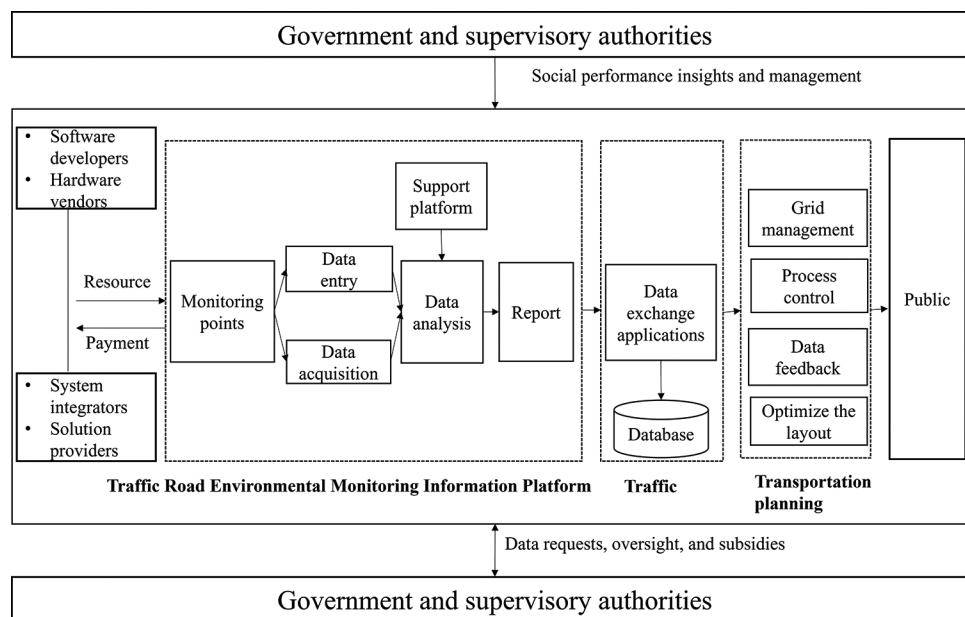


Figure 1. Research framework. Source: Drawing by the authors

- (ii) Conventional monitoring objects in traffic hotspot areas: These objects monitor the environmental quality within and along the boundaries of traffic hotspot areas, including road transportation hubs, bus hubs, rail transit stations, train stations, airports, and highway service areas. Although not integrated into Beijing’s environmental protection monitoring system and do not play any part in urban environmental quality assessments, they support the formulation of relevant transportation industry policies.
- (iii) Supervisory monitoring objects in traffic hotspot areas: These objects monitor pollutant emissions to ensure compliance with requirements and monitor the effectiveness of environmental protection facilities in traffic hotspot areas. Like the second category of objects, these areas are not integrated into Beijing’s environmental protection monitoring system and do not play any role in urban environmental quality assessments but support environmental protection management within the transportation industry.

According to stakeholder analysis theory, the main stakeholders involved in platform implementation include the municipal government and development agencies, service providers, and the general public. The impact of these three parties on the monitoring platform can be analyzed by analyzing the complex relationship among the formulation of policies and regulations, transportation planning updates, and industrial and economic development.

First, the government releases information about the layout of the transportation planning center in its

policy documents to serve the public interest and meet public health needs. Through real-time monitoring of pollutant emissions, it plans and improves transportation infrastructure in the short term, determines the reasonable distribution of monitoring points, improves the accuracy, completeness, and extensiveness of the data, and works toward achieving the overall healthy and sustainable development of society.

Second, service providers are involved in the early stage of platform design. The main service providers can be divided into two categories: (i) System integrators and solution providers and (ii) hardware suppliers and software developers. The interests of service providers can be divided into two main dimensions: (i) meeting customer needs and enhancing the platform’s competitiveness by providing high-quality operational services, and (ii) improving profitability and ensuring sustainable development by reducing operating costs and realizing benefits. The service providers must commit to investing in the development of technology research and development personnel and using advanced technology such as network and 3S (which refers to the integration of geographic information systems, global positioning systems, and remote sensing) to build a transportation environmental monitoring service platform. In addition, they must adapt to the new environment through flexible development, keep the technology updated, and seek convenient and efficient data transmission service solutions.

Third, travelers exert a cyclical, cumulative effect on the platform’s implementation stage and the stable operation

of transportation services. Through the policy promotion and business maturity described in relation to the previous stage, the platform itself has seen improvements in data reliability and timely data monitoring by the government and the Ministry of Communications. At the same time, the upgraded transportation environment monitoring information platform has become more mature and stable, thereby becoming more attractive to travelers, leading to an increase in market demand and market share.

### 3.2.2. Research scope

Since 2012, due to the rapid development of Beijing's economy and the accelerated process of urbanization, the transportation sector, identified as one of the three key industries targeted for energy conservation and emissions reduction in Beijing, has vigorously promoted green modes of transportation and energy-saving measures (Sun *et al.*, 2021). By 2020, the campaign against transportation pollution had been successfully completed, and the BRTEMIP was recognized as essentially sound. More effective resource management and utilization methods had been adopted to enable the transportation industry to meet the needs of social and economic development while reducing its negative impact. For example, optimizing the transportation structure and increasing the proportion of green modes of travel (Li *et al.*, 2020).

Looking ahead to 2035, the goal is to achieve a greater harmony between transportation development and nature, leveraging scientific advancements in the ecological governance of the transportation system. This objective is consistent with the requirements of achieving a higher level of ecological and environmental protection in relation to transportation development, thus ensuring the harmonious coexistence of transportation development and the natural environment. Such harmony will be underpinned by a more solid material foundation and institutional guarantees. In 2021, the 14<sup>th</sup> 5-year Plan for the Development of a Modern Comprehensive Transportation System proposed actions designed to achieve green and low-carbon transformation. These actions include strengthening carbon emissions accounting, establishing a carbon emissions monitoring platform, and promoting the construction of near-zero carbon transportation demonstration zones (Wang, *et al.*, 2023). Simultaneously, the 14<sup>th</sup> 5-Year Plan for Ecological and Environmental Protection in Beijing introduced a series of measures designed to protect and preserve the environment, including formulating implementation plans for the promotion and deployment of new energy vehicles, vigorously promoting the transition from "oil-to-electricity" for vehicles, replacing various petrol- or diesel-powered vehicles with pure electric or hydrogen fuel

cell vehicles, and optimizing the transportation structure (Wang *et al.*, 2020).

The BRTEMIP is designed to effectively grasp information about the quality of the environment, the sources of pollution emissions, and changing trends in these aspects. This platform provides data support for compiling transportation development plans, conducting scientific research on transport-related environmental protection, and submitting statistical reports on the environmental impact of transportation. The main goals are to provide networked and digitized traffic environmental monitoring information, achieve multi-indicator and full-coverage traffic environmental monitoring, strengthen the comprehensive application and analysis of environmental and traffic data, integrate traffic environmental monitoring data for information sharing, and achieve "integrated business processing" and "fine management."

## 4. Results

### 4.1. Analysis and monitoring of the urban road environment

Guided by planning objectives, functional positioning, and layout standards, this study primarily investigates the layout scheme of the urban road traffic and transportation environmental monitoring network within and around the Fifth Ring Road in Beijing. It focuses on the development of the urban road infrastructure, as shown in [Figure 2](#).

First, an analysis of the population density distribution map in Beijing was conducted to identify densely populated areas near urban roads during peak traffic hours. Based on this analysis, the layout of roadside stations was determined accordingly. Second, road segments within the Fifth Ring Road and its surrounding areas, where traffic flow during peak hours ranks in the top decile for the city as a whole, were selected as monitoring objects for busy traffic levels. We considered the existing environmental monitoring layout plan of Beijing's environmental protection system, and made adjustments and optimizations to the layout scheme, utilizing existing environmental monitoring stations in some cases. The goal of this approach is to reduce the amount of capital invested in monitoring points while achieving comprehensive monitoring of information on the environmental quality of key urban road segments in Beijing. Finally, using the standard six environmental air quality factors (including CO, PM<sub>10</sub>, PM<sub>2.5</sub>, NO<sub>x</sub>, and O<sub>3</sub>) and equivalent continuous A-weighted noise, sites with suitable conditions were identified for monitoring additional factors such as black carbon, benzene series compounds, and non-methane total hydrocarbons. Automated stations were proposed for continuous online monitoring (Salami, 2021).

The planning approach adopted for the environmental monitoring network of urban roads in Beijing encompasses strategically positioning monitoring points, considering both residential areas sensitive to traffic pollution and road segments with high traffic volumes. The focus lies on routine environmental quality monitoring during peak hours, particularly targeting urban roads in densely populated areas. Priority is given to specific regions with a notably high density, such as Sihui, near Beijing East Railway Station, Beijing Railway Station, Beijing North Railway Station, Dongzhimen, Dinghuiqiao, and the Central Business District (CBD). Areas around train stations are temporarily excluded from consideration.

Simultaneously, attention is directed toward identifying busy traffic segments within the Fifth Ring Road and its environs. Road segments with a traffic flow in the top decile for the city as a whole during peak hours are selected for monitoring. This approach ensures the implementation of a comprehensive monitoring strategy covering both residential and traffic-heavy areas.

The planning process extends to include expressways and national roads, involving steps to verify data accuracy at the provincial level. Geographic information systems software is employed to set buffers, conduct spatial overlay analysis, identify areas containing ecologically sensitive zones, and determine potential monitoring targets. Preliminary focus areas are selected as monitoring objects within traffic hotspots, which encompass service areas, toll booths, and tunnels, among other features. Further refinement is achieved by incorporating existing online monitoring stations, and the final plan is determined by merging, combining, and optimizing processes.

The Beijing Environmental Monitoring Center proactively planned four traffic environmental monitoring stations, which are strategically placed on the east and west Sixth Ring Roads, as well as two expressway stations on the G6 Tibet and the Southeast Jingjin or Jinghu G2 expressways. These stations are designed to monitor traffic-related pollutant emissions and changes in environmental quality and evaluate the effectiveness of traffic-related environmental protection facilities and management measures. Based on the results of the monitoring measures described above, suggestions and solutions for achieving optimization are proposed.

In summary, this detailed planning process is part of a holistic strategy aimed at effectively monitoring and managing various aspects of the environment associated with urban road transportation in Beijing.

#### 4.2. Analysis and monitoring of the hub stations

This research concentrates on formulating a plan for the environmental monitoring of urban roads in Beijing,

which encompasses strategically positioning monitoring points. Consideration is given to both residential areas sensitive to traffic pollution and traffic segments with high traffic volumes, aiming to identify hubs central to significant transportation movements.

The methodology includes identifying hub stations that host a substantial number of sensitive protection targets within the impact range. This step aims to identify hubs with a considerable potential impact on sensitive targets. Moreover, this approach involves carefully considering both transportation activity levels and concentrations of sensitive protection targets within the impact ranges. This integrated analysis guides the final selection of monitoring objects within the hub stations.

Using this method, a meticulous plan for monitoring objects was developed, encompassing highway service areas and rail transit stations. Highway passenger transport hubs, characterized by heightened transportation activity and the movement of a large number of passenger vehicles and travelers, cause significant air pollution and noise. Notably, sensitive protection targets in the surrounding environment include residential areas, hospitals, and schools, with the evaluation range extending 50 m beyond the facility boundary. This nuanced understanding of the distribution of transportation activity levels and the density of sensitive protection targets informed the strategic selection of six hubs – Liuliqiao, Sihui, Zhaogongkou, Beijiao, and two others – as monitoring objects within the highway passenger transport hub category.

In summary, this detailed and systematic approach ensured a thorough assessment and monitoring strategy tailored to the specific dynamics of these transportation hubs. The selection of monitoring objects and factors, such as environmental air pollutants and noise levels, is based on a comprehensive understanding of the interplay between transportation activity and sensitive protection targets.

## 5. Discussion

Figure 1 illustrates how relevant government and development departments issue transportation planning requirements to safeguard the public interest and manage the city's transportation. The design and construction of the traffic road environmental monitoring information platform constitute the main focus of the research framework. In the early stage of the platform design, the ministry of communications secures resources for technological innovation from service providers, such as software and hardware developers, to install technology at various monitoring points. Within this framework, monitoring data traverse from diverse monitoring points to the central platform, forming a comprehensive and

dynamic repository. Once integrated into the monitoring information platform, a sophisticated interplay unfolds. By seamlessly leveraging geographical information data and thematic databases interfaced with the support platform, the monitoring information platform undertakes a multifaceted analysis of the environmental monitoring data. The culmination of this analytical prowess is manifested in the presentation of detailed analytical results presented within comprehensive reports. This iterative process ensures a nuanced understanding of the environmental dynamics, facilitating informed decision-making and policy formulation.

Designing the platform forms the main part of the research design. An estimated cost analysis of the existing project construction informs a budget estimate for the preliminary construction of the platform. Specific costs for various components are detailed in Table 1 below.

In accordance with the stipulations set out by the Ministry of Transport, specific monitoring data crucial for reporting undergoes a scrupulous submission process. This subset of monitoring data is meticulously channeled into the Ministry of Transport's dedicated database through a meticulously designed data exchange. This two-pronged approach not only ensures compliance with regulatory requirements but also creates a robust framework for data transparency and regulatory adherence. To streamline and enhance the efficiency of this intricate system, operators are tasked with a dedicated reporting function within the monitoring information platform. This dedicated reporting function empowers them to input traffic

environmental monitoring data and analysis outcomes into the system promptly and efficiently. The integration of real-time reporting functions empowers operators to respond swiftly to emerging trends, thus contributing to the adaptability and responsiveness of the overall environmental monitoring ecosystem.

Strategically deployed in critical locations such as tunnels, toll stations, and service areas, the monitoring points serve as the frontline data collection nodes. This strategic placement ensures comprehensive spatial coverage, capturing environmental nuances across diverse urban landscapes. The multiplicity of monitoring points, each tailored to specific environmental considerations, collectively forms a resilient network contributing to the overarching goals of effective environmental monitoring, management, and regulatory compliance.

The platform stands out for its systematic, comprehensive, representative, and advanced features. It adopts a multifaceted and systematic approach to monitoring, covering key aspects of the road environment, such as traffic flow, air quality, noise pollution, and road congestion. In addition, it offers diverse functions, including real-time monitoring and data analysis, ensuring a holistic approach to monitoring and management. Moreover, the platform extends its coverage across the entire city, encompassing not only main and secondary roads in bustling urban areas but also outer ring roads, highways, and national roads, showcasing its comprehensive nature. Consequently, decision-makers have access to a wealth of comprehensive traffic road environment monitoring data, facilitating the formulation of effective policies and plans.

One of the platform's key strengths lies in its meticulous selection of representative road sections during construction. These sections encompass various types of roads and traffic conditions, providing decision-makers with valuable insights from ongoing monitoring and data analysis. Furthermore, the platform is highly advanced and committed to aligning with the development and requirements of existing policies. By offering real-time and accurate monitoring data and analysis, the platform ensures both relevance and utility. To achieve this, the platform employs state-of-the-art monitoring technology and data processing methods, ensuring that its data are reliable and accurate to meet the needs of policy formulation and implementation.

The application program for traffic congestion monitoring and management has yielded significant results through practical application. First, the platform enables real-time monitoring and management of urban traffic congestion, providing users with real-time traffic reports and navigation features to choose the optimal travel route. Second, through data analysis and exploration, it identifies

**Table 1. Overview of platform cost estimate**

Construction projects	Construction content	Investment (10,000 Yuan)
System research and development	Hardware devices	114.89
	Data collection implementation	10.00
	Application system development	159.00
	Data acquisition terminal equipment	152.00
Project research	Pre-project research, consulting, and design costs	9.50
	Cost of the overall planning of the project	6.50
	Project supervision, management, and agreement	19.30
	System integration fee	32.20
Monitoring points	Traffic noise online monitoring system	50.00
	Sewage online monitoring system	150.00
	Ambient air quality online monitoring system	200.00
<b>Total</b>		<b>903.39</b>

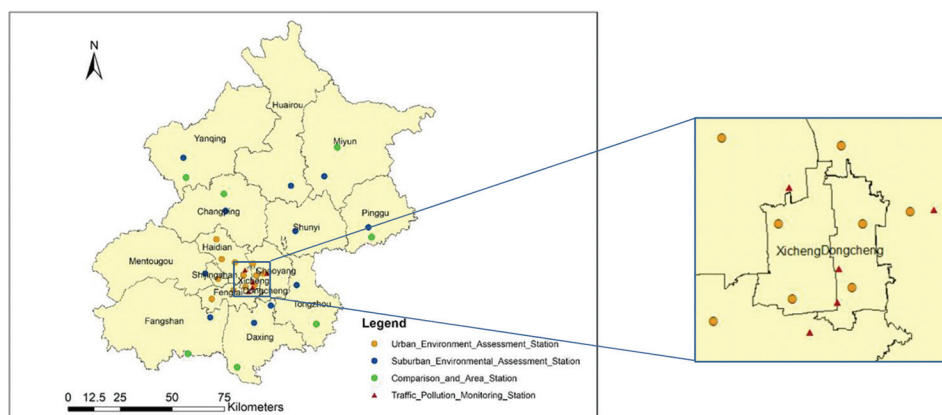


Figure 2. Monitoring of the urban road environment. Source: Drawing by the authors

congested road sections and their causes, offering effective solutions to alleviate congestion and improve the efficiency and quality of urban transportation. Finally, the application program enhances the decision-making capabilities and management quality of both government bodies and enterprises, thereby making a positive contribution to the improvement and optimization of the urban transportation environment.

The success of the traffic road monitoring information platform depends on comprehensive engagement with various stakeholders, each playing a unique and vital role. Government and supervisory authorities, who play a pivotal role in regulatory compliance and urban policymaking, require accurate monitoring data for informed decision-making. Equally important is public engagement, addressing public concerns, increasing awareness, and encouraging participation. Software developers are considered high-priority stakeholders because they shape the platform's technological backbone, ensuring its efficiency and promoting innovation. Collaboration with solution providers, which is regarded as moderate to high importance, enhances the platform's functionality and scalability. Finally, data analysts, playing a significant role, contribute their expertise in interpreting monitoring data, thus providing evidence-based decision-making support. Effective engagement with all stakeholders is therefore essential for the holistic development, continuous improvement, and long-term sustainability of the platform.

## 6. Conclusion

This paper uses BRTEMIP as an example to explore the construction and application of urban traffic transportation environmental monitoring information platforms. Firstly, the paper introduces the architecture and design principles of this platform, covering aspects such as data collection and processing, data sharing and utilization, and

application development. Secondly, using traffic congestion monitoring and management as an example, the paper presents application cases to demonstrate the platform's effectiveness and practicality. Finally, it envisages the future development of this platform, including improvements in data collection and processing technology, strengthening of data sharing and utilization mechanisms, and the development of more intelligent applications.

In the future, as urbanization and population growth accelerate, the demand for urban traffic transportation environmental monitoring and management will continue to increase (Liang *et al.*, 2019). Therefore, this platform will play an increasingly important role, contributing significantly to improving and optimizing the urban traffic transportation environment.

However, despite its importance, the operation of the monitoring platform still faces numerous limitations and challenges. Therefore, this study provides relevant suggestions for different stakeholders. In terms of technology, there is a need for the platform's data processing and decision support capabilities to adapt to complex data characteristics and diverse application scenarios. This need for adaptation requires service providers to research and develop corresponding algorithms, models, and tools. Moreover, to meet the needs of multi-scenario applications, advanced technology must be introduced to the traffic road environmental information monitoring platform to support sustainable monitoring and cope with the challenges posed by environmental uncertainty. In terms of cost, deploying and maintaining a large number of sensors and equipment by government bodies and the Ministry of Transportation requires considerable resources, including energy consumption and considering environmental impact, which can be costly. Therefore, formulating budget costs and transportation planning should involve collaboration with service providers. In

addition, obtaining timely feedback and suggestions from the public is crucial to addressing the environmental needs of society in a cost-effective manner and achieving healthy and sustainable development.

In summary, the BRTEMIP provides crucial data support for improving the monitoring and management quality of the transportation industry, formulating transport-related environmental protection policies, and conducting transport-related research into environmental protection, all of which are of vital importance. The construction and application of this platform exemplify important trends within the field of urban traffic transportation, making important contributions to the improvement and optimization of the urban traffic transportation environment. Currently, China is vigorously promoting the construction of smart cities and digital transformation (Wu *et al.*, 2023). The use of the urban traffic transportation environmental monitoring information platform constitutes a crucial step toward realizing smart, digital cities. We believe that, through joint efforts between the government and enterprises/service providers, this platform will continue to evolve and make further significant contributions to the sustainable development of urban traffic and transportation.

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## Conflict of interest

The authors declare they have no competing interests.

## Author contributions

*Conceptualization:* Xu Zhao

*Formal analysis:* Wembo Guo

*Investigation:* Ning Lyu

*Methodology:* Mengqiu Cao

*Writing – original draft:* Xu Zhao

*Writing – review & editing:* Mengqiu Cao, Wenbo Guo, Ruonan Wang

## Ethics approval and consent to participate

Not applicable.

## Consent for publication

Not applicable.

## Availability of data

The datasets used in this study are available from the corresponding author upon reasonable request. The data can be accessed by contacting Professor Ning Lyu at 2009001@bisu.edu.cn. Please note that certain restrictions may apply to the use of the data.

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## ORIGINAL ARTICLE

Residential urban heritage space identification,  
delimitation, and potential assessment model  
based on space syntaxYukun He<sup>1\*</sup>, Keji Chen<sup>2</sup>, and Xiao Han<sup>3</sup><sup>1</sup>Department of Architecture, Graduate School of Engineering, Kyoto University, Kyoto City, Kyoto, Japan<sup>2</sup>Department of Architecture, Graduate School of Engineering, The University of Tokyo, Bunkyo City, Tokyo, Japan<sup>3</sup>Department of Landscape Architecture, School of Architecture, Southeast University, Nanjing, Jiangsu, China(This article belongs to the *Special Issue: Advanced Technologies and Practices in Built Environment and Cultural Heritage*)**Abstract**

In the era of post-modernization, profound transformations in urban spaces have led to significant shifts in the spatial composition paradigms of contemporary urban heritage. Research on this process is crucial for elucidating the spatial pathways and compositional changes in the modernization transformation of urban heritage. This study aims to establish identification indicators and assessment systems for the spatial structure of urban residential environments exhibiting historical characteristics and heritage potential through a comparative analysis of residential urban heritage spatial paradigms in historic cities in China and Japan. First, grounded in space syntax theory, this study selected residential urban heritage in Suzhou's Pingjiang Historic District and Uji's Nakauji District as research cases. Utilizing road network data, this study analyzed the Life Integration ( $\text{Int.V}_{R1000}$ ) and Global Integration ( $\text{Int.V}_{R5000}$ ) of urban heritage spaces, thereby constructing a spatial topology system for heritage spaces. Second, the study employed urban spatial entropy indicators, such as architectural density entropy, spatial morphology entropy, and function mixing entropy, to quantitatively describe the spatial structure, consequently establishing a heritage space morphological structure indicator system. Finally, spatial clustering methods are used to integrate the spatial topology system with the morphological structure indicator system, resulting in a feature model for residential urban heritage spaces. The research results indicate that the transformation path of residential space paradigms is mainly influenced by spatial topology, affecting the structure of residential heritage spaces in three aspects: functional layout, building density, and spatial form. This phenomenon, in turn, impacts population distribution and the migration of living spaces. However, at the same time, the "resistance effect" of street and lane spaces and the limitations of architectural forms on spatial functions have protected the integrity and authenticity of the internal space.

**Keywords:** Space syntax; Spatial entropy; Residential urban heritage; Potential assessment; China-Japan comparison; Historic cities

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## 1. Introduction

In the era of post-modernization, urban spaces are undergoing profound changes. These changes not only affect the structure of modern cities but also challenge our traditional understanding of urban heritage spaces. Urban heritage includes not only historical buildings, monuments, and cultural landscapes but also extends to traditional neighborhoods and city centers. Collectively, these elements endow the city with rich historical and cultural characteristics, reflecting its diversity, identity, and social cohesion. Within this context, residential urban heritage spaces emerge as an important subset of urban heritage, offering insights into city life and social structures from the perspective of residents (Ashrafi *et al.*, 2021). These spaces represent the evolution of urban residential patterns and social structures over different periods, often containing unique architectural styles, road space forms, and land use statuses. However, the intervention of power, capital, and diverse social forces complicates the quest for balance between historical preservation and the modern development of residential urban heritage spaces (Bafna, 2003). Therefore, investigating the spatial paradigm shifts of residential urban heritage spaces during the modernization process, exploring the impact of their spatial structures and land use patterns on their modern transformation, and proposing strategies for their development and preservation have emerged as important topics in the protection of urban historical heritage (Li *et al.*, 2021).

## 2. Research background

### 2.1. Related research and research objectives

The road system and land use status within urban spaces are external manifestations of urban residential life and social organization. The use of digital technology for investigating road topology and land use morphology in urban spaces has found widespread application across various disciplines, such as planning (Jia *et al.*, 2019), architecture (Del Espino Hidalgo, 2019), and landscape (Du *et al.*, 2019). Moreover, research focusing on the spatial attributes of urban heritage has witnessed significant development (Ashrafi *et al.*, 2021; Pizarro-Reyes *et al.*, 2022).

In terms of research subjects, studies primarily involve traditional villages, urban industrial heritage, and core historical heritage spaces (Huang & Shi, 2015). For example, research delves into the spatial forms and characteristics of urban industrial heritage, exploring the relationship between spatial forms and industrial development, such as the case of industrial heritage in Shenyang (Liu *et al.*, 2019). There is also an analysis of the spatial features of Changchun's automotive industrial heritage to evaluate the project cases in planning and construction, proposing pathways for

spatial regeneration (Li & Han, 2021). In addition, research examines internal spaces of historic cities, such as studies based on road connectivity to describe touristic spatial forms within city areas (Li & Xu, 2018). Other investigations focus on optimizing courtyard environments in Suzhou's four great gardens through space syntax analysis (Zhao *et al.*, 2017), or explore individual urban heritage buildings, such as spatial forms and their conservation and utilization in Daqing Hongqi Village's Ganda Lei architecture (Zhao & Chen, 2022). These studies predominantly concentrate on heritage spaces in cities with high commercial value and development potential, leaving a gap in research exploring the internal spatial topology of residential heritage spaces primarily serving residential functions.

In terms of research methods, on the one hand, quantitative descriptions of heritage spatial forms through spatial topology, along with the proposal of planning or conservation strategies, have emerged as the mainstream approach. For instance, research has been conducted to analyze the spatial structure of coastal settlements in Guangzhou, leading to the proposal of adaptive development strategies for surrounding historic towns (Zhang & Ke, 2016). Similarly, research has analyzed the spatial connectivity values within the core area of Gansu Tianshui City's historic district, proposing spatial activation strategies (Tian *et al.*, 2021). Moreover, analyses have been conducted on the spatial distribution of heritage resources in Changsha city, integrating them with cultural spaces and proposing tourism planning strategies based on traffic connectivity (Lu & Guo, 2014). In Chongqing city, spatial network analyses have been conducted on "isolated" areas within historical districts, aiming to identify optimization strategies (Cui *et al.*, 2016). On the other hand, research based on land-use attributes concerning the spatial use and distribution of urban heritage spaces is scant. A majority of studies concentrate on the distribution characteristics of heritage spaces within a broader spatial context, such as the spatiotemporal distribution of industrial heritage in the northwest region and the spatiotemporal distribution characteristics and tourism relevance of intangible cultural heritage in Shanxi (Zhou *et al.*, 2012). Internal studies of heritage spaces include hierarchical entropy analysis of spatial distribution in Pingyao historic city in Shanxi to guide its tourism development planning and the use of information entropy to evaluate the tourism value of the silk roads heritage (Du & Liu, 2011).

It is evident that current research on urban heritage spaces places more emphasis on the spatial structure of urban heritage, specifically spatial topology. Conversely, there is a dearth of research concerning the material structure of spaces, such as their internal use attributes and land distribution. Research methodologies are mainly

single-faceted, lacking integration of both aspects and neglecting exploration into the correlation between spatial topology and material structure.

When it comes to methodological approaches, the theory of space syntax, a technique for analyzing urban spatial connectivity based on road networks, has significantly advanced the quantification and scientific understanding of topological relationships within urban heritage spaces. This theory is applicable to multi-scalar spatial analysis, ranging from individual heritage buildings to large-scale urban heritage sites. Particularly in the dissection of urban spatial topological relationships, space syntax offers a plethora of analytical metrics and interpretive methodologies. For example, studies have explored the connectivity and improvement strategies of public spaces in traditional villages (Sun *et al.*, 2017), as well as investigated the correlation between spatial morphology and connectivity in Nanjing's Xuanwu historical district (Zhao *et al.*, 2017).

Concurrently, the burgeoning theory of spatial entropy has also been employed in the analysis of urban spatial information (Liu *et al.*, 2021). A series of studies have emerged, focusing on urban spatial expansion patterns, such as those utilizing spatial entropy models to measure the primary driving forces in urban spatial expansion (Li *et al.*, 2016), and research identifying modes of urban expansion based on localized changes in spatial entropy (Zeng *et al.*, 2018). Notably, there is a paucity of studies that concurrently engage in both topological analysis of urban spatial structures and spatial entropy analysis.

In summary, this study focuses on residential urban heritage spaces within the broader context of urban heritage. By integrating space syntax theory and spatial entropy theory, this research undertook a quantitative analysis of these residential urban heritage spaces from both topological and material structural perspectives. Building on this groundwork, this study interprets the constitutive paradigms and characteristics of residential urban heritage spaces, offering a classification and evaluation that lays the theoretical groundwork for further exploration of the heritage potential of such spaces in future urban development endeavors. In addition, the study conducted a comparative analysis of similar residential urban heritage space paradigms in Japan, investigating the similarities and differences in the constitutive paradigms of residential urban heritage spaces across varying regional conditions.

## 2.2. Terminology explanation

### 2.2.1. Space syntax: Deciphering the topological relationship system of urban spaces

Space syntax is a theoretical and methodological approach aimed at quantitatively describing the structure of human-

occupied spaces, spanning from architecture to settlements, cities, and landscapes. It delves into studying the intricate relationship between spatial organization and human society. First introduced in the 1970s by Bill Hillier and his colleagues at the University of London, the core concept of this theory is "Spatial Configuration," which refers to the topological logic between various spatial elements within a spatial system (Hillier & Julienne, 1984). Space syntax posits that the spatial topology of urban transportation networks significantly influences the operational dynamics and development of urban spaces by affecting the mobility patterns of space users. This methodology facilitates the exploration of the relationship between residential urban heritage spaces and residents' mobility behaviors, as well as their position and interrelations within the broader urban context. Consequently, it deepens our understanding of the topological significance of residential urban heritage spaces within cities.

### 2.2.2. Spatial entropy: Revealing the probabilistic composition of urban material structure spaces

Spatial entropy, a concept derived from information theory, is employed to quantify the levels of uncertainty and disorder within urban spatial structures (Tiesdell *et al.*, 1996). In the realm of urban planning, spatial entropy serves as a valuable tool for comprehending the distribution patterns of various elements within the city and their interrelationships. From an information-theoretical standpoint, high spatial entropy suggests a more dispersed and diverse distribution of elements within urban spaces, whereas low spatial entropy indicates a more concentrated and uniform distribution (Chen, 2012).

In urban planning, spatial entropy can be calculated by assessing the distribution ratios of specific types of spatial constituents within different spatial units, such as neighborhoods or building clusters. Specifically, the formula for information entropy can be employed to compute spatial entropy:

$$H(X_i) = -\sum p(x_i) \log p(x_i) \quad (1)$$

In this context,  $p(x_i)$  represents the distribution ratio of a particular type of spatial composition within a given spatial unit. By averaging the information entropy across all spatial units, we can obtain the entropy value for the overall space.

## 3. Research design

### 3.1. Case subjects

In constructing models for comparative research, we have selected Suzhou's Pingjiang District in Jiangsu, China, and Uji City in Kyoto Prefecture, Japan, as case studies (Figure 1C).

Gusu District boasts five World Cultural Heritage Sites, including Pingjiang Historic District, Shantang Street, Canglang Pavilion, Lion Grove Garden, and the Grand Canal, along with 174 cultural relic protection units. This study focused on the Pingjiang Historic District located in the northeastern corner of historic Suzhou, as illustrated in Figure 1A. The Pingjiang Historic District serves as the epicenter for the preservation of the historic city’s appearance. Spanning 2500 years, it has maintained a dual grid pattern characterized by “streets adjacent to waterways, roads parallel to rivers.” Preserving large-scale traditional Suzhou-style living scenes, it currently stands as China’s quintessential Residential Urban Heritage space, primarily serving residential functions.

Uji City boasts two World Cultural Heritage Sites: Byodo-in Phoenix Hall and Ujigami Shrine. The Nakauji Historic District, nestled in the core area of Uji City, is illustrated in Figure 1B. Serving as the core cultural heritage area of Uji City, the Nakauji Historic District embodies a city layout, architectural styles, and social

organization formed by the Phoenix Hall of Byodo-in and traditional living spaces known as “Machiya” from the Japanese Heian period. It has become a tourist hub pivoting around cultural relics and traditional living spaces.

The primary distinction between the two cities lies in their overall spatial topology and individual architectural structures. The Pingjiang Historic District is organized around Pingjiang Road, featuring a grid-like spatial structure comprising traditional Chinese courtyard houses interconnected by alleys. In contrast, the Nakauji Historic District radiates from the southwest side of Uji Bridge, distinguished by “Machiya” residences lining the main streets, serving both commercial and residential purposes. Through this comparison, our aim was to explore the characteristics and variations of residential urban heritage spaces under different spatial structures, focusing on street space and architectural composition. This approach enabled us to derive more comprehensive research findings.

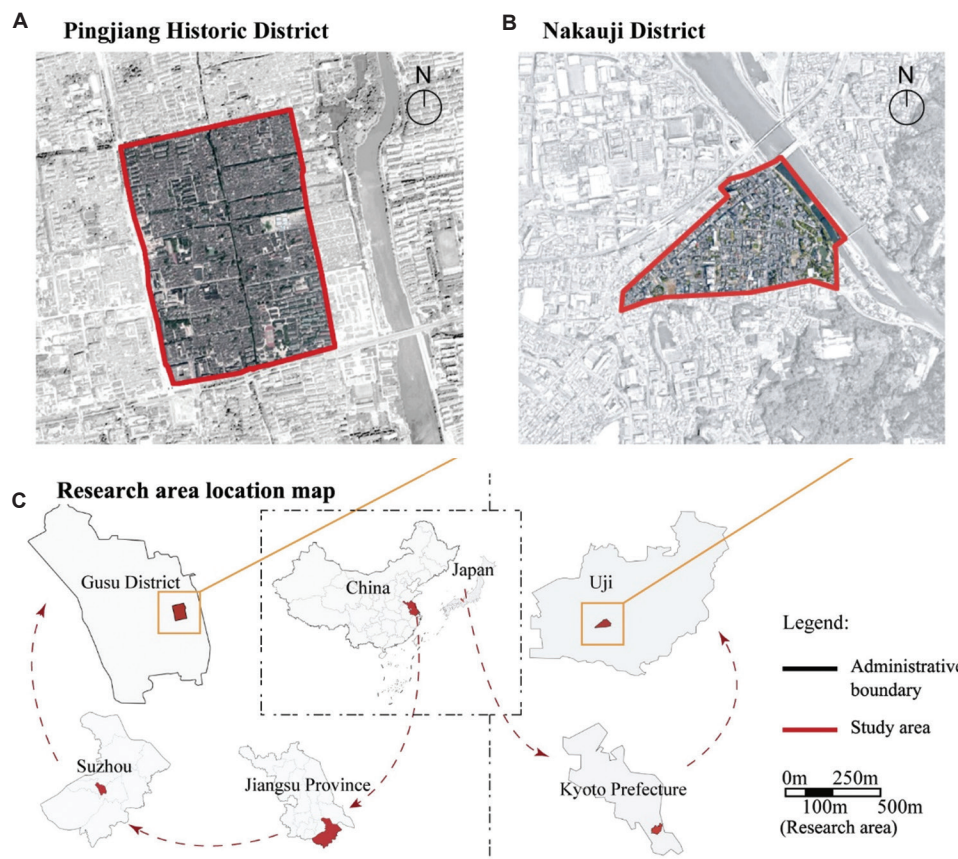


Figure 1. Research sites. (A) Location map of Pingjiang historic district. (B) Location map of Nakauji district. (C) World location map of the research area. Source: Drawings by the authors

### 3.2. Assessment indicators for residential urban heritage spaces

Drawing on research pertaining to urban spatial morphology and material spatial composition (Carmelino & Hanazato, 2019), this paper divides the structural paradigms of residential urban heritage spaces into two systems: the Spatial Topology Relationship System and the Spatial Material Structure System.

#### 3.2.1. Spatial Topological Relationship System

Grounded in graph theory, space syntax simplifies the complex urban road network by abstracting its elements into nodes and edges. By utilizing metrics such as distance and degree, each node (or axial line) is quantified to determine its spatial significance within the broader urban network (Hillier, 1996). Notably, the “Integration Index” stands out among these metrics. This index accounts for the connectivity between a node and all other nodes in the system, along with its role in path selection. It provides valuable insights into the key roads and primary material flow pathways within residential urban heritage spaces. The calculation method is as follows:

$$Int. (i) = w_1 D(i) + w_2 C(i) + w_3 H(i) \quad (II)$$

In this formula,  $i$  represents a specific node,  $D(i)$  represents the degree of connectivity for that node,  $C(i)$  represents the choice value, and  $H(i)$  represents the depth value. The weights  $w_1$ ,  $w_2$  and  $w_3$  control the influence of different factors in the integration index.

The analysis results of the Integration Index are influenced by the radius of human activity within the space. By setting the range of human activity for daily life circles (1000 m) and long-distance movement behavior (5000 m), the Integration Index is transformed into two dimensions: Local Centrality ( $Int.V_{R1000}$ ) and Global Centrality ( $Int.V_{R5000}$ ). By employing this approach, we can accurately locate and define the topological relationships within the heritage space, as well as the spatial topology of the overall area.

#### 3.2.2. Spatial Material Structure System

When conducting urban space analysis within the framework of the spatial material structure system, the following are the basic calculation formulas and brief definitions for these indicators:

(a) Architectural density entropy (ADE):

ADE is used to measure the concentration level of buildings within different spatial units, thereby reflecting the density of buildings. The calculation is as follows:

$$ADE(X_i) = -\sum pr(x_i) \log pr(x_i) \quad (III)$$

In this context,  $pr(x_i)$  represents the proportion of the number or area of buildings within a specific spatial unit.

(b) Spatial morphology entropy (SME):

SME considers key factors such as the area, perimeter, maximum width, and compactness of spatial units. The calculation is as follows:

$$SME(X_i) = -\sum_{j=1}^n \log(w_1 a_j + w_2 p_j + w_3 m_j + w_4 c_j) \quad (IV)$$

Here,  $n$  is the number of morphological features within that spatial unit,  $a_j$  represents the area of a specific spatial unit,  $p_j$  represents the perimeter,  $m_j$  represents the maximum width, and  $c_j$  represents the compactness of that spatial unit. The weights  $w_1$ ,  $w_2$ ,  $w_3$  control the influence of different factors in the SME.

(c) Function mixing entropy (FME):

FME serves as an indicator that reflects the functional diversity within a space by statistically analyzing the distribution of different types of urban points of interest (POIs) within each spatial unit. The calculation is as follows:

$$FME(X_i) = -\sum_{j=1}^n (pe_j) \cdot \log(pe_j) \quad (V)$$

Here,  $FME(X_i)$  represents the FME for a specific spatial unit  $X_i$ , and  $n$  is the number of different types of urban POIs. For each POI type  $j$ , its proportion  $pe_j$  within the spatial unit is calculated. This proportion is then multiplied by its logarithm, and the results for all POI types are summed to obtain the FME.

(d) Heritage space entropy (HE):

HE classifies each spatial unit based on specific attributes of the heritage space (such as historical significance and cultural value) and calculates the entropy value to assess the diversity and complexity of the heritage space. This process aids in identifying important historical and cultural areas. The calculation is as follows:

$$HE(X_i) = -\sum_{j=1}^n (h_j) \log(h_j) \quad (VI)$$

Here,  $HE(x_i)$  represents the HE of a specific spatial unit  $X_i$ , and  $n$  is the number of different heritage attributes.  $h_j$  denotes the proportion of each heritage attribute  $j$  within the spatial unit.

(e) Residential entropy (RE):

RE calculates the entropy based on the distribution of different residential uses within a spatial unit, thereby reflecting the diversity of residential areas and changes

in living patterns. The formula for calculating RE is as follows:

$$RE(X_i) = -\sum_{j=1}^n (r_j) \cdot \log(r_j) \quad (\text{VII})$$

Here,  $RE(X_i)$  represents the RE of a specific spatial unit  $X_i$ , and  $n$  is the number of different residential uses.  $r_j$  denotes the proportion of each residential use  $j$  within the spatial unit.

(f) Population density entropy (PDE):

PDE measures the diversity and degree of change in population distribution by analyzing the population distribution within spatial units. The formula for calculating PDE is as follows:

$$PDE(X_i) = -\sum_{j=1}^n (peo_j) \cdot \log(peo_j) \quad (\text{VIII})$$

Here,  $PDE(X_i)$  represents the PDE,  $n$  indicates different spatial units, and  $peo_j$  is the population density ratio within the  $i^{\text{th}}$  spatial unit.

### 3.3. Data sources and processing

In this study, we integrated the Spatial Topology System with the Material Structure System to delve deeply into the paradigm of residential urban heritage space composition. We employed a comprehensive approach, utilizing multiple data sources such as planning documents, urban road system data, multi-source online map data, and POI data for cross-validation.

In the Gusu District of Suzhou, we use Open Street Map data for the Gusu District Road system, multi-source online map data, and refer to the “Suzhou Historic and Cultural City Protection Special Plan (2035)” to spatially divide the research object – Pingjiang Historic District. We defined the research scope: north to Baita East Road, east to Cang Street, west to Lindun Road, and south to Ganjiang East Road. Based on the distribution of residential spaces, we divided it into 33 subsystems (Figure 2A).

The urban spatial data of Uji City mainly come from the “Topographic Map-Terrain Map History (2022)” and “Basic Map Information Main Project (2022)” GML data published by the Geospatial Information Authority of Japan. After field research, we clarified the distribution of residential urban spaces and heritage spaces in the Uji area of Uji City and determined the boundaries and analysis scales of the research objects based on residents’ travel methods, dividing the urban area of Uji City into 15 subsystems (Figure 2B).

Based on space syntax theory and graph theory, the urban road network systems of Uji City and Suzhou’s

Pingjiang District were transformed into Axial Maps to represent their topological relationships. This process serves as the foundation for subsequent analyses of the Spatial Topology System.

In addition, in this study, we utilized POI data from the Google API to analyze FME. This data was collected in 2022. To ensure the consistency and accuracy of the data, uniform data processing was carried out. Data analysis was conducted on the open-source geographic information system platform, QGIS 3.22. This platform is capable of processing, analyzing, editing, and visualizing geographic data. It features the Space Syntax Toolkit, which aids users in generating segment maps, conducting spatial topology analyses, managing geographic information, and executing data analysis operations. This toolkit serves as an invaluable resource for comprehensively understanding the spatial configurations and relationships within residential urban heritage spaces.

## 4. Analysis results of case studies

### 4.1. Analysis results

Building on the aforementioned analytical framework and data resources, we conducted a spatial syntactic and material structure analysis of the historical districts of Nakauji District and Pingjiang Historic District.

#### 4.1.1. Spatial syntactic analysis results

The performance of the research cases was analyzed in the following two dimensions: Life Integration ( $\text{Int.V}_{R1000}$ ) and Global Integration ( $\text{Int.V}_{R5000}$ ):

(a) Pingjiang Historic District

Figure 3A presents the analysis results for Life Integration. Pingjiang Road and its fishbone-like distribution of east-west branches (such as Daxin Bridge Lane, Xuan Bridge Lane, Daru Lane, and Xiao Family Lane) exhibit high local centrality due to their network-like layout, enhancing accessibility for external tourists. Conversely, areas with lower local centrality witness the east-west main streets gradually transitioning into primary entrances for residents, while complex, winding alleys become the most difficult areas for external tourists to access. Particularly, noteworthy is the eastern part of the site, where local centrality exhibits low values.

Figure 3B displays the analysis results for Global Integration. Pingjiang Road, along with its main intersecting roads, Ganjiang Road, and the secondary intersecting road, Lindun Road, become the areas with the highest global centrality. At the same time, Pingjiang Road, Cang Street, and Baita East Road also exhibit relatively high global centrality. However, within the Pingjiang

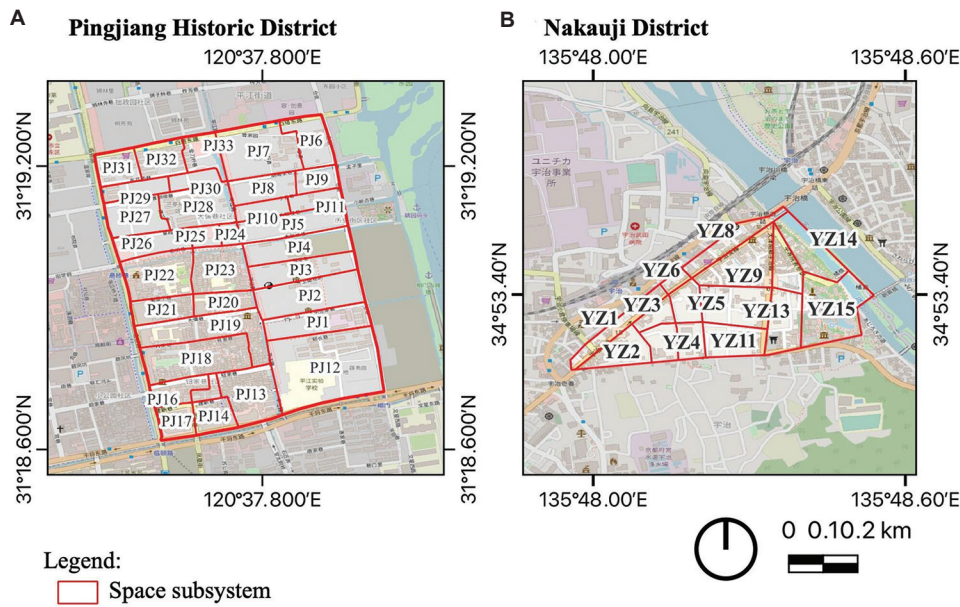


Figure 2. Spatial subsystem segmentation map of the research site. (A) Schematic diagram of spatial subsystems in Pingjiang historic district. (B) Schematic diagram of spatial subsystems in Nakauji district. Source: Drawings by the authors



Figure 3. Pingjiang historic district spatial topology analysis diagram. (A) Life integration (Int.V<sub>R1000</sub>) analysis map of Pingjiang historic district. (B) Global integration (Int.V<sub>R5000</sub>) analysis map of Pingjiang historic district. Source: Drawings by the authors

historic district, the accessibility of small alleys is relatively low, thus reducing their likelihood of being targeted by “destination traffic.”

(b) Nakauji District

Figure 4A depicts the analysis results for Life Integration, revealing that Uji Bridge Road and its north-south branches (such as Byodo-in Approach, Prefectural Road 3, and Prefectural Road 247) have become focal points for tourism owing to their radial layout. However, in the central and southern parts of the site, particularly on both sides of Honmachi Road, there are areas with low Life Integration values.

Figure 4B displays the analysis results for Global Integration, indicating that the main artery of Uji Bridge Road and the secondary artery of Prefectural Road 15 in Nakauji exhibit the highest levels of Global Integration. In addition, Prefectural Road 3 and Byodo-in Approach demonstrates high levels of Global Integration. Meanwhile, the accessibility of small lanes within the Nakauji District remains relatively low and poses a greater challenge for navigation.

(c) Spatial topological structure comparative analysis

Based on the above analysis, both areas demonstrate a trend of gradually decreasing centrality concerning Life Integration and Global Integration, in accordance with the hierarchy of roads. In both cases, low-centrality areas such as side streets and alleys constitute the primary living spaces for residents.

However, due to the grid-like spatial topology of the Pingjiang Road district, its centrality forms a fishbone-like structure composed of Pingjiang Road and its branches. Therefore, the spatial centrality of the Pingjiang Road district exhibits block-like distribution characteristics. Within each block, the distribution of centrality is relatively balanced, with blocks closer to the main thoroughfares displaying higher centrality, while those on the periphery exhibit lower centrality.

In contrast, the Nakauji district, characterized by its radial structure, forms a linear structure centered on the main thoroughfare – Byodo-in Front Approach. As a result, high global centrality is observed along both sides of the main road in Nakauji, gradually diminishing as the distance from the branching roads increases.

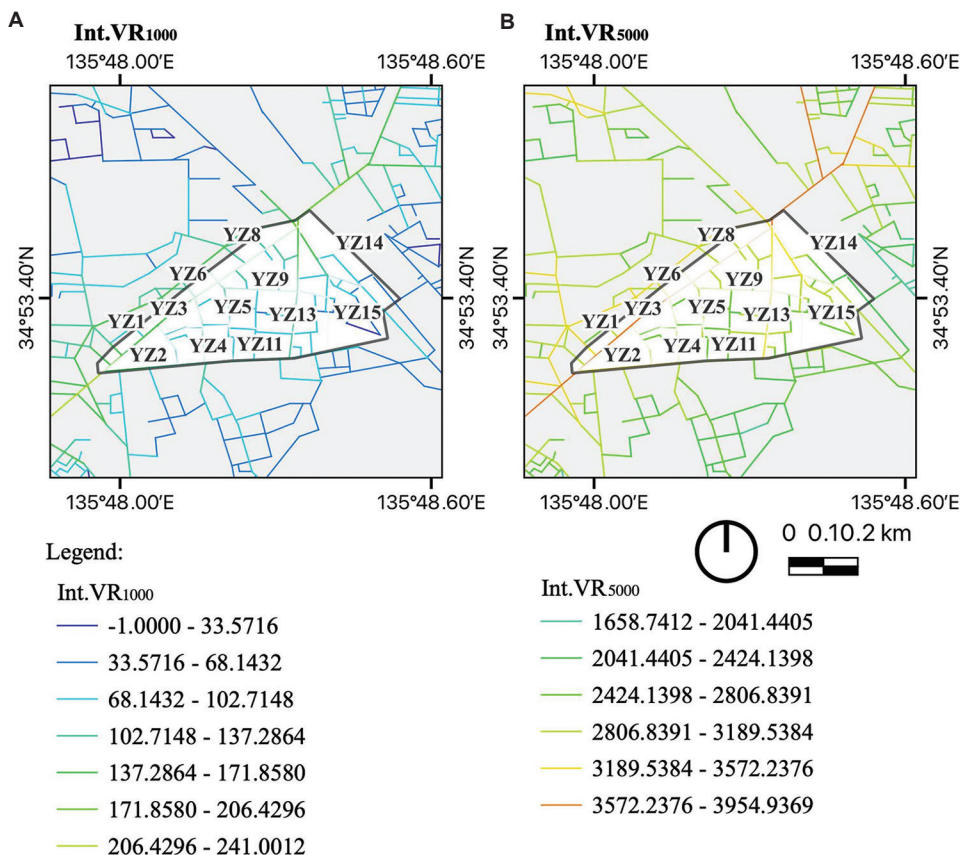


Figure 4. Nakauji district spatial topology analysis diagram. (A) Life integration analysis map of Nakauji district. (B) Global integration analysis map of Nakauji district. Source: Drawings by the authors

## 4.1.2. Spatial material structure analysis results

Combining the analysis of the Spatial Topology System, the observations for the two districts are as follows:

### (a) Pingjiang historic district

Figures 3A and B, along with Table 1, indicate a significant correlation between the Spatial Topology System and ADE within the Pingjiang Historic District. Specifically, the centrality of the road network in the Pingjiang Historic District influences its architectural distribution. Spatial subsystems such as PJ2, PJ17, and PJ29, which exhibit high ADE, are located in areas characterized by high Life Integration. In contrast, subsystems such as PJ1, PJ6, PJ8, and PJ9, which maintain traditional living spaces, demonstrate lower Life Integration. Overall, the distribution of ADE in the Pingjiang Historic District is minimally influenced by Global Integration, indicating that intrinsic spatial topology mainly governs its architectural distribution.

On the other hand, FME exhibits a robust negative correlation with RE. Subsystems such as PJ22, PJ26, PJ28, PJ29, and PJ32, characterized by high FME, are located on the western side of the east-west branching roads within the Pingjiang Road. These areas, such as the Nan Shishizi Lane, Xuanqiao Lane, Daru Lane, and Niuji Lane, demonstrate a lower FME and RE, indicating a more straightforward functional distribution and serving as primary living spaces for residents.

Moreover, a significant correlation is observed between SME, PDE, and HE. This observation suggests that in urban heritage spaces with high heritage value, more resources and efforts are invested in shaping the spatial morphology. Modern Spatial Structure Paradigms are gradually infiltrating these areas, increasing their level of complexity, and accommodating a diverse population.

### (b) Nakauji district

The analysis results for the Nakauji district in Uji City, as presented in Figure 4A and B, Table 1, reveal a negative correlation between road centrality and ADE, contrasting with Suzhou's Pingjiang Road. In areas with higher centrality values, such as the YZ09 area around Uji Bridge and the YZ14 area along the Uji River, ADE gradually increases toward the interior of the district. However, in areas with lower centrality in the southwest, such as YZ3, YZ4, and YZ5, ADE peaks. As it further approaches areas with higher centrality, such as YZ1 and YZ2, ADE exhibits a declining trend. Field research suggests that due to Japan's private land ownership system, land consolidation proves challenging. High-centrality core areas are often subdivided into smaller plots to accommodate diverse business formats and commercial buildings, resulting in uniformly distributed high-density, low-area building clusters.

Simultaneously, a significant negative correlation is observed between FME and ADE. Areas with higher FME exhibit evident commercial activity and significant diversity in business formats. For example, spatial subsystems ZY8, ZY9, and ZY12 along Uji Bridge Road and Byodo-in Approach demonstrate high FME. In contrast, residential areas connected by alleys, such as ZY7, ZY10, and ZY13, display lower FME.

Furthermore, a certain correlation exists between FME and both SME and PDE. In spatial subsystems with high FME such as ZY8, ZY9, and ZY12, a trend toward complex spatial morphology and population density distribution is observed. In contrast, areas such as ZY7, ZY14, and ZY15 with lower FME tend to exhibit more uniform spatial morphology and population density distribution.

The distribution of HE reveals that heritage resources in Nakauji are more concentrated compared to the Pingjiang Historic District. For instance, the area ZY15, where Byodo-in Phoenix Hall is located, significantly exhibits the highest heritage value. However, adjacent areas such as ZY8, ZY12, and ZY14 possess relatively lower heritage values, concentrating some important heritage residences and commercial facilities, receiving a certain level of protection and development. In contrast, residentially dominated spatial subsystems such as ZY10, ZY11, and ZY13 exhibit relatively lower HE. Although they possess some heritage value, they lack attention and protection, and residents' daily living spaces are alienated from the core district areas.

### (c) Spatial material structure comparative analysis

Both areas rely on spatial topology systems for material structure distribution. High-centrality areas exhibit high levels of functional mixing entropy, PDE, and HE, while low-centrality areas feature low ADE and functional mixing entropy. However, different spatial topological structures and individual building structures play varying roles in this process.

From the perspective of the impact of spatial topology, in the Pingjiang Historic District, Life Integration and Global Integration have distinct influences on spatial material distribution. Life Integration demonstrates a higher correlation with ADE, while Global Integration exhibits a positive correlation trend with functional mixing entropy. This observation suggests that the spatial material distribution in the Pingjiang Historic District is not solely influenced by external-to-internal permeation along high-centrality routes. The intersections of the internal grid pattern also form areas with higher spatial entropy. Internal and external forces create a "grid-like permeation" pattern through spatial topology, altering the district's spatial material composition. In contrast, in the Nakauji District,

Table 1. Spatial topology indices and spatial entropy of Pingjiang historic district and Nakauji district

Space subsystem	Spatial topological relationship index		Spatial material structure index					
	Int.VR <sub>1000</sub>	Int.VR <sub>5000</sub>	ADE	SME	FME	HE	RE	PDE
PJ1	275.4203	3422.6041	0.0689	5.7279	1.2286	0.9791	0.0000	5.7279
PJ2	300.2710	3497.5107	0.0424	6.8704	2.8219	1.5165	0.0000	6.8704
PJ3	293.3148	3423.6908	0.0515	6.5546	1.7610	1.3814	0.0000	6.5546
PJ4	337.1602	3446.8352	0.0463	5.1293	1.9143	0.5917	0.0000	5.1293
PJ5	316.3227	3454.8873	0.0400	6.7814	2.1868	1.1851	0.0000	6.7814
PJ6	237.9058	3226.9057	0.0633	6.1699	1.2886	1.1582	0.0000	6.1699
PJ7	288.7248	3190.5764	0.0479	6.8202	1.3758	1.1979	0.0000	6.8202
PJ8	334.3810	3386.3182	0.0674	6.0224	1.0530	0.8512	0.0000	6.0224
PJ9	214.6408	3127.0772	0.0956	5.1293	0.0000	0.9190	0.0000	5.1293
PJ10	345.9085	3388.2226	0.1188	5.2854	2.1710	0.7793	0.0000	5.2854
PJ11	263.4079	3385.9328	0.1035	5.4594	0.0000	1.0958	0.0000	5.4594
PJ12	272.3853	3545.7680	0.0290	6.7944	2.5208	1.1575	0.9985	6.7944
PJ13	304.6724	3499.6894	0.0760	5.7814	2.6915	1.2847	0.7889	5.7814
PJ14	385.2705	3733.0777	0.2206	3.7004	2.8606	0.9612	0.8905	3.7004
PJ15	330.0984	3407.5117	0.2137	3.9069	2.0000	0.8366	0.0000	3.9069
PJ16	347.5750	3522.0270	0.1302	4.7004	1.8608	0.7063	0.0000	4.7004
PJ17	503.7999	3975.1887	0.9285	0.0000	2.4871	0.0000	0.0000	0.0000
PJ18	277.8073	3278.9345	0.0392	6.8948	2.0904	1.0429	0.0000	6.8948
PJ19	261.9686	3312.6197	0.0488	6.3750	2.6806	1.4394	0.0000	6.3750
PJ20	304.7651	3407.1504	0.1239	4.7004	2.2557	1.5053	0.0000	4.7004
PJ21	329.9875	3462.6337	0.1128	5.3219	1.1568	1.6269	0.8813	5.3219
PJ22	259.8916	2526.1947	0.0646	5.5236	2.5908	1.3260	0.8590	5.5236
PJ23	338.8275	3432.7840	0.0525	6.4263	2.1867	0.8037	0.0000	6.4263
PJ24	361.9375	3329.1525	0.2543	3.7004	1.4591	1.1401	0.0000	3.7004
PJ25	309.7091	3119.9233	0.2170	3.8074	1.8464	1.2958	0.0000	3.8074
PJ26	370.5423	3344.7216	0.1115	5.3219	2.2473	1.3818	0.6098	5.3219
PJ27	369.9855	3283.0082	0.0953	5.2854	2.2494	0.7283	0.7321	5.2854
PJ28	319.8631	3140.0868	0.0572	5.8329	2.4817	1.2195	0.8043	5.8329
PJ29	394.9316	3365.6879	0.1571	5.0444	2.5528	1.5199	0.5328	5.0444
PJ30	343.4552	3302.4609	0.1541	5.0875	0.0000	0.7335	0.8740	5.0875
PJ31	429.5790	3479.1305	0.1223	4.5850	2.2751	0.7383	0.0000	4.5850
PJ32	344.7233	3300.6306	0.1318	4.3923	2.7639	1.4937	0.8631	4.3923
PJ33	339.9806	3284.9111	0.0993	4.7549	2.2576	0.8767	0.5033	4.7549
YZ1	143.5612	3469.6176	0.0397	5.5637	1.5482	0.1068	0.7698	5.2711
YZ2	141.0005	3330.1969	0.0471	5.3653	0.6495	0.0000	0.9059	5.6645
YZ3	117.5609	3021.4225	0.0927	4.0931	1.5482	0.0000	0.9128	4.5216
YZ4	98.8732	2873.2477	0.0779	4.5736	1.2459	0.0000	0.6500	4.4402
YZ5	114.4147	3003.2022	0.1190	5.0649	1.3456	0.0000	0.9012	5.3088
YZ6	142.5599	3410.3346	0.1530	3.7004	2.0239	0.0000	1.4313	3.7004
YZ7	111.9186	2954.4419	0.2032	3.7255	0.9837	0.0000	1.5033	3.7255
YZ8	139.9555	3387.5021	0.0512	5.6224	2.4752	0.9495	0.9379	5.3854

(Contd...)

Table 1. (Continued)

Space subsystem	Spatial topological relationship index		Spatial material structure index					
	Int.VR <sub>1000</sub>	Int.VR <sub>5000</sub>	ADE	SME	FME	HE	RE	PDE
YZ9	117.7827	3160.3264	0.0359	6.7167	2.3423	0.7737	0.9681	6.6892
YZ10	87.8204	2817.8822	0.0401	6.5057	0.4857	0.5946	0.7219	6.1996
YZ11	96.1079	2814.3358	0.0502	5.7796	0.9837	0.8061	0.8454	5.8043
YZ12	120.3480	3248.3679	0.0510	5.6561	2.7648	0.9951	0.8302	5.3034
YZ13	83.9771	2852.0998	0.0471	5.6668	1.6673	0.6124	0.9921	5.4651
YZ14	91.9263	3022.6343	0.0440	4.1699	0.9475	0.9911	1.4399	3.9477
YZ15	57.6069	2758.8220	0.0545	4.5744	0.0000	1.1853	1.3433	4.4104

Note: In the table, a value of “0.000” indicates that the feature attributes for the specified region are identical.

Abbreviations: ADE: Architectural density entropy; FME: Function mixing entropy; HE: Heritage space entropy; Int.VR<sub>1000</sub>: Life Integration; Int.VR<sub>5000</sub>: Global Integration; PDE: Population density entropy; RE: Residential entropy; SME: Spatial morphology entropy.

the difference in the impact of Life Integration and Global Integration on material structure is relatively small, mainly affecting the northeast-southwest axis of “Uji Bridge Road-Byodo-in Front Approach,” indicating a “unidirectional permeation” from the exterior to the interior with minimal internal impact and permeation.

Regarding the influence of individual building structures on material distribution, the traditional courtyards in the Pingjiang Historic District remain enclosed and are less likely to be developed into commercial spaces along the street. Their larger scale also implies that changes predominantly occur in a block-distributed manner within the site. In addition, the winding alleys between courtyards create a “resistance effect” to external resources, thereby stabilizing spatial entropy and preserving the authenticity and integrity of residential spaces. In the Nakauji District, the traditional Japanese “Machiya” buildings, with their front-shop-back-residence model, limit the availability of functional spaces for external capital. Material changes mainly occur along the main roads, thus maintaining the overall integrity and stability of population entropy and residential space entropy within the living spaces. However, larger “Machiya” are often subdivided to accommodate more businesses and achieve higher architectural returns, resulting in a more uniform distribution of high-density, low-area building clusters along the main roads, consequently reducing the ADE.

## 5. Identification, demarcation, and potential assessment model for residential urban heritage spaces

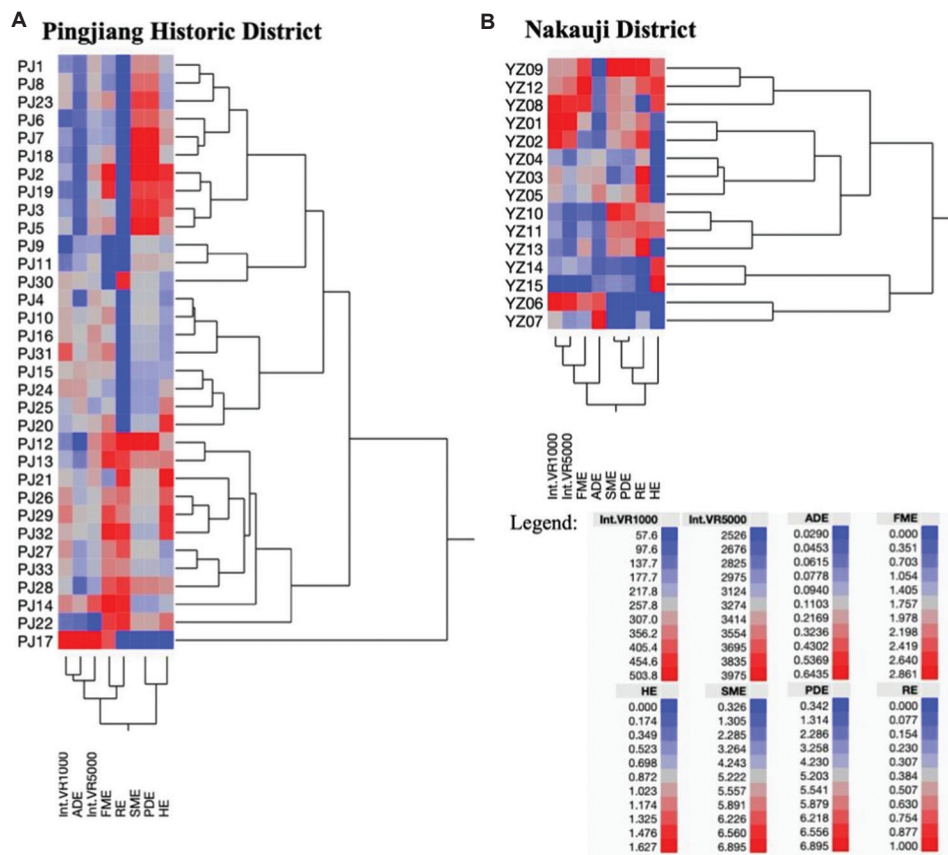
### 5.1. Identification and assessment of residential urban heritage spaces

When studying the identification and potential determination of residential urban heritage spaces, it is

crucial to accurately categorize spaces to understand their composition and value. To achieve this goal, this study proposes a classification model based on spatial clustering methods, combined with dendrogram and cubic clustering criterion analysis. This approach enables the division of the residential urban heritage spaces of Suzhou’s Pingjiang Historic District and Uji City’s Nakauji District into seven different categories. Through this classification model, the historical value of different areas can be clearly identified, thereby providing more accurate theoretical support for the in-depth protection and value excavation of residential urban heritage spaces.

During the analysis, spatial topology indicators such as Life Integration and Global Integration are combined with spatial material structure indicators, including ADE, SME, FME, HE, RE, and PDE. The aim is to perform spatial clustering on the sub-spaces within the study area, emphasizing architectural cluster zones and focusing on both the material flow structure and material distribution structure of heritage spaces. The clustering results are depicted in Figure 5A and B.

Based on the cluster distance tree of spatial subsystems within the research area and the application of the cubic clustering criterion, combined with on-site survey data and expert assessments, three modern commercial areas (PJ14, PJ17, and PJ22) located in the Pingjiang Historic District were excluded from further consideration. Subsequently, the heritage spaces were divided into seven categories to facilitate the potential assessment of residential heritage spaces. These categories take into consideration various aspects, such as current regional status, development status, and heritage potential. They encompass the Core Historical Heritage Preservation Area, Core Historical Heritage Development and Commercial Integration Zone, Residential Historical Heritage Potential Zone,



**Figure 5.** Hierarchical clustering analysis of spatial topology and spatial entropy in the research sites. (A) Hierarchical cluster distance tree of spatial topology structure and spatial entropy in Pingjiang historic district. (B) Hierarchical cluster distance tree of spatial topology structure and spatial entropy in Nakauji district. Source: Drawing by the authors

Historical Heritage Development Imbalance Zone, Peripheral Commercial Zone Adjacent to Historical Heritage, Residential Development Zone Adjacent to Historical Heritage, and Modern Commercial Zone. The characteristics of each category are shown in Table 2.

### 5.2. Demarcation and classification of residential urban heritage spaces

After categorizing the data from the model evaluation, importing it into QGIS 3.22 will yield the residential urban heritage space classification maps, as depicted in Figure 6A and B. Based on the demarcation of different areas on the map, targeted development and protection strategies can be applied to the residential urban heritage spaces in both locations.

As presented in Figure 6A and B, areas exhibiting relatively lower levels of Life Integration and Global Integration, alongside decreased ADE, typically display moderate SME and lower FME. This observation reflects that residential urban heritage spaces, characterized by diverse architectural forms, are functionally oriented to

cater to residents' various living needs. Consequently, the value of residential urban heritage in these areas is relatively high. In contrast, areas featuring enhanced centrality and reduced ADE often undergo large-scale modern development of traditional living spaces.

## 6. Comparative analysis and discussion of residential heritage space paradigms in China and Japan

### 6.1. Analysis of the spatial paradigm of residential heritage spaces in the Pingjiang historic district

Figure 6A illustrates the significant spatial paradigm changes occurring within the Pingjiang Historic District, largely influenced by Global Integration, representing external factors. Along the north-south sides of the site, particularly the western side proximate to the main external roads, commercialization and touristification have spurred the introduction of modern commercial and residential developments within the residential heritage spaces. These developments have imparted a negative impact on the overall

Table 2. Classification and characteristics of residential urban heritage district space

Area name	Current development status	Potential	Characteristics	Nakauji district	Pingjiang historic district
Core historical heritage preservation area	Not developable	High	This is the core area, carrying extremely valuable historical and cultural heritage. Strict protection is needed to ensure the integrity and sustainability of cultural heritage resources.	ZY14, ZY15	-
Core historical heritage development and commercial integration zone	Fully developed	Low	Adjacent to the core historical and cultural heritage area, this area has achieved a fusion of residential and commercial attributes. The commercial potential of the heritage has been developed, forming a vibrant area.	ZY8, ZY9, ZY12	PJ1, PJ2, PJ3, PJ5, PJ6, PJ7, PJ8, PJ18, PJ19, PJ23
Residential historical heritage potential zone	Protection Needed	High	Primarily residential in nature. Retains traditional living environments and characteristics, with the potential for full development in the future.	ZY10, ZY11, ZY13	PJ9, PJ11, PJ30
Historical heritage development imbalance zone	Overdeveloped	Low	Located around the historical heritage, covering both residential and commercial functions. Modern development has occurred, but activities are not strictly controlled.	ZY6, ZY7	PJ15, PJ20, PJ24, PJ25
Peripheral commercial zone adjacent to historical heritage	Development-protection balance achieved	Middle	Develops commercial activities around the historical heritage area while ensuring the preservation of the area's characteristics. Business and heritage mutually promote each other.	ZY1, ZY2	PJ12, PJ13, PJ21, PJ26, PJ27, PJ28, PJ29, P32, PJ33
Residential development zone adjacent to historical heritage	Development-protection balance achieved	Middle	Built around the historical heritage area and mainly used for residential purposes. Provides a modern living environment while preserving the area's characteristics.	ZY3, ZY4, ZY5	PJ4, PJ10, PJ16, PJ31
Modern commercial district	Overdeveloped	Low	Mainly consists of modern commercial buildings.	-	PJ14, PJ17, PJ22

Note: In the table, a dash (“-”) indicates that the category is not applicable to the specified region.

spatial character, creating areas characterized by heritage development imbalances (e.g., PJ15, PJ13, and PJ25).

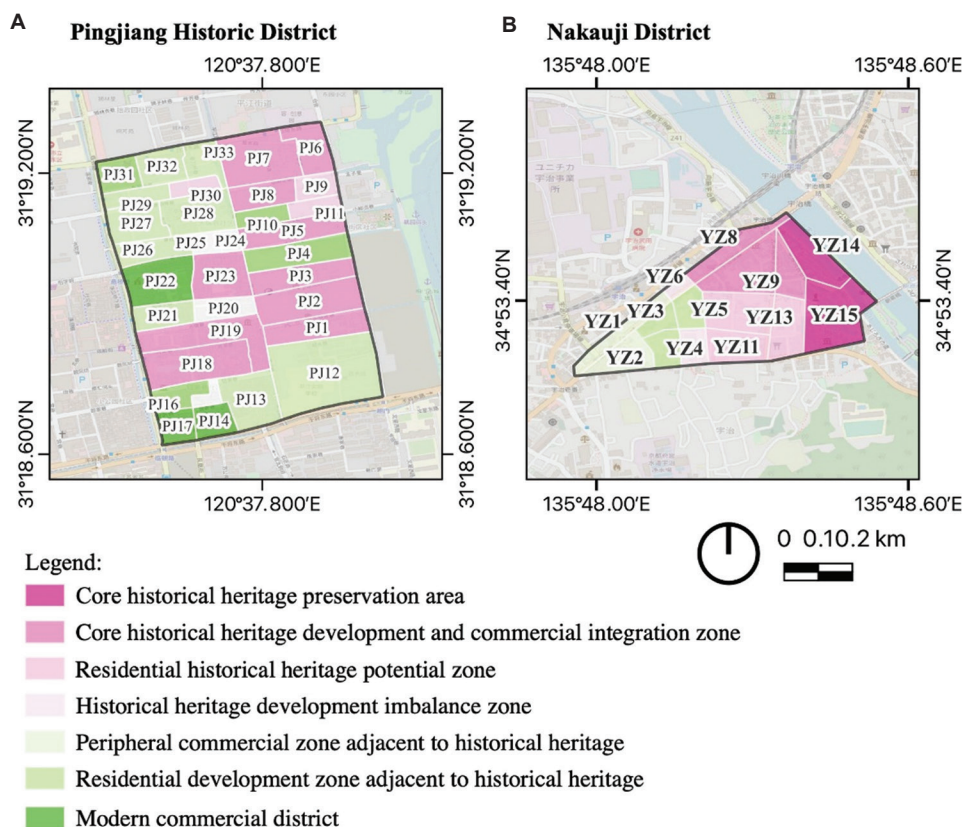
Simultaneously, due to its grid-like spatial topology, the intersections of internal and external roads form high-centrality points. Changes in these areas have facilitated the infiltration of modern urban spatial characteristics, thereby transforming the traditional residential historic district. This transformation is notably evidenced by escalated spatial density entropy and spatial form entropy along the Pingjiang Road, propelling its transformation into a contemporary urban historic commercial district or areas harmonizing heritage development with commerce (e.g., PJ23, PJ2, and J19).

On the other hand, the presence of enclosed courtyards and winding alleyways engenders a certain “resistance” effect. In areas characterized by lower levels of Life Integration and Global Integration (e.g., PJ9 and PJ11), these features have preserved the residential spaces

and living habits of the local populace. These areas reflect entrenched residential patterns perpetuated over centuries among the local residents, boasting high heritage conservation value and delineating zones with potential for residential heritage preservation.

## 6.2. Analysis of the spatial paradigm of residential heritage spaces in the Nakauji District

Figure 6B illustrates the Nakauji Historic District as a linear fusion center amalgamating commerce and culture along the “Uji Station-Uji Bridge Road-Byodo-in Approach-Byodo-in’s Phoenix Hall” axis. This configuration elevates the degree of spatial functional mix, resulting in heightened levels of PDE and spatial form entropy. Consequently, the material structure of the space tends toward increased complexity, creating zones characterized by historical heritage integrated with commercial development (e.g., ZY8, ZY9, and ZY12). Simultaneously, the inner perimeters of the commercial streets’ “Machiya” and areas featuring



**Figure 6.** Comparative classification map of residential heritage spaces in the research sites. (A) Residential heritage space assessment classification map of Pingjiang historic district. (B) Residential heritage space assessment classification map of Nakauji district. Source: Drawings by the authors

diminished accessibility (e.g., ZY10, ZY11, and ZY13) preserve zones with potential for residential heritage conservation.

On the other hand, the resource agglomeration effect, spurred by historical heritage, has empowered certain enterprises to consolidate land and acquire construction capabilities for the entire area. This phenomenon has precipitated the formation of modern commercial and residential districts encircling the core area of World Heritage protection (e.g., ZY3, ZY4, and ZY5). Consequently, the traditional Japanese residential spatial paradigms inherited from the Edo period have been replaced by the latest high-end apartments and shops within these plots (e.g., ZY6 and ZY7), thereby engendering zones characterized by imbalanced historical heritage development, thus adversely affecting the overall spatial character.

### 6.3. Case comparative compare analysis

In the analysis of the two case studies, we observed that spatial topology and architectural structure exert significant influence on the material composition of

residential urban heritage spaces. External forces penetrate the site along paths characterized by higher centrality, thereby introducing modern spatial paradigms. In the case of Pingjiang Road Historic District, its grid-like spatial structure creates areas of elevated centrality within the site itself. Changes occurring within internal spaces synergize with external forces, collectively altering the material composition of the space. This change frequently manifests as block-by-block spatial transformation, influenced by the scale and form of traditional courtyards.

In contrast, the development of the Nakauji Historic District is externally driven, influenced by a strong destination pull (Byodo-in’s Phoenix Hall). The transformation unfolds along major transportation routes, representing a form of spatial change that radiates from the external periphery inward.

Moreover, both sites employ distinct mechanisms to resist the intrusion of external forces based on their respective spatial and architectural structures. Within the Pingjiang Road Historic District, the “resistance” is primarily generated by the morphology of streets and alleys, which protects the deeper residential urban heritage

spaces. Conversely, within the Nakauji Historic District, the spatial configuration of traditional commercial buildings, known as “Machiya,” limits the expansion of commercial capital, thereby safeguarding the internal residential urban heritage spaces.

## 7. Conclusion and outlook

Grounded in space syntax and spatial entropy theories, this study constructs an analytical model for residential urban heritage spaces, encompassing spatial topology and material structure systems. The model delineates the intrinsic compositional logic of residential urban heritage spaces across multiple dimensions – ranging from the life centrality and global centrality of streets to population distribution, building density, and spatial morphology – and assesses and categorizes the value of residential heritage.

The findings indicate that the renewal and touristification of historic districts primarily follow streets characterized by higher life centrality and global centrality. This dynamism changes the structure of residential heritage spaces in terms of business operations, functional layout, and architectural forms, leading to the aggregation of a diverse population and the outward migration of residential spaces. The pathways of these spatial paradigm shifts are mainly influenced by spatial topological relationships. However, whether it pertains to the expansion of consumer services or the functional layout related to residents’ lives, substantive changes seldom penetrate the inner parts of the district. This phenomenon is primarily attributable to the “resistance” effect exerted by street and alley spaces, coupled with the limitations imposed by architectural forms on commercial spaces, which collectively protect the integrity and authenticity of the internal spaces. Therefore, the preservation of alley spaces and the regulation of the forms and types of businesses along the streets emerge as effective measures for protecting internal residential spaces.

Within the context of grand narratives surrounding historic districts, a focus on the daily lives and living spaces of local residents, alongside the protection of their immediate interests, emerges as the foundation for the sustainable development of residential urban heritage spaces. Future research will further refine this model, thereby enhancing its efficacy on guiding the conservation and development of residential urban heritage spaces.

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## Conflict of interest

The authors declare that they have no competing interests.

## Author contributions

*Conceptualization:* Yukun He, Xiao Han

*Formal analysis:* Yukun He

*Investigation:* All authors

*Methodology:* Yukun He

*Writing – original draft:* Yukun He

*Writing – review & editing:* All authors

## Ethics approval and consent to participate

Not applicable.

## Consent for publication

Not applicable.

## Availability of data

The spatial data for Uji City can be obtained from the Japan Geospatial Information Authority, which is publicly accessible via their official website: <https://www.gsi.go.jp>. Data concerning Suzhou City can be obtained from the Suzhou Housing and Urban-Rural Development Bureau, available on their official website: <https://www.suzhouhui.com/point/2898.html>. Point of Interest (POI) data was gathered using Google Cloud APIs, details of which can be found on the Google Cloud website: <https://cloud.google.com/apis>. Some of the base maps used in this study can be sourced from OpenStreetMap: <https://www.openstreetmap.org>.

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## ORIGINAL ARTICLE

## An analysis of the development path of ethnic villages under the protection of traditional Jiarong culture

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## Abstract

Most of the villages in the north-west ethnic areas of Sichuan are located within a culturally rich zone. However, during the process of village modernization, the protection and inheritance of traditional culture are often overlooked. This study has investigated the construction techniques and spatial components of traditional villages in Lixian, Sichuan Province, from the perspective of cultural inheritance. It analyzes and synthesizes representative design language and proposes a design concept that combines spatial perspective and cultural inheritance to conduct research on design paths aimed at strengthening functional positioning, optimizing spatial layout, improving village style, and improving infrastructure. The objective is to establish a research path to maintain the village-style during post-disaster process reconstruction and village development, thus protecting the unique local architectural culture and achieving comprehensive village development. In addition, we explored issues such as the lack of architectural style and the lagging development of human settlements, aiming to promote rural revitalization and integrated urban-rural development in this area.

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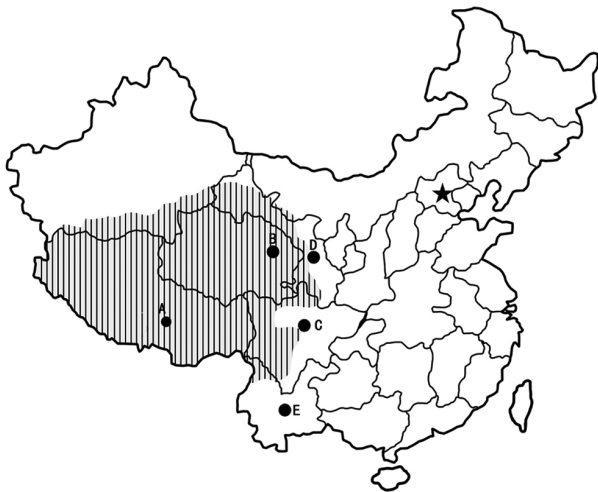
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**Keywords:** Ethnic village; Design path; Sustainable development; Rural revitalization; Protection of traditional culture

## 1. Introduction

Sichuan harbors the second-largest Tibetan population in China, mainly concentrated in the transition zone between the first and second steps of the Tibetan Plateau and the Sichuan Basin, as well as the Hengduan Mountain area along the upper reaches of the Minjiang River (Ren *et al.*, 2022; Wang *et al.*, 2022) (Figure 1). The Hengduan Mountain area exhibits significant cultural diversity, distinguishing itself as one of the most culturally varied regions in China (Li, 2012). Within the hinterlands of the Hengduan Mountain area in western Sichuan province lies an important branch of the Tibetan group — the Jiarong Tibetan (Figure 2). Tibetan culture stands out from other ethnic groups through various facets, such as vibrant festival activities, distinctive ethnic costumes, and



**Figure 1.** Tibetan area in China. The area is represented by the shade on the map. The star symbol represents Beijing. (A) Lahsa. (B) Xining. (C) Chengdu. (D) Lanzhou. (E) Kunming. Source: Drawing by the authors



**Figure 2.** Jiarong Tibetan area. The area is represented by the shade on the map. (A) Daofu. (B) Jinchuan. (C) Barkam. (D) Heishui. (E) Lixian. (F) Wenchuan. (G) Baoxin. (H) Tianquan. (I) Kangding. (J) Danba. (K) Xiaojin. (L) Muli. Source: Drawing by the authors

unique residential buildings (Li & Chen, 2012). Notably, the construction skills of Jiarong Tibetan Diaolou have been inscribed on China’s National Intangible Heritage List (Liu *et al.*, 2020), while Tibetan-Qiang Diaolou and Village have been included in the preliminary list of World Heritage sites. Different ethnic groups in the region engage in communication, influence, and cultural exchanges while simultaneously maintaining their distinct characteristics, thereby forming a unique ethnic corridor on the Chinese cultural landscape. This area also constitutes the core area

of the “Tibetan-Yi Corridor” proposed by Xiaoton Fei (Gao & He, 2010) (Figure 3).

Research on Tibetan traditional villages and dwellings has seen continuous development, progressing from basic data mapping and integration of construction technology to spatial exploration. Various research methods have been employed, encompassing multiple aspects such as typology, geography, and culturology. Internationally, notable studies include one by Strauss *et al.* (2023), which investigated the sustainable management of agricultural soil in Germany. Their results indicated that structural landscape elements, organic fertilization, and conservation tillage, as well as local government control of land sales and growth and regulation of the rural land market, ensure the sustainable development of land supply within appropriate areas. Similarly, Borri & Corradi (2019) studied the preservation and conservation of Italian building guidelines for interventions of cultural heritage, particularly in the Umbria region in Italy following the 2016 Central Italy earthquake. Their study aimed to evaluate structural engineers’ and conservators’ perspectives to inform preservation efforts. Professor Yasushi Kamikitake of the University of Tsukuba conducted a survey on traditional building groups, considering the surrounding environment as a whole. He delimited “traditional building groups with historical features,” including the historical building itself and other environmental elements that constitute historical scenes, which were incorporated into the protection of traditional building groups. This approach facilitated unified restoration and maintenance to highlight the authenticity of traditional building groups within the village, creating a sense of wholeness in the space.

Domestically, Li (2012) examined the architectural and cultural aspects of the Tibetan region, proposing principles and ideas for the development of traditional Tibetan residences. Dong & Jin (2012) focused on wood-frame buildings in Shangri-La, studying aspects such as siting, layout, and façade structure of traditional rural dwellings. Their aim was to study adaptive design strategies for eco-friendly rural dwellings tailored to local conditions, thereby promoting sustainable development in Tibetan rural areas. Qu *et al.* (2019) discussed the impact of tourism development on the protection of local cultural inheritance. They explored how residents in Tibetan areas of Sichuan province sometimes sacrifice their own culture to integrate into tourism development and modern society. Hou *et al.* (2021) investigated and analyzed the unique texture and stone-built process of exterior walls in traditional villages of the Jiarong Tibetan area. Their findings provided techniques and methods for the preservation and inheritance of traditional



**Figure 3.** The Tibetan-Yi Corridor area. The area is represented by the shade on the map. (A) Lahsa. (B) Chamdo. (C) Xining. (D) Lanzhou. (E) Xi'an. (F) Chengdu. (G) Kangding. (H) Xichang. (I) Kunming. (a) Salween (Nu River). (b) Lancang River. (c) Jinsha River. (d) Yalong River. (e) Dadu River. (f) Nin River. (g) Yangtze River. Source: Drawing by the authors

architectural texture culture. In general, these studies hold far-reaching significance for exploring the underlying structures of Tibetan traditional villages and dwellings. However, comprehensive and systematic studies on village development and traditional culture protection in western Sichuan ethnic areas, especially in the Jiarong Tibetan area, are still lacking. Specifically, there is a dearth of systematic research guidance and practical experience on how to maintain distinctive features in village construction. As rural revitalization and urban-rural integration gradually progress, and with an increasing emphasis on ethnic unity, there is a need to explore new paths to modernize ethnic areas while respecting and inheriting traditional culture.

Since 2019, our team has been actively involved in the new round of planning and design of Guantian Village, located in Li County, Aba Prefecture. This initiative coincided with the new round of urban-rural overall planning in Li County, which necessitated adjustments in certain industries to align with changes in urban functions and population dynamics. Consequently, new requirements emerged for land use, infrastructure, and cultural expression within Guantian Village. Drawing on field investigations of villages, as well as the sorting of basic data, our approach incorporated expert interviews and questionnaires to glean insights into the villagers' aspirations regarding spatial functionality and architectural characteristics. In particular, considerable emphasis was placed on meeting the design demands associated

with the burgeoning e-commerce industry oriented by characteristic agricultural products and the tourism industry oriented by characteristic culture. Building on the village's existing spatial pattern with the monastery as its focal point, our design scheme meticulously identified core landscape elements and conducted comparative studies of other villages and buildings within the same cultural milieu. This exploration facilitated the development of a locally relevant architectural design language. In the first phase of the project, we concentrated on pilot testing style coordination around the residential buildings surrounding Baodian Temple. Tailoring our approach to the unique circumstances of each building, we proposed various building optimization strategies, which ranged from architectural decoration materials to color matching, with innovative optimization schemes introduced. Residents were actively engaged in the renovation design and construction process, garnering positive social feedback and serving as a case reference for establishing similar village design research systems in the future.

## 2. Analysis of background and current situation

The urban-rural relationship and rural transformation represent an important category of political economy research. Changes in rural production relations reflect the development of productive forces, and the current rural problems in China serve as a concentrated reflection of the evolution of urban-rural relations. This study aims to address how to facilitate the circulation of urban and rural elements while inheriting local culture, an important aspect of our investigation. Tibetan inhabited areas often contend with challenging natural conditions, and their unique cultural expressions are particularly susceptible to influences — both natural or artificial — during the development process. The Jiarong Tibetan population, as an important branch of the Tibetan community, boasts important characteristics in its architectural culture. Our study focuses on villages and buildings within the core area of Jiarong Tibetan territory. Leveraging the opportunities presented by rural revitalization and the inheritance of traditional national culture, we aim to delineate the developmental trajectory of these villages. Ultimately, our goal is to promote the protection and inheritance of villages and buildings in other Tibetan areas.

Given the unique natural conditions of the Jiarong Tibetan area, settlements in this area prioritize the integration of natural features such as mountains and rivers into their planning. The rugged terrain, characterized by abundant mountains and limited arable land, has shaped the distinct site selection, building layout, structural

characteristics, and choice of construction materials. For example, mindful of preserving arable land for farming, Tibetan communities have traditionally constructed their houses on mountain slopes using locally sourced materials. This strategic positioning not only shields against winter winds but also maximizes exposure to sunlight, ensuring adequate warmth for inhabitants (Figure 4).

The majority of residences in this area are built as Diaolou, featuring stone and wood structures that represent a dignified and stable appearance with a rugged aesthetic. These residential buildings typically feature flat roofs in the Tibetan style, adorned with decorative eaves and corners, characterized by simple shapes (Yu, 2019). Moreover, rooted in the longstanding traditions of living and production practices, local beliefs in the natural order of heaven and earth, and reverence for the Earth God have imbued traditional dwellings in this area with distinct religious significance. Architectural decorations often include intricate religious motifs painted and carved onto walls, doors, windows, and roofs (Fu *et al.*, 2022; Zhang & Luo, 2020). The decoration style of Jiarong Tibetan residential houses not only inherits the essence of Jiarong culture but also fosters the integration and development of craftsmanship. Vernacular houses incorporate various factors in their color selection, resulting in the rich and vibrant color system characteristic of Tibet architecture after centuries of development (Fu *et al.*, 2022). Preference is given to colors that offer strong and honest contrasts. Common colors used in architectural decoration include white, signifying warmth, kindness, and good manners (Zhang & Luo, 2020); yellow, representing Buddha, respect, and nobility, introduced with the advent of Buddhism (China Architecture & Building Press, 2016); red, symbolizing solemnity, power, and honor, with connotations of protecting the law; and black, evoking majesty and serving to ward off evil. Dark blue and pure white

decorative patterns adorn eaves, doors, and windows, while white stones are often placed at the four corners of the roof (Zeng, 2011) (Figure 5). Painted murals also hold special significance, featuring religious symbols such as the religious Vakra and Victory Umbrella, Swastikas associated with fire and sun worship, and patterns on door and window frames related to totems. These murals not only reflect the aesthetic preferences and values of the local populace but also represent their pursuit and vision (Ling, 2020).

Located at the gateway of the Tibetan-Qiang Ecological Civilization Corridor, Lixian in Sichuan province serves as a pivotal border area bridging the rich cultural heritage of the south-west ethnic minorities and the Central Plains culture. The county town of Zagunao boasts a profound historical precipitation, with evidence of human inhabitation dating back to the Neolithic age. Remarkably, numerous relics have endured through the ages, including the historical Chama Road (Figure 6), the Tang dynasty (618 – 907) ruins of Weizhou town (Figure 7), and the Diaolou of Zagunao (Figure 8). These treasures represent invaluable cultural and historical assets of the town (Sichuan Nationalities Press, 1997).

Guantian Village occupies a terrace approximately 5 km from the outskirts of Zagunao Town (Figure 9), characterized by a village structure of a typical monastery setting (Figure 10). Established around the Tibetan Buddhist Gelug temple in 1653, the village's layout was designed in close proximity to the temple. Notably, the northern side of the temple features a structure inspired by the Nepalese Xiarengeqing Gold Tower, known as the Jixiangyongcun Tower (Figure 11) (Song, 2011). Despite the pagoda's damaged state, the entire religious complex and its remnants retain significant cultural tourism value.

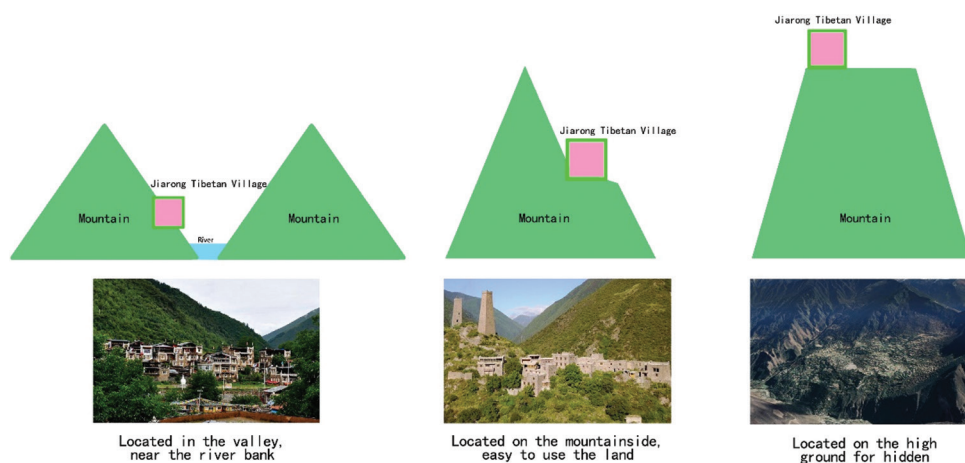


Figure 4. Common site selection of the Jiarong Tibetan villages. Source: Drawings by the authors



Figure 5. The general appearance of Jiarong Tibetan buildings. Source: Photos by the authors

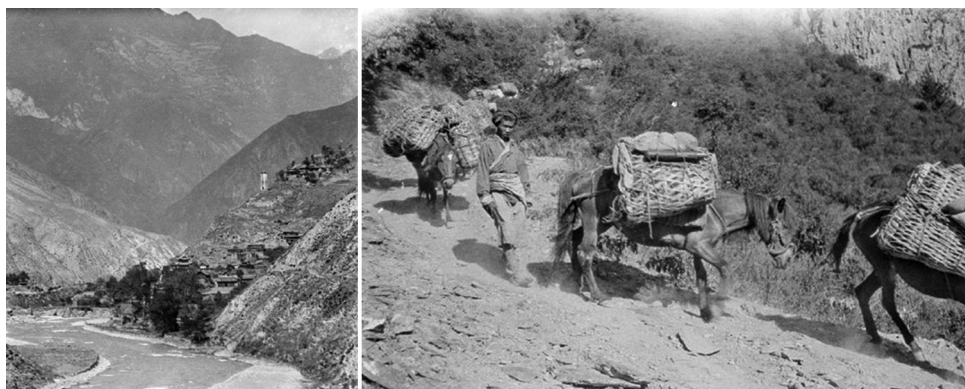


Figure 6. The ancient Chama Road. Source: Photos from the website: [https://k.sina.com.cn/article\\_6896501755\\_p19b1043fb0010011ab.html#p=11](https://k.sina.com.cn/article_6896501755_p19b1043fb0010011ab.html#p=11)



Figure 7. The ruins of the Weizhou town in the Tang dynasty (618 – 907). Source: Photos by the authors

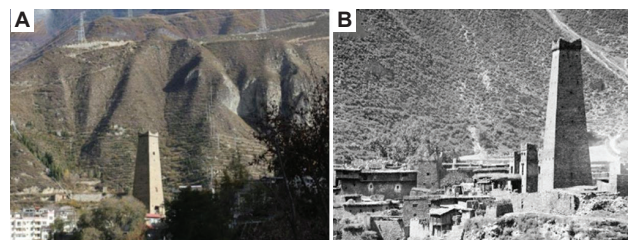


Figure 8. The Diaolou of Zagunao. Source: (A) Photo by the authors; (B) Photo from the website: [https://k.sina.com.cn/article\\_6896501755\\_p19b1043fb0010011ab.html#p=11](https://k.sina.com.cn/article_6896501755_p19b1043fb0010011ab.html#p=11)

### 3. Materials and methods

#### 3.1. Sample selection

Recognizing the significant impact of the village core area as a model, Baodian Temple was selected as the focal point of the village, with surrounding residential buildings undergoing renovation as part of a pilot project (Figure 12). Positive feedback from these design interventions was used to promote overall awareness and encourage resident participation in achieving style optimization. To address

the inherent challenge of balancing the architectural style of residential buildings with the practical needs of villagers while simultaneously protecting and inheriting the traditional Tibetan culture of Jiarong, the project selected building A-28 as the first transformation sample. This building was chosen due to its exemplification of common issues found in residential buildings in the region, such as excessively modern structural elements, unconventional forms, and unauthorized constructions such as colored steel sheds (Figure 13).

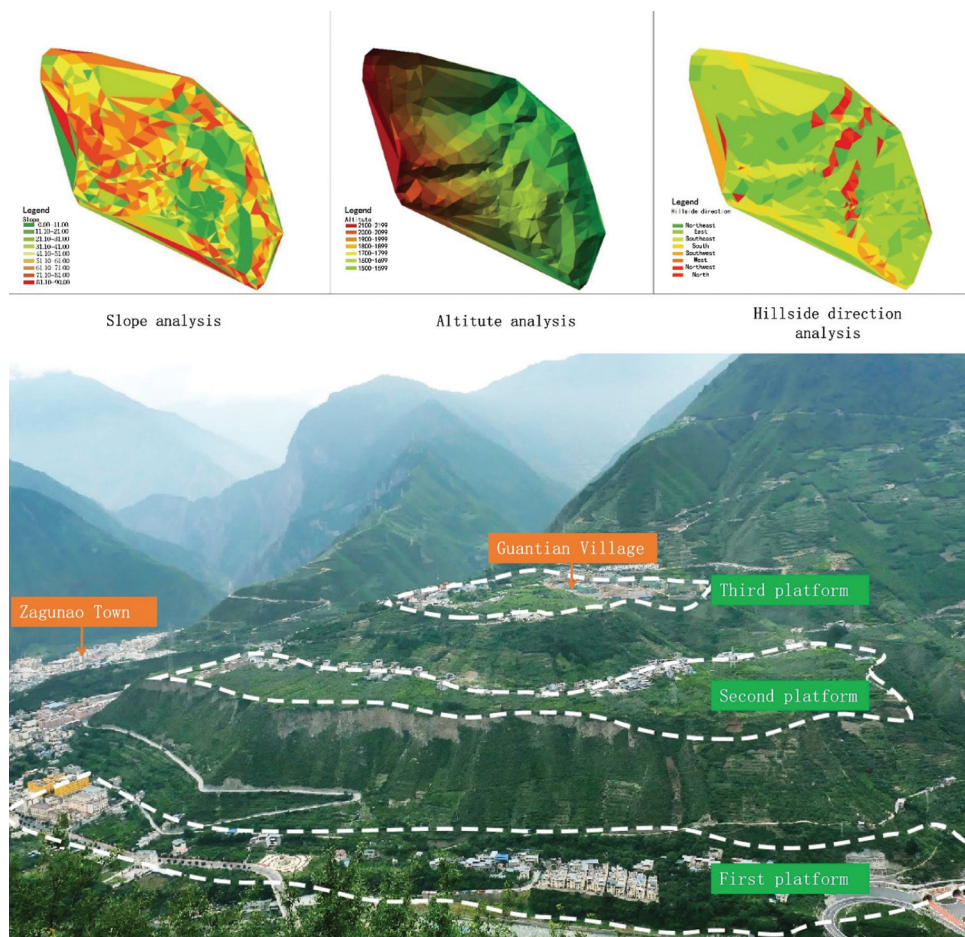


Figure 9. Geomorphologic status of Guantian Village. Source: Drawing by the authors



Figure 10. The spatial structure of Guantian Village. Source: Photos by the authors

### 3.2. Research method

In this study, the original research data were derived from comprehensive sources, including fieldwork, building surveys, literature reviews, archival research, and expert

interviews. We distributed approximately 80 questionnaires to gather additional insights. Our evaluation of buildings primarily focused on architectural integrity, the incorporation of traditional architectural elements, spatial



Figure 11. Jixiangyongcun Tower. Source: Photo from the website: [https://k.sina.com.cn/article\\_6896501755\\_p19b1043fb0010011ab.html#p=11](https://k.sina.com.cn/article_6896501755_p19b1043fb0010011ab.html#p=11)



Figure 12. Selection of area for the pilot project. Source: Drawings by the authors



Figure 13. Selection of building for the pilot project. Source: Photos by the authors

patterns, building materials, and construction difficulty. In addition, we delved into the industrial structures and agricultural economic indicators of existing villages, as well as the local traditional construction technologies and cultural characteristics. Furthermore, our research mainly centered on exploring the developmental history of villages, particularly examining the evolving relationship between villages and monasteries. Special emphasis was

placed on analyzing changes in development modes and driving forces of the villages before and after the earthquake. Notably, our investigation scrutinized the complete relocation of residents from the former high mid-level mountain to the current area after the earthquake and its impact on the village's spatial pattern and architectural style. Through rigorous identification and comparison of buildings in Guantian Village, coupled with expert

consultations, we formulated a targeted classification and renovation scheme for the first batch of renovated buildings. Our study also involved devising strategies conducive to cultural inheritance, heritage preservation, and village regeneration in the area. Throughout the renovation design process, we ensured the feasibility of renovation projects during the renovation design process. The research framework is demonstrated in Figure 14.

The research framework is detailed as follows:

- (i) Cultural background research: This includes an examination of the historical development of Guantian Village, the evolution of settlements, and an analysis of Jiarong Tibetan residential architecture skills.
- (ii) Fieldwork: This includes field visits to buildings, villages, and elements of the historic environment, which includes taking photographs, mapping and simulating important environmental elements, conducting surveys, and creating village spaces and buildings.
- (iii) Oral interviews: Interviews were conducted with villagers and local scholars to complement historical research and explore the preservation and inheritance of historical development, spatial patterns, and architectural design language.
- (iv) Comparative study: This aims to construct a village protection and development system based on architectural heritage, environment, and community, providing reference strategies for rural revitalization and traditional culture protection.

## 4. Fieldwork and data processing

### 4.1. Building quality and feature evaluation

The current residential houses in Guantian Village were relocated following the Wenchuan earthquake (2008). Although some of these buildings were considered to present ethnic elements to a certain extent, they markedly differed from the existing historical buildings in the village, such as

the Baodian Temple. These newer constructions exhibited chaotic architectural features and adhered to different construction standards, making it difficult to reflect the living habits and cultural customs of the local residents. The construction of resettlement houses prioritized the rapid resettlement of residents, leading to an original planning approach that failed to reflect the features of the Tibetan residential style. At present, most residential buildings consist of 2 – 3-storey brick-concrete structure with poor construction quality, with only a small portion featuring certain ethnic elements. The feature evaluation centered around Baodian Temple as the core area within the existing village, extending to the surrounding area. This assessment utilized the features of Baodian Temple as a reference point to coordinate the surrounding residential buildings and public spaces. Historical environmental elements in the vicinity were identified and cataloged to inform protection efforts. A total of 65 typical residential buildings in Guantian Village, assigned to Group 1 and Group 2, were selected and uniformly numbered (Figure 15).

The buildings were evaluated with reference to the indexes of building integrity, application of traditional building elements, spatial patterns, building materials, and construction difficulty. The current architectural evaluation mainly divided existing buildings into one to four categories according to factors such as elevation integrity, incorporation of national cultural elements, and tonal unity (Figure 16). The overall dilemma lies in several aspects: the discordant colors and styles of the building, significant disparities in elevation decoration, and the widespread practice of unauthorized additions such as color steel sheds.

After investigating 65 typical residential houses in Guantian Village, it was found that the overall structure and style of the buildings appeared overly modern. Among these, 29 residential houses featured whitewashed concrete exterior walls, while 28 had simple side wall decorations,

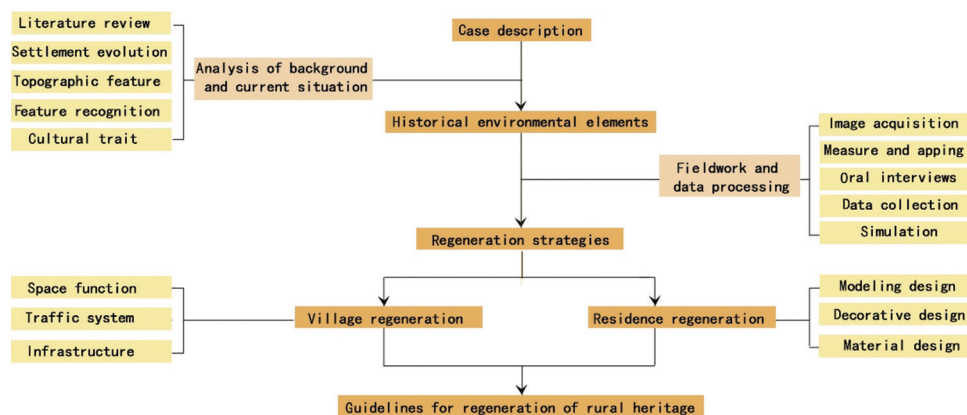


Figure 14. Research framework. Source: Drawing by the authors

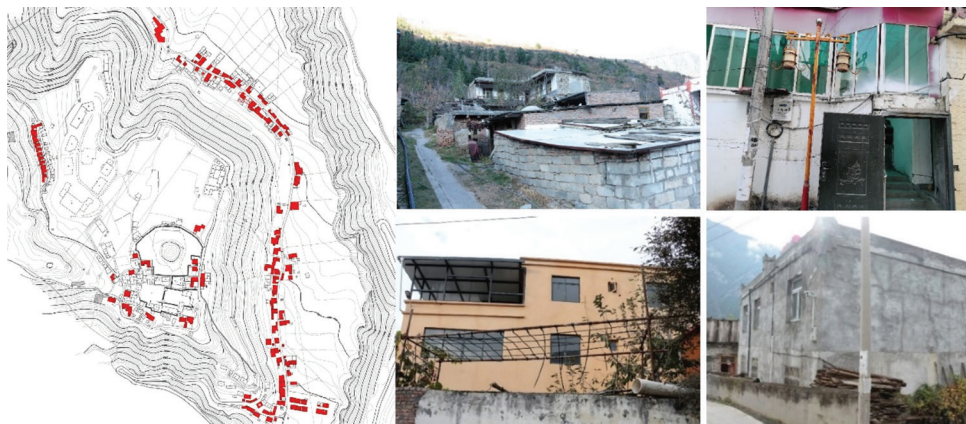


Figure 15. Current architectural features. Source: Photos by the authors

	Category one	Category two	Category three	Category four
Building category				
Quality analysis	2-3 floors Elevation: intact, mostly with tile veneer, good appearance no chaos Take up a proportion of 22%	2-3 floors Elevation: intact, Mostly plaster veneer, good appearance no chaos Take up a proportion of 45%	1-2 floors Elevation: relatively complete, mostly plastered walls, with slight damage and disorderly construction Take up a proportion of 25%	1-2 floors Elevation: more dilapidated, mainly plaster walls, building structure safety factor is high, no chaos Take up a proportion of 8%
Feature analysis	2-3 floors The elevation is more complete, integrating national elements, rich decoration, color coordination, good appearance, doors and windows have a certain decoration.	2-3 floors The elevation is complete, integrating ethnic elements, color coordination, good appearance, doors and windows have certain decoration.	1-2 floors The facade is complete, without ethnic elements and the color is not unified with other buildings. No decoration on doors and windows.	1-2 floors The elevation is complete, mostly gray walls, no facade decoration.

Figure 16. Current architectural style classification. Source: Photos by the authors

some displaying varying colors (Table 1). Ethnic elements of the residences were mainly reflected in the form of simple horn roofs and flat, small square windows with Baka paintings on the window eaves (Figure 17).

## 4.2. Overview of problems

### 4.2.1. The limited space-bearing capacity and the missing functional zoning

Most villages with characteristics in ethnic areas are ecologically fragile, necessitating a strong emphasis on their ecological functions. Guantian Village is prone to geological disasters, has limited construction land, and boasts a reduced arable area. Moreover, the construction of the Buddhist College in the village has consumed a significant portion of land, posing challenges to the village's future population growth and carrying capacity.

### 4.2.2. The rough scenery in the village and the insufficient cultural excavation

The natural and cultural landscapes in Guantian Village lack effective integration. Following the Wenchuan earthquake in 2008, most of the residential buildings underwent reconstruction, resulting in a chaotic overall appearance. Furthermore, the preservation of traditional Tibetan culture in Jiarong was inadequate, leading to disparities in construction quality. In addition, there are post-earthquake village ruins in the upper mid-levels behind the village, which have remained uninhabited for an extended period, presenting a deserted state. Despite these challenges, the village boasts a century-old Tibetan Buddhist temple and the remnants of a pagoda known as the "Western Frontier Pagoda King." While the former has recently undergone renovation, glowing with newfound charm, the latter has long remained idle.

**4.2.3. The backward infrastructure and the inconvenience of living conditions**

At present, the village has only one motor road providing access to the county. However, due to its poor conditions, traffic flow is hindered, impacting the smooth circulation of urban and rural resource elements. Moreover, the village suffers from a lack of water supply and drainage facilities, leading to the disorderly discharge of human and livestock sewage. Consequently, this has resulted in serious pollution, contributing to a poor living environment and exacerbating the gap between urban and rural areas.

**5. Protection and utilization strategy of Guantian Village cultural heritage**

During the participation process, we conducted in-depth investigations, research, and analysis. Several structural talks were held with relevant local departments to supplement and improve the content of the current investigation records. This allowed for an understanding of local protection policies, management conditions, social economy, planning, and development. The strategies proposed in this paper were formulated after a thorough examination of the relevant environmental factors within the same cultural area and extensive communication with villagers to gauge their genuine aspirations. As a result,

these strategies objectively reflect the original cultural expression of the area and truly demonstrate residents’ visions for village development. They provide a scientific basis for the strategy of protection and utilization of characteristic culture and help address potential contradictions in the reality of cultural protection and utilization. Throughout the research process, we applied basic theories of urban and rural planning, architectural design, and cultural heritage protection. By aligning with relevant policies and regulations of urban construction planning in Lixian County, we conducted research and analysis guided by principles such as “discard the dross and select the essential,” “discard the false and retain the true,” “proceed from one point to another,” and “from the surface to the inside.” Leveraging firsthand information obtained through research, we employed research and analysis techniques such as pattern complementation, functional principles, and holistic systems thinking. In addition, we adopted research methods such as reference, analogy, association, and inspiration to integrate cultural construction into the whole space system.

**5.1. Village regeneration strategy**

**5.1.1. Integration of landscape and village and optimization of the space function**

With the development of rural tourism, there has been a notable shift in the pattern of multi-interests, leading to a diversification of the main body of life and a corresponding change in spatial typology. Planning initiatives must fully consider the current circumstances and conditions of the village, maintaining the existing industrial chain and ecological quality while making necessary adjustments to basic functions and effectively improving the integration of scenic villages (Fang & Zhu, 2022). The plan entails organizing the existing land, with a focus on integrating construction land and delineating functional areas such as the Jiarong New House group and the e-commerce logistics park group. This approach aims to address the problem of land supply resulting from industrial development and overcome the bottleneck in land use (Figure 18).

Table 1. Analysis of architectural color





Color	Cutline	Quantity	Proportion
Whitewall		29	29/65
Reddish-brown Bianma wall (Light)		4	4/28
Reddish-brown Bianma wall (Middle)		9	9/28
Reddish-brown Bianma wall (Dark)		15	15/28



Figure 17. National elements in the current architecture. Source: Photos by the authors

**5.1.2. Enhancing the traffic system within the scenery of the village**

According to the functional orientation of Guantian Village, the plan aims to delineate all types of land use indicators (Figure 19) and promote the landscape, agricultural landscape, and overall aesthetics through the renovation of the living environment within the village area. This initiative seeks to promote the development of rural global tourism by leveraging the area's open rural landscape resources. Embracing the concepts of "one village, one product" and "one scene, one industry" within the framework of the new local theory, the plan endeavors to strengthen the connection between villages and national and provincial roads and

reconstruct the traffic system within villages, emphasizing the role of slow traffic (Figure 20). Relying on the construction of Jixiang Eternal Pagoda Site Park, the pagoda site wall will be transformed into a public space to display Tusi Culture, Buddhist pagoda historical images, ethnic art, and other contents. By making full use of the spatial pattern and ecological resource background of the village, the plan seeks to link the original village ruins in the high mountains, enrich the tourists' experience, and extend the stay time of tourists in the village. Finally, a diverse array of content covering agricultural product production, mountain sports and leisure activities, village sightseeing, and cultural experiences will be curated. This includes the creation of special village scenes such as colorful flowers blanketing

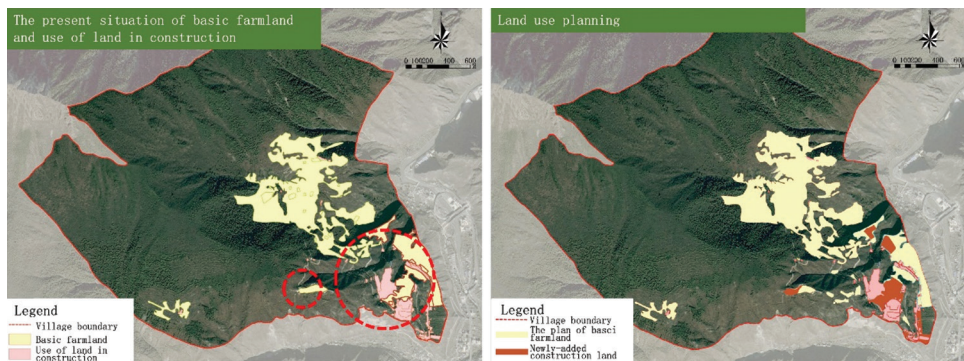


Figure 18. Adjustment of land use in key areas. Source: Drawings by the authors

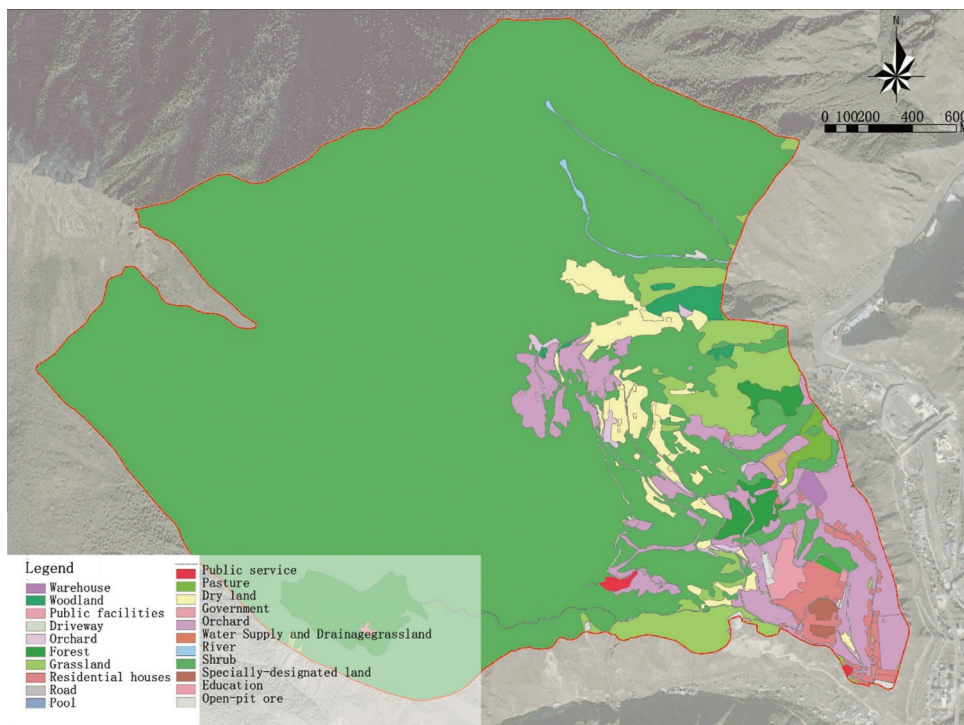


Figure 19. Village land use planning. Source: Drawing by the authors

the mountains in spring, the melodic strains of folk music echoing through the valley in summer, the tantalizing taste of autumn harvest feasts, and the heartwarming ambiance of winter singing and dancing around bonfires.

**5.1.3. Improving infrastructure via multiple sharing**

The coordinated allocation of public service facilities in villages and towns is an important measure to promote the overall planning of urban and rural areas, as well as an in-depth expansion of the connotation of equality. We chose key areas as examples to create key projects (Figure 21 and Table 2). Our approach involves two main aspects: improving public infrastructure such as rural road traffic, water supply and drainage, power and telecommunications, and disaster prevention, and optimizing tourist service facilities such as accommodation, catering, leisure amenities, and tour sign systems. Our aim is to realize the expectations of villagers for a better quality of life, implement convenience in daily life and tourism activities, and promote the coordination and sustainable development of various elements of village life.

**5.2. Traditional residence regeneration strategy**

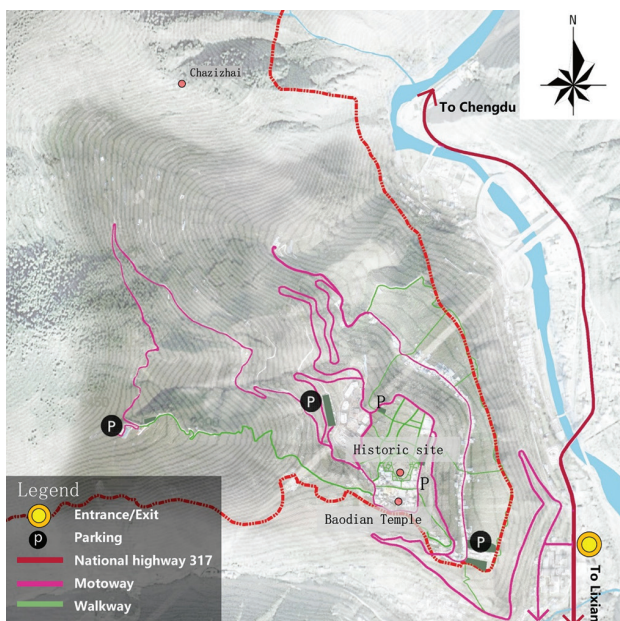
**5.2.1. Façade renovation**

The Jiarong Tibetan area adopts the architectural technique known as “stone as room,” which involves constructing buildings using stone and wood structures, resulting in a rectangular and compact layout (Zhang & Wang, 2008). Based on the different load-bearing structures, this technique can be divided into two types: blockhouses with pure wall load-bearing structures and wall-column mixed loading-

bearing structures. Due to the mechanical structure, the walls are typically thick, ranging from 0.8 m to 1.2 m, providing excellent thermal insulation and defense capabilities. The walls exhibit a trapezoidal façade outline, with approximately 3% to 5% bottom-up contraction depending on the height of the wall and the size of the slope of the hill (Song, 2011). The natural color of the wall stone is often intuitively displayed or coated with white paint, with pattern decorations commonly featuring Tibetan Buddhism elements, such as conch shells (Zhang *et al.*, 2014). A prominent feature of façade decoration is the incorporation of the dark red Bianma wall, which evolved from the roof structure. This wall contrasts with the color of the main wall, forming a visually striking effect and

**Table 2. The detailed list of land use adjustments for key projects**

Present Situation	Adjustment
1. Standardized breeding center	Change the 0.76-ha original orchard to a standardized breeding center
2. Logistics base	Change the 1.29-ha original orchard to a logistics base
3. Homestead	Change the 0.83 ha original orchard to homestead
4. Parking	Change the 0.08 ha original grassland and 0.16 ha. orchard to parking
5. Homestay	Change the 0.08-ha original orchard and 0.08 ha. farmland to homestay
6. Parking	Change the 0.04-ha original orchard to parking
7. Homestead	Change the 4.09-ha original orchard to a homestead
8. Hotel	Change the 0.76-ha original orchard to a hotel
Total	7.85 ha



**Figure 20.** Traffic planning map. Source: Drawing by the authors



**Figure 21.** Detailed land use adjustments for key projects. Adjustments of the current land to: (1) Standardized breeding center. (2) Logistics base. (3) Homestead. (4) Parking. (5) Homestay. (6) Parking. (7) Homestead. (8) Hotel. Source: Drawing by the authors

contributing to the unique aesthetic of Tibetan architecture (Figure 22). The Bianma wall has become a symbol of spiritual culture in Tibetan architecture. The preservation and inheritance of the Bianma wall signifies the protection and embodiment of the distinctive regional culture of Tibetan areas, which holds great significance for the design of modern Tibetan architecture (Jiang & Zhao, 2019).

The walls of the existing residential buildings are all painted in light colors, and the structure and materials of

these buildings are not in line with the local construction culture. In addition, the simple spaces formed by colored steel sheds, built without approval, and destroy the façade relationship of traditional Tibetan residential buildings. Therefore, the renovation designs focus on the elevation, considering the material, tone, and pattern. It aims to restore the stone and wood structures of the external walls of Jiarong Tibetan folk houses and follows traditional intangible heritage construction techniques (Figure 23). The design uses local materials, with stone affixes to the



Figure 22. Material and decoration of the exterior wall. Source: Photos by the authors



Figure 23. Traditional Diaolou construction skills. Source: Photos by the authors

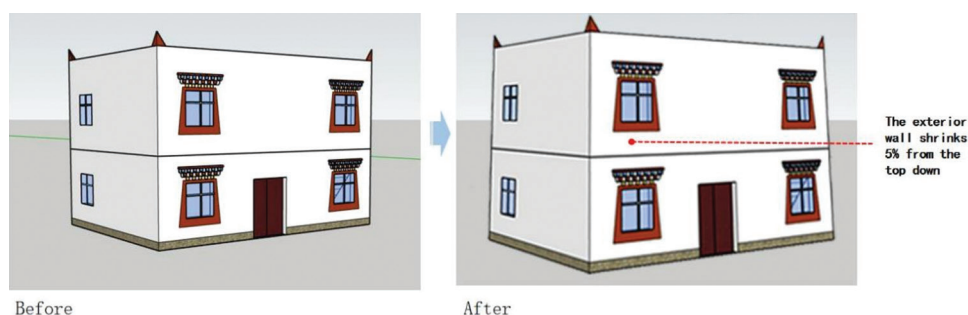


Figure 24. Building wall receiving treatment. Source: Drawings by the authors

foundation of the original wall, to both decorate and increase its thickness for improved thermal insulation. This process also creates a trapezoidal façade outline of the wall (Figure 24). During the construction, when the wall is laid 2.5 – 3 feet, “wall reinforcement,” such as round or square wooden beams or flat wood pieces (Figure 25), should be placed in the wall to strengthen and support the wall, preventing the wall from cracking. The overall tone of the building follows the characteristics of the natural color of the materials used in Jiarong Tibetan residences. The Bianma wall is decorated at the floor connection, cornice, and courtyard wall, rather than uniformly painted (Figure 26). At the same time, simple auspicious patterns such as swastikas or Tibetan eight treasure patterns can be incorporated to better restore the features and characteristics of local dwellings. This approach aims to create a rugged, atmospheric, heroic, and rugged plateau style of Tibetan architecture through texture and tone.

### 5.2.2. Roof modification

The roof of Jiarong Tibetan residential houses serves as the primary space for drying food and clothes in daily life, thereby necessitating strict load-bearing and waterproofing requirements. Common residential buildings in this area usually feature single-layer or double-layer roof structures, which are characterized by the distinctive layout of stone, wood, and yellow mud (Figure 27). The color palette mainly comprises white, black, vermilion, and geometric pattern combinations, lending strong decorative and identifying elements to the roofs. In addition to the layout of the building site, the four corners of the parapet wall are raised and whitewashed, a feature commonly known as “bull horn top” (Ling, 2020; Gao *et al.*, 2018). White stones are placed atop these corners, revered as symbols of the gods in four cardinal directions. Specially designed holes in the stone plates are inserted with wooden poles to hang the colorful prayer flags, which move with the wind like the residents chanting. Embedded within the middle of the wall backing the mountain is a “Simmering Pagoda,” where pine and cypress branches burn daily (Figure 28), filling the air with smoke every day — an



Figure 25. Wall reinforcement setting. Source: Drawing by the authors

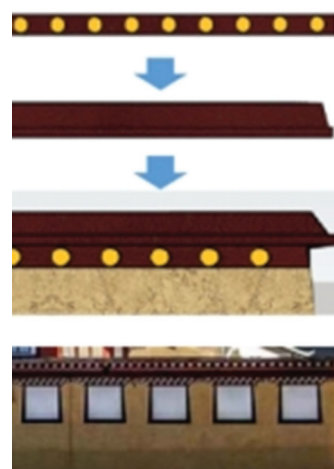


Figure 26. Bianma wall decoration. Source: Drawing by the authors

expression of reverence for the mountain god by the local residents.

The roofs of the existing residential houses are constructed with modern reinforced concrete material, featuring only a symbolic “horn top” molded on the four corners. The renovation proposes optimization suggestions

for both the roof structure and decoration. It entails restoring the traditional roof structure atop the existing one, using native materials such as wood beams, purlins, branches, sand, and clay, in accordance with the traditional layered operation process, thereby reflecting the inherent beauty of



Figure 27. Roof structure. Source: Photo by the authors



Figure 28. Roof decoration. Source: Photo by the authors

the traditional roof structure (Figure 29). The corners of the parapet are raised and whitened to create a stronger “horn top.” Craftsmen place white stones, sourced from the sacred mountain, on the four corners of the roof to honor the tradition of “white stone worship” (Wang, 2021). In addition, a “Simmering Pagoda” is constructed on the east side of the roof, adorned with white stones piled on top, encircled by five-color prayer flags, and with white, yellow, red, and blue Lungta (known as Fengma Flag) placed in the south-east and north-west directions of the roof (Ding & Liu, 2009) (Figure 30). These enhancements cater to residents’ demand for worshipping the mountain god while accentuating cultural colors and embodying traditional style.

### 5.2.3. Decorative design

The decoration of doors and windows holds the most significant cultural and aesthetic importance in Tibetan homes in Sichuan, often serving as expressive elements infused with religious beliefs and ancestral reverence, supplemented by paintings and carvings. Conventionally, Jiarong Tibetan folk houses generally featured a single entrance door. With the advent of modern social stability, the height of these doors has been restored to approximately 2 m, while their width usually spans between 1.2 m and 1.4 m (Zhang, 2014). Door decoration is concentrated on the lintel, door frame, and other components, which are divided into two categories: primary colors and tinted colors. Lintels generally showcase 2 – 3 layers in a cantilevered form, while the door frames consist mostly of 1 – 2 layers of carved motifs, decorated with geometric patterns and swastikas and painted in vermilion, black, and white colors. In more exquisite buildings, door panels may depict graphics such as chafing, white pagodas, and Tibetan eight treasures, with some featuring door gods carved in the shape of a dragon head, inspired by the imagery of the Bon-Religion Water God.

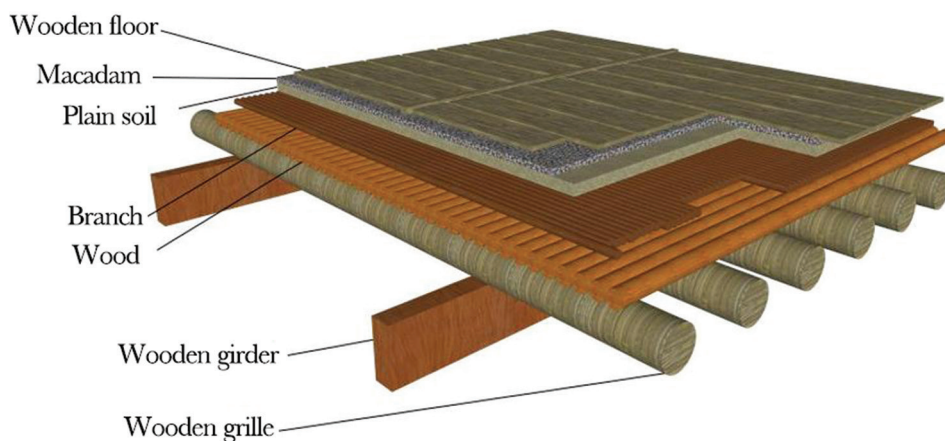


Figure 29. Traditional roof structure. Source: Drawing by the authors

To meet structural requirements and defense needs, traditional Jiarong Tibetan folk houses are characterized by small windows and predominantly feature overhanging eaves, constructed akin to the roof cornices. The process involves building 2 – 4 layers of vertical and horizontal bracing extending outward layer by layer, with the top layer usually adorned with stone pieces in hues of red, blue, black, white, and other

colors, serving as focal decorative elements (Li, 2016). Externally, windows are framed with lattice wood frames, while internally, flat sashes are installed. This design, compared with flat windows lacking eaves, yields a more pronounced decorative effect, particularly with the incorporation of color or plant motifs. In addition, window apertures are usually adorned with white or black trapezoidal patterns known as Baka (Figure 31),

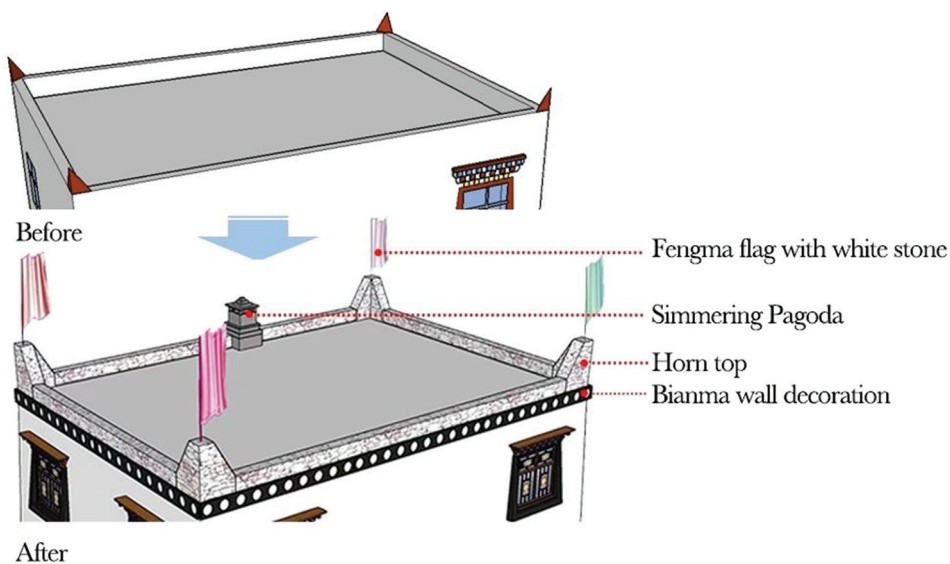


Figure 30. Roof decoration. Source: Drawing by the authors



Figure 31. Decoration of doors and windows. Source: Photos by the authors

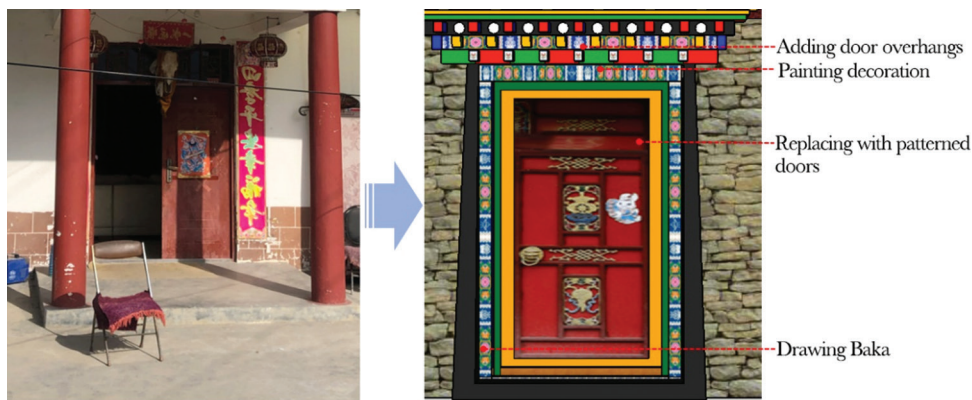


Figure 32. Renovation design of door. Source: Drawings by the authors

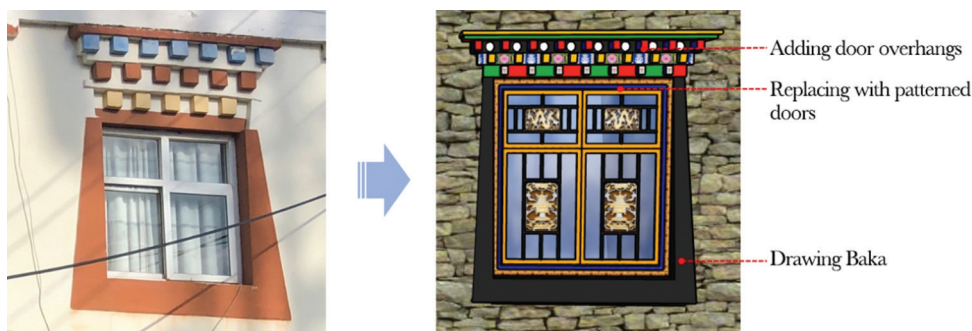


Figure 33. Renovation design of windows. Source: Drawings by the authors

which symbolize traditional totemic worship motifs (Ding & Liu, 2009). This design, coupled with wall divisions, contributes to the visual reinforcement of the stability of the building.

The current residential doors and windows feature large openings, primarily constructed from modern metal materials. However, this design presents challenges in adapting to the unique local climate conditions and fails to align with the functions of traditional Jiarong residential doors and windows within the overall courtyard layout. To address this challenge, the renovation strategy focuses on optimizing the material, structure, and style of doors and windows. The aim is to restore traditional wooden elements while integrating traditional patterns to enhance the overall aesthetic. As part of this overhaul, door, and window openings are reduced during wall renovations to improve the insulation of the building. In terms of design, door and window covers are adorned with thick black or white trapezoidal frames (Baka), which exhibit Tibetan characteristics. This choice not only serves as a decorative touch but harmonizes with the surrounding walls, strengthening the overall architectural image to achieve the visual effect of traditional Jiarong Tibetan folk houses (Figures 32 and 33).

## 6. Conclusion

The protection and development of villages in ethnic areas possess unique characteristics. This study delves into the theory and practice of traditional architectural design and decoration of Guantian Village, as well as villages sharing similar cultural backgrounds. It identifies elements conducive to coordination with the Tibetan village style in this area and implements these findings in practical applications. These achievements and practical experiences encapsulate the concept of protecting the authenticity of Tibetan villages. Furthermore, three strategies are synthesized: establishing an overarching planning framework for village landscapes, strengthening the protection of architectural features in core areas, and refining the construction technology of specific building structures. Through field investigations and analyses of traditional houses in Guantian Village, this paper summarizes the problems related to the lack of style and architectural characteristics in the development and construction of monastery-centered villages. It demonstrates the feasibility of the style transformation and the integration of village and landscape construction. By adhering to the concept and strategy of village development aimed at protecting cultural characteristics, the study

reasonably formulates protection and development strategies centered on the Baodian Temple. These strategies include practical methods and technologies for façade transformation, selection of decorative materials, showcasing characteristic cultural elements, and enhancing environment construction. Moreover, the study actively explores the relationship between overall village development and the protection of cultural landscapes, aiming to devise a feasible plan suitable for the rural revitalization of Jiarong Tibetan villages.

Today, the protection of characteristic local cultures relies on the joint efforts of rural planning, landscape design, and architectural design. However, due to the complexity of ethnic cultures, the current study still exhibits limitations and shortcomings. It is confined to a case study of a single region, failing to provide sufficient material for a comprehensive discussion on the development and utilization of Tibetan villages as a whole. Further theoretical research and practical case studies are crucial for comprehensively understanding the complexity of village development in China's ethnic minority areas. In the future, it is necessary to further refine the development and utilization strategies for villages across different Tibetan cultural backgrounds, solving numerous problems encountered in protecting distinctive cultures while balancing the development of modern villages with historical and cultural inheritance. Our study provides useful planning strategies for the overall protection of rural cultural patterns in the Jiarong Tibetan area, which is primarily characterized by architectural renovation and village planning, as well as the renewal and sustainable development of other villages with similar cultural characteristics, or in similar cultural circles.

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## Conflict of interest

The authors declare that they have no competing interests.

## Author contributions

*Conceptualization:* Hao Wu, Hongtao Liu

*Formal analysis:* Hao Wu

*Investigation:* All authors

*Methodology:* Hao Wu

*Writing – original draft:* Hao Wu

*Writing – review & editing:* Hao Wu, Hongtao Liu, Francesco Abbamonte

## Ethics approval and consent to participate

Not applicable.

## Consent for publication

Not applicable.

## Availability of data

Data are available on reasonable request from the corresponding author.

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## ORIGINAL ARTICLE

## From finance to legacy: Exploring Bank of China's modern buildings as serial cultural heritage

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In the early 20<sup>th</sup> century, China underwent profound societal transformations across cultural, political, economic, and military domains, culminating in the birth of its first national bank, the Bank of China. Enduring for over a century, the Bank of China stands as a testament to the emergence and evolution of a modern nation-state. The edifices housing this paramount institution, as well as their geographical locations and architectural designs, serve as prime examples for studying modern Chinese architecture and social history. This article, rooted in field surveys, traces the development history and current conservation status of the 26 existing Bank of China buildings. It analyzes their locations, construction backgrounds, architectural features, and functional uses. Through an assessment of the historical, artistic, scientific, and socio-cultural values of these bank buildings, this study employs the perspective of “serial cultural heritage” to propose a value-based thematic interpretation aimed at revitalization. In particular, it accentuates that analyses and interpretation of values are fundamental prerequisites for rebuilding and displaying the cultural identity of these buildings.

**Keywords:** Bank of China; Bank branches; Conservation and revitalization; Heritage value studies; Modern bank buildings; Modern history; Serial cultural heritage; Value-based thematic interpretation

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**1. Introduction**

A bank functions as a pivotal financial institution that facilitates credit intermediation through various services such as deposits, loans, remittances, and savings (Riuoire & Chen, 1997). Modern bank buildings symbolize an architectural legacy stemming from the modernization of the financial industry, serving as spatial embodiments of banking philosophies and recognized as a distinctive architectural category (Jacobi, 2019). The development of bank buildings is closely related to the trade of goods and the growth of economies (Heathcote, 2003; Jansson, 2021). Thus, bank architecture, evident in shifts in form and space, closely parallels economic development, societal contexts, and cultural patterns across different epochs since the Middle Ages (Pang, 2006; Wei, 2006).

The banking industry played a major role in facilitating the 18th-century Industrial Revolution, a seminal milestone in human history (Andrei, 2012), marking an era of

significant technological strides. According to Ashton (1997), the Industrial Revolution's expansion paved the way for the establishment of a financial sector centered around modern banking systems. Consequently, the development and shaping of banking architecture were closely intertwined with the culmination of the Industrial Revolution. Before this period, banking spaces lacked a distinct architectural style or form, defined instead by the interplay between bankers, monetary activities, and the spaces they occupied (Leader, 2021). Essentially, any structure associated with economic activities and trade could be termed a "banking building" (*Commerce and Exchange Buildings Listing Selection Guide*, 2011). However, with the advent of the Industrial Revolution and propelled by new technologies and materials, bank buildings gradually adopted standardized architectural styles and internal spatial designs (Li *et al.*, 2005).

As the 21<sup>st</sup> century unfolds, there has been a growing acknowledgment that industrial heritage should be comprehended and interpreted within urban landscapes (Merciu *et al.*, 2014; Zhang *et al.*, 2021; Zhang *et al.*, 2022). People have progressively recognized the historical value and symbolic significance of bank buildings as important industrial heritage sites. For instance, Black (1996; 2000) investigates the new headquarters of the London and Westminster Bank in the early 19<sup>th</sup> century, revealing that bank buildings carry symbolic meanings of strength and status, along with esthetic significance in the metropolitan landscape. In addition, scholars such as Barnes & Newton (2018; 2019) and Barnes *et al.* (2020) have scrutinized the symbolism embedded in British banking architecture of the 19<sup>th</sup> century. By tracing the history of Gibson Hall, the National Local Bank of London, from its design and construction to its demolition, they have revealed the evolution of urban conservation and civic consciousness in Britain over the century. Simultaneously, practical concerns have arisen as historical bank buildings face demolition and neglect due to the obsolescence of their original functions and the emergence of new businesses (Guggenheim, 2014). In the past few years, certain researchers have also proposed the idea that modern bank buildings are the most appropriate historic resources for contemporary adaptive reuse (Morales, 2019).

The rise of banking was intricately linked to the expansion of trade, the ascent of the merchant class, and the augmentation of personal wealth and prosperity (Pan, 2003). In East Asia, the colonization initiated by European nations resulted in the imposition of Western architectural styles on cities and regions. Particularly notable is the post-19<sup>th</sup> century period, where the deepening impact of colonization spurred heightened trade and cultural exchange,

giving rise to new financial institutions characterized by architectural styles distinct from the traditional norms in East Asia. Oh (2007) summarizes the spatial layout and design characteristics of representative bank buildings in Korea, while some scholars have critically identified bank buildings as "colonial architecture" (Colombijn, 2022). In China, research on modern bank buildings spans three main directions: historical origins (Chen, 2010; Hao *et al.*, 2013; Yan, 2014; Wang, 2020), architectural changes (Li, 2006; Chen, 2007; Fang *et al.*, 2008; Zhou, 2019; Zhang, 2020), and conservation and restoration analyses of specific cases (Lan, 2009; Xu, 2013; Xu *et al.*, 2014; Gao, 2016; Xu, 2021).

Despite China's increasing attention to preserving such historical buildings, commercial interests often drive owners to demolish old structures and erect new ones, undermining the preservation of historical information and causing significant damage to their physical form and cultural value. This situation warrants introspection within the architectural conservation community.

The Bank of China, as the nation's oldest financial institution, boasts a widespread presence in such buildings, making it an ideal case study for exploring modern China's architectural style and social evolution. These preserved Bank of China buildings, scattered across various cities, serve as living testimonials to both the architectural trends of the colonial period and the development of modern Chinese financial building esthetics. Moreover, they offer a unique opportunity for the discussion of conservation, restoration, and adaptive reuse of historic architectural heritage. However, studies dedicated to these Bank of China buildings remain limited. Existing studies predominantly focus on interpreting architectural style and artistic value (Xu & Hu, 2018; Xu & Cheng, 2020), with scarce attention given to presenting and interpreting their historical and cultural significance as a collective entity through the lens of adaptive reuse.

This paper, built upon empirical research and comprehensive data synthesis, presents a catalog of 26 modern bank buildings in China. It investigates their historical origins, business operations, present conservation status, and utilization plans. Through historical research and a broad analysis of Bank of China buildings as an integrated entity, this paper aims to formulate a set of coherent value interpretation and presentation strategies before embarking on renovations for any specific building. By introducing the concept of "serial cultural heritage," these strategies seek to interconnect various historic sites, adeptly conveying the cultural nuances and profound social significance embedded within these modern bank buildings during their restoration and subsequent adaptive reuse. This approach aims to sustain the complete cultural identity of Bank of China buildings.

## 2. Data sources and method

### 2.1. Presentation of the case study

The emergence of modern banks in China coincided with the imperative requirements of the nation's commodity economy development and the downfall of traditional financial institutions. Before the 19<sup>th</sup> century, China's financial landscape predominantly relied on regional practices rooted in private-sector trade and outmoded financial entities such as ticket houses and money changers (Table 1). However, these traditional institutions, characterized by archaic business concepts and cumbersome capital operations, struggled to respond promptly to evolving market dynamics amid political turmoil, resulting in credit busts and a total decline. This decline paved the way for the birth of modern financial institutions, specifically banks (Writing Group of Modern Chinese Financial History, 1985). Finance has always played an indispensable role in the emergence and growth of all sectors within China's modern economy throughout its history, as emphasized by Wu (2019).

The Bank of China stands as the quintessential representative of early modern banks. As the only financial institution in China to span a century, its development and decline have witnessed the evolution of the modern financial history of the Chinese nation. The surviving remnants of its financial infrastructure across various locations not only represent the continued existence of

individual buildings but also serve as tangible vessels through which historical contexts can be understood. Therefore, through an explorative and interpretative approach to assessing the values of financial industry heritage encapsulated in Bank of China buildings, this research holds prospective and practical significance in guiding understanding and action.

### 2.2. Data sources

The selection of the 26 modern bank buildings in this study is based on materials provided by the Party History Office of the Bank of China in 2021. The selection process, involving a field study conducted from 2021 to 2022, is based on several key considerations:

- (i) All 24 buildings selected in mainland China were constructed before 1949, with most structures approaching the age threshold of 100 years, thus imbued with significant historical value.
- (ii) The two buildings located in Hong Kong, despite being constructed in 1950 and 1989, respectively, are globally renowned for their artistic values and significance in modern architectural history associated with the Chinese-American architect I. M. Pei (Ieoh Ming Pei, 1917–2019). Due to their irreplaceable role in connecting mainland China with international finance after 1949, they were selected as standing witness to the changing global dynamics during the late colonial era.

Table 1. Comparison of the functional patterns of traditional and modern financial industries in China

Nature of the financial industry	Industry classification		Functional mechanism	Business scope	Primary target audience
Traditional financial industry	Pawnshop business	Pawn store	Collateral in kind	Short-term loan	Middle and lower social strata
	Silver money banking industry	Money shop Banknote	Cross-border tax exchange	Stored loan Negotiable payments	All social strata
Modern financial industry	Banking industry	Government bank	Short-term financing	Commercial loan	Government comprador class
		Commercial bank		Industrial loan	National industry and commerce
		Government-business joint venture banking		Funds deposit National public debt	All social strata All social strata
	Insurance sector	Insurance company	Venture capital investment	Property insurance Personal insurance	All social strata All social strata
	Trust sector	Trust company	Credit investment	Trust investment	All social strata
	Securities industry	Securities company	Long-term financing	Equity and debt trading	All social strata
	Leasing industry	Leasing company	Short-term financing	Financial credit Material credits	All social strata All social strata

Note: The table presents the various functions and business scopes of traditional and modern financial industries in China. Source: Table by Jun Wang

(iii) The unified ownership of most selected buildings by Bank of China Limited (except for the two in Hong Kong, which are legally separated) enables the integration of resources from a master planning perspective. This structure ensures that the research outcomes can feasibly inform architectural revitalization and display needs in the future.

The authors conducted a survey of each of these banks based on this directory. The specific work carried out includes:

- (i) Data collection: Collecting historical archives, documents, historical photographs, and old architectural design drawings.
- (ii) Architectural mapping: Mapping and photographing important buildings where survey maps were absent.
- (iii) Oral interviews: Engaging in interviews with experienced senior staff to compensate for narrative gaps in the archives.
- (iv) Functional analysis: Documenting and comparing the historical and current functions of the building.
- (v) To study the history and development pattern of Chinese bank buildings, the authors collected data from field surveys and discussed the characteristics of these buildings from multiple perspectives, including building distribution, construction timeline, architectural style, and current functionalities.

### 2.3. Analysis methods

#### 2.3.1. Adoption of a “serial cultural heritage” approach

The concept of serial cultural heritage emerges from the Operational Guidelines for the Implementation of the Convention Concerning the Protection of the World Cultural and Natural Heritage (UNESCO, 1980). It denotes a category of heritage comprising multiple sites that share common meanings and values (Poshyanandana, 2019). This approach resolves constraints in the conservation, utilization, and management of intrinsically related heritage resources due to geographical separation or different resource types.

The Bank of China's modern building resources span various regions of the nation, deeply intertwined with the country's overall historical development. Assessing the value of individual buildings in isolation fails to establish a coherent linkage between these structures and their collective relationship with modern history. This failure results in an incomplete representation of their symbolic values and impedes a comprehensive understanding of their historical backgrounds and geographic significance.

Therefore, recognizing the uniqueness of the Bank of China's modern buildings and their distinctive role as financial sector heritage, this paper advocates deviating from traditional conservation paradigms of a one-size-fits-

all approach. It proposes adopting a serial cultural heritage approach to interconnect modern buildings scattered across the country (Figure 1). Moreover, considering Bank of China's modern buildings' attributes as part of financial sector heritage, we draw upon a value analysis framework developed by the Heritage Lottery Fund in the United Kingdom (UK), in partnership with the Demos Research and Policy Center in the United States (US), to comprehensively enhance the effectiveness of its adaptive utilization (Clark & Maer, 2008). This approach involves examining the intrinsic value, instrumental value, and institutional value of these buildings, thereby identifying core values and developing a revitalization framework (Figure 2).

#### 2.3.2. Adoption of the “value-based thematic interpretation” approach

Thematic interpretation, a well-established approach to heritage interpretation (ICOMOS, 2008), simplifies heritage values into understandable, digestible themes for visitors. Building a thematic framework involves interpreting the core values of the heritage in layers, typically structured with a primary theme at the top, several sub-themes circling the main theme, and a series of stories categorized under various sub-themes (Figure 3).

The Bank of China's modern buildings are rich in historical narratives. Leveraging the above research methodology allows us to distill historical values ingrained in these architectural heritages. This process aids in formulating future planning schemes for interpreting the values of the Bank of China's buildings (Figure 4).

## 3. History of the Bank of China

The Bank of China, a national financial institution, was originally established as a commercial bank. Its name reflects pivotal historical events it bore witness to, including the fall of the Qing government and the birth of the Republic of China. These events fundamentally shaped the bank's trajectory, business scope, and functional role.

### 3.1. Budding period: The central bank of the Qing dynasty (1905–1912)

The Bank of the Treasury, founded in Beijing in August of 1905, served as the precursor to the Bank of China. By February 1908, it transformed into the Bank of the Qing Dynasty, assuming the role of a central bank. By 1911, the Bank of the Qing Dynasty had expanded to establish 35 branches in provincial capitals and entry ports, thus becoming the most extensive bank in the late Qing dynasty (Editing Committee of the History of Bank of China, 1995).

In 1912, Dr Sun Yat-sen (1866–1925) approved the transformation of the Bank of the Qing Dynasty into the

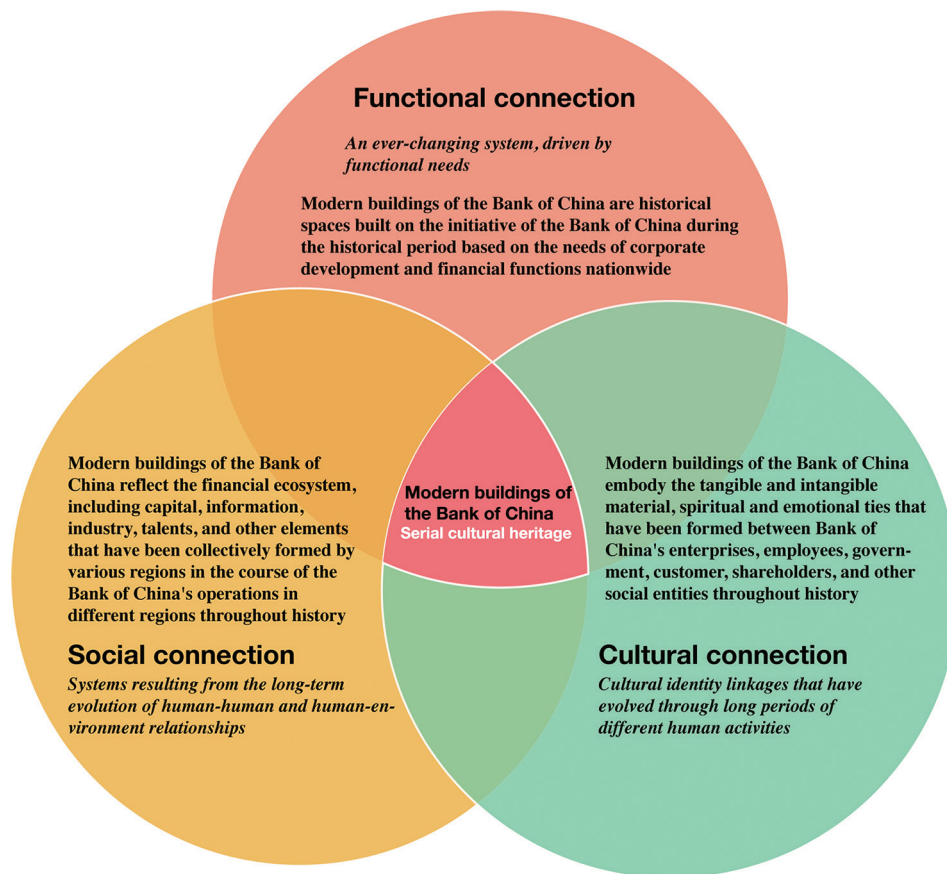


Figure 1. The intrinsic relevance of the Bank of China's modern buildings as serial cultural heritage. Source: Drawing by Jun Wang & Mengyuan Zhou

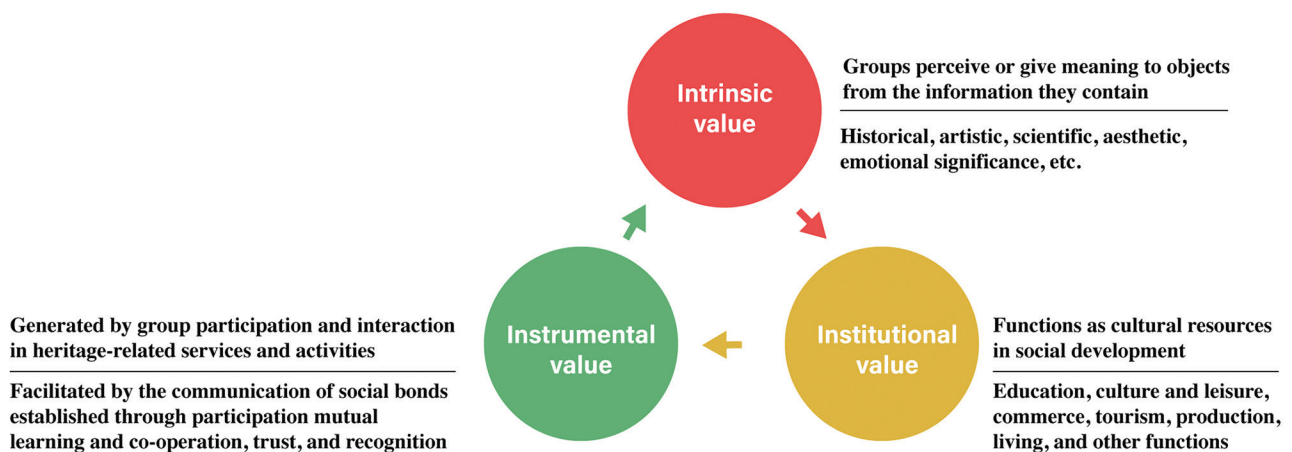


Figure 2. Framework for value analysis. Source: Drawing by Jun Wang

Bank of China. This bank carried out the functions of a central bank of a newly formed nation-state, including collecting and redeeming military bills, currency issuance, acting as an agent for the state treasury, collecting taxes, selling public bonds, and servicing foreign debts. The Bank

of China played a vital role in stabilizing the financial system and supporting the newly formed government. On August 1, 1912, the Bank's Head Office was established in the original location of the Bank of the Qing Dynasty on Xijiaominxiang Lane, Beijing. Subsequently, all former

Bank of the Qing Dynasty branches were restructured into Bank of China branches.

**3.2. Rising period: The central bank of Nanjing Provisional Government and the Northern Warlord Government (1912–1918)**

After the Xinhai Revolution (1911), the Northern Warlord Government emerged as the actual central government, with the Bank of China retaining its status as the national bank. However, during these turbulent times, the Bank of China became the favored source of revenue for warlords

seeking funds for military expenses and campaigns. This situation hindered, to a certain extent, the normal operations and performance of the Bank of China's branches. However, in the 1920s, the Bank of China introduced the concept of "regional banks," which were responsible for overseeing the operation and issuance of all branches, offices, and tax collection centers within their districts. They managed inter-branch relations within their districts, while branches outside the district fell under the direct jurisdiction of the head office. From 1912 to 1928, the Bank of China, relying on institutional reforms and business adjustments, effectively fulfilled its central banking functions and played a significant role in countering foreign banks and stabilizing the financial system.

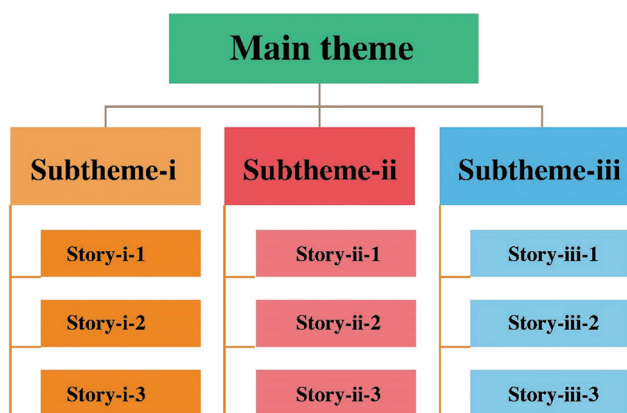


Figure 3. Thematic framework for value interpretation. Source: Drawing by Jun Wang

**3.3. Transition period: The International Exchange Bank (1928–1949)**

In October 1928, the National Government established a new central bank, leading to the reorganization of the Bank of China as a "government-chartered international exchange bank" with a focus on foreign exchange operations. In 1929, the Bank of China established a manager's office in London, setting a precedent for Chinese financial institutions to open branches in the global financial hub. This office became a vital center for the centralized transfer

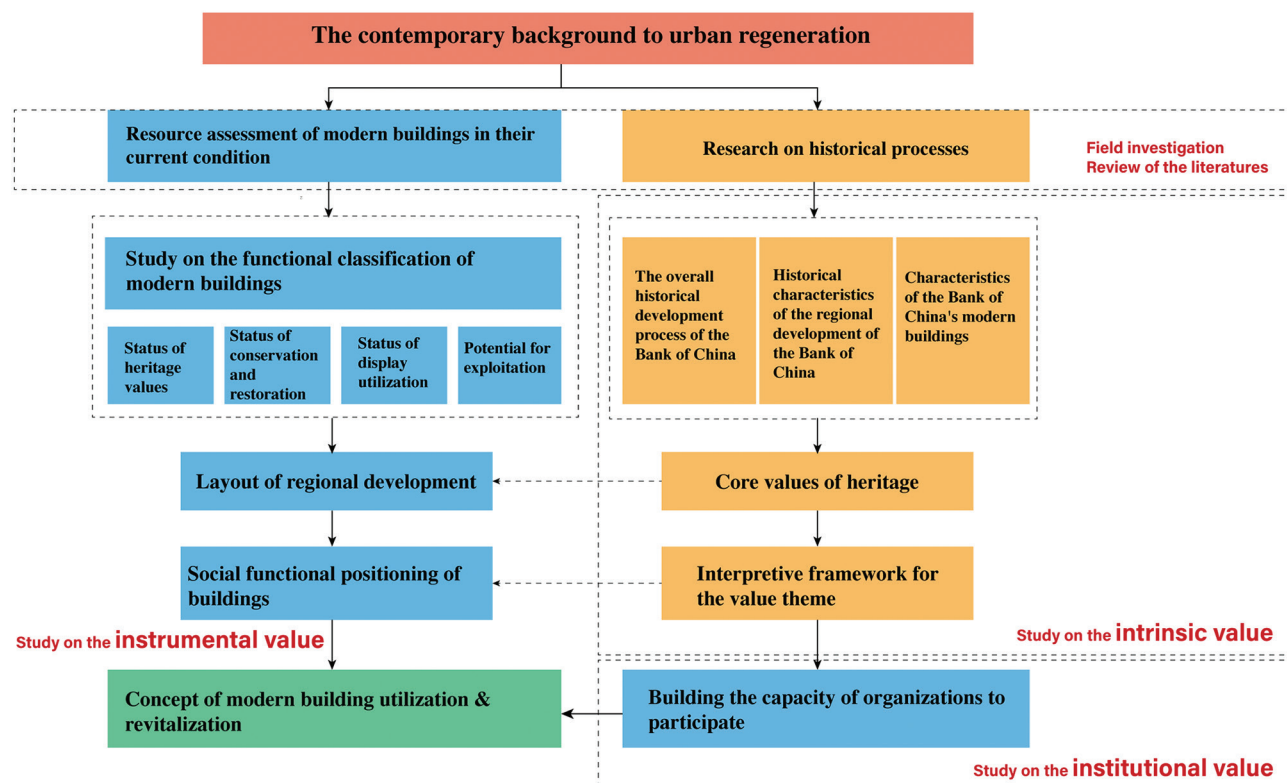


Figure 4. General analytical framework. Source: Drawing by Jun Wang

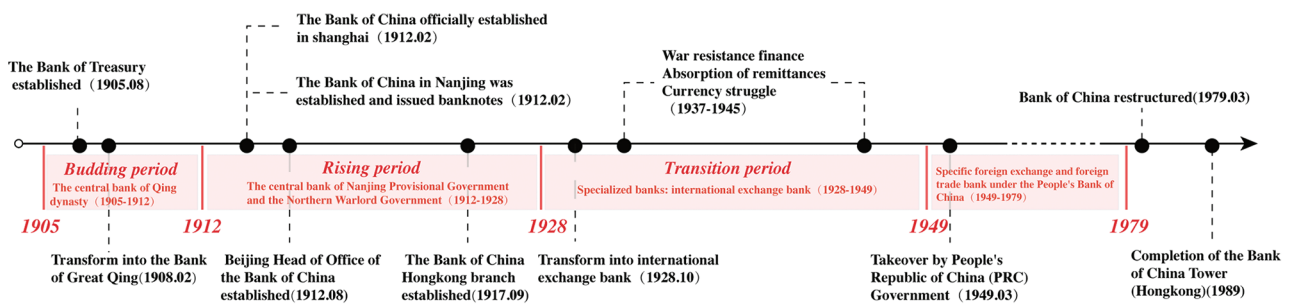


Figure 5. History of the Bank of China. Source: Drawing by Jun Wang

of overseas foreign exchange funds, serving the country’s import and export trade and playing a significant role in the international finance arena.

Following the outbreak of the Anti-Japanese War in 1937, the Bank of China proactively established international channels, promoted foreign trade, and sought overseas remittances to support the domestic anti-fascist war of resistance through its overseas institutions. Between 1939 and 1945, the Bank of China collected a total of 230 million US dollars in overseas remittances, significantly contributing to balancing foreign exchange receipts and payments.

After the year of 1949, the People’s Republic of China (PRC) Government assumed control of the Bank of China, eventually designating it as a specific foreign exchange and foreign trade bank under the People’s Bank of China. Since then, the socialist economic reform policy has canceled most inland banks, while Bank of China Hong Kong branches play a vital role in connecting mainland China and overseas businesses. It was not until 1979 that the Bank of China regrouped.

In brief, the intricate association between the Bank of China and the Chinese government has witnessed various dimensions of China’s financial, fiscal, political, and social matters throughout the first half of the 20<sup>th</sup> century (Figure 5). Over the past five decades, the Bank of China has not only witnessed China’s transformation into a modern nation-state but has also adeptly adapted to the multifaceted and ever-changing global landscape. In addition, it has relied on its worldwide branches to ensure the efficient mobilization of social capital, especially during financial crises, and has perpetually played a pivotal role in connecting the financial sector to stabilize the nation’s financial order during challenging times.

#### 4. Siting and development of the Bank of China buildings

The historical evolution of the Bank of China’s buildings is intrinsically linked to its overarching objectives and operational requirements. This section delves into the

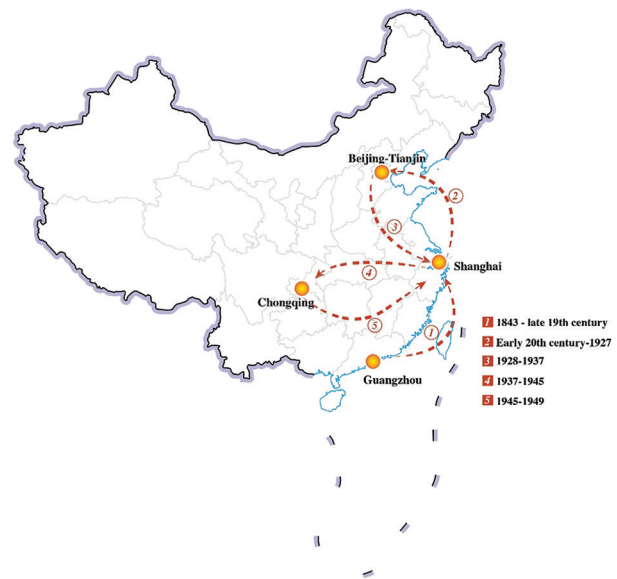


Figure 6. Changes in China’s financial center in the 19<sup>th</sup>–20<sup>th</sup> centuries. Source: Drawing by Jun Wang

historical context surrounding the establishment and utilization of these significant structures.

On a macro scale, the expansion of financial enterprises drove the establishment of branch offices – a trend notably evident within the Bank of China. The 1918 Statute of the Bank of China explicitly stipulates the need to establish branch offices in provincial capital cities and key commercial centers, alongside the central office in the capital (Editing Committee of the History of Bank of China, 1995). The strategic placement and layout of Bank of China’s office buildings in the modern era are closely intertwined with the shifting dynamics of China’s financial epicenter during the first half of the 20<sup>th</sup> century. Overall, this regional shift traced a path following “Guangzhou–Shanghai–Beijing–Tianjin–Shanghai–Chongqing–Shanghai” (Wu, 1994) (Figure 6).

By the end of the 19<sup>th</sup> century, after 50 years of economic development since the opening of the port in

1843, Shanghai had risen to become the foremost internal trade port, surpassing Guangzhou (Wu, 2002). This transformation gave rise to a cross-regional and national financial industry, culminating in the establishment of the Bank of China's inaugural office in February 1912 at the former site of the Bank of the Qing Dynasty, located at No. 50, Hankou Road, Shanghai (Figure 7).

However, under the dominance of the Northern Warlord Government, northern China emerged as a vast arena for financial activities. This shift propelled the financial hub of northern China, anchored around Tianjin–Beijing, to rapidly surpass Shanghai, thus becoming the nation's financial epicenter. It was not until the fall of the Northern Warlord Government in 1927 that the National Government of Nanjing established the central bank in Shanghai and relocated the head offices of the Bank of China and the Bank of Communications to Shanghai. This marked the renewal shift of the financial center to the southern regions.

In 1937, as the Japanese invasion of China gradually encroached upon the eastern seaboard, the capital of the National Government of Nanjing relocated to inland Chongqing. Consequently, financial institutions along the coast, headed by the Bank of China, also migrated to Chongqing. This migration shifted the financial center westward, making Chongqing the epicenter of the financial industry during the war.

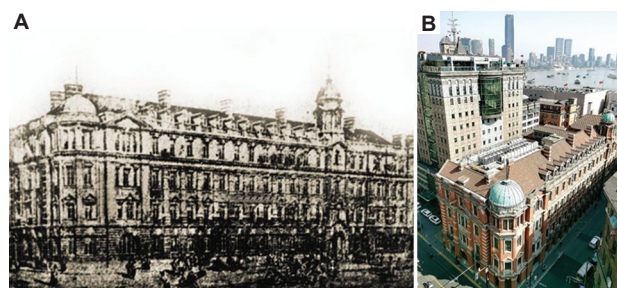
Following the victory in the Anti-Japanese War in 1945, Shanghai regained its status as the national financial center. Financial institutions and administrative centers gradually relocated to the east. Throughout this transitional period, the Bank of China played a key role in establishing, relocating, and strategically repositioning financial institutions in response to changing trends within national and regional financial hubs.

This context necessitated the banking industry to adapt to changes in financial centers while expanding their operations and adjusting the scale of their branches accordingly. Between 1912 and 1930, the Bank of China expanded its branches to meet the varied financial service requirements of different regions, reaching a total of 229 domestic branches by 1942 (Editing Committee of the History of Bank of China & Second Historical Archives of China, 1991). This historic institutional context provides a comprehensive overview of the origins and dispersion of the Bank of China's historic architectural legacy, which continues to resonate in contemporary times.

## 5. Analysis of the status of the Bank of China buildings

### 5.1. Distribution of modern bank buildings

Urban construction and socioeconomic development in the country during the second half of the 20<sup>th</sup> century



**Figure 7.** The former site of the Bank of Qing Dynasty in Shanghai, where the Bank of China opened on February 5, 1912. (A) Historic Images. (B) Current appearance (2022). Source: (A) Photo by the Party History Office of the Bank of China; (B) Photo by Xiaofan Du

resulted in the disappearance of most structures once used by the Bank of China. Through our field research, we have identified 26 modern buildings associated with the Bank of China that hold historical significance and stand as relics of the past.

These modern buildings span provinces and cities such as Heilongjiang, Liaoning, Beijing, Tianjin, Shandong, Shanxi, Jiangsu, Shanghai, Zhejiang, Fujian, Guangxi, Yunnan, Chongqing, Hubei, and Hong Kong. Two distinct geographical patterns have emerged: a horizontal spread along the Yangtze River and a vertical distribution along the east coast. This distribution closely correlates with varying levels of economic development across different regions. Cities located along rivers and coastlines possess inherent transportation advantages, thriving as bustling trade and commerce hubs, surpassing inland cities in economic development. Moreover, the substantial presence of banking offices in cities along eastern rivers and coastal areas formed the foundation for the preservation of these financial buildings (Figure 8).

On a micro level, the arrangement and construction of banks during the early Qing dynasty, coupled with the surge in the construction of bank buildings during the 1930s due to the dramatic increase in business activities, share a common trait: strategic placement in areas with financial potential, often serving as transportation hubs. Most of the existing Bank of China buildings are nestled within the core neighborhoods of various cities (Table 2). As documented in the Bank's history, these buildings were located in the “central business districts and transport hubs, solidly constructed, and representing the first-class buildings of the time” (Editing Committee of the History of Bank of China & Second Historical Archives of China, 1991, p.173). Consequently, Bank of China buildings in several regions swiftly transformed into iconic symbols of the local urban landscape soon after their construction (Cartier, 1999).



Figure 8. Map of the existing modern buildings of the Bank of China. Source: Photos by Jun Wang and Xiaofan Du (except for the photos of the two buildings in Hong Kong, which are obtained from the Internet); Drawing by Jun Wang

### 5.2. Time of construction, building layout, and architectural style

The emergence of China's modern banking industry introduced the Western world's financial concepts and, along with them, Western-style bank architecture. Contemporary Western materials, technology, capital, talent, and ideas facilitated the adoption of this new architectural style in China. Modern Western-style bank buildings, distinguished by their grandeur appearance, notably differ from traditional Chinese money changers in terms of decorative materials, spatial layout, and architectural style, particularly in building expansion scale and modern form and design.

Lefebvre (1992) regards banks as abstract spaces where capitalist and neo-capitalist countries engage

in production. In this sense, the modern buildings of the Bank of China serve as functional carriers, embodying the empirical value of architecture and construction and reflecting cultural and architectural significance.

#### 5.2.1. Construction time

The modern buildings of the Bank of China, as physical structures, encapsulate a temporal panorama of modern architectural evolution spanning a hundred years. Based on the earlier discussion of the Bank of China's historical evolution, these existing modern buildings can be classified into four phases: late Qing Dynasty buildings (before 1912), buildings from the period of the Northern Warlord Government (1912 – 1928), buildings from the period of

**Table 2. Existing Bank of China Buildings and their addresses**

No.	Name of the building	Provinces	Current address
1	The former site of the Bank of China Harbin Branch	Heilongjiang	No. 365, Jingyu Street, Daowai District, Harbin, China
2	Bank of China Dalian Branch	Liaoning	No. 7, Zhongshan Square, Dalian
3	Former site of the Bank of the Treasury of the Qing Dynasty	Beijing	No. 25, Xijiaominxiang Lane
4	Bank of China Tianjin Branch	Tianjin	No. 80, Jiefangbei Road, Heping District
5	Bank of China Yantai Branch	Shandong	No. 33, Customs Street, Zhifu District, Yantai, China
6	Former site of Bank of China Qingdao Branch		No. 64-66, Zhongshan Road, Shinan District, Qingdao, China
7	The old site of the Bank of China Shanxi Branch	Shanxi	No. 41 (formerly No. 32), Gulou Street, Taiyuan, Shanxi Province, China
8	The former site of the Bank of China Nanjing Branch (Nanjing Branch1)	Jiangsu	No. 66, Xianguan Dajie, Gulou District, Nanjing, China
9	Bank of China Jewelry Gallery New Buildings (Nanjing Branch2)		No. 23, Baixia Road, Qinhuai District, Nanjing, China
10	Bank of China Suzhou Branch		Dexinli, Gate of Heaven Community, Gusu District, Suzhou, China
11	The former site of the Bank of China in Wuhu	Anhui	No. 86, Zhong Er Street, Jinghu District, Wuhu, China
12	Bank of China Shanghai Branch (Shanghai Branch1)	Shanghai	No. 50, Hankou Road
13	Bank of China Hongkou Building (Shanghai Branch2)		No. 894 North Sichuan Road
14	Bank of China Tongfu Building (Shanghai Branch3)		No. 801-803, West Nanjing Road
15	Former site of the Bank of China office and warehouse in Shanghai (Shanghai Branch4)		No. 1040, North Suzhou Road
16	Bank of China on the Bund (Shanghai Branch5)		No. 23, Zhongshan Dong Yi Road
17	Former site of Bank of China, Anchang, Shaoxing	Zhejiang	No. 75, East Street, Anchang Town, Shaoxing City, China
18	Bank of China Moganshan Office		No. 373 and 374, Yinshan Street, Moganshan
19	Former site of Bank of China Huzhou Sub-branch		No. 61, Ping'an Lane, Yishang Street, Wuxing District, Huzhou, China
20	Former site of Bank of China Hankou Branch	Hubei	No. 1021 and 1023, Zhongshan Road, Dazhi Street, Jiangnan District, Wuhan, China
21	The former site of the Bank of China in Chongqing	Chongqing	No. 41, Xinhua Road, Xiaoshizi, Yuzhong District, Chongqing, China
22	Bank of China Kunming Branch	Yunnan	No. 269, No. 270, No. 271, Guardian Road, Kunming, China
23	Bank of China Gulangyu Office	Fujian	No. 30, Wangyan Road, Xiamen, China
24	Former site of the Beihai Exchange Office of the Bank of China	Guangxi	The intersection of Customs Road and Zhuhai East Road, Beihai, China
25	Bank of China Building (Hong Kong)	Hong Kong	No. 2A, Des Voeux Road Central, Hong Kong
26	Bank of China Tower (Hong Kong)		No. 1, Garden Road, Hong Kong

Note: The streets in the table are all located in historically important urban areas. Source: Table by Jun Wang

**Table 3. Construction time of the Bank of China's modern buildings**

Construction time	Location of the Bank of China modern buildings (city)	Total
Before 1912	Beihai, Shanghai Hankou Road, Harbin, Dalian, Beijing, Suzhou, Shaoxing, Huzhou, Taiyuan	9
1912 – 1928	Tianjin, Yantai, Nanjing Xiaguan, Wuhu, Hankou, Gulangyu Island	6
1928 – 1949	Qingdao, Nanjing Qinhuai, Shanghai Zhongshan East Road, Shanghai Sichuan North Road, Shanghai Nanjing West Road, Shanghai North Suzhou Road, Moganshan, Chongqing, Kunming	9
1949 – 1997	Hong Kong	2

Note: This table classifies Bank of China buildings according to the timeline and indicates their locations. Source: Table by Jun Wang

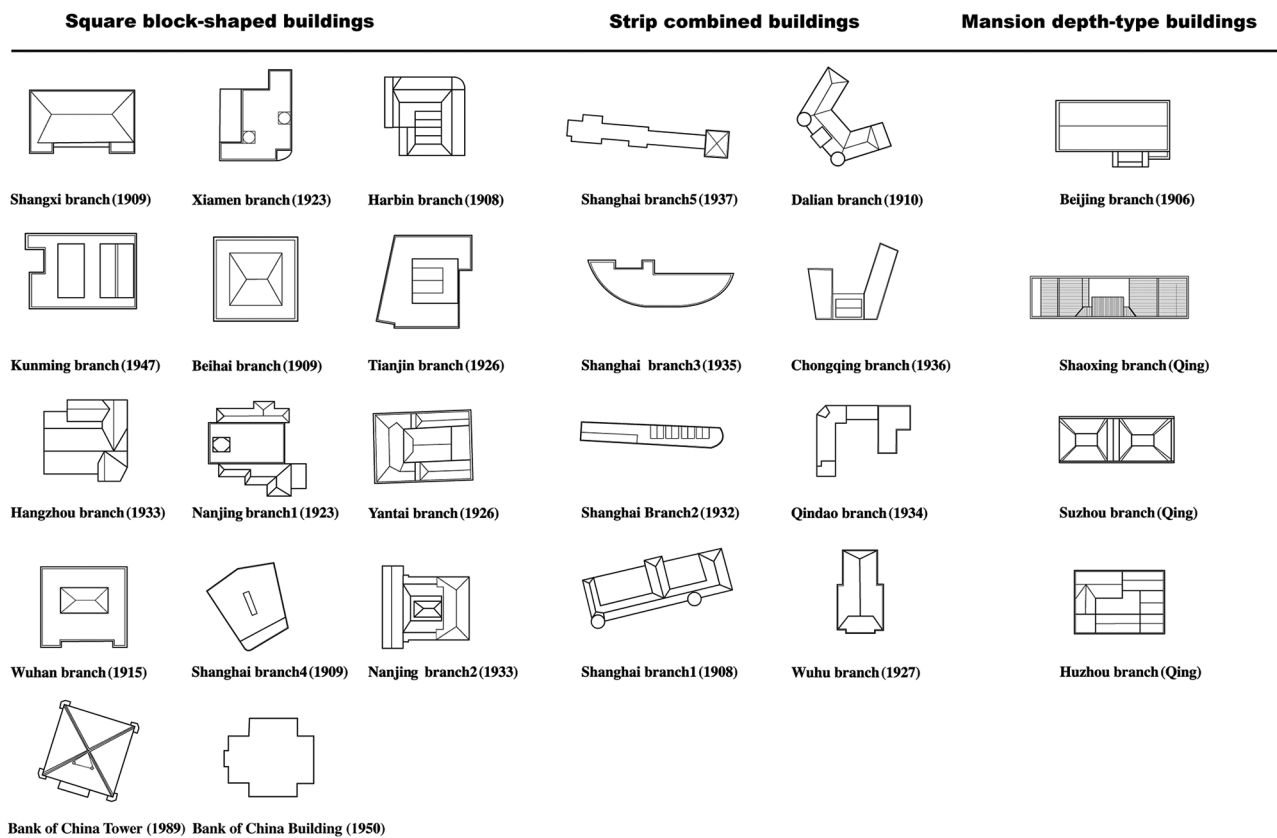


Figure 9. Bank of China's modern buildings Plan Layout Type Statistics. Source: Drawing by Jun Wang J

the National Government of Nanjing (1928 – 1949), and British Hong Kong buildings (1949 – 1997) (Table 3).

### 5.2.2. Building layout

The existing 26 modern buildings of the Bank of China exhibit three main types of layouts: square block-shaped buildings, strip combined buildings, and mansion depth-type buildings (Figure 9), which are detailed as follows:

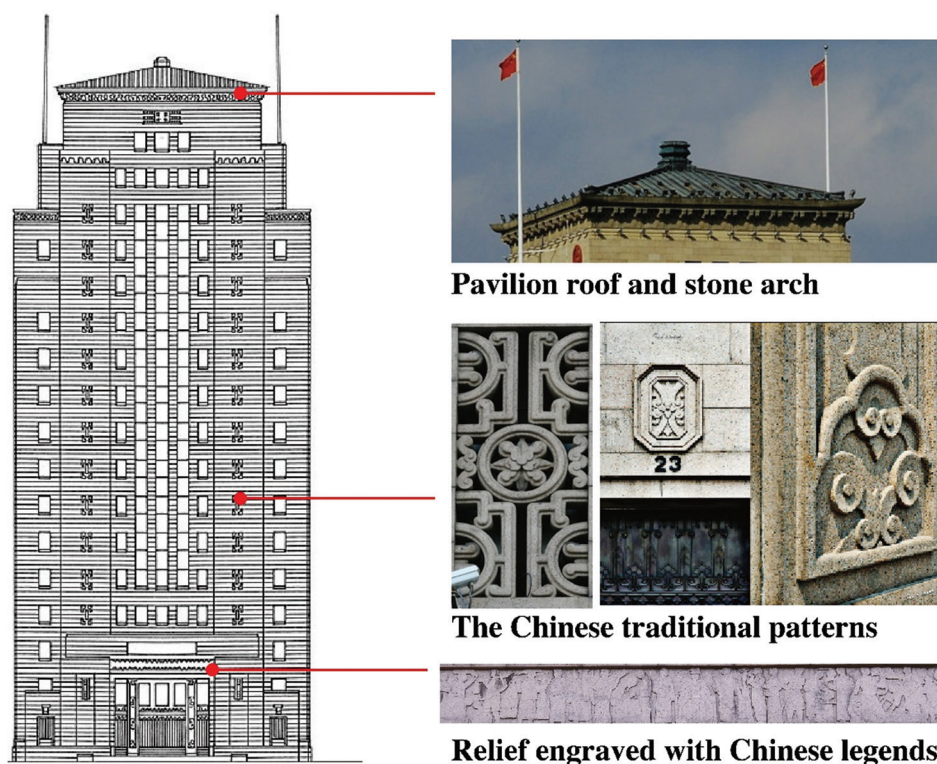
- (i) Square block-shaped buildings: These structures adopt a central layout often arranged in a square plan form. Characterized by buildings centered amidst open space, they integrate the creation of public business halls, becoming the spatial symbol of modern financial buildings. Over time, these buildings evolved from early layouts with cross-flow patterns around patios to more functional spaces surrounding bright, spacious public halls, enhancing functional space and passenger flow efficiency.
- (ii) Strip-combined buildings: These structures typically consist of long, narrow buildings or a combination of multiple strip-like buildings. Similar to square block-shaped buildings, they also incorporate the concept of a public business hall.



Figure 10. Differences in commercial space layout between traditional and modern banks. (A) Interior of the Shaoxing branch building, with mixed commercial and residential usage. (B) Interior space of the Tianjin branch building, with a spacious lobby and organized office compartments. Source: Photos by Jun Wang

- (iii) Mansion depth-type buildings: This architectural style incorporates courtyards or other interior spaces that provide depth to the building's layout, often enhancing the building's esthetics and functionality.

From a design perspective, modern bank buildings differ significantly from traditional financial institutions, which featured mixed residential and business spaces (Xie *et al.*, 2013). Modern bank buildings compartmentalize spaces for public services, emphasizing moving line design, spatial organization, and risk management. These buildings encompass public areas for external business,



**Figure 11.** Bank of China building in Shanghai (Shanghai branch 5) with Chinese cultural elements. Source: Drawings and photos by Jun Wang (based on an elevation plan by the Party History Office of the Bank of China)

internal office areas, and auxiliary annexes (Figure 10). They represent a transition from the traditional financial buildings of the late Qing dynasty to advanced modern financial spaces, offering a visual narrative of China's evolution and development while retaining cultural identity (Figure 11).

Just as the soaring domes and vaults of European religious buildings create a sacred space that guides worshippers' spirits upward, Bank of China's architecture also serves as a guide – though not for spiritual ascension, but for a sense of order. The design of flat space instills a sense of rigor, trustworthiness, and authority. In these modern bank buildings, the lobby serves as the core space that directs and organizes the flow of the public. It is through this central hub that visitors and clients navigate the building, conducting their financial transactions, inquiries, and interactions.

From this viewpoint, Bank of China's modern buildings exemplify architectural space planning, predominantly guiding public flow through the lobby and ensuring a harmonious resource allocation.

### 5.2.3. Architectural style

The architectural styles of Bank of China buildings have evolved over time. In the early period, many banks adopted

Renaissance or eclectic styles, exemplified by buildings such as the Oriental Exchange Bank in Tianjin and the Russo-Chinese Bank. Some banks embraced Classical Revivalism, as seen in the Citibank in Tianjin. However, after the 1920s, influenced by modernist trends, some banks adopted a simpler and brightly modernist style, exemplified by the Belgian Bank in Tianjin.

Within the fusion of Chinese and Western architectural influences, these buildings encompass a diverse range of architectural styles, spanning traditional late Qing-dynasty Chinese structures, colonial verandas, classical revival, eclecticism, Art Deco, and modern buildings with nationalist themes. This diversity stems from historical construction practices influenced by foreign architectural concepts blending with indigenous building traditions. This transformation reflects the evolving cultural mindset of Chinese architects during this period, characterized by a trajectory from passive absorption and assimilation to a phase of imitation, borrowing, and culminating in architectural expressions, reflecting both local identity and scientific principles (Lai, 2008). This process illustrates a dynamic interplay between the "East" and the "West" within architectural discourse, signifying a shift in Chinese architectural values and esthetic trends toward



Figure 12. Schematic representation of the style and date of construction of the existing modern buildings of the Bank of China. Source: Photos by Jun Wang and Xiaofan Du (Except for the photos of the two buildings in Hong Kong, which are obtained from the Internet)

modernization. This transformation holds particular esthetic and artistic value, as depicted in Figure 12.

### 5.3. Preservation and revitalization of modern buildings

Following the establishment of the People's Republic of China in 1949, the Bank of China underwent a transition in which it was acquired by the People's Bank of China (PBOC) and subsequently designated as a subordinate unit within the internal management of the PBOC. This transition brought about complex changes in the property rights and utilization rights of the modern buildings. At present, these modern buildings serve various purposes: some continue as original financial service spaces, while others have been repurposed as specialized exhibition halls or for commercial use. Unfortunately, certain modern buildings now lie vacant, deteriorating, and in desperate need of preservation and restoration. Based on our field research, these buildings fall into six functional categories: financial function, specialized museum exhibition function, office function, residential function, mixed-use, and unused (Table 4).

Despite their profound historical and architectural value, the majority of Bank of China's modern buildings

have not undergone innovative adaptive reuse, which can be attributed to challenges stemming from issues related to property rights entanglements, a lack of comprehensive research, and unfavorable cost-benefit considerations.

Seven modern buildings have been converted into exhibition spaces, including industry museums and cultural business establishments. These adaptive functions represent a continuation of the modern buildings' life cycle and serve as supplementary means of interpretation (Figure 13). However, notable shortcomings persist concerning heritage interpretation and exhibition education

- (i) Curatorial concepts and content: The exhibition spaces often lack innovative approaches to narrating historical journeys, typically dominated by generalized history exhibits that fail to convey individuality, emotions, and memories.
- (ii) Forms of exhibitions: They primarily rely on traditional modes such as graphics and text, with insufficient incorporation of engaging exhibits, information technology, and other interactive elements.
- (iii) Operational system: The absence of professional curators not only hampers deep integration with the historic lineage concerning exhibition positioning but

Table 4. Usage statistics of existing Bank of China's modern buildings

Function Type	Name of the building	Current use
Financial institutions	Former site of the Bank of China Dalian branch	CITIC Bank
	Former site of the Bank of the Treasury of the Qing Dynasty	ICBC Bank
	Former site of the Bank of China Qingdao branch	ICBC & BOC Bank
	Former site of the Bank of China Shanxi branch	PBOC Bank
	Bank of China Wuhu branch	ICBC Bank
Office spaces	Bank of China building (Hong Kong)	Bank of China Hong Kong Private Banking
	Former site of the Bank of China office and warehouse in Shanghai	JK1933 Office
Museum/Exhibition	The former site of the Bank of China Nanjing branch	Used by government agencies and institutions
	Former site of the Beihai Exchange office of the Bank of China	Beihai Modern Customs Museum
	Former site of Bank of China, Anchang, Shaoxing	Bank of China Education Base
	Bank of China Tianjin branch	Bank of China Museum Tianjin branch
Residential	Old Bank of China Gulangyu office	People's Bank Currency Museum
	Bank of China Moganshan office	Leased as a guest house
	Bank of China Suzhou branch	Local inhabitants
Hybrid functions	Bank of China Kunming branch	Historic displays and bank operations
	Former site of Bank of China Hankou branch	Mission schools and bank operations
	Bank of China Shanghai branch	Historic displays and bank operations
	Bank of China Hongkou building	ICBC use and residency
	Bank of China Tongfu building	ICBC use and residency
	Bank of China on the Bund	Historic displays and bank operations
	Bank of China Tower (Hong Kong)	Bank operations and other types of business
Idle	The former site of the Bank of China in Chongqing	Lying idle
	Bank of China Yantai Branch	
	Bank of China Nanjing Jewellery Gallery New Buildings	
	The former site of the Bank of China Harbin branch	
	Former site of Bank of China Huzhou sub-branch	

Note: The table provides statistics on the preservation and use of the existing modern buildings of the Bank of China, based on the author's fieldwork and web-based data searches. Source: Table by Jun Wang



Figure 13. Modern bank buildings functioning as museums. (A and B) Classical revival exterior and interior exhibits of the Wuhan branch modern buildings. (C and D) Classical revival exterior and interior exhibits of the Tianjin branch modern buildings. Source: Photos by Jun Wang

also impedes sustaining post-renovation interpretation, heritage education, and activity organization.

These challenges underscore the importance of comprehensively understanding the historical context, contemporary needs, and architectural characteristics of the buildings. Failing to address these aspects can lead to multifaceted issues in heritage conservation and utilization.

## 6. Discussion

Transitioning from functional architectural entities to cultural and monumental spaces, modern buildings ideally merit preservation and innovative utilization. Unfortunately, the lack of value recognition and an overly singular mode of utilization often result in property rights conversion, prolonged idling, or even demolition of these valuable structures. This common challenge pervades numerous modern buildings across urban China, presenting a shared issue in urban renewal and

conservation endeavors. Consequently, there is a pressing need to delve deeper into the value positioning of such buildings in the context of urban regeneration and to explore innovative approaches for adaptive utilization, as emphasized through the analysis of the Bank of China case.

## 6.1. The value of modern bank buildings in urban renewal contexts

In contemporary China's pursuit of a "conservation-oriented society," the renovation of buildings for sustainable use has garnered attention (Zheng, 2007). Bank-type modern buildings, pivotal in shaping urban historic landscapes and significant in urban renewal planning, harbor immense potential for research and utilization. However, unlike the well-established heritage conservation systems in the West, China's approach to conserving and utilizing these buildings is still at its nascent stage, lacking systematic value assessment and mature sustainable use experiences. Nonetheless, through the analysis of the Bank of China case, several identified value dimensions deserve future attention in the renewal and refurbishment of bank-type modern buildings, including:

- (i) **Historic value:** These buildings symbolize the birth of China's modern financial industry, embodying its conscious commitment to national development during times of societal transformation. They stand as a witness to the dynamic evolution of various facets of modern society, including economy, culture, military, ideology, science, and technology, providing a quintessential reference for narrating the nation's contemporary development.
- (ii) **Artistic value:** Modern bank buildings masterfully organize functional financial and cultural spaces within constrained physical parameters. Representing high-quality, early modern financial architectural heritage within China, these buildings reflect both Chinese and Western cultural influences, shaping city skylines and mirroring constantly changing modern aesthetic trends.
- (iii) **Socio-cultural value:** As banking industry pioneers, modern bank buildings were the spatial embodiment of the banking system revolution. These structures transformed modern financial culture, shaping public understanding and trust in financial services, disseminating modern financial cultural concepts, and fostering social memory and imagination.

## 6.2. From value analysis to display: A vital pathway for revitalization

China's modern era has its own special cultural characteristics and historical trajectory (Zhang *et al.*, 2020). The historical and cultural significance of the Bank of China's

modern buildings renders them socially and politically crucial in urban renewal. As symbols of the national financial institution, the renovation and revitalization of these buildings are usually led by the government, limiting possibilities of purely commercial renovation.

Previous surveys have shown that museum-oriented approaches, while capable of revealing historic connotations and attracting public interest, often lack systematic value assessment and historic research in curation. Repetitive exhibitions encroach on valuable space within these modern buildings. Public knowledge gaps about modern financial architecture indicate a broader societal deficiency in recognizing the value of such architecture. This gap emphasizes the need to establish an effective link from value analysis to interpretation and display. Rethinking the history behind these modern buildings and abandoning inherent notions of demolition and reconstruction in modern urban design are pivotal. A proposed use strategy, based on value analysis, offers suggestions for future adaptive reuse while preserving cultural identity.

### 6.2.1. Master planning: Zoning utilization

Based on historic value, geographic location, and social environment, we have constructed a master plan of "three metropolises, five areas, and multi-point linkage." This composite plan forms a pattern of three metropolises as geographic centers and five major areas as cultural zoning, providing a basic direction of value interpretation across different areas (Figure 14).

### 6.2.2. Intrinsic value: Interpretation analysis framework

By analyzing the historical process, construction, and layout of the Bank of China's modern buildings, we can see their fundamental drive rooted in a public and nationalistic ethos. Evident in the pursuit of national independence, wealth, and strength, and original intent to serve society, these buildings epitomize a commitment to global integration with equality and openness. Their spirit of innovation has been a catalyst for industry transformation. Recognizing this intrinsic value, we have developed a framework to interpret this core value through various themes, further refining it through a structured approach called "General theme-Sub-themes-Topics," applied across multiple exhibition themes (Figure 15).

### 6.2.3. Instrumental value: Social function positioning

The value interpretation framework is an essential prerequisite in conserving and utilizing buildings, anchoring decision-making processes. Considering the heritage value, history, culture, and preservation status is crucial when determining these building's social

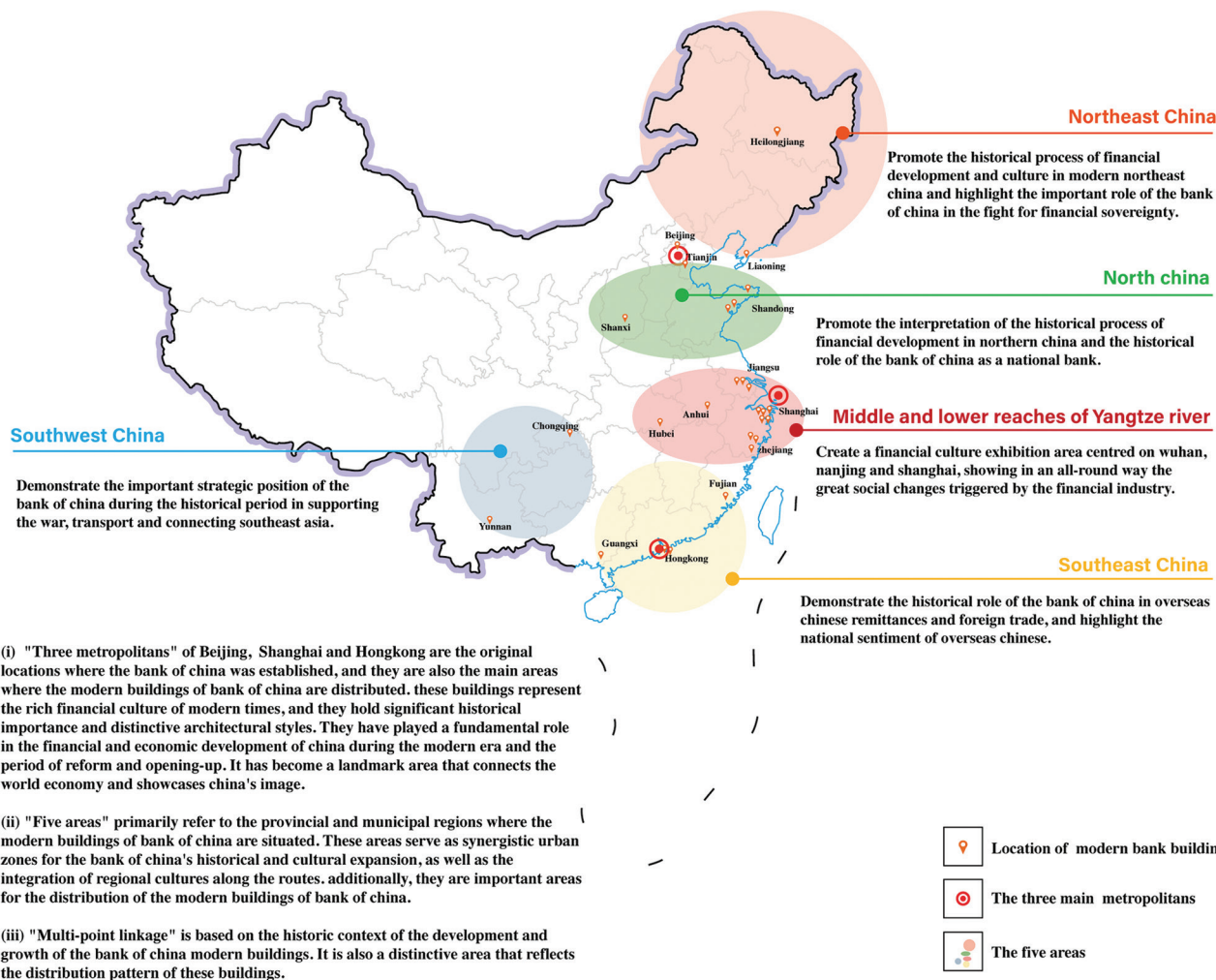


Figure 14. A master plan of "Three metropolises, Five areas, and Multi-point linkage" for the existing Bank of China buildings. Source: Drawing by Jun Wang and Xiaofan Du

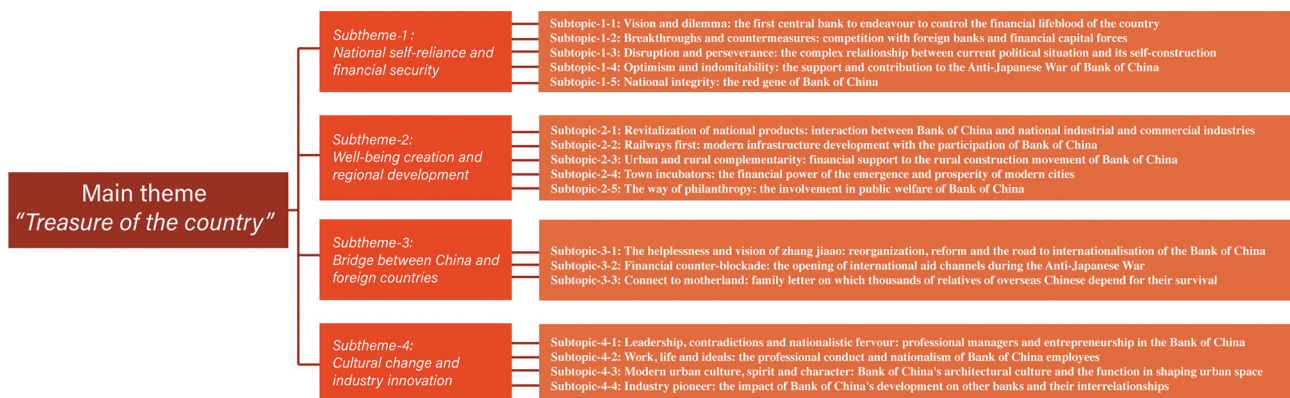


Figure 15. Interpretation framework for existing Bank of China buildings. Source: Drawing by Jun Wang and Xiaofan Du

functions. This aids in identifying suitable adaptive reuses, encompassing cultural education, financial and commercial activities, tourism and leisure, and cultural

landmarks. Renovators can drive innovative development while adhering to value interpretation principles, transforming spaces into innovation and entrepreneurship

hubs, libraries, financial clubs, study centers, landmark attractions, and cultural meeting rooms. This approach aligns with development needs with local economic and cultural legacy perpetuation.

#### **6.2.4. Institutional value: Organizational capacity building**

The adaptive reuse of modern buildings implies sustainable development. Therefore, revitalizing and utilizing Bank of China's modern buildings while offering functional services to society necessitates fostering strong social bonds around these architectural heritages. Specific measures include enhancing collaboration between responsible enterprises, heritage protection departments, and the public. They can organize diverse economic and cultural activities to involve the entire society in the preservation and utilization of the modern buildings of the Bank of China.

## **7. Conclusion**

China, like many post-colonial nations, boasts a significant legacy of modern bank buildings influenced by Western financial concepts and architectural culture. As the witnesses to the colonial era fade away, these buildings increasingly signify past memories. Consequently, many will be considered as cultural heritage, acquiring new meaning in contemporary contexts. This paper addresses the challenge of studying these buildings comprehensively, ensuring good integration into urban environments while preserving their cultural identities.

Using the Bank of China, a pioneer of China's modern financial industry, as a case study, this paper analyzes the history and current situation of its remaining architectural heritage. The findings highlight the rich historical value embedded in the Bank of China's modern buildings, symbolizing critical events in China's modern architectural, social, and cultural history. Unfortunately, a lack of comprehension regarding the historical and cultural significance of these buildings among owners often results in a standardized and crude approach to renovation, leading to the erosion of historical integrity.

In this paper, these bank buildings are regarded as a serial cultural heritage, interpreted across various thematic values, and future directions for their use from the perspective of regional development are proposed. Emphasizing the necessity for ongoing value research and interpretation across all stages of modern building lifecycles, this paper underscores the shared mission and responsibility of architects and restorers to present and renovate the architectural heritage in a manner that preserves historic significance while creating a "living" tradition to meet contemporary societal needs.

This paper holds significance in two key aspects. First, amidst limited practitioners and financial education in China, it contributes to enhance public understanding of bank buildings. By reducing one-sided criticisms of these structures as mere colonial heritage, it highlights their significance as national treasures of the early 20<sup>th</sup> century. Second, considering the property rights and historical symbolism of these buildings, their renovation and management necessitate government intervention. This paper provides directions for their subsequent protection and utilization from the perspective of value interpretation and demonstration.

Furthermore, the interconnections between heritage protection, value interpretation, and adaptive reuse of buildings warrant further exploration. Extensive discussions on building renovation design, feasibility, and tailored support construction will be crucial for these buildings to play a significant role in improving the aesthetics and vitality of urban space within the contemporary urban renewal landscape of China.

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## **Conflict of interest**

The authors declare that they have no competing interests.

## **Author contributions**

*Conceptualization:* Jun Wang, Mengyuan Zhou

*Formal analysis:* Jun Wang, Mengyuan Zhou

*Investigation:* Jun Wang, Mengyuan Zhou

*Methodology:* Jun Wang, Mengyuan Zhou

*Writing – original draft:* Jun Wang

*Writing – review & editing:* All authors

## **Ethics approval and consent to participate**

Not applicable.

## Consent for publication

Not applicable.

## Availability of data

Raw data can be shared with readers upon reasonable request to the corresponding author.

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## ORIGINAL ARTICLE

RuiXue Multi-Hall-Human machine collaboration  
in reciprocal structuresPhilip F. Yuan<sup>1\*</sup>, Yueyang Wang<sup>2</sup>, Tianyi Gao<sup>3</sup>, and Yingzi Hu<sup>1</sup><sup>1</sup>Department of Architecture, College of Architecture and Urban Planning, Tongji University, Shanghai, China<sup>2</sup>Shanghai Fab-Union Architectural Technology and Digital Fabrication Co., Ltd, Shanghai, China<sup>3</sup>Shanghai Research Institute for Intelligent Autonomous Systems, Tongji University, Shanghai, China(This article belongs to the *Special Issue: Chinese Cities of Tomorrow: Computing and Prototyping Intelligent Forms of Future Urbanism*)**Abstract**

This article centers on the RuiXue Multi-Hall architectural design project in Chengdu, China, with a specific focus on a comprehensive workflow framework that integrates reciprocal geometric design and digital construction methods, primarily within the context of shell structures. The research expands on the concepts of structural design, adjustments of performance parameters, and the optimization of free-form shells. In addition, it outlines the spatial design approach for the shell structure. The study delves into reciprocal geometric design for the existing shell structure, establishing a library of reciprocal geometric shapes suitable for architectural design. The primary focus is on the application of these shapes to the shell structure, optimizing parameters for several grids within the library, and comparing various design schemes. Furthermore, the article discusses digital construction methods for the existing shell space and reciprocal structure, with a specific emphasis on the material performance of timber components. This discussion includes reciprocal timber structures and 3D-printed roofs for shell surfaces, all guided by a geometric control system to facilitate an interactive design and construction process. This research on reciprocal geometric design and digital construction methods for shell structures holds dual significance. It not only traces the historical development of reciprocal structures but also explores innovative construction methods using digital technology. The establishment of a comprehensive framework for reciprocal geometric design-construction is expected to catalyze innovative breakthroughs in future architectural design, spanning aspects such as space, form, materials, and structure.

**Keywords:** Parametric design; Reciprocal structures; Automation; Performance-driven design; Robotic arm; Shell structure

**1. Introduction**

Since the latter half of the 20<sup>th</sup> century, numerous scholars have engaged in theoretical research and the development of reciprocal structures. Prominent figures in this field include Graham Brown, John Chilton, Olga Popovic Larsen (Larsen, 2007), and Vito Bertin. Their collective efforts have propelled reciprocal structures beyond their

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traditional two-dimensional framework, enabling their application to more intricate, free-form surfaces in this digital age. This transformation in structural design is attributed to the synergy between computational power and mathematical algorithms. This synergy has given rise to a diverse range of structural design software platforms.

These innovative platforms are gradually replacing conventional physical design methods by offering more precise and efficient simulation capabilities. They facilitate a variety of structural modeling techniques, including finite element analysis, the force density method, and the dynamic equilibrium method. In addition, simulation algorithms play a pivotal role in the creation of digital fabrication tools that support parametric design, prefabrication, environmental control, precise positioning, and collaboration between humans and machines. These tools foster the concept of digital architecture, seamlessly integrating design, construction, and esthetics. In this context, technological advancements and iterative tool development contribute to the enrichment of esthetics.

Nonetheless, architects should remain vigilant in ensuring that their focus extends beyond esthetics. Functionality, construction feasibility, and economic viability should continue to be primary concerns.

This article introduces methods for the development of intelligent reciprocal systems for shell construction by establishing a comprehensive geometric control system and a digital wooden frame construction framework. The following research objectives were expected to be achieved:

- (i) The project's boundary limitations were defined by site constraints and internal conditions. The research team explored shell formation methods within these geometric boundaries.
- (ii) The structural performance of large-span, column-free shells was optimized through the application of reciprocal geometry. This approach utilizes parametric geometric design and shape optimization to enhance the efficiency and constructability of architectural structures.
- (iii) Intelligent reciprocal systems for shell construction were developed by establishing a comprehensive geometric control system and a digital wooden frame construction framework. This system clarifies the geometric logic of reciprocal structures during construction, integrating various geometric elements to achieve seamless digital design-construction synergy guided by reciprocal geometry.

In the digital era, reciprocal structures have become significantly more structurally robust and efficient. Their geometric properties hold immense potential for the creation of complex shell structures. Digital tools empower

architects to venture into innovative design possibilities and seamlessly incorporate construction considerations at the outset of the design phase. This approach has the potential to streamline the entire architectural process. The future of reciprocal structures hinges on the fusion of various fields, including the sciences and computer technology. Through this interdisciplinary collaboration, we can forge more innovative and sustainable architectural structures.

## 2. Reciprocal structure development overview

### 2.1. The three main phases of reciprocal structures

Early reciprocal structures were frequently constructed using wood, which was a readily available material. The transmission characteristics of these wooden members facilitated simple assembly, construction of nodes, and swift disassembly of these structures. Consequently, reciprocal structures piqued the interest of numerous human communities and found their origins in various early civilizations. They boast a lengthy and intricate history of development.

#### 2.2. Phase one: Early sprouting stage

In approximately 55 BC, Julius Caesar built a military bridge across the Rhine River, showcasing a structural design reminiscent of a reciprocal system (Caesar, 1851). This bridge utilized a brilliant technique of reciprocal components, seamlessly integrating with the turbulent river, effectively incorporating the swift water flow into its structural equilibrium. By employing simple nodes and reciprocal mechanisms, such as rope knots or wooden pegs, this remarkable 400 m-long bridge was rapidly constructed in just 10 days, making a substantial contribution to Caesar's subsequent military triumphs.

#### 2.3. Phase two: Preliminary research stage

From ancient times until the 20<sup>th</sup> century, the development of reciprocal structures had remained relatively stagnant. During this extended period, reciprocal geometry found its primary application in roofing and flooring, emphasizing radiating, and rotating patterns. Nevertheless, new forms of reciprocal geometry gradually emerged, including three-dimensional weaving, reciprocal extensions, and the proliferation of individual units.

In his renowned treatise "Codex Atlanticus" (De Vinci, 1978), Leonardo da Vinci sketched military bridges resembling the structures described in Julius Caesar's "Commentarii de Bello Gallico" (Caesar, 1851). Da Vinci exhibited his innovation in crafting various bridge types tailored to diverse construction environments. These

inventions encompassed inclined-support truss bridges and woven-arch bridges.

Da Vinci's journey in the realm of reciprocal geometries began with the initial two-dimensional linear interweaving of truss bridges, evolving into the two-dimensional curved extensions seen in woven-arch bridges. He artfully applied the principles of weaving to explore reciprocal geometries grounded in regular geometric shapes, such as triangles and polygons. Furthermore, these geometric principles served as a foundation for the development of dome structures that could be expansively extended outward (De Honnecourt, 2012).

## 2.4. Phase three: Theoretical clarity and diverse practical stages

Since the beginning of the 21<sup>st</sup> century, exploration into reciprocal structures, both geometrically and structurally, has become increasingly diverse, gradually evolving into a systematic field of research and synthesis. At the turn of the 20<sup>th</sup> and 21<sup>st</sup> centuries, scholars such as Graham Brown, John Chilton, and Olga Popovich-Larsen played a pivotal role in advancing systematic studies (Larsen, 2007; Popovic Larsen, 2014; Larsen, 2019), laying the foundation for refining the definition and the fundamental theoretical framework of reciprocal structures. Piekarski (2023) developed a static analysis model for structural grillages, taking into account the bending stiffness, shear stiffness, and axial stiffness of reciprocal beams. The results provide valuable theoretical support for the structural design and application of reciprocal beam grillages.

Overall, reciprocal geometry underwent substantial theoretical development and extensive practical exploration during the 21<sup>st</sup> century. This period of exploration was predominantly centered around rotational reciprocal geometry, with limited research on woven reciprocal geometry. Gradually, this exploration began to delve into the core issue of reciprocal geometry research, which revolves around studying the simplest geometric forms and the fundamental principles governing the structural performance of reciprocal geometry units.

Advancements in computational design technology and research on diverse geometric prototypes and materials have greatly expanded the generation mechanisms, prototype meshes, and even the structural units of reciprocal geometry, offering more extensive forms of expression. However, as long as the fundamental structural characteristic of reciprocal geometry, which involves "mutually supporting and transmitting forces," is understood, this geometric form, closely linked to the expression of structural performance, continues to hold significant long-term development potential.

## 2.5. Research on the geometric theory of mutual support structures worldwide

In the 21<sup>st</sup> century, with the establishment of numerous structural practices involving reciprocal geometry and the rapid development of parametric software, top-down generative tools, and various generative algorithms have increasingly found applications in reciprocal geometry structural designs.

In 2011, Pavel initiated a study on the geometric characteristics of reciprocal structural units, suggesting that plate reciprocal units have more complex connection methods and shape-influencing parameters (Baverel & Pugnale, 2014). In 2013, Pavel explored the assembly of double-layer structures with spatial thickness, utilizing genetic algorithms and dynamic relaxation form-finding methods (Douthe & Baverel, 2013). In 2018, Pavel integrated form-finding methods for reciprocals under geometric parameter constraints with the optimization of mechanical parameters. Pavel employed a translation optimization algorithm for rods to make the reciprocal units as coplanar as possible or easily approximated by larger surfaces (Mesnil *et al.*, 2018). These research findings were then applied by Pavel to the design and construction of a 50 sqm<sup>2</sup> exhibition hall. This application led to the proposition of a coplanar optimization method for reciprocal mesh construction and the establishment of the external frame-shell hybrid structure system in construction (Douthe *et al.*, 2018; Kuzmenko *et al.*, 2021).

In 2014, Uwe Tessendorf's team at ETH Zurich introduced a space mesh tangent transformation algorithm (Thönnissen & Werenfels, 2011). Concurrently, Dario Pagliari's team at the University of Aalborg proposed a space mesh node transformation algorithm (Parigi & Pugnale, 2014). In addition, the team led by Song Peng at Nanyang Technological University developed a software package for interpenetrating geometry meshing, employing an interpenetrating geometry unit tessellation algorithm (Song *et al.*, 2013).

## 2.6. Digital construction practice

The development of digital technology in the 21<sup>st</sup> century has spurred advancements in the research and application of reciprocal structures, thereby diversifying this field. An exemplary illustration of these achievements is Wang Shu's "Decayed Dome," which was exhibited at the 2010 Venice Biennale (Frampton *et al.*, 2017). Renowned Japanese architect Shigeru Ban has also played a significant role by conducting workshops on wooden reciprocal structures at esteemed institutions such as Rice University and Tongji University. Moreover, he has ventured into the exploration of diverse reciprocal structures for timber, as observed in

projects such as the Oguni Onsen Spa in Oita, Japan, and the Swatch Omega Headquarters.

In 2010, Sanbe designed a complex 3D canopy for the Rokko Mountain observatory. This distinctive canopy boasts a 16-meter diameter and is constructed from interconnected geometric units (Larsen, 2014). The canopy's design is rooted in the principles of the Voronoi diagram, with its individual members dimensioned using the SFG solver (Goto *et al.*, 2011). The steel pipes employed in this structure come in two sizes: 50 mm for the primary framework and 15–20 mm for the secondary support structure. The final design minimizes the total length of the structural members, optimizing both efficiency and functionality.

### 3. RuiXue blending into the rural landscape

The architectural design of RuiXue Multi-Hall seamlessly integrates with the natural landscape (Figure 1) by employing computational structures, resulting in a multidimensional geometric shell that harmonizes with the surrounding environment. This unique form, reminiscent of mountains and drifting clouds, establishes a meaningful connection with the earth and emphasizes tree preservation, encapsulating rural forestry esthetics.

The amalgamation of architectural and spatial design enables the creation of a continuous indoor-outdoor space, facilitating various cultural activities, exhibitions, forums, and agricultural presentations. The use of eco-friendly materials, robotic manufacturing, weaving techniques, and 3D-printed walls exemplifies intelligent construction practices that not only support rural revitalization but also pay homage to traditional craftsmanship.

## 4. The architectural shape design of free-form shells

### 4.1. Rationalization of the boundary of a free curve

A two-step method is proposed for achieving stable control of plane boundary shapes in building projects. The method first utilizes linear line segments to approximate discrete, nearly straight-line curve segments with low discreteness. Next, it employs second-order rational circular arcs to approximate curve segments with higher discreteness, ensuring continuity at the splicing points. This method results in a relatively stable control line for the plane boundary shape. Subsequently, the three-dimensional cable-net space is computed using the particle-spring method and divided into indoor and semi-outdoor spaces based on architectural form and function. The building consists of interconnected shells on the north side, forming an indoor exhibition hall, a main office area, and a logistics

area on the southwest side. In addition, semi-outdoor spaces are created by small-scale shells located between functional blocks. On the south side, a shell, combined with a central courtyard and variations in site elevation, facilitates the construction of a semi-outdoor theater with stair stands and stage space (Figure 2).

### 4.2. Shell structure performance optimization

The process of optimizing the shell shape begins with the rationalization of the boundary control curves to achieve a smooth and reasonable initial shape (Figure 3). Subsequently, the particle-spring algorithm is employed to compute a stable shell shape, followed by multi-round functional space optimization to obtain the fundamental free-form continuous shell prototype. This procedure primarily focuses on the two-dimensional spatial parameter optimization of the architectural entrance space (E1–E6) and the internal space of the shell (S1–S7).

To enhance the height-to-function ratio and prevent an imposing scale from a human perspective, the height of the



Figure 1. Ruixue Multi-Hall blending into the rural landscape. Source: Photos by Wongke

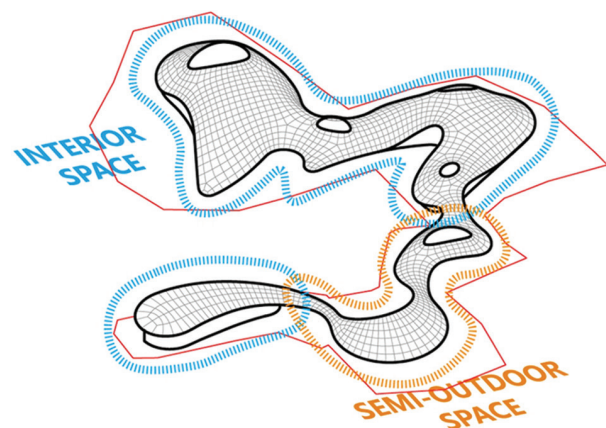


Figure 2. Zone definition and division. Source: Drawing by Yingzi Hu

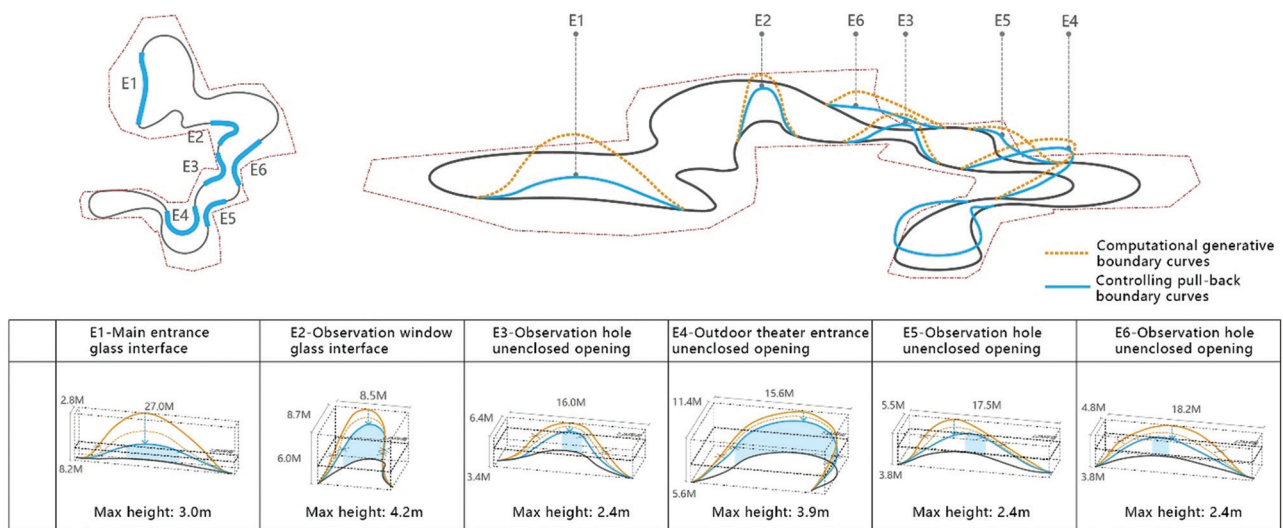


Figure 3. Boundary opening optimization. Source: Drawing by Yingzi Hu

primary entrance (E1) was reduced from 8.2 m to 3 m. The openings E3–E6 are situated in the transitional region of the outdoor gray space and are not enclosed by additional vertical elements. E3, E5, and E6 serve as secondary exhibition entrances that establish visual connections with the enclosed courtyard and the expansive skyline. To achieve this, the net height of these openings was reduced from 3.8 m to 2.4 m, a sufficient dimension for secondary passages and visual communication.

E4, on the other hand, is positioned at the steps of the outdoor theater grandstand. The overall slope of the opening mirrors the step-by-step retreat of the grandstand and is designed to accommodate gatherings of people in the courtyard. Consequently, the height of this opening was adjusted from the initially calculated value of 5.6 m to a net height of approximately 3.9 m, ensuring suitability for viewing and performance.

After optimizing the height function of the boundary control curves, it is essential to further rationalize the three-dimensional boundary. This rationalization process ensures that each segment of the curve boundary can exist on a tilted or horizontal plane in one dimension, facilitating subsequent construction positioning. This process can be achieved by following the rationalization steps typically applied to plane boundaries. It involves smoothing and simplifying the three-dimensional curve boundaries through the continuous blending of low-order rational curves. In the end, a combination of three types of curves is utilized, which includes three-degree plane curves, two-degree circular arcs, and straight-line segments (Figure 4).

An algorithm-parameter analysis was initiated to optimize the internal space within the shell structure. This analysis

considered four primary parameters involved in the initial shell formation: ground anchor points, axial anchor points, elasticity, and load. In addition, the parameter governing the boundary pull-back curve was introduced. Subsequently, by numerically adjusting these parameters, as depicted in Figure 5, the internal spatial design of the building was refined based on empirical and structural considerations.

It is important to note that ground anchor points, axial anchor points, and the pull-back curve remain constant and do not undergo further numerical adjustments. The remaining parameters of load ( $W$ ), length deformation coefficient ( $L$ ), and elasticity ( $S$ ) are selected as the three adjustable factors for comparative optimization.

Before modifying the shell surface parameters, the height-to-span ratio for the primary exhibition hall was established at 1:5 to achieve an optimal spatial effect. With a main exhibition hall span of 34 m, the estimated height of the north main shell space, excluding the preset 0.6 m of the structural layer, amounts to approximately 7.4 m. Subsequently, for the four smaller subspaces (S3, S4, S5, and S7), the forming height needs to be maintained around 3.2 m after accounting for the structural layer (0.6–0.8 m) to meet the desired net space height requirements effectively.

The parameter  $W$ , which represents roof load, was initially studied while keeping other parameters constant. Three values were considered: 60, 80, and 100. It was observed that the shell space obtained when the  $W$  parameter was set to 80 was the most reasonable. Under the other values, the shell space was either too low or too short, making it difficult to accommodate internal functions and leading to spatial redundancy. Once the roof load parameter stabilized at  $W = 80$ , the length deformation

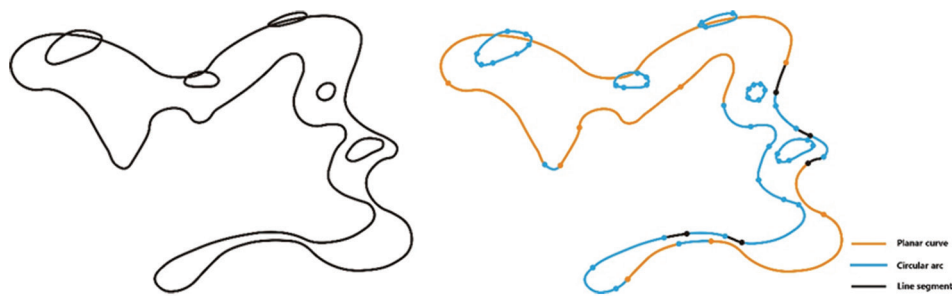


Figure 4. Rationalization of boundary curves. Source: Drawing by Yingzi Hu

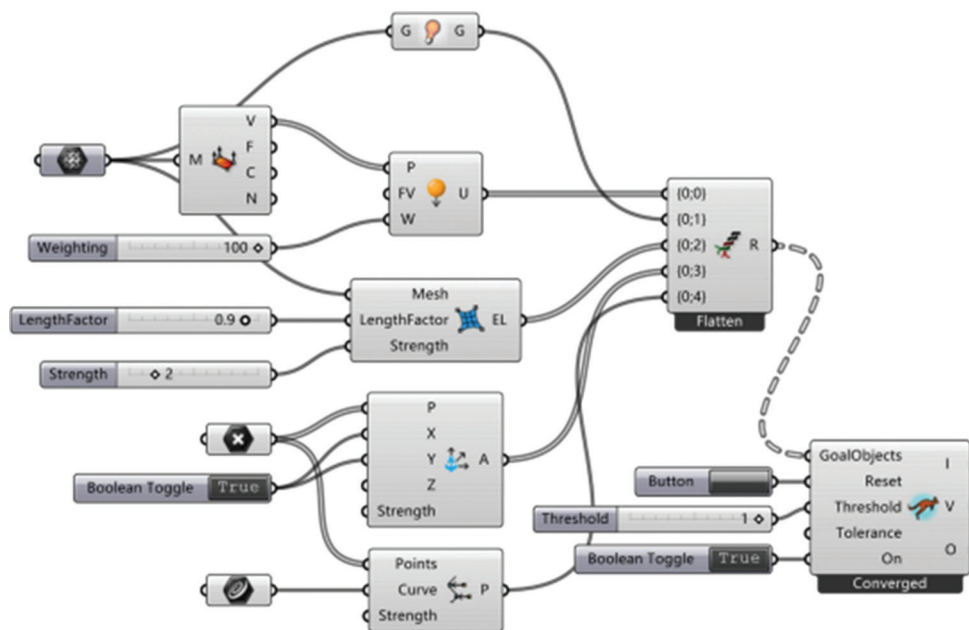


Figure 5. Five major parameters for shell design and battery arrangement. Source: Drawing by Philip F. Yuan

coefficient of elasticity, denoted as  $L$ , was further adjusted. Three values were considered for  $L$ : 0.8, 0.9, and 1.0. Through a comparison of spatial height, the optimal value was determined to be 0.9.

The optimal parameters for the shape-finding process of a shell structure were established through a series of numerical experiments. Three adjustable parameters –  $W$ ,  $L$ , and  $S$  – were considered. The results revealed that the ideal values for these parameters were  $W = 80$ ,  $L = 0.9$ , and  $S = 3$ . With these parameters, the overall height of the shell surface ranged from 3.2 to 7.4 m, and the indoor net height varied from 2.6 to 6.8 m. These results fulfill a variety of functional requirements for indoor space, spanning from the main exhibition area to the transitional gray space (Figure 6).

### 4.3. Reciprocal geometry design for shell structures

To incorporate reciprocal geometry into the realm of architecture, the initial step involves the careful selection

of appropriate geometric tessellations. Taking into account the potential geometric requisites of architectural design, construction considerations, and cost constraints, we have chosen 11 geometric tessellations, all of which possess a single vertex type, from the set of regular polygon tessellations. This category of tessellation is commonly referred to as Archimedean tiling (Grünbaum & Shephard, 1987).

Once we have identified a geometric tessellation grid that satisfies the necessary criteria, the transformation into reciprocal geometry can be undertaken. The process begins with determining the midpoint for each line segment within Figure 7. Subsequently, each line segment undergoes a counterclockwise rotation by a specific angle, denoted as  $\alpha$ , around its midpoint. It is important to note that the direction of rotation is not a critical factor, but for illustrative purposes, this article employs a counterclockwise direction. Following this rotation, each line segment is extended in both directions

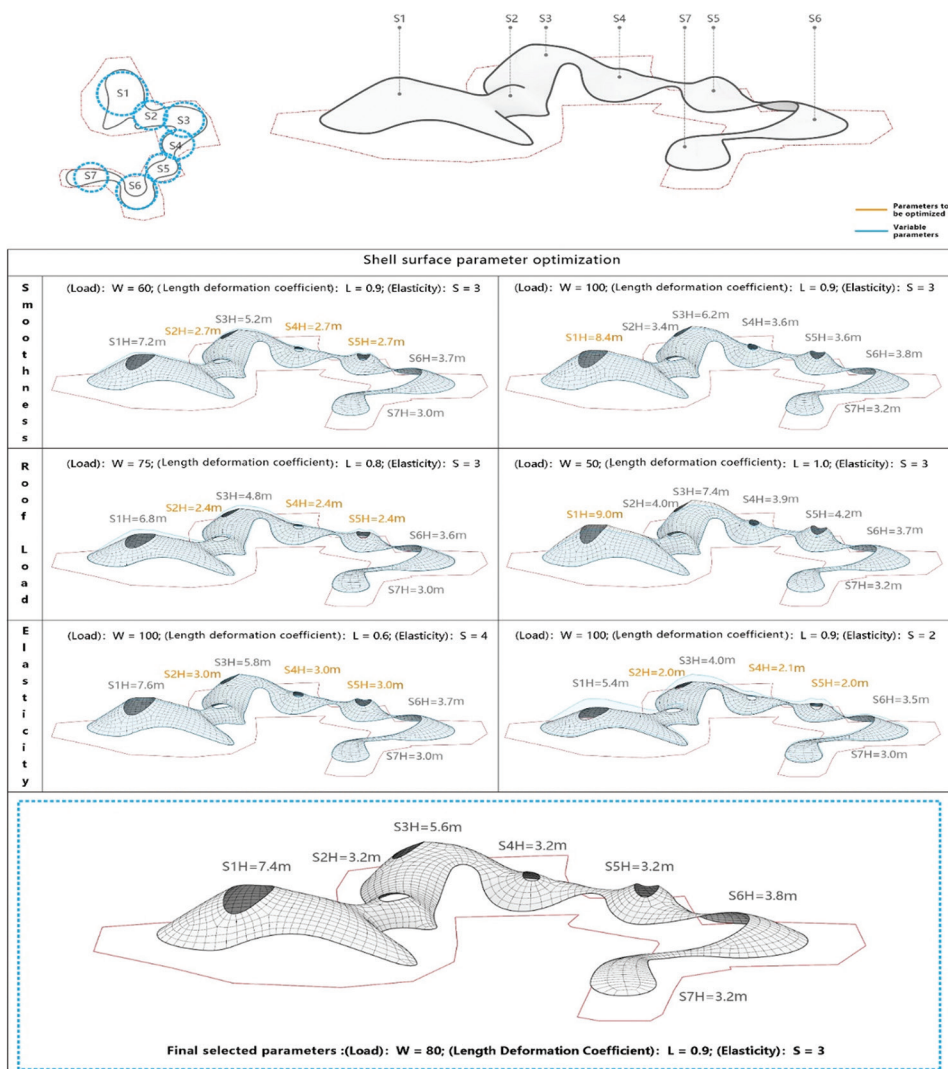


Figure 6. Computational subd to NURBS surface rational optimization. Source: Drawing by Yingzi Hu, editing by Yueyang Wang

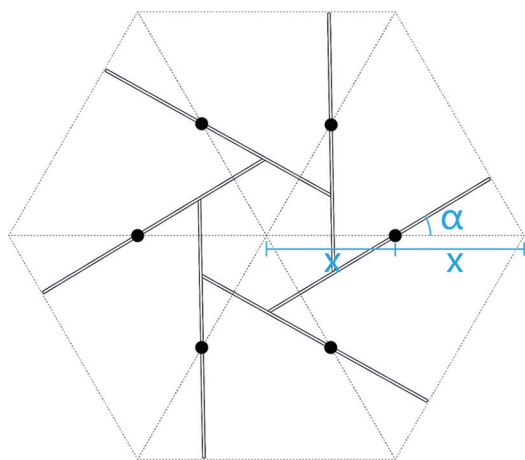


Figure 7. Geometric design of interpenetration for shell structures. Source: Drawing by Yingzi Hu

until it intersects with the nearest line segment. This approach yields diverse reciprocal geometry grids, which result from varying the rotation angle of the basic grid (Figure 7).

For the 11 basic geometrically reciprocal grids, A–K, a reciprocal geometrical library, can be established by adjusting the rotation angle, denoted as  $\alpha$ . The rotation angle  $\alpha$  spans two intervals: from  $0^\circ$  to  $90^\circ$  and from  $90^\circ$  to  $180^\circ$ , corresponding to the mirror relationship of complementary angles. Therefore, taking the rotation angle range of  $0^\circ$  to  $90^\circ$  as an example, we have compiled a reciprocal geometrical shape library with a 15-degree interval, as shown in Figure 8. It is important to note that the algorithm allows for arbitrary non-integer values for the rotation angle, providing flexibility in defining these angles.

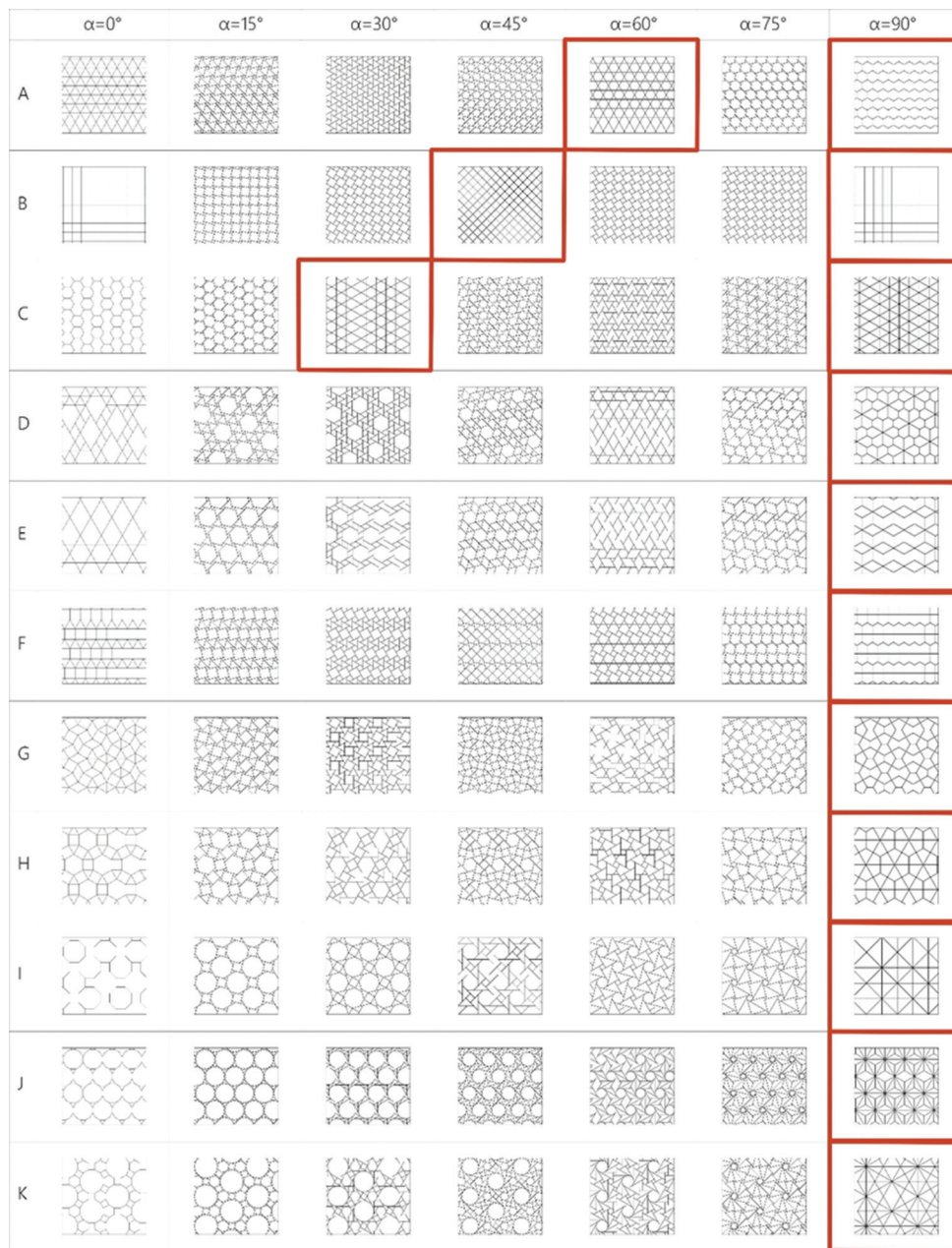


Figure 8. Reciprocal geometry library. Source: Drawing by Yingzi Hu, editing by Yueyang Wang

It is worth emphasizing that certain regular polygon grids, such as A-60, B-45, and C-30, may, when rotated at specific angles, form geometric patterns that do not exhibit reciprocal relationships due to their inherent geometric characteristics. Furthermore, when the rotation angle  $\alpha$  for all grid types is set to  $90^\circ$ , it results in the formation of a stable coupled pattern that is the reverse of the initial grid. However, this pattern also lacks a reciprocal relationship. In addition, we observe that A and C grids interact with each other as the angle changes, leading to the creation of reciprocal grids with consistent geometric features.

#### 4.4. Shell mapping of reciprocal geometry

We explore three methods for applying the reciprocal geometric library to generate structural systems for desired shell surfaces. The first method begins with simpler geometric surface shapes. The three-dimensional curved surface is directly subdivided into a basic grid composed of equilateral triangles, squares, and hexagons. Subsequently, line segments are rotated and extended around the midpoint in three-dimensional space to complete the transformation of the reciprocal grid in space (Figure 9).

There are two fundamental methods for generating 3D meshes for reciprocal structures on shell surfaces. The first method involves initially dividing the overall surface into three-dimensional quadrilaterals or hexagons, followed by conducting a structural transformation of the reciprocal mesh in space. While this approach is simple and intuitive, it imposes stringent requirements on the original geometric surface and can only support regular polygon meshing (Figure 10).

The second method entails utilizing the shell surface as the parent body and then executing a rotation mapping from the plane element onto the shell's parent body. This method guarantees that the reciprocal geometry remains

stationary in the X and Y directions, allowing for a seamless fit with the shell surface.

An algorithm is introduced to generate geometric prototypes of reciprocal grids. With input parameters, including the base figure mesh number, the reciprocal transformation angle, and the optimized shell surface, this algorithm can rapidly and effortlessly produce the reciprocal structure by transforming any grid at any angle. Subsequently, the reciprocal structure can be efficiently applied to the shell surface, creating a preliminary shape reference (Figure 11).

Four fundamental grids, labeled as B, C, F, and G, have been chosen for comparison. Grids B and C exhibit distinct geometric characteristics and boast excellent construction feasibility. On the other hand, grids F and G are comprised simple triangles and quadrilaterals, exhibiting a balanced scale. The initial geometric edge length for all four grids is set at 1.2 m. Following the installation of graphic inlays, a reciprocal geometric transformation is employed to achieve a relatively moderate structural scale and mechanical effect (Figures 12 and 13).

For comparison purposes, rotation angles  $\alpha$  of  $15^\circ$  and  $30^\circ$  have been selected. However, in the case of grid B, which lacks structural reciprocal properties when rotated by  $30^\circ$ , a  $45^\circ$  rotation is employed for scheme comparison. The estimation of material consumption is based on a rod element with a cross-section of  $400 \times 200$  (Figure 14).

In summary, following the reciprocal support transformation, the structural units within the grid, comprised triangles and squares in both F and G, expand

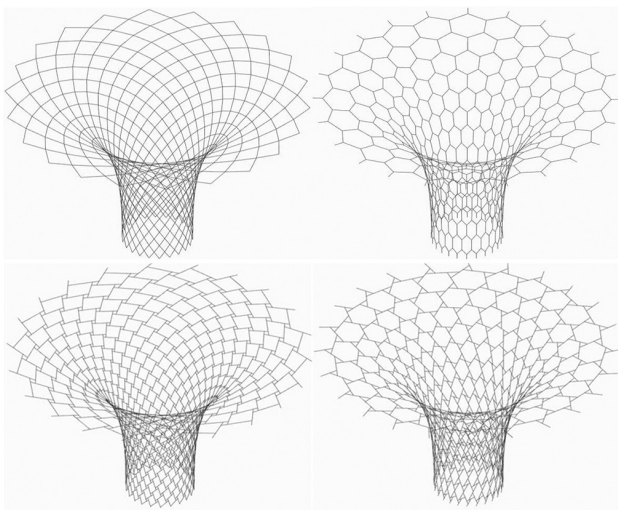


Figure 9. Spatial grid transformation. Source: Drawing by Yingzi Hu

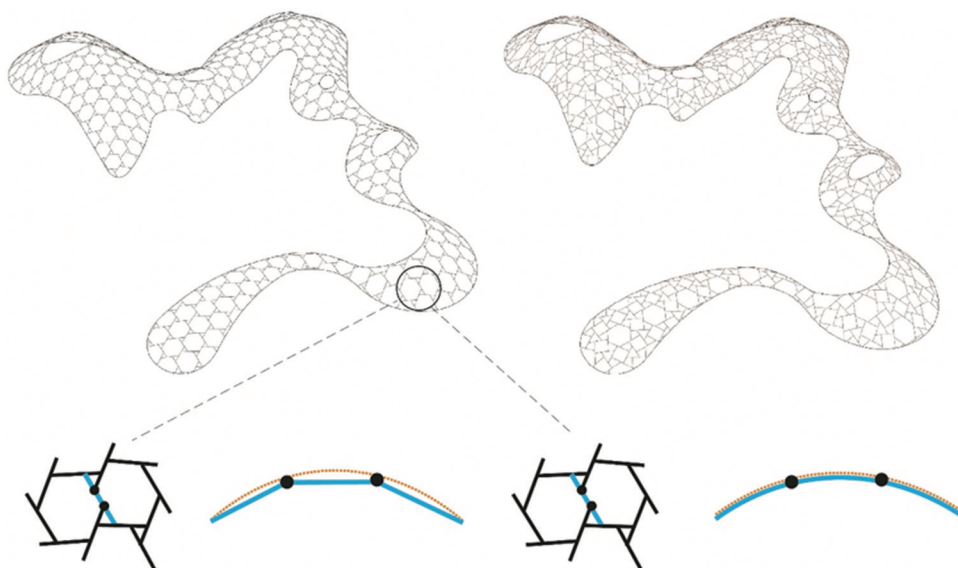


Figure 10. Unit beam generated by the particle-spring method (left) and unit beam generated by the angle-preserving mapping method (right). Source: Drawing by Yingzi Hu

to include three distinct types: triangles, squares, and irregular pentagons. At  $\alpha=15^\circ$ , the minimum length of the structural edges for the two types of reciprocal geometric pentagonal units is merely 0.12 m, a dimension smaller than the predefined structural member thickness. This situation is highly impractical for construction purposes. However, at  $\alpha=30^\circ$ , the shortest edge length for the pentagonal unit

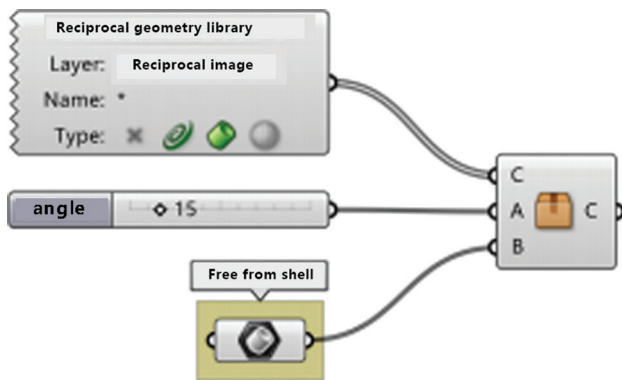


Figure 11. Workflow of organizing the application of reciprocal geometry in shell structures. Source: Drawing by Philip F. Yuan

increases to 0.45 and 0.35 m, rendering it a more viable option for construction. Nonetheless, when considered in conjunction with the number of unit boundaries, achieving optimal geometric shape effects during the construction process remains challenging.

The comparison between the most basic B and C classes of reciprocal grids reveals notable differences. First, the C class grid exhibits higher material efficiency than the B class grid when mapped onto a shell structure with the same scale and rotation angle. Second, both B and C class grids can achieve a relatively stable equidistant point shape during the conversion process of reciprocal structures, implying that the node where the rods intersect is located at the equidistant point of the rod. After continuous adjustment of the rotation angle parameter,  $\alpha$ , and inverse solution, it can be concluded that the B grid can attain a unique reciprocal state at a  $27.6^\circ$  rotation, while the C grid can achieve a special reciprocal state at a  $16.1^\circ$  rotation. On reaching this state, the overall structural performance of these two classes of reciprocal grids can be optimized (Figure 15).

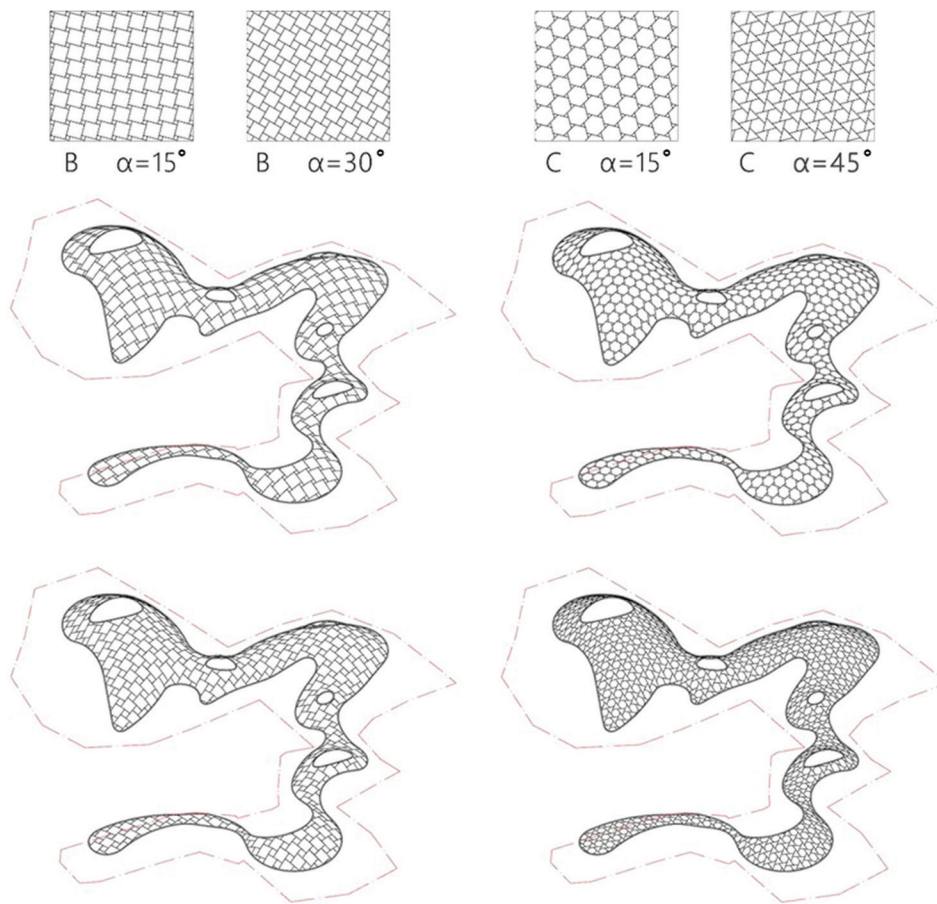


Figure 12. The application of B and C grid reciprocal geometric shell. Source: Drawing by Yingzi Hu

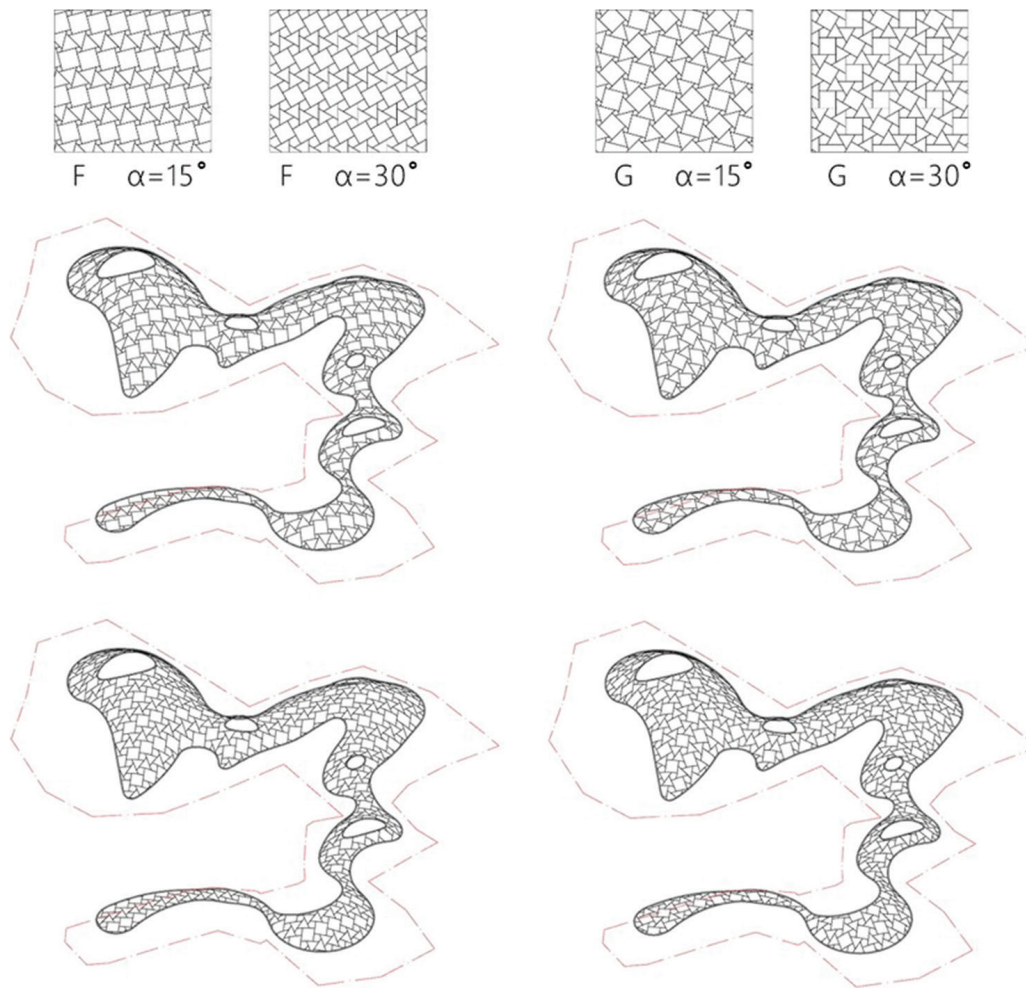


Figure 13. The application of reciprocal geometric shell surfaces to grids F and G. Source: Drawing by Yingzi Hu

	B1 grid a=15°	C1 grid a=15°	F1 grid a=15°	G1 grid a=15°
Material quality	261.4m <sup>3</sup>	203.8m <sup>3</sup>	321.9m <sup>3</sup>	322.2m <sup>3</sup>
Unit scale	Unit maximum span of 0.85 m minimum of 0.31 m	Span is uniformly 0.580 m	Unit maximum span of 0.92 m minimum of 0.18 m	Unit maximum span of 0.92 m minimum of 0.18 m
Unit type	2 types of squares	Regular hexagon + equilateral triangle	Square + equilateral triangle + pentagon	Square + equilateral triangle + pentagon
Construction feasibility	The units have a simple form but a significant difference in spans	The units have a simple form and the spans are uniform	The units have complex forms with significant differences in spans	The units have complex shapes with significant differences in spans
	B1 grid a=30°	C1 grid a=45°	F1 grid a=30°	G1 grid a=30°
Material quality	288m <sup>3</sup>	241.9m <sup>3</sup>	342m <sup>3</sup>	342.5m <sup>3</sup>
Unit scale	Unit maximum span of 0.85 m minimum of 0.62 m	Unit maximum span of 0.85 m minimum of 0.62 m	Unit maximum span of 0.61 m minimum of 0.45 m	Unit maximum span of 0.70 m minimum of 0.35 m
Unit type	2 types of squares	Regular hexagon + equilateral triangle	Square + equilateral triangle + pentagon	Square + equilateral triangle + pentagon
Construction feasibility	The units have simple shapes with relatively small differences in spans	Units have a simple form with relatively small differences in spans	The units have complex forms with relatively small differences in span	The units have complex shapes with a slightly larger difference in span
A mutually supporting grid formed by rotating the C1 grid, with reasonable unit scale, simple form, and the least amount of wood required for the same scale, is the optimal solution among multiple mutually supporting grids compared				

Figure 14. Comparison of parameters for four types of grids. Source: Drawing by Yingzi Hu and editing by Yueyang Wang

The spatial impact of the hexagonal reciprocal grid weakened right angles and provided a more accurate representation of the space inside the shell (Figure 16). Furthermore, the smallest triangular unit meets the

fundamental construction requirements and can be expanded to incorporate additional functions, such as the placement of point-source lighting. Ultimately, the C grid with a 16.1° angle was chosen as the final architectural structural solution.

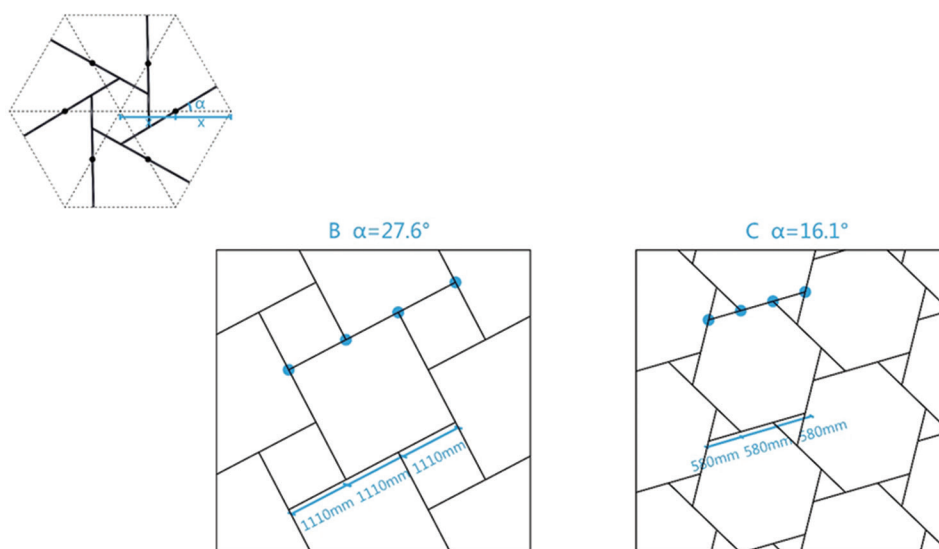


Figure 15. Special reciprocal states of B- and C-type grids. Source: Drawing by Yingzi Hu

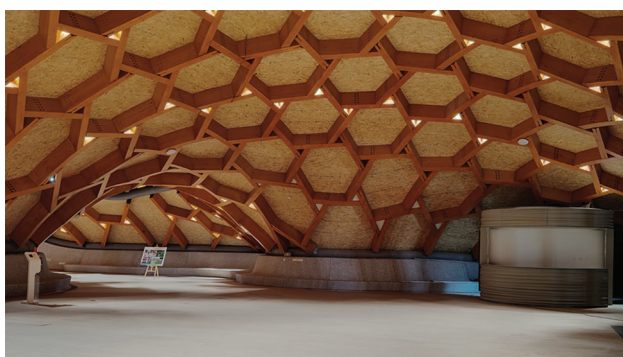


Figure 16. The construction effect of the hexagonal reciprocal grid. Source: Photo by Wongke

## 5. Reciprocal wood structure construction

### 5.1. Structural performance-based design of reciprocal timber units

After conducting geometric optimization of the structural members and developing the spatial model, the initial evaluation of the structural performance of the system was carried out. This assessment was performed under specific conditions, considering loads of 1.3 times the dead load and 1.5 times the live load on the roof.

The results of this analysis revealed that the overall bending moment distribution of the system falls within an acceptable range of  $\pm 20$  kNm. Moreover, the overall stress levels were observed to be in the range of 1.2 to  $-0.9$  N/mm<sup>2</sup>, with the maximum shear stress registering at 1.197 MPa, which is well below the established limit of 2.0 MPa. Furthermore, a significant portion of the shear stress values

is below 0.15 MPa, indicating the system's commendable resistance to deformation (Figures 17 and 18).

For the overall axial force analysis of a timber roof, certain components are exposed to axial compression of 170 kN, while others experience axial tension of 75 kN. From a structural performance perspective, it is crucial for these members to possess adequate compressive and tensile strength to resist deformation. Components subjected to lower tensile forces and appropriate compressive forces can have more balanced material properties, allowing for the design of relatively uncomplicated connections.

Based on mechanical performance calculations, four distinct types of wooden structural unit beams have been proposed. The B1 and B2 beams, which experience lesser axial forces, are constructed using glued laminated timber beams with a cross-section of 450×180 mm. The B3 beams, subjected to the highest axial forces, require increased stability to meet their tensile and compressive requirements, as well as a smaller overall quantity. Consequently, these are replaced with wood-faced square steel beams, offering improved stability.

For the outer rational curve boundary ring beams and the structural ring beams at the five skylight openings, structural stability and precise on-site construction positioning are paramount. These beams are designated as B4 and utilize circular steel beams with 355×16 mm as the primary material (Figure 19).

Based on mechanical performance calculations, four types of wood structural unit beams were proposed. B1 and B2 beams, which experienced smaller axial forces,

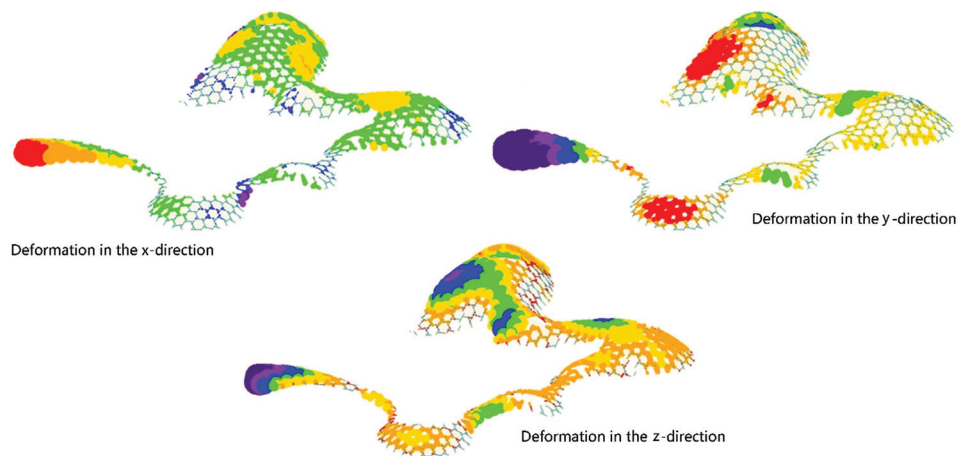


Figure 17. Deformation analysis of the overall structure. Source: Drawing by Yingzi Hu and editing by Yueyang Wang

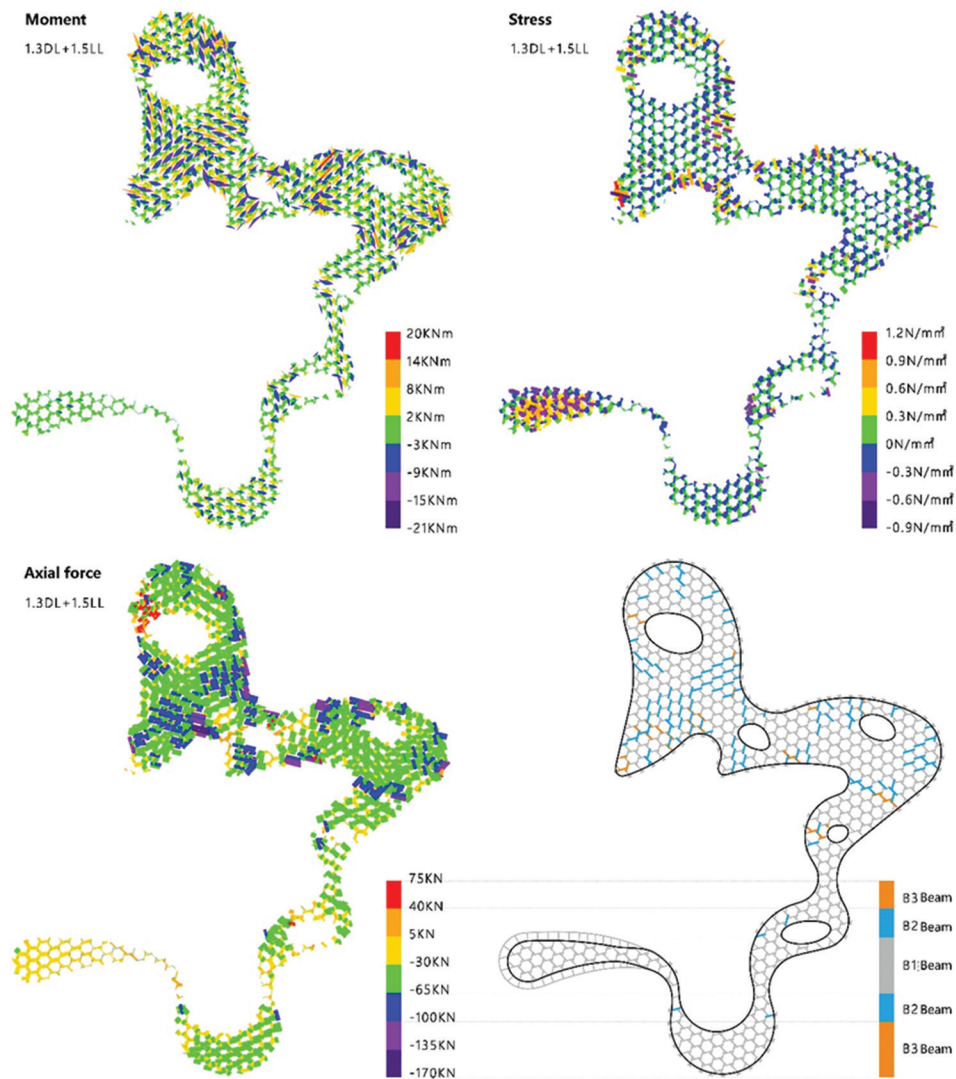
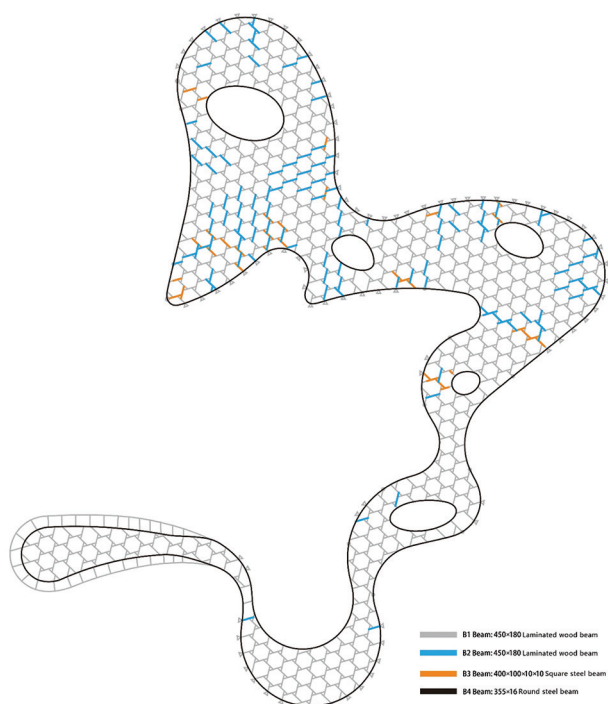


Figure 18. Structural performance calculation. Source: Drawing by Yingzi Hu and editing by Yueyang Wang  
Abbreviations: DL: Dead load; LL: Live load.



**Figure 19.** Structural unit classification. Source: Drawing by Yingzi Hu and editing by Yueyang Wang

were constructed using 450×180 mm glued laminated timber beams. For B3 beams, which were subjected to the largest axial forces, we opted for more stable wood-clad steel beams to meet their tensile and compressive requirements. B4 beams, known for their superior structural stability and ease of on-site construction positioning, were constructed using 355×16 mm circular steel beams (Figure 20).

## 5.2. Locally-rooted digital construction

The assembly of prefabricated complex shell structures imposes stringent requirements on processing accuracy and efficiency. Given the project's need for glued laminated timber components with varying shapes, sizes, hole positions, and slot openings, maintaining processing accuracy within  $\pm 1$  mm for joint fabrication is crucial. Therefore, the utilization of robotics is instrumental in ensuring the precision of interconnected components. The project employs two KUKA 7-axis robots. One is equipped with a main spindle motor boasting a maximum rotation speed of 18,000 rpm, while the other is fitted with an electric chainsaw designed for cutting and slotting. A deepening process toolkit, specifically developed for digital timber construction, allows designers to select appropriate processes and tools based on the specific type of joints.

At the software control level, FURobot serves as a bridge between designers and robots. It not only translates models into processing paths and codes but also simulates potential issues during robotic processing using digital twin technology and makes corresponding adjustments. For each component, the robot requires a series of different operations and their corresponding processing paths (Figure 21).

The first step involves determining the precise location of the component to be processed within the factory environment, achieved through visual positioning technology. Subsequently, geometric calculations are performed on the slots to be milled to determine the most suitable tools and processes. Deep slots in typical steel-wood joints intended for steel plate insertion are processed by another robot. During this process, the first robot can replace the special milling cutter required for subsequent hole punching and slot opening (Figure 22). It is important to note that the cylindrical body of the milling cutter affects the design form of the nodes during processing, primarily causing rounding at the node turning position.

The robotic mass customization method effectively ensures the smooth completion of large-scale customized components, enhancing processing accuracy while significantly reducing processing time and costs.

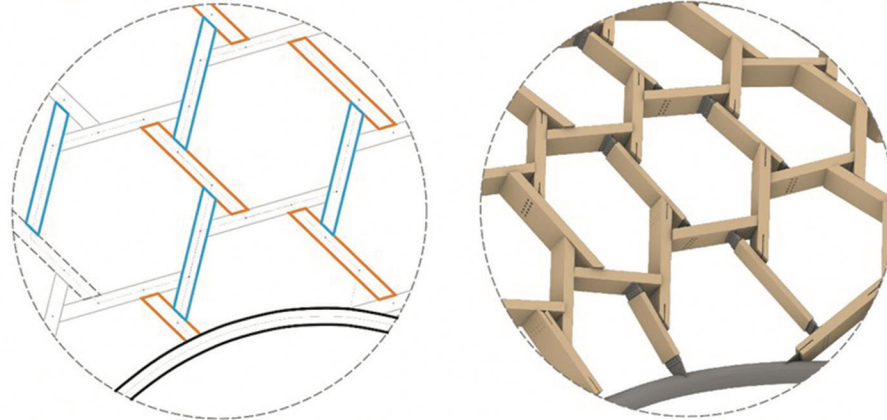
The installation of a timber structure is predicated on a three-beam unit, as illustrated in Figure 23. Initially, the central axis of the positioning line is located on the plane and then raised to the desired elevation. Throughout the construction process, the central axis at the intersection of each beam is periodically reassessed for precision, employing total stations, GPS-RTK technology, or drone scanning. This practice aims to ensure accuracy and minimize the accumulation of discrepancies.

## 6. 3D-printed panels based on shell geometry

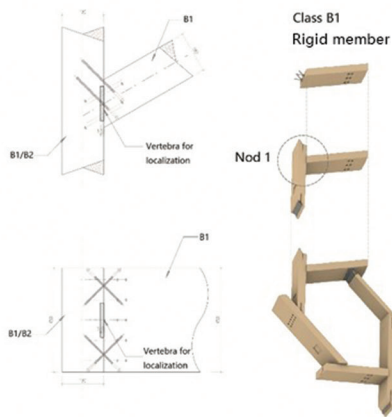
A large-scale modified plastic 3D-printed roof was chosen to complete the intricate, double-curved geometric shell surface of the project. The individual roof panels were processed to create a layered undulation running parallel to the curved surface's edge. This undulation mirrors the building's dynamic, aerodynamic form of the building (Figures 24 and 25).

The integration of a reciprocal timber structure and a 3D-printed roof (Figure 26) in the design-construction process exemplifies the boundless potential of digital architecture during the design refinement phase and its capacity to enhance intelligent execution during the construction stage.

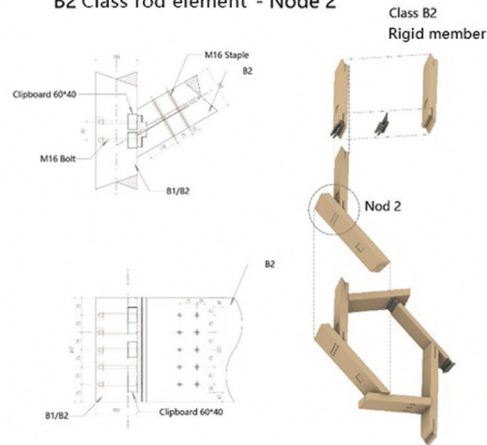
Local node distribution chart



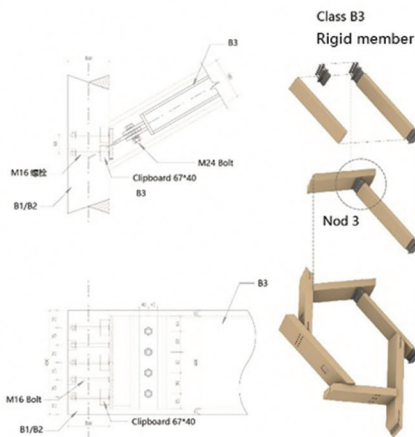
B1 Class rod element - Node 1



B2 Class rod element - Node 2



B3 Class rod element - Node 3



B4 Class rod element - Node 4

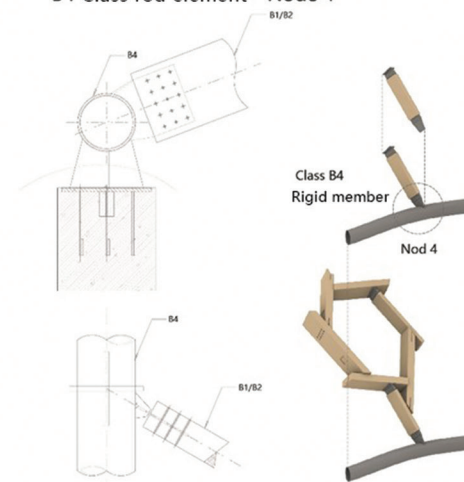


Figure 20. Forms and node construction of various types of structural units. Source: Drawing by Yingzi Hu and editing by Yueyang Wang

## 7. Future outlook

In the design and construction of the Ruixue Multi-Hall project, the reciprocal geometry of the shell structure

has consistently showcased its distinctive geometric characteristics and mechanical properties, facilitating the synergy between form and space, structure and performance, and material and construction. To a great

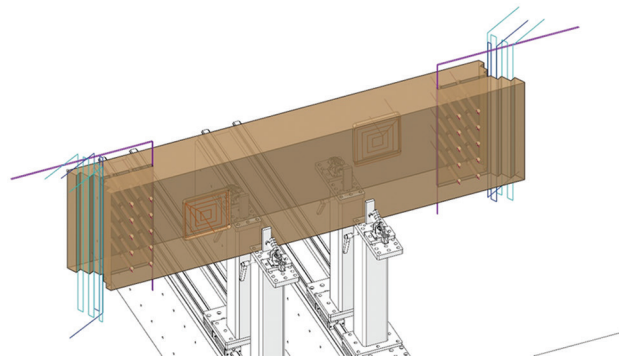


Figure 21. Trajectory planning of robotic timber fabrication. Source: Drawing by Tianyi Gao

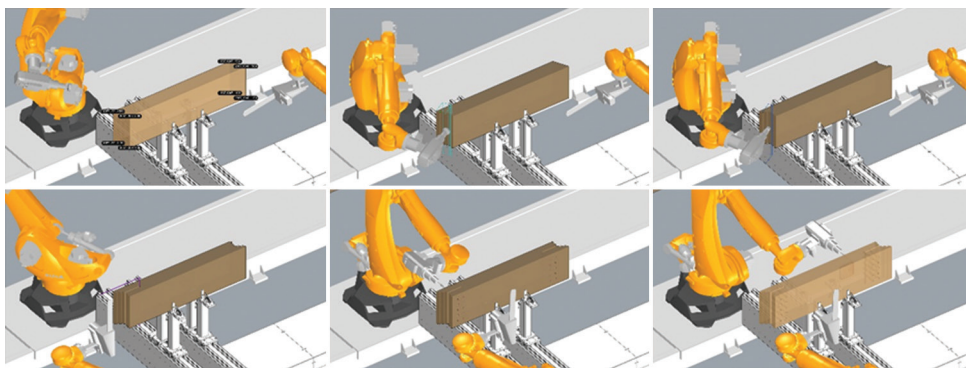


Figure 22. Fabrication process. Source: Drawing by Tianyi Gao



Figure 23. Prefabricated wooden floor with three beams. Source: Photo by Wongke



Figure 24. Effects of roofing techniques. Source: Photo by WongKe

extent, it has successfully implemented a seamless workflow from the design phase to the construction of the reciprocal structure. Nonetheless, there are several aspects of the overall research that warrant further, more specialized exploration:

- (i) Develop a more comprehensive reciprocal geometry library. The existing library is confined to regular polygons and conditions where a single node is densely covered. Expanding this library to encompass irregular polygons, configurations with multiple nodes in dense arrangements, and larger scales would

enhance the versatility of reciprocal geometry in architectural design.

- (ii) Investigate a broader array of applications for reciprocal structure formation methods. Current methods primarily rely on the geometric optimization of structural members. Examining ways to employ rationalized members for creating spatial structures could streamline the design process, although necessitating addressing challenges associated with controlling construction errors.



Figure 25. Roofing effect resulting from folding unit panels. Source: Photo by WongKe



Figure 26. Roof panel shape. Source: Photo by WongKe

In the realm of architectural design utilizing reciprocal geometry, a holistic approach seamlessly integrates context, site, space, form, function, geometry, structure, and construction to give rise to an array of exquisite and imaginative structures. With the indispensable support of cutting-edge computer technology and ongoing exploration, architects have the capacity to transform these visions into tangible reality, allowing them to delve into the poetic expression of structural esthetics. This exploration represents the wellspring of architects' boundless passion.

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## Conflict of interest

The authors declare that they have no competing interests.

## Author contributions

*Conceptualization:* Philip F. Yuan

*Formal analysis:* Philip F. Yuan

*Investigation:* Philip F. Yuan

*Methodology:* Philip F. Yuan

*Writing – original draft:* Yingzi Hu

*Writing – review & drafting:* Yueyang Wang, Tianyi Gao

All authors read and approved the final manuscript.

## Consent for publication

Not applicable.

## Availability of data

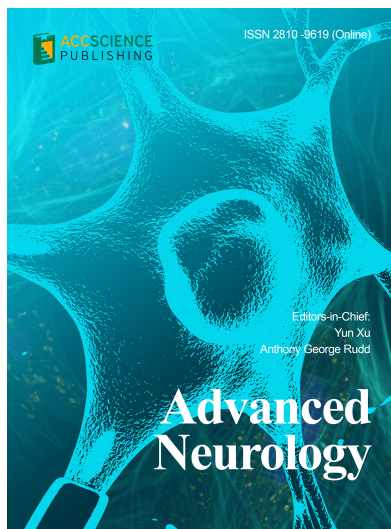
Not applicable.

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