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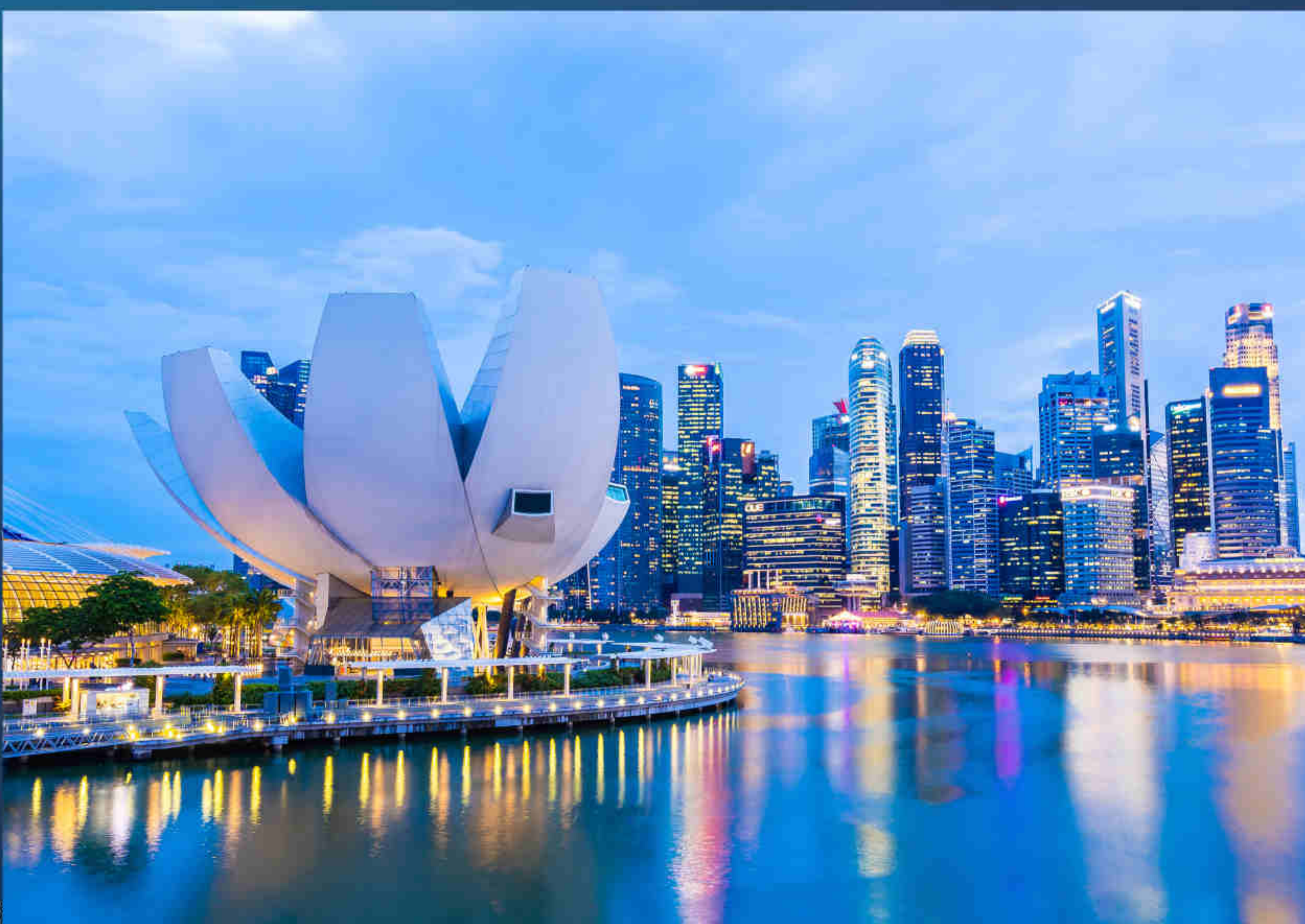

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A Quantitative Method for Cultural Landscape Zoning in Traditional Chinese Villages and Its Applications: A Case Study Based on Chongqing

SONG Zhengjiang[1], ZHAO Yao[2], LONG Bin[3]

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ABSTRACT: In China, the traditional village is an important agricultural civilization legacy in its rural cultural landscape. Influenced by multiple factors like physical geography and human society, cultural landscape characteristics in traditional villages have obvious intraregional similarities and interregional differences within a particular space. To examine spatial differentiation in cultural landscapes in traditional villages and determine their spatial distribution characteristics and historical evolutionary paths, the cultural landscape zoning method in traditional villages was explored in this study. The goal was to facilitate systematic regional protection, development, and use of traditional villages.

First, the cultural landscape factor system in traditional villages was decomposed into 21 types of cultural landscape factors. Those factors belonged to four classes: natural environment, spatial form,dwelling type, and social culture. Second, the data on cultural landscape factors were collected and analyzed. Quantitative factors were normalized by the Statistical Package for the Social Sciences (SPSS) software. Third, Principal Component Analysis (PCA) was used to quantitatively analyze the quantitative factors to extract principal components and perform hierarchical clustering. Finally, cultural landscape zoning in traditional villages was achieved with a GIS map expression method by combining the qualitative sensory impressions of descriptive factors. Also, 320 traditional villages in Chongqing City were chosen as research objects, and the proposed zoning method was empirically applied.

Results demonstrated the following:(1) A systematic cultural landscape zoning method in traditional villages was formed. That method comprised factor decomposition, data acquisition and processing, principal component extraction, and hierarchical clustering-zoning. (2) Cultural landscape characteristics in traditional villages in Chongqing can be divided into four zones: a commercial culture dominant type in the west, an immigrant-culture dominant type in the center, a defense-culture dominant type in the northeast, and an ethnic cultural integration type in the southeast.

Chongqing was chosen as the study area, and 320 traditional villages covering the entire Chongqing City were chosen as research objects in the empirical study. Results showed that an optimized zoning method that combines quantitative and qualitative analyses of "principal component extraction combined with hierarchical clustering" was feasible and had high operability. Also, optimization of the traditional village zoning method was manifested in two main aspects. On one hand, the informationretention rate of the "zoning factor" increased significantly from the traditional 20%-30% to at least 80%. This refines and enhances the dominant expression of cultural landscape characteristics and decreases the loss of "non-dominant factor" information. It also decreases the subjectivity of the zoning outcome. The extracted principal factors were gained from recombining cultural landscape factors in various traditional villages according to a weight relation. Such a weight relation was calculated by the SPSS software according to pure mathematical statistical relations, and reduced the subjectivity associated with weight determination in the traditional "expert

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scoring method."

In future studies, the migration paths of cultural landscape factors among different zones in traditional villages, their evolutionary mechanism and influencing characteristics, and the macro-, meso-, and micro-applications of zoning outcomes must be further examined.

KEYWORDS: traditional villages; cultural landscape; zoning; principal component analysis; hierarchical clustering method; Chongqing

Introduction

Traditional villages, asboth historical witnesses and important heritage of China's agricultural civilization, are one of the important cultural landscapes created by humankind throughout their historical evolution [1]. The concept of "traditional village cultural landscapes" derives from "cultural landscapes," a category of cultural heritage introduced within the World Heritage framework in 1992. Synthesizing domestic and international research, Tang Maolin defines "cultural landscapes" as landscapes formed by human utilization of natural materials to satisfy specific needs, essentially superimposing the results of human activities onto natural landscapes [2]. In China, this concept was first comprehensively elucidated in the *Guiyang Recommendation*, which describes it as the "joint work of long-term interaction between nature and humanity." It is characterized as a significant type of cultural landscape that is not only created by human action but also encompasses that action itself. This landscape embodies the diverse survival wisdom possessed by village societies and ethnic groups, reflects the intrinsic connection between humanity and nature, and represents the crystallization of agrarian civilization. It is distinct from both landscapes intentionally designed by humans and natural landscapes bearing few traces of human modification [3]. Influenced by natural geography and human society, the cultural landscape of traditional villages exhibits marked spatial differentiation, manifesting as similarities within certain regions and differences between them. Zoning is an effective method for exploring the spatio-temporal differentiation characteristics and evolution paths of traditional village cultural landscapes.

The study of traditional villages can be divided into three major stages: the initial stage (prior to 1996), dominated by descriptive studies; the developmental stage (1996-2005), characterized by the continuous expansion of research methods and depth; and the active stage (post-2005), featuring the coexistence of traditional themes with "soft" factors such as place identity and organizational behavior[4]. In recent years, with the integration of multiple disciplines such as human geography, ethnology, architecture, and urban and rural planning, studies have progressively moved towards the typology and zoning of traditional villages [1]. Regarding the content of research on traditional village cultural landscapes zoning, the focus has shifted from a single cultural landscape element to a more comprehensive cultural landscape zoning approach. Studies focusing on single elements mainly concentrate on village morphology [5], dwellings [6], landscapes [7], ethnicity [8], and infrastructure [9]. In contrast, comprehensive cultural landscape zoning involves the regional division of whole villages [10] or settlements [11] covering multiple elements, as well as research on regional formation mechanisms [12]. In terms of research scale, macro and meso scales are dominant, while research at the micro-scale is gradually increasing. The macro-level focuses on the whole country [13], the meso-level studies concern regions [14], provinces [15], cities [16], and the micro-level concentrates on localities [12] and counties [17]. In terms of research methods, qualitative research is the main approach, and quantitative research is gradually integrated on the basis of qualitative research. Qualitative research is most commonly conducted using descriptive methods [18], multi-factor overlay methods [19], dominant factor methods [10], and historical-geographical methods [20]. Descriptive methods are largely obsolete due to their strong subjectivity and lack of standardization, while the other methods are still commonly used. Integrated quantitative methods involve correlation analysis and extraction of dominant factors [1]; determining factor weights via "expert scoring method" to standardize elements; and calculating village similarity for clustering [21]. This also includes using cluster analysis to group factors by type, followed by correlation analysis for categorical zoning [22]. An overview of current research reveals that the content has become increasingly rich and in-depth, the research scales have been gradually refined, and the research methods have strengthened quantitative analysis. However, quantitative analysis still has certain shortcomings. First, regarding the selection of "dominant factors," although quantitative research has been explored, it often still involves pre-determining a factor as an independent or dependent variable and then analyzing its correlation with other factors to verify the correctness of the selection. Furthermore, the dominant factor method retains only about 30% of the information [1)], resulting in a significant loss of information from non-dominant factors. This method is actually a dominant factor-based zoning, rather than a zoning of the "overall characteristics of cultural landscape". Second, regarding methods like multi-factor overlay and similarity clustering, although they attempt to move away from purely subjective weight assignment, methods such as the Delphi method or Analytic Hierarchy Process (AHP) still rely heavily on human judgment. This leads to subjective bias in the zoning process and a lack of objectivity in the results. Therefore, drawing on the aforementioned methods, this paper introduces a quantitative analysis method combining Principal Component Analysis (PCA) for dimensionality reduction with hierarchical clustering, which not only fully reflects the characteristics of cultural landscapes but also avoids the subjective influence of weighting values. By combining quantitative and qualitative methods, this paper explores a more comprehensive, objective, and accurate method for zoning traditional villages.

Chongqing borders Shaanxi, Sichuan, Guizhou, Hunan, and Hubei provinces, and its unique natural and cultural environments haveshaped the diversity and complexity of its traditional villages. To better grasp the characteristics of Chongqing's traditional village cultural landscape system, this study selected 320 "traditional villages"[2)] listed by the national and Chongqing municipal governments as research subjects. An attribute system of cultural landscape factors was constructed, and SPSS was used to extract principal component factors and perform cluster analysis on quantitative indicators. Based on the clustering results, zoning was carried out in combination with descriptive indicators and qualitative sensory impressions to reveal the spatial differentiation characteristics of traditional villages in Chongqing. This work aims to improve the methods of zoning traditional villages and to provide a foundation for subsequent research on their protection and development.

1 Studyarea and data sources

1.1 Overview of thestudy area

Chongqing is located in the eastern part of Southwest China, bordering Hubei and Hunan to the east, Sichuan to the west, Guizhou to the south, and Sichuan and Shaanxi to the north.It covers an area of approximately 82,400 km^2 and administers 38 county-level divisions, including 26 districts, 8 counties, and 4 autonomous counties, with which collectively contain 8,015 village committees [23]. Located in the eastern part of the Sichuan Basin, the terrain descends from east to west, with complex and diverse landforms, a well-developed water system, and a climate that combines the characteristics of mountainous and valley areas. Historically, Chongqing has served as an intersection for the "Ba," "Shu," and "Chu" cultures, and its administrative divisions have undergone numerous splits and mergers over time.

1.2 Data sources

The research data were obtained from three sources: (1) Research samples. A total of 110 villages in Chongqing have been listed in the five batches of "Traditional Chinese Villages Lists" by national ministries, including the Ministry of Housing and Urban-Rural Development (MOHURD). Furthermore, the Chongqing municipal authorities have designated 22 municipal-level traditional villages, 45 historic and cultural villages (across two batches), and 444 villages hosting protected cultural relics protection units (across three batches). After removing duplicates and villages in highly urbanized areas, a total of 320 village samples were obtained (Figure 1). (2) Documentary data. This includes official announcements on traditional villages from the MOHURD, archives on traditional villages from the Chongqing Municipal Commission of Housing and Urban-Rural Development, promotional materials on historical and cultural villages from the Municipal Planning and Natural Resources Bureau, and the list of cultural relics protection units. (3) Geographical data. Digital Elevation Model (DEM) data were obtained from the SRTMDEM 30M data sourced via the Geospatial Data Cloud of the Chinese Academy of Sciences (http://www.gscloud.cn).

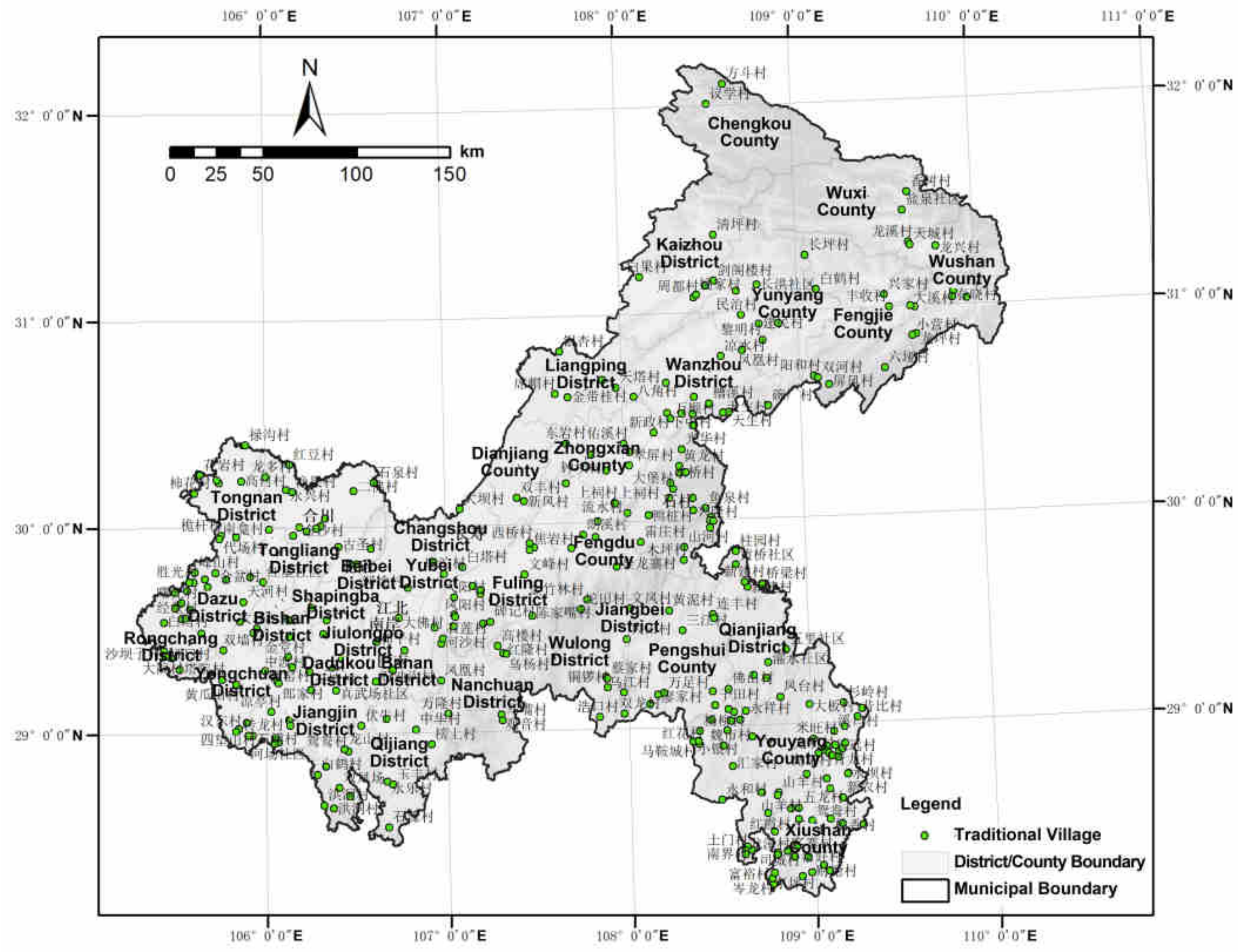

Figure 1 Spatial distribution of traditional villages in Chongqing

2 Research methods

2.1 Deconstruction of traditional village cultural landscape

The formation of traditional village cultural landscape zones is mainly influenced by geographical environment, regional culture, and economic and social factors [13]. The identifiability and distinctiveness of regional characteristics are reflected by cultural landscape factors [10]. The zoning results will vary greatly depending on the research perspective, factor type, sample size, and delineation method [24]. To enhance the reliability of zoning results, a more comprehensive range of factor types and a larger sample size should be used to support them. This study is based on the principles of authenticity of information that forms the core of the landscape, representativeness of landscape features that are excavated and selected from different historical periods, recognizability that is easy to identify, collect, and express intuitively, and consensus broadly acknowledged within social or academic domains. Referring to existing studies and the regional profile of Chongqing [1, 15, 16, 25], this study established a deconstruction framework of 21 factors across four categories: natural environment, spatial form, dwelling type, and social culture. These factors are categorized into quantitative (data-based) and qualitative (descriptive) types based on their inherent properties (Table 1).

Table 1 Attributes ofcultural landscape factors in traditional villages of Chongqing

Category	Cultural landscape Factor type	Subtype of cultural landscape factors	Data type
Natural environment	Landforms	Low-altitude plains, medium-altitude plains, low-altitude plateaus, medium-altitude plateaus, high-altitude plateaus, low-altitude hills, medium-altitude hills, high-altitude hills, gently undulating low mountains, gently undulating medium mountains, gently undulating high mountains	Quantitative
	Elevation	H<500 m, 500 m⩽H<1000 m, 1000 m⩽H<3500 m	
	Watershed Scale	Micro(S< 100 km^2), small (100 km^2)⩽S< 500 km^2), medium-sized (500 km^2) ⩽S< 1000 km^2), large (1000 km^2⩽S)	
	Site Selection[3)]	Near mountains and near water, near mountains andfar from water, far from mountains and near water, far from mountains and far from water	
	Relation to Mountains	Flatland, hillside, foothill, mountainside, mountaintop	
	Relation to Water	No adjacent water, point-type, single-sided, double-sided, through-type, and ring-type	
	Proximity to Rivers	Adjacent (D< 300 m), near (300 m⩽D< 600 m), far (600 m⩽D< 900 m), none (900 m⩽D)	
Spatial form	Grouping Pattern	Clustered, strip-shaped, grouped, scattered	
	Morphological type	Punctate, strip, tiered, compact, centripetal, free-form, enclosed	
	Village environment	Feng shui forest & pond, feng shui forest (no pond), pond (no feng shui forest), none (no forest, no pond)	
	Village orientation[4)]	Backed by mountains and facing water, with multiple directions of mountain support, one direction of mountain support, multiple directions of road support, and one direction of core area.	
Dwelling form	Dwelling type	Traditional Chinese courtyard houses, stilted houses, shop-houses, watchtowers, Western-style houses, and fortified manor houses	
	Building materials	Rammed earth, adobe bricks, bamboo-wattle and daub, wooden boards, stone strips, rubble, blue bricks, red bricks, etc.	Descriptive
	Facade features	Tripartite facade proportion, entrance, eaves, gate tower, roof ridge ornaments, etc.	
	Roof form	Overhanging gable, flush gable, hip-and-gable, fire gable wall, pyramidal, hip roof	
	Building-Ground Interface	Ground-level, semi-stilted (Diaojiaolou), and fully stilted (Ganlan)	
	Typical buildings	Basic building information recording, planimetric survey, and elevation survey	
Social culture	Era of construction	Yuan Dynasty and earlier, Ming Dynasty, Qing Dynasty, Republic of China period and later	Quantitative
	Ethnicity	Han, Tujia, Miao, Gelao, etc.	
	Intangible cultural heritage	Ethnic songs, handicrafts, folk activities, traditional customs, clan order, village planning wisdom, etc.	Descriptive
	Dominant culture	Industrial-commercial culture, agricultural culture, immigrant culture, defense culture, salt culture, ethnic culture, etc.	

2.2 Data collection and standardization processing

For descriptive factors, the Rapid Ethnographic Assessment Procedure (REAP) was employed, employing methods such as photography, field surveying, questionnaires, and interviews to collect data, archive photographs, and organize qualitative descriptions. For quantitative factors, one approach is to use REAP to collect statistical data from literature and survey materials. Second, the Tianditu platform was used to search for place names and employed visual interpretation to identify and statistically analyze relevant factor information. Third, villages were abstracted as points by selecting the geometric centers of their representative architectural clusters to determine longitude and latitude coordinates. These coordinates were then imported into ArcGIS for vectorization [26] and integrated with Digital Elevation Model (DEM) data to conduct analysis and statistics on the geospatial information associated with the factors.

Data-based factors cannot be directly statistically analyzed due to differences in information type and dimension. Standardization is required to eliminate the influence of dimension on the analysis [27].

(1) Construction of the original data sample matrix X of village cultural landscape factors:

$$X=\begin{bmatrix} x_1^T \\ x_2^T \\ \vdots \\ x_n^T \end{bmatrix}=\begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1p} \\ x_{21} & x_{22} & \cdots & x_{2p} \\ \vdots & \vdots & & \vdots \\ x_{n1} & x_{n2} & \cdots & x_{np} \end{bmatrix}$$

Here,x_{ij} is the value of the j-th cultural landscape factor variable in the i-th village, n is the number of village samples, p is the number of cultural landscape factor types, and $n > p$.

(2) Normalization. The matrix X is normalized to obtain the matrix Z. Use SPSS data transcoding to resolve inconsistencies in the types and dimensions of indicators in matrix X:

$$Z=\begin{bmatrix} z_1^T \\ z_2^T \\ \vdots \\ z_n^T \end{bmatrix}=\begin{bmatrix} z_{11} & z_{12} & \cdots & z_{1p} \\ z_{21} & z_{22} & \cdots & z_{2p} \\ \vdots & \vdots & & \vdots \\ z_{n1} & z_{n2} & \cdots & z_{np} \end{bmatrix}$$

$Z_{ij}=\dfrac{x_{ij}-\overline{x}_j}{s_j}$, and here, $\overline{x}_j$ is the arithmetic mean of x_j, s_j is the standard deviation of x_j. $\overline{x}_j=\dfrac{1}{n}\sum_{i=1}^{p}x_{ij}$, $s_j=\dfrac{1}{n-1}\sum_{i=1}^{p}(x_{ij}-\overline{x}_j)^2$.

2.3 Principal component analysis

Principal component analysis is a method that simplifies the structure of a dataset by using the concept of dimensionality reduction [28]. Principal component analysis of village cultural landscape factors involves transforming multiple factors that were originally correlated with each other using SPSS to extract a small number of uncorrelated principal components (PCs) that comprehensively reflect the information carried by the original multiple factors. These principal component factors are the principal components of the original multiple factors. Characterized by their small number, mutual uncorrelation, and retention of over 80% of the original information content, these principal components achieve the goal of dimensionality reduction when they replace the original set of factors in analysis [29]. The extraction steps are as follows:

(1) Calculate the correlation coefficient matrix R for matrix Z:

$$R=[r_{ij}]_{n\times P}=\frac{Z^TZ}{n-1}$$

(2) Calculate the eigenvalues of the correlation coefficient matrix R:

$$|R-\lambda I_p|=0$$

Solving this yields p eigenvalues, where $\lambda_1\geqslant\lambda_2\geqslant\cdots\geqslant\lambda_p\geqslant0$.

(3) Determine the value of m such that the cumulative variance contribution rate of the principal components exceeds 80%:

$$\frac{\sum_{j=1}^{m}\lambda_j}{\sum_{j=1}^{p}\lambda_j}\geqslant 0.8$$

For each $\lambda_j(j=1,2,\cdots,m)$, solve the system of equations $Rb=\lambda_j b$, thus obtaining the unit vector $b_j^0=\dfrac{b_j}{\|b_j\|}$.

(4) Calculate the m component score coefficients $u_{ij}=z_i^T b_j^0$(for $j=1,2,\cdots,m$) of $z_i=(z_{i1},z_{i2},\cdots,z_{ip})^T$ to obtain the coefficient matrix U:

$$U=\begin{bmatrix} u_1^T \\ u_2^T \\ \vdots \\ u_p^T \end{bmatrix}=\begin{bmatrix} u_{11} & u_{12} & \cdots & u_{1m} \\ u_{21} & u_{22} & \cdots & u_{2m} \\ \vdots & \vdots & & \vdots \\ u_{p1} & u_{p2} & \cdots & u_{pm} \end{bmatrix}$$

Where u_i represents the principal component vector of the i-th variable.

(5) Establish the principal component extraction model:

$$\begin{cases} F_1=u_{11}X_1+u_{21}X_2+\cdots+u_{m1}X_m \\ F_2=u_{12}X_1+u_{21}X_2+\cdots+u_{m1}X_m \\ \vdots \\ F_m=u_{1m}X_1+u_{2m}X_2+\cdots+u_{mm}X_m \end{cases}$$

Here, F_1, F_2, $\cdots$, F_m denote the m extracted principal components; u_{ij} represents the coefficients from the decision matrix U; and X_1, X_2, $\cdots$, X_p are the standardized values of the original factors.

2.4 Hierarchical clustering analysis

Hierarchical clustering is a method that progressively merges clusters from many to few based on inter-cluster distances at different levels[27]. In the hierarchical clustering of principal components derived from village cultural landscape factors, the information carried by the principal component factors serves as the attribute set. Initially, each village is treated as a distinct cluster, constituting the first level. Using the "inter-village distance" (village similarity) as the statistic, the villages with the smallest "inter-class distance" are merged into a new cluster, forming the second level. Subsequently, the new clusters from the second level are grouped based on inter-class distances. This process is repeated recursively until all villages are aggregated into a single large cluster. The final "number of clusters" can be pre-specified according to practical needs or determined by evaluating the reasonableness of sample attribution using expert judgment [30].

2.5 Zoning of traditional village cultural landscapes

The zoning of traditional villages falls within the category of "formal cultural regions," referring to the distribution range of people or landscapes possessing shared cultural attributes that are formed naturally without external imposition [31]. However, due to the processes of spatial transition and regional variations, there exists a degree of long-distance dispersal of villages with similar characteristics and short-range intermixing of villages with different characteristics. Therefore, based on the principal component clustering of quantitative factors, it is necessary to combine the regional differences described by descriptive factors such as building materials, facade features, roof forms, building-ground interface, typical building documentation, intangible cultural heritage, and dominant culture. Based on principles such as similarity of cultural landscape characteristics, geographic contiguity, convergence of development processes, equal development levels, distinct core and peripheral areas, and county and district administrative divisions as boundaries [5)], spatial overlay should be carried out to seek commonalities and refine boundaries. the cultural landscape regions of traditional villages are delineated by combining quantitative and qualitative methods.

3 Analysis and results

3.1 Spatial distribution of cultural landscape factors

Based on the aforementioned framework for deconstructing traditional village cultural landscape factors and the corresponding data collection methods, the collected and organized 14 quantitative factor information items were processed by ArcGIS to form corresponding spatial distribution maps, which intuitively express the spatial distribution characteristics of the quantitative factors (Figure 2).

3.2 Extraction of principal component factors

3.2.1 Model validation

A strong correlation between factor variables is a prerequisite for principal component analysis, so it is necessary to test whether the model is suitable. The KMO value shown in Table 2 is 0.853, which is much greater than 0.5 (the value ranges from 0 to 1, and the closer it is to 1, the stronger the correlation) [29], indicating that the correlation between the factors is relatively strong. Meanwhile, the approximate chi-square distribution value of Bartlett's test for sphericity is 4223.528, with 91 degrees of freedom and a significance of 0.000, which is much smaller than 0.001 [29]. Therefore, the data model, through the KMO and Bartlett's double test of sphericity, can effectively summarize the interrelationships and common characteristics among cultural landscape factors, indicating that the sample data meet the analysis conditions.

Table 2 Correlation test between KMO and Bartlett

KMO sampling suitability measures		0.853
Bartlett's test for sphericity	Approximate Chi-Square	4223.528
	Degrees of freedom (df)	91
	Significance (Sig.)	0.000

3.2.2 Eigenvalues and contribution rates

The principal component eigenvalues and contribution rates are the basis for selecting the number of principal components[27]. The principal component eigenvalues and variance contribution rates of the village cultural landscape factors are shown in Table 3. Based on the criterion of eigenvalues $\lambda \geqslant 1$ [27], five principal components were extracted. Their cumulative variance contribution rate reached 84.845%, satisfying the statistical requirement that the cumulative contribution rate exceed 80%. This accounts for 84.845% of the information content of the original factors. Therefore, the first 5 principal components were selected to replace the original 14 quantitative factors for analysis.

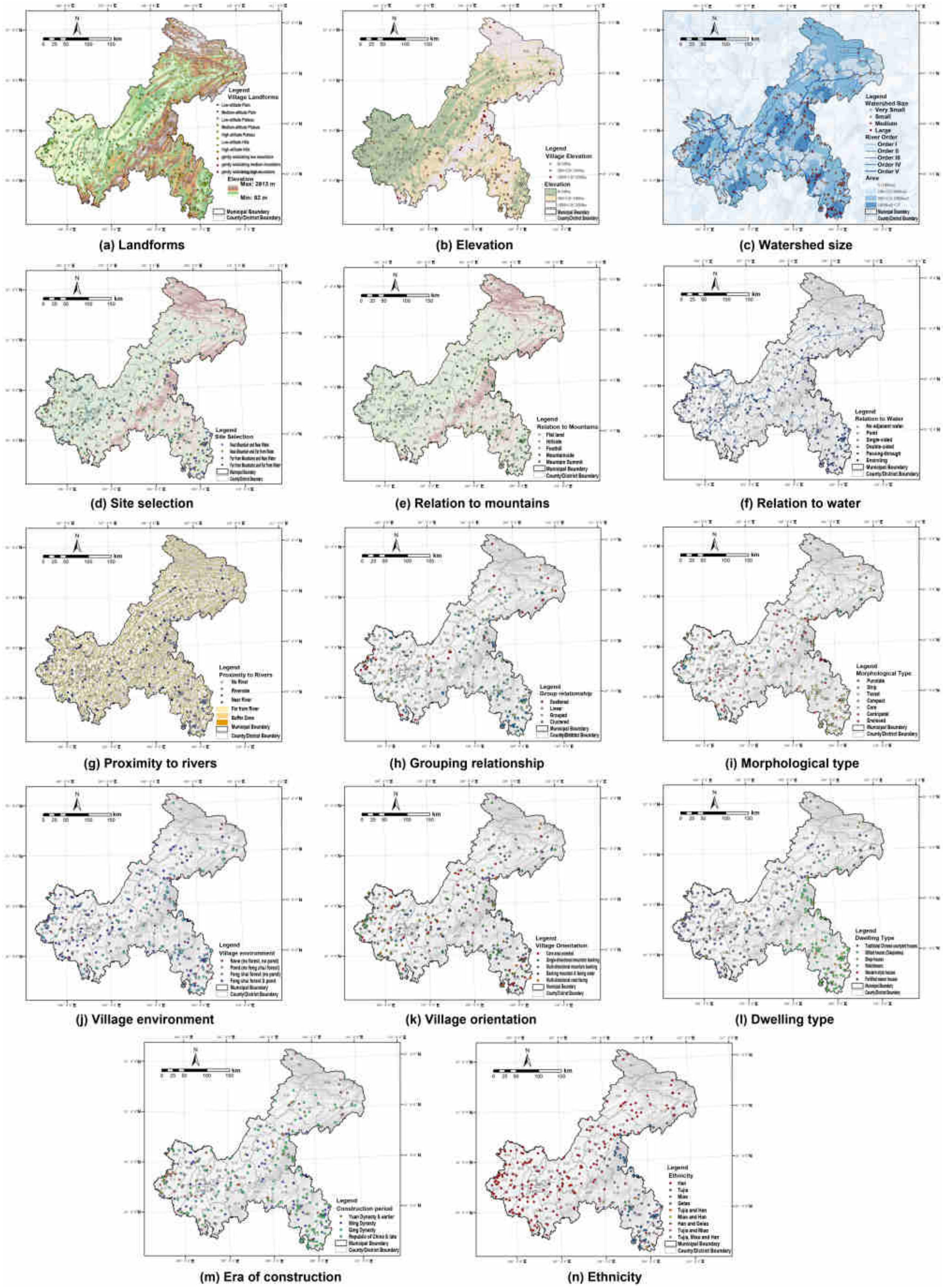

Figure 2 Spatial distribution characteristics of quantitative cultural landscapes in traditional villages of Chongqing based on subtypes

Table 3 Eigenvalues and variance contribution rates of principal components of cultural landscape factors

Principal component	Initial eigenvalues			Extraction sums of squared loadings		
	Total	Percentage of variance	Cumulative%	Total	Percentage of variance	Cumulative%
1	6.196	44.261	44.261	6.196	44.261	44.261
2	2.297	16.405	60.666	2.297	16.405	60.666
3	1.212	8.657	69.323	1.212	8.657	69.323
4	1.161	8.291	77.614	1.161	8.291	77.614
5	1.012	7.231	84.845	1.012	7.231	84.845
6	0.700	4.997	89.842	—	—	—
7	0.380	2.715	92.557	—	—	—
8	0.353	2.521	95.078	—	—	—
9	0.278	1.984	97.063	—	—	—
10	0.119	0.847	97.909	—	—	—
11	0.108	0.774	98.683	—	—	—
12	0.082	0.587	99.270	—	—	—
13	0.060	0.431	99.701	—	—	—
14	0.042	0.299	100.000	—	—	—

3.2.3 Principal component function

Five principal components were selected as principal component factors for analysis. Their factor loading matrices are shown in Table 4. The factor loading vectors represent the contributions of factors to each principal component. The principal component function is expressed as the standardized values of the 14 original variables multiplied by the coefficients of the decision matrix, and then summed [6]. The five principal component functions are:

$$F_1 = 0.025X_1 + 0.029X_2 + 0.006X_3 - 0.032X_4 + 0.060X_5 + 0.052X_6 + 0.058X_7 + 0.001X_8 + 0.060X_9 + 0.058X_{10} - 0.007X_{11} - 0.043X_{12} - 0.059X_{13} + 0.037X_{14}$$

$$F_2 = -0.231X_1 - 0.231X_2 - 0.007X_3 + 0.199X_4 + 0.031X_5 + 0.051X_6 + 0.068X_7 + 0.022X_8 + 0.070X_9 + 0.084X_{10} - 0.081X_{11} + 0.026X_{12} + 0.087X_{13} - 0.087X_{14}$$

$$F_3 = 0.144X_1 + 0.141X_2 + 0.157X_3 + 0.075X_4 + 0.049X_5 + 0.046X_6 + 0.136X_7 + 0.270X_8 + 0.086X_9 + 0.112X_{10} + 0.409X_{11} + 0.414X_{12} + 0.064X_{13} - 0.390X_{14}$$

$$F_4 = 0.083X_1 + 0.081X_2 + 0.266X_3 + 0.002X_4 - 0.071X_5 - 0.002X_6 - 0.006X_7 + 0.636X_8 - 0.086X_9 - 0.037X_{10} - 0.454X_{11} - 0.161X_{12} - 0.028X_{13} - 0.084X_{14}$$

$$F_5 = -0.169X_1 - 0.138X_2 + 0.869X_3 - 0.058X_4 - 0.022X_5 - 0.174X_6 + 0.011X_7 - 0.162X_8 + 0.029X_9 - 0.009X_{10} + 0.230X_{11} - 0.118X_{12} - 0.026X_{13} + 0.210X_{14}$$

As can be seen from Table 4, X_5, X_9, X_{13}, X_7, and X_{10} exhibit the highest factor loadings on F_1 and are positively correlated, mainly reflecting the influence of relation to mountains, grouping patterns, era of construction, proximity to rivers, and spatial forms. On component F_2, variables X_2, X_1, and X_4 show the most significant loadings; specifically, X_2 and X_1 are negatively correlated, whereas X_4 is positively correlated. These factors primarily reflect the influence of elevation and landform. Variables X_{12}, X_{11}, and X_{14} have the highest loadings on F_3, with X_{12} and X_{11} showing positive correlations and X_{14} showing a negative correlation. This component primarily embodies the influence of dwelling type and village environment. Variable X_8 exhibits the highest loading on F_4 with a positive correlation, mainly reflecting the influence of village orientation. Finally, variable X_3 has the highest loading on F_5 and is positively correlated, primarily reflecting the influence of the Watershed Size.

3.3 Hierarchical clustering of principal components

Each of the 320 villages was considered as acluster, with the five principal component factors as its attributes. SPSS cluster analysis was performed using the between-groups linkage method and squared Euclidean distance as the distance measure. No predetermined range was set for the number of clusters, and a cluster dendrogram was drawn. As shown in Figure 3, at the distance coefficient

d= 5, it clusters into 81 clusters; d= 10, clusters into 20 clusters; d= 15, clusters into 7 clusters; d= 20, clusters into 3 clusters; and d= 25, clusters into 1 cluster. It can be seen that different distance coefficients correspond to different numbers of clusters. The number of clusters was set to 2-10 for further analysis. The corresponding area codes of each village in each cluster were obtained. The area codes were imported into the corresponding village attribute table in ArcGIS. Spatial geographic maps of clusters 2-10 were drawn and compared. It was found that the spatial distribution of villages in clusters 2-3 was too fragmented and intermixed. If divided into 2-3 characteristic areas, these solutions would show clear deficiencies in terms of intra-regional cultural landscape similarity, distinctiveness between core and peripheral areas, convergence in developmental processes, and comparability in development levels. The spatial distribution of villages in clusters 5-10 shows that a small number of villages are now clustered together. The main reason for this is that they are located in areas of ethnic integration, typical immigrant areas, and areas on the edge of municipal boundaries. This result is suitable for reference in the next step of sub-region division. Based on the influence of Chongqing's topography, hydrology, climate, and other natural environment and human environment, such as population migration and social organization, on the characteristics of village cultural landscape [25, 32], it was determined that a cut-off distance of d= 16 yields a reasonable clustering of the 320 villages into 4 categories.

Table 4 Principal component factor loading matrix

Cultural landscape factors	Principal component F_1	Principal component F_2	Principal component F_3	Principal component F_4	Principal component F_5
X_1 (Landforms)	0.062	-0.350	0.158	0.089	-0.170
X_2 (Elevation)	0.073	-0.351	0.155	0.087	-0.139
X_3 (Watershed Sizel)	0.015	-0.010	0.173	0.286	0.874
X_4 (Site Selection)	-0.080	0.301	0.082	0.003	-0.059
X_5 (Relation to Mountains)	0.150	0.046	0.053	-0.077	-0.022
X_6 (Relation to Water)	0.129	0.077	0.050	-0.002	-0.175
X_7 (Proximity to Rivers)	0.145	0.104	0.150	-0.006	0.011
X_8 (Village orientation)	0.002	0.033	0.297	0.685	-0.163
X_9 (Group Relationship)	0.150	0.107	0.095	-0.092	0.029
X_{10} (Morphological type)	0.145	0.128	0.123	-0.040	-0.009
X_{11} (Village Environment)	-0.018	-0.122	0.450	-0.489	0.232
X_{12} (Types of dwellings)	-0.106	0.039	0.456	-0.173	-0.119
X_{13} (Era of construction)	0.147	0.132	0.070	-0.030	-0.026
X_{14} (Ethnicity)	0.093	-0.132	-0.429	-0.090	0.212

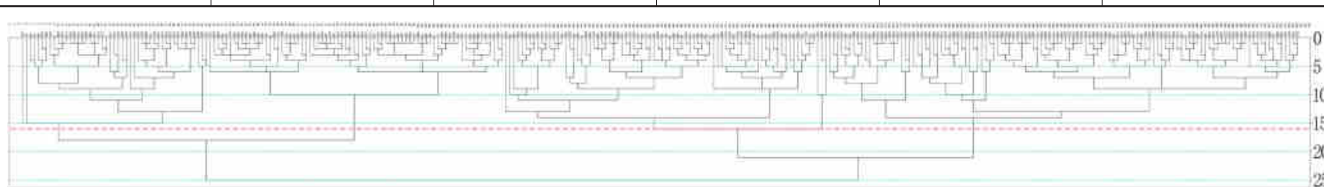

Figure 3 Clustering dendrogram of principal component factors

3.4 Results and typical characteristics of cultural landscape zoning in traditional villages

3.4.1 Results of cultural landscape zoning in traditional villages

By combining quantitative factor clustering results with descriptive factors such as architecture, ethnicity, and dominant culture to identify common features, spatial overlay and boundary fine-tuning were performed, ultimately dividing Chongqing's traditional villages into four cultural landscape zones. Drawing on the "tripartite" naming convention [33], the zones were named according to the structure: "Geographic Location — Dominant or Blended

Culture Type — Common Name." The four major traditional village cultural landscape areas in Chongqing are: the Western Commercial Culture-Dominated Traditional Village Landscape Zone, the Central Immigrant Culture-Dominated Traditional Village Landscape Zone [7], the Northeastern Defense Culture-Dominated Traditional Village Landscape Zone, and the Southeastern Ethnic Culture Integration Traditional Village Landscape Zone (Figure 4).

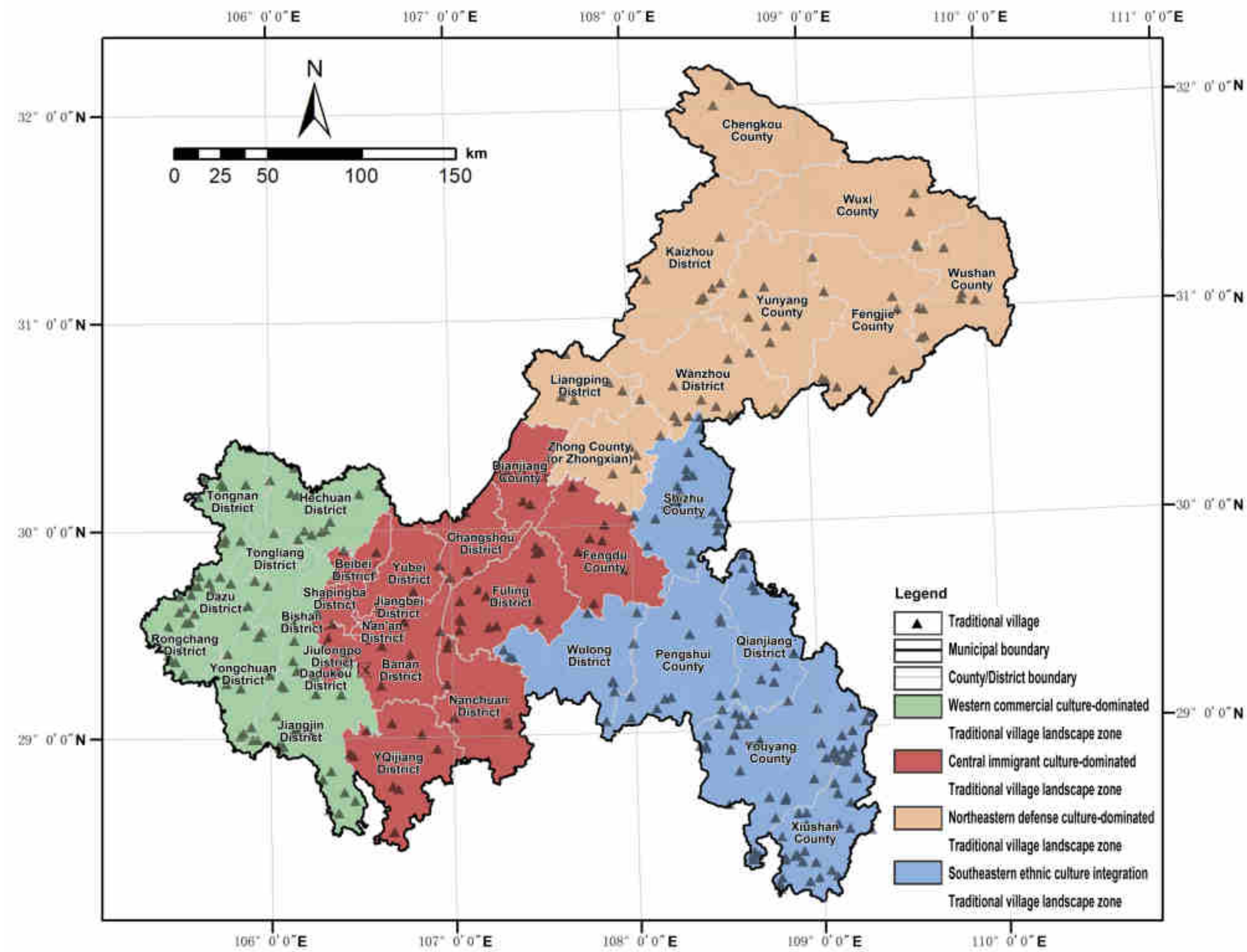

Figure 4 Division of traditional villages in Chongqing

3.4.2 Typicalc haracteristics of traditional village cultural landscape zones

The Western Commercial Culture-Dominated Traditional Village Landscape Zone encompasses eight districts and counties, including Hechuan and Jiangjin. The terrain is mainly plains and plateaus. Villages are commonly located in plains and typically near water orrivers. The spatial form of villages is most characterized by clusters and strips. Commercial villages rarely have feng shui forests or ponds, while feng shui forests are more common than ponds in agricultural villages. The houses are mostly oriented towards roads or mountains; the types of dwellings are diverse, with both ground-level and stilted Building-Ground Interfaces, and the shophouses and Western-style houses are the most distinctive; the ethnic group is mainly Han Chinese. The social culture includes industrial and commercial culture, hilly agricultural culture, Hakka immigrant culture, and Buddhist and Taoist stone carving culture, with commercial culture being the most prominent. Social organizations are mainly composed of guilds (Huiguan) based on trade and regional ties.

The Central Immigrant Culture-Dominated Traditional Village Landscape Zone includes 15 districts and counties such as Qijiang and Fuling. The terrain is mainly hilly and low mountainous, a typical parallel ridge-and-valley region. Villages are often located in hilly areas, close to mountains and water; the spatial form of villages is mainly clustered, dense, and centripetal. Most of them have feng shui forests, while ponds are relatively rare. Houses are mostly oriented backed by mountains, and are divided into single-direction and multi-directional based on the terrain. Dwelling types are diverse, with ground-level dwellings being the most common. The traditional Chinese courtyard houses are the most prominent, while the walled houses are the most distinctive. The watchtowers are made of a combination of earth and stone. The ethnic group is Han, with some ethnic minorities present in the southern area bordering Guizhou. Social culture includes migration culture, hilly and mountainous agricultural culture, and military defense culture, with migration culture being the most prominent. With clans as the basic social structure, the size of the clan determines the size of the village, and there are close connections within the clan.

The Northeastern Defense Culture-Dominated Traditional Village Landscape Zone comprises nine districts and counties, including Wushan and Wanzhou. The terrain and landforms are diverse, ranging from hills, low mountains, medium mountains, and high mountains from south to north. Villages tend to be located near mountains or water, often situated at the foot or summit of mountains. The most common spatial forms of villages are clustered, dense, and centripetal. Villages generally have feng shui forests, but few ponds. The houses are mostly oriented towards the mountains; the style of dwellings is relatively simple, and the ground-level approach is the most common. Chinese-style houses and watchtowers are the most common. In the Zhongshan area, they are mostly in a straight line. Courtyard houses are mostly located in low mountains and hilly areas. Watchtowers are mainly made of stone, and in the Dabashan area, stone is used for walls and roof tiles. The ethnic group is mainly Han, with Tujia as a secondary ethnic group. Social culture includes defensive culture, salt culture, immigrant culture, Ba-Chu culture, agricultural culture, goddess culture, and Wu (Shamanic) culture, with defensive culture being the most prominent. Villages are based on clans as their basic social structure, with strong clan blood ties.

The Southeastern Ethnic Culture Integration Traditional Village Landscape Zone encompasses six districts and counties, including Youyang and Xiushan. The terrain is dominated by low mountains and hills, making it a typical mountainous area. Villages tend to be located near mountains or water, often situated at the foot or ountainside; their spatial forms are most distinctive in clusters and strips. The village environment is based on feng shui forests, and there are often ponds in the flatter areas. The orientation is determined by the mountain as a backdrop, or by the water if there is water nearby, and if there is no water, the orientation is determined by considering both the mountain behind and the direction facing the mountain. The dwellings are characterized by their distinctive features, especially the stilted houses. The stilted houses of the Tujia, Miao, and Gelao ethnic groups have their own unique features in terms of terrain utilization, shape, stilt structure, details, and roofs, due to the influence of their geographical environment and the degree of integration with other ethnic groups. The ethnic groups are mainly Tujia and Miao, with Han and Gelao as secondary groups. Social culture includes agricultural culture, immigrant culture, commercial culture, and ethnic culture, with minority cultures being the most prominent. Villages are built together by clan blood ties, and there are also a small number of contractual clan-type villages (Table 5).

Table 5 Comparison of typical characteristics of traditional village cultural landscape zones in Chongqing

Category	Western commercial culture-dominated traditional village landscape feature zone	Central immigrant culture-dominated traditional village landscape feature zone	Northeastern defense culture-dominated traditional village landscape feature zone	Southeastern ethnic culture integration type traditional village landscape feature zone
Natural Environment	 Dazu Hongxing Community	 Dashun Village, Fuling	 Longxi Village, Wushan	 Ranjiawan Village, Wulong

(Continued)

Category	Western commercial culture-dominated traditional village landscape feature zone	Central immigrant culture-dominated traditional village landscape feature zone	Northeastern defense culture-dominated traditional village landscape feature zone	Southeastern ethnic culture integration type traditional village landscape feature zone
Village Panorama	 Xingjia Village, Jiangjin	 Anzhen Village, Fuling	 Dongyan Ancient Village, Zhongxian County	 Yangjiazhai Village, Youyang
Street and Alley Spaces	 Jiguang Village, Dazu	 Anzhen Village, Fuling	 Ximao Village, Liangping	 Dazhai Village, Xiushan
Residential Buildings	 Songjiang Village, Yongchuan	 Anzhen Village, Fuling	 Yongping Village, Wanzhou	 Yongxiang Village, Youyang
Intangible Cultural Heritage	 Songjiang Village, Yongchuan	 Fengyang Village, Fuling	 Dongyan Ancient Village, Zhongxian County	 Dazhai Village, Xiushan
Residential Buildings	 Songjiang Village, Yongchuan	 Anzhen Village, Fuling	 Yongping Village, Wanzhou	 Yongxiang Village, Youyang
Intangible Cultural Heritage	 Songjiang Village, Yongchuan	 Fengyang Village, Fuling	 Dongyan Ancient Village, Zhongxian County	 Dazhai Village, Xiushan

Conclusion

The study of cultural landscape zoning in traditional villages and its methods represents a direction worthy of in-depth exploration in the cultural geography of traditional villages. This paper optimizes the zoning method by combining Principal Component Analysis (PCA) with hierarchical clustering. The new method was then applied to the zoning of the traditional village cultural landscape in

Chongqing to verify its feasibility. The main conclusions are as follows: (1) A comprehensive zoning method for traditional village cultural landscapes was established, characterized by the workflow: "Factor Deconstruction — Data Collection and Processing — PCA and Hierarchical Clustering — Zoning." First, cultural landscape factors were deconstructed and selected from four aspects: natural environment, spatial form, dwelling type, and social culture. Secondly, factor information was collected, and SPSS was used to standardize the quantitative factors. Next, SPSS was used to extract principal component factors and perform hierarchical clustering. Finally, combining descriptive factors with qualitative impressions, ArcGIS was used to delineate the cultural landscape zoning of traditional villages. (2) The traditional village cultural landscapes in Chongqing can be classified into four zones: the Western Commercial Culture-Dominated Traditional Village Cultural Landscape Zone, the Central Immigrant Culture-Dominated Traditional Village Landscape Zone, the Northeastern Defense Culture-Dominated Traditional Village Cultural Landscape Zone, and the Southeastern Ethnic Culture Integration Type Traditional Village Cultural Landscape Zone. The characteristics of each zone in terms of natural environment, spatial form, dwelling type, and social culture have been summarized.

By optimizing the quantitative zoning method through "Principal Component Analysis combined with hierarchical clustering", this paper explores and validates a more objective, reasonable, and accurate approach for characterizing traditional village cultural landscapes. This represents a further advancement in traditional village cultural geography research and quantitative zoning studies. The new method increases the information retention rate of the zoning factors and reduces the subjectivity of assigning weights among the zoning factors. Specifically, the retained information content was elevated from 20%-30% to over 80%, enhancing the explicit expression of characteristics from "non-dominant factors." Principal components are obtained by combining the factors according to the weight relationships determined by SPSS software based on pure mathematical statistics, which reduces the subjectivity of the traditional "expert scoring method" in determining weight values. Future research should further examine the migration paths, evolution mechanisms, and impact characteristics of traditional village cultural landscape factors in different regions, as well as the application of zoning results at macro, meso, and micro scales.

Sources of Figures and Tables

Figures 1-4 in the text were created by the author.

Table 1 in the text was compiled by the author, and Tables 2-4 are the results calculated and derived by the author using SPSS software based on the data. The images in Table 5, including the second and third photos of the natural environment, the first aerial view of the village, the first and third photos of the street and alley spaces, the third photo of residential buildings, and the second and third photos of intangible cultural heritage, are from "Archives of Traditional Chinese Villages". The remaining photos were taken by the author.

Notes

1) Traditional zoning analysis typically involves 10 to 15 cultural landscape factors. However, usually only 2-3 "dominant factors" are selected for zoning, resulting in an information retention rate of only approximately 20%-30%. This paper focuses on the study of "natural villages." For entries in the official "lists" that are designated as administrative villages, their representative natural villages were selected as the research subjects.

2) This paper focuses on the study of "natural villages." For entries in the official "lists" that are designated as administrative villages, their representative natural villages were selected as the research subjects.

3) Traditional village siting is influenced by feng shui philosophy, emphasizing the principle of "backing the yin and embracing the yang (Fu Yin Bao Yang), and backing mountains while facing water" to adapt to and utilize nature; thus, mountains and water become the most critical factors. The method for judging the distance between villages and mountains and rivers is as follows: the distance between villages and mountains and rivers is measured by the farming radius (the article takes agricultural villages as the main research object). The two-dimensional farming

radius is calculated by ideal, normal, and extreme walking times. Considering the rugged terrain, the accessible radius within a given travel time in a three-dimensional landscape is significantly smaller than the theoretical radius on a two-dimensional map. Therefore, it is necessary to introduce the topographic position index, traffic conditions, etc., to adjust the two-dimensional farming radius. After correction, the equivalent radius on a two-dimensional map corresponding to the actual three-dimensional travel distance is approximately 300 m, 600 m, and 900 m. This paper adopts 600 m as the critical threshold for distinguishing between "far" and "near." Detailed calculation methods are available in Reference [16].

4) Village orientation determines visual conditions, lighting, and settlement microclimate, making it a crucial consideration for siting and settlement.

Chongqing is located in the southwestern mountains, with abundant sunshine and varied terrain. The orientation of villages in Chongqing is unlike other parts of China, where a single dominant orientation prevails. Instead, they follow the terrain. This article divides the orientation of villages based on factors such as mountains, water, and roads. For a detailed orientation model diagram, please refer to the reference [16].

5) Using the administrative boundaries of districts and counties as the boundaries of cultural zones is to facilitate the practical needs of subsequent protection, development, and management work based on the zoning results.

6) It should be noted that the Principal Component Analysis in SPSS yields the initial factor loadings $f_{i,j}$ not the coefficients u_{ij} of the decision matrix U. The relationship between the two is: $u_{ij}=\frac{f_{ij}}{\sqrt{\lambda_i}}$, for $j= 1, 2, \cdots, m$.

7) Due to high urbanization in the "Nine Districts of the Central City" (main urban area) of this region, a large number of traditional villages have vanished. This study involves only a small sample size, which cannot fully demonstrate its cultural landscape characteristics. However, to maintain the integrity of the cultural regions, these areas have been incorporated into the Central Traditional Village Cultural Region of Chongqing.

References

[1] LI, J., YANG, D. H., & XIAO, D. W. (2020). A quantitative study on the cultural landscape division of the traditional settlements and vernacular dwellings in Hainan Island. *Development of Small Cities & Towns*, 38(5), 39-48.

[2] TANG, M. L. (2000). The inventory and progress of cultural landscape study. *Progress in Geography*, (1), 70-79.

[3] China-Guizhou International Symposium on the Protection and Sustainable Utilization of Village Cultural Landscapes. (2008). *Suggestions on "Village Cultural Landscape Protection and Development"* [Working paper]. Guizhou Provincial Department of Culture, Peking University, Tongji University.

[4] ZHANG, H. L., CHEN, J., & ZHOU, C. S. (2017). Research review and prospects of traditional villages in China. *City Planning Review*, 41(4), 74-80.

[5] JIANG, L. Y. (2018). *The Study of the Traditional Village form and the Characteristics of the Residence in Hezhou* [Master's thesis]. Guangxi University, Nanning.

[6] WANG, W. Q., & CHEN, Y. (1994). Discussion on the division of the humanistic background of Chinese traditional houses. *Architectural Journal*, (7), 42-47.

[7] SHEN, X. Y., LIU, P. L., DENG, Y. Y., et al. (2006). Landscape communities of traditional settlement in Southern China and their values of conservation and utilization. *Geographical Research*, (3), 485-494.

[8] WANG, Y. (2018). *Cultural Regionalization Research on Construction Techniques of Manchu Traditional Dwellings in Northeast China* [Master's thesis]. Harbin Institute of Technology, Harbin.

[9] WEI, C., MIAO, K., XIAO, D. W., et al. (2017). Characteristic division and protection thinking on infrastructure. *Modern Urban Research*, (11), 2-9.

[10] HUANG, S. X. (2018). *Researching the Traditional Villages and Houses of the Zhangzhou Area Based on the Cultural Geography* [Master's thesis]. South China University of Technology, Guangzhou.

[11] LI, J., YANG, D. H., & XIAO, D. W. (2020). Study on the cultural divisions and interregional transition relations of the traditional settlement in Hainan Island: Starting from the layout of vernacular dwelling and settlement morphology in Hainan Island. *Architectural Journal*, (S2), 8-15.

[12] ZHANG, J. (2021). *From Distinction to Integration: A study of Landscape Characteristics and Generative Mechanism of Historic Villages in Southeast Chongqing* [Master's thesis]. Chongqing University, Chongqing.

[13] LIU, P. L., LIU, C. L., DENG, Y. Y., et al. (2010). Landscape division of traditional settlement and effect elements of landscape

genes in China. *Acta Geographica Sinica*, (12), 1496-1506.

[14] CUI, X. X. (2019). *Study on the Distribution of Traditional Villages in Northeast China from the Perspective of Cultural Geography* [Master's thesis]. Harbin Institute of Technology, Harbin.

[15] ZENG, Y. (2016). *Cultural Geographic Research on Traditional Settlement and Housing Types in Guangdong* [Master's thesis]. South China University of Technology, Guangzhou.

[16] SONG, Z. J. (2020). *Research on Chongqing Traditional Villages and Their Protection and Development from the Perspective of a Cultural District* [Master's thesis]. Chongqing University, Chongqing.

[17] XIANG, K. C. (2021). *Research on the Spatial Distribution and Regionalization of Minority Traditional Villages in Liping County, Guizhou* [Master's thesis]. Chongqing University, Chongqing.

[18] ZHAI, F. D. (1994). Discussion on the regional factors of residential culture: Folk house cultural geography research one. *Journal of Social Science of Hunan Normal University*, (4), 108-113.

[19] FENG, Z. F. (2014). *Researching of Traditional Villages and Houses of Guangzhou Area Basing on the Cultural Geography* [Master's thesis]. South China University of Technology, Guangzhou.

[20] GAO, F. (2017). *Research on the Protection and Development of Traditional Villages and Houses Based on Cultural Geography—In Aba Prefecture as an Example* [Master's thesis]. Southwest University of Science and Technology, Mianyang.

[21] ZHENG, W. W., DENG, Y. Y., LUO, L., et al. (2016). Quantitative evaluation of similarity among traditional settlement culture landscapes in Xiangxi area. *Human Geography*, 31(2), 55-60.

[22] ZHANG, R., & LU, Q. (2021). Quantitative analysis of distribution characteristics of traditional villages in Guilin and relevant influencing factors. *South Architecture*, (1), 15-20.

[23] Chongqing Municipal Bureau of Statistics, & National Bureau of Statistics Chongqing Investigation Team. (2020). *Chongqing statistical yearbook 2020*. China Statistics Press.

[24] ZHOU, Z. H. (1997). *Research on Chinese Historical and Cultural Regions*. Fudan University Press.

[25] SONG, Z. J. (2021). Research on the protection and development of Chongqing's traditional villages from the regional perspective. *In Space governance for high-quality development: 2021 proceedings of China urban planning annual conference (09 Urban Cultural Heritage Protection)* (pp. 833-842).

[26] SONG, Z. J., LONG, B., & ZHAO, Y. (2020). Study on the spatial distribution of Chinese traditional villages in Chongqing. *Development of Small Cities and Towns*, 38(4), 72-81.

[27] HOU, W. (2006). Discussing a comprehensive evaluation by principal component. *Application of Statistics and Management*, (2), 211-214.

[28] YU, C. H. (2014). *SPSS and Statistical Analysis*. Publishing House of Electronics Industry.

[29] HAN, X. H., ZHANG, Y. H., SUN, F. J., et al. (2012). Method for determining index weights based on principal component analysis. *Journal of Sichuan Ordnance*, 33(10), 124-126.

[30] YANG, W. Z., & ZHANG, T. (2011). *SPSS Statistical Analysis and Detailed Industrial Application Cases*. Tsinghua University Press.

[31] ZHOU, S. Y., KONG, X., & ZHU, H. (2004). *Cultural Geography*. Higher Education Press.

[32] SONG, Z. J., & LONG, B. (2019). Research on the construction characteristics and protection and development of Ranjiawan traditional villages in Chongqing. *In Vibrant Urban and Rural, Beautiful Habitat—Proceedings of Annual National Planning Conference 2019 (17 Mountainous Urban and Rural Planning)* (pp. 115-122). China Architecture & Building Press.

[33] YAO, J. Q. (1988). The clustering analysis on the classification of the areal types of agriculture. *Scientia Geographica Sinica*, (2), 146-155, 199.

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Quantitative Analysis of Contemporary Residential Bathroom Design Through AI Visual Recognition: Object-Design Characteristic Mapping of 1,500 Cases

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ABSTRACT: This study presents a novel methodology for quantitatively analyzing contemporary residential bathroom design characteristics by combining Large Language Model (LLM) image recognition capabilities with text mining techniques. We collected 1,500 bathroom images from ArchDaily and analyzed 1,492 valid cases using Claude API, applying natural language processing and topic modeling to the generated text data. Our analysis reveals a remarkable near 1∶1 balance between material nouns (physical objects) and abstract nouns (design attributes), empirically demonstrating that contemporary bathrooms have evolved from purely functional spaces to venues for aesthetic self-expression. We identified "sophisticated modern minimalism" as the dominant design language, characterized by achromatic palettes and refined simplicity. Through Latent Dirichlet Allocation (LDA) topic modeling, we uncovered six major design themes: Luxury Modern, Nature-Friendly, Functional Vanity Space, Lighting/Open-concept, Industrial, and Minimalism. This research demonstrates the viability of AI-based architectural image analysis and presents methodological innovations by applying discovery science approaches to architectural design research.

KEYWORDS: AI image recognition; bathroom design; text mining; topic modeling; architectural data analysis; Claude API; discovery science

Introduction

Background and research context

The emergence of Large Language Models (LLMs) in the 21st century has brought significant advances in artificial intelligence (AI) technology. Recent multimodal LLMs such as GPT-4 and Claude demonstrate capabilities approaching or exceeding human performance in image recognition and analysis, enabling high-level interpretations of spatial aesthetics, styles, and relationships between design elements[1,3]. While the architectural field actively explores AI applications, research has primarily focused on technical domains such as generative design and parametric modeling [4].

Large-scale analysis of aesthetic and cultural characteristics in architectural design remains dependent on subjective interpretation by human researchers, leading to critical limitations: restricted sample sizes due to manual analysis constraints, inconsistent analytical standards across researchers, and difficulty in capturing temporal

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trends objectively. These limitations are particularly acute in analyzing residential spaces where aesthetic preferences rapidly evolve alongside technological and social changes.

Among residential spaces, bathrooms represent a distinctive integration of functionality and aesthetics, reflecting technological advancement, lifestyle changes, and cultural values [5]. The bathroom has transformed from a purely utilitarian space to a site of personal expression and wellness. This space now serves as a convergence point for personal identity, self-care aspirations, and design preferences. However, systematic large-scale research on contemporary bathroom design trends remains insufficient, with existing studies limited to ergonomic considerations, universal design metrics, or small-sample qualitative analyses.

Discovery science approach in architecture

Discovery science approaches utilizing big data analysis and machine learning have produced innovative outcomes across various fields including medicine, biology, and materials science. This data-driven methodology, which inductively derives patterns from large-scale datasets rather than testing predetermined hypotheses, complements traditional hypothesis-driven research approaches. While urban big data research is increasing in architecture, large-scale data analysis of architectural design itself remains in its early stages.

The gap between available data and analytical capabilities presents a unique opportunity. Digital architectural media archives like ArchDaily have accumulated vast repositories of professionally curated project documentation, yet these remain largely unexplored through systematic quantitative analysis. By combining LLM-based image analysis with text mining, we can convert subjective design attributes into objective data, enabling analysis of large-scale projects with consistent standards previously impossible.

Research objectives and contributions

This study aims to develop and validate a novel methodology for large-scale analysis of contemporary residential bathroom design characteristics using LLM-based image recognition and text mining techniques. Our specific objectives are:

Empirical validation of AI capabilities, to verify AI's architectural space recognition capabilities through systematic extraction and analysis of objects and design features from 1,500 bathroom images, establishing benchmarks for accuracy and consistency.

Quantification of design language, to quantify compositional elements and stylistic characteristics of contemporary bathroom design through systematic analysis of material and abstract nouns, identifying the balance between functional and aesthetic descriptors.

Spatiotemporal trend identification, to identify design trends and regional characteristics according to spatiotemporal context, revealing how global standardization coexists with local preferences and how major events (e.g., COVID-19) influence design evolution.

Latent pattern discovery, to derive latent design clusters through topic modeling, uncovering implicit design themes that may not be apparent through traditional analysis methods.

This research contributes to architectural scholarship by: (a) introducing a reproducible methodology for large-scale design analysis, (b) providing empirical evidence for the evolution of bathroom spaces from functional to aesthetic-functional hybrids, and (c) demonstrating how discovery science approaches can reveal hidden patterns in architectural design data.

1 Related work

1.1 AI-Based architectural image analysis

Architectural applications of computer vision have evolved significantly over the past decade. Early work on achieved architectural style classification of building facade windows using Support Vector Machines, establishing foundational approaches for computational style recognition [7]. Subsequent research significantly improved accuracy to 94.5% using Convolutional Neural Networks (CNNs) for architectural heritage image classification, demonstrating deep learning's superior performance in recognizing architectural elements such as altars, apses, bell towers, and columns [6].

Building on these classification approaches, further research advanced the field by demonstrating deep learning's capacity to classify and measure visual similarity between different architects' designs through the eye of artificial intelligence. Their work showed how AI could identify subtle stylistic patterns that characterize individual architects' work, providing a foundation for understanding AI's analytical capabilities in architectural aesthetics [8].

Recent research has expanded beyond classification to analytical applications. Recent research applied deep neural networks to architectural conceptual design, demonstrating how AI can evaluate existing designs, extract significant building blocks, and recombine them into novel compositions. Their work established foundational approaches for AI-assisted design analysis that inform our methodology [2].

A comprehensive review of artificial intelligence applied to conceptual design in architecture, synthesizing classification, analysis, and generation approaches. Their framework establishes the theoretical foundation for applying AI to architectural design research, directly informing our methodology for analyzing bathroom design aesthetics [4].

The emergence of multimodal LLMs, marks a paradigm shift in architectural image analysis. These models demonstrate capabilities for simultaneous interpretation of functional and aesthetic characteristics, achieving human-level understanding in many contexts. However, systematic application of these capabilities to large-scale architectural datasets remains unexplored, particularly in residential interior spaces where subjective aesthetic judgments have traditionally dominated analysis.

1.2 Text mining in architectural research

Text mining applications in architecture have primarily focused on analyzing textual sources to understand design discourse and user perception patterns. Recent approaches combining AI-generated descriptions with text analysis represent a methodological innovation, where AI serves not merely as an auxiliary tool but as an analytical instrument capable of consistent, large-scale analysis.

The convergence of AI capabilities in architectural analysis—as comprehensively reviewed [4]—with text mining methodologies forms the foundation of our hybrid approach. By converting visual information to text through AI, then applying natural language processing techniques, we can extract quantitative insights from qualitative design attributes at unprecedented scale.

1.3 Bathroom design studies

Scholarly inquiry into bathroom design reflects its evolution from purely functional to culturally significant space. The foundational work "The Bathroom" [5] systematized ergonomic design principles, establishing metrics for functional efficiency that served as the baseline for bathroom design for decades. This function-first approach provides the historical reference point against which we measure contemporary bathroom design's evolution toward aesthetic-functional hybridity.

Contemporary research has traced the bathroom's transformation into a space of self-care and identity construction, examining how bathroom renovations reflect changing lifestyle aspirations and cultural values. Quantitative analyses have typically focused on specific aspects such as universal design indicators for accessibility or parametric optimization of layouts for spatial efficiency.

However, large-scale analysis of design aesthetics using AI-driven image analysis, as attempted in this study, represents an unexplored frontier in bathroom design research. By applying the AI capabilities demonstrated in architectural analysis [2,8] to this specific spatial typology, we can systematically examine how contemporary bathrooms balance functional requirements with aesthetic aspirations.

2 Methodology

2.1 Research design overview

This study employs a systematic five-phase methodology combining AI image analysis with text mining techniques, representing a dual transformation approach: visual to linguistic, then linguistic to quantitative data. This approach builds on the AI applications in architecture reviewed [4] and leverages the vision capabilities of Large Language Models [1,3].

2.2 Data collection and database construction

We collected 1,500 residential projects containing bathroom images from ArchDaily's 'Houses' category, published between January 2015 and December 2024. Selection criteria included: (1) residential projects with dedicated bathroom photography, (2) professional architectural photography (excluding renderings), and (3) complete metadata availability.

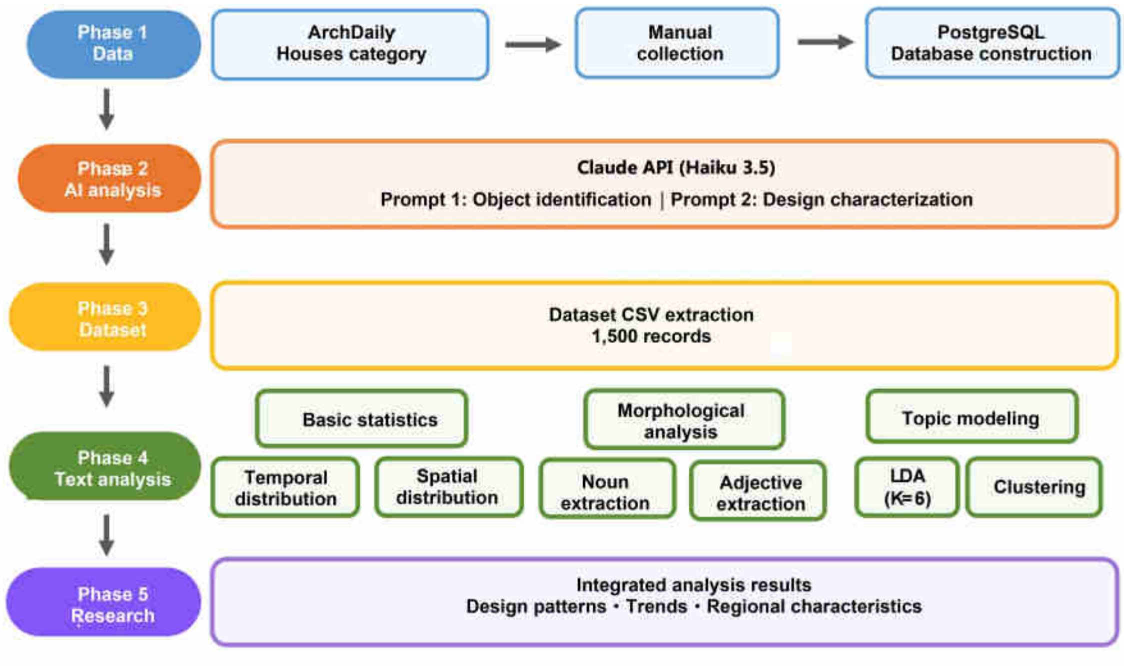


Figure 1 Research methodology flowchart

Geographic distribution was deliberately structured to capture global trends while acknowledging platform biases: Americas (40%), Europe (30%), and Asia-Pacific (30%). This distribution reflects both ArchDaily's user base and global architectural production patterns. For each project, we collected: representative bathroom image(s), project name, architect/firm, geographic location, completion year, and total floor area. Data was stored in a PostgreSQL database with image files linked via UUID references.

2.3 AI image analysis protocol

We utilized Anthropic's Claude API (claude-3-haiku-20240307) for image analysis, selected based on the technical specifications and vision capabilities documented in the Claude 3 Technical Report [1]. The model's multimodal capabilities, as analyzed in the context of artificial general intelligence emergence [3], provided the foundation for consistent architectural description generation. Two distinct prompts were applied to each image:

Prompt 1 (object identification), describe all objects visible in this bathroom image. List each item you can identify, including fixtures, furniture, materials, and decorative elements.

Prompt 2 (design characterization), describe the interior design characteristics of this bathroom. Focus on style, atmosphere, color scheme, materials, lighting, and overall aesthetic qualities.

API responses were parsed in JSON format and stored with timestamps and version tracking. Quality control involved manual verification of 150 randomly selected responses (10% sample), achieving 96% adequacy rating for relevant content extraction.

2.4 Text processing and classification

AI-generated texts underwent systematic preprocessing using R and the KoNLP package for Korean natural language processing:

Morphological analysis, Extracted nouns and adjectives of two or more characters using extractNoun() and SimplePos09 functions.

Stopword removal, Developed a domain-specific dictionary of 220 stopwords including morphological errors (e.g., 'image', 'visible') and generic terms (e.g., 'provide', 'use', 'component') that added no analytical value.

Synonym consolidation, Merged semantically equivalent terms (e.g., 'wash basin'/'sink', 'grey'/'gray') using a manually curated synonym dictionary.

Noun classification, categorized extracted nouns into two distinct classes based on physical tangibility.

Material nouns, physical objects or materials that can be touched (e.g., 'sink', 'tile', 'mirror').

Abstract nouns, concepts, attributes, or qualities without physical form (e.g., 'design', 'luxury', 'comfort').

This classification enabled analysis of the balance between functional and aesthetic descriptors in bathroom design language, directly testing the evolution from the function-first approach [5].

2.5 Quantitative analysis methods

We performed comprehensive statistical analyses including:

Frequency Analysis, calculated occurrence frequencies for all nouns and adjectives, identifying dominant design vocabulary.

Co-occurrence Analysis, examined pairwise relationships between adjectives and nouns to understand design attribute associations.

Temporal trend analysis, applied moving averages and regression analysis to identify design evolution patterns.

Geographic comparison, conducted ANOVA and post-hoc tests to identify regional design preferences (significance level: $p < 0.05$).

Balance score calculation, developed a metric to quantify the ratio between material and abstract descriptors.

2.6 Topic Modeling Implementation

Latent Dirichlet Allocation (LDA) was applied to identify underlying design themes, following approaches used in architectural style analysis [8]. Model optimization involved:

Parameter tuning, tested topic numbers $K = 4$ through $K = 12$, evaluating perplexity (lower is better) and coherence scores (C_v measure, higher is better).

Optimal selection, determined $K= 6$ as optimal based on interpretability and statistical metrics (coherence score: 0.52).

Topic labeling, named topics based on top 10 keywords per topic, validated through expert review.

Temporal analysis, tracked topic prevalence changes across time periods to identify trend shifts.

3 Results and analysis

3.1 Dataset characteristics and spatiotemporal distribution

The final dataset comprises 1,500 bathroom projects with 16 variables (8 metadata, 2 AI-generated texts, 6 derived metrics). AI-generated text showed 100% completeness with average lengths of 127 words (Object prompt) and 93 words (Design prompt).

Temporal distribution and pandemic impact, analysis revealed significant temporal clustering, with 71% of projects concentrated between 2019-2022, peaking in 2021 (290 projects, 19.3%). This surge reflects pandemic-driven priorities, providing a unique window into COVID-era design preferences, though limiting long-term trend analysis (Figure 2a).

Geographic bias and cultural representation, geographic distribution revealed expected Western-centric bias: Europe (33.1%) and Americas (28.4%) dominated with 61.5% combined representation. Asia (23.4%) showed growing presence, while Oceania (11.9%) and Africa (1.2%) remained underrepresented. This bias reflects both ArchDaily's audience and global architectural media production patterns, suggesting findings primarily represent Western and developed Asian markets (Figure 2b).

Project scale analysis, floor area distribution exhibited extreme positive skewness (mean: 1,102 m^2, median: 280 m^2), indicating influence of luxury outliers. Temporal analysis revealed intriguing patterns:

(1) 2016-2020: Preference for larger projects (mean 1,532 m^2), reflecting pre-pandemic luxury residential boom.

(2) 2021-2025: Shift toward compact housing (mean 492 m^2), suggesting pandemic-influenced priorities toward efficiency and sustainability.

Regional variations in project scale reflected cultural and economic contexts. Japan demonstrated remarkable homogeneity (mean= 154 m^2, median= 130 m^2, SD= 48 m^2), embodying compact living culture. Australia showed extreme variance (mean 3,466 m^2, median 300 m^2), indicating polarized market between modest homes and luxury estates.

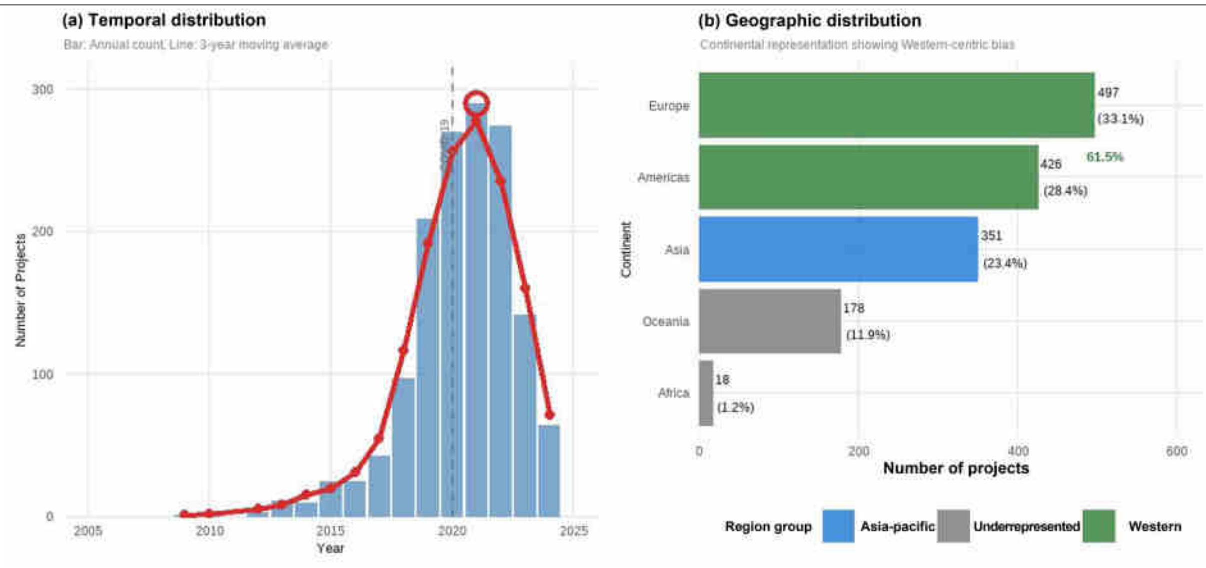


Figure 2 Spatiotemporal distribution (n=1,500). (a) Annual projects with 3-year average. (b) Continental distribution

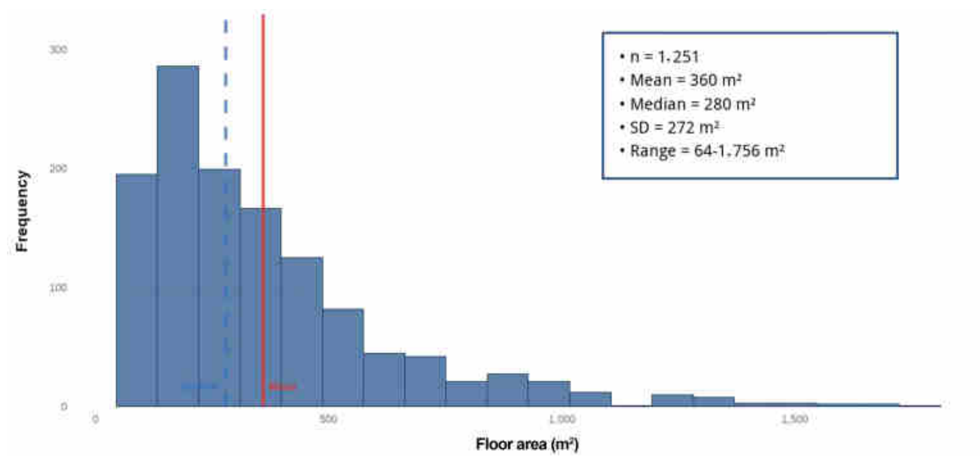


Figure 3 Area distribution histogram with regional overlays (excluding top/bottom 5%)

3.2 Bathroom components: The Material-abstract balance

After data cleaning and validation, 1,492 records (99.5% of the original 1,500) were deemed suitable for analysis. From these 1,492 valid records, we extracted 1,366 unique nouns appearing 36,990 times total. After excluding compound terms and proper nouns (6,299 occurrences, 17.0%), classification of the remaining 30,691 occurrences revealed significant insight into contemporary bathroom conceptualization:

The 1∶1 Balance principle, material nouns (185 unique, 15,728 occurrences, 42.5%) and abstract nouns (188 unique, 14,963 occurrences, 40.5%) demonstrated near-perfect balance. Individual descriptions averaged 10.5 material nouns and 10.1 abstract nouns, confirming equal attention to physical components and design attributes. This near-perfect 1∶1 ratio (42.5% vs 40.5%) provides quantitative evidence that bathrooms have transcended pure functionality to become spaces of aesthetic expression, supporting the proposition that contemporary bathrooms serve as sites of identity construction.

Material noun hierarchy, top material nouns revealed clear functional hierarchy:

Essential fixtures, sink (1,044), mirror (620), toilet (498).

Finishing materials, tile (891), wood (601), stone (456).

Structural elements, wall (794), floor (623), ceiling (387).

Ambience creators, lighting (752), window (751), plant (340).

The high frequency of ‘window’ (751) and ‘plant’ (340) signals contemporary emphasis on natural light and biophilic design, reflecting growing wellness priorities in residential design. This represents a shift from the function-first approach [5] to holistic environmental design.

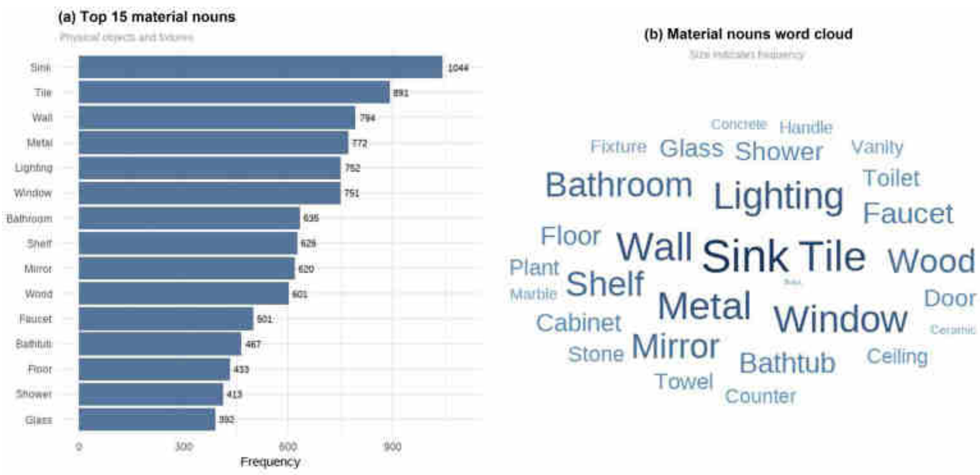


Figure 4 Top 15 material nouns-hierarchical bar chart and word cloud

Abstract noun patterns, Abstract nouns revealed design language standardization:

(1) Conceptual dominance, design (999), frame (711), material (697), installation (691).

(2) Color hegemony, white (650), gray (630), black (535)—achromatic palette accounting for 68% of color mentions.

(3) Sensory descriptors, texture (423), atmosphere (387), warmth (234).

The overwhelming dominance of achromatic colors (white/gray/black: 1,815 combined mentions vs. all chromatic colors: 823) indicates significant standardization in contemporary bathroom aesthetics, possibly driven by global design media influence and resale value considerations.

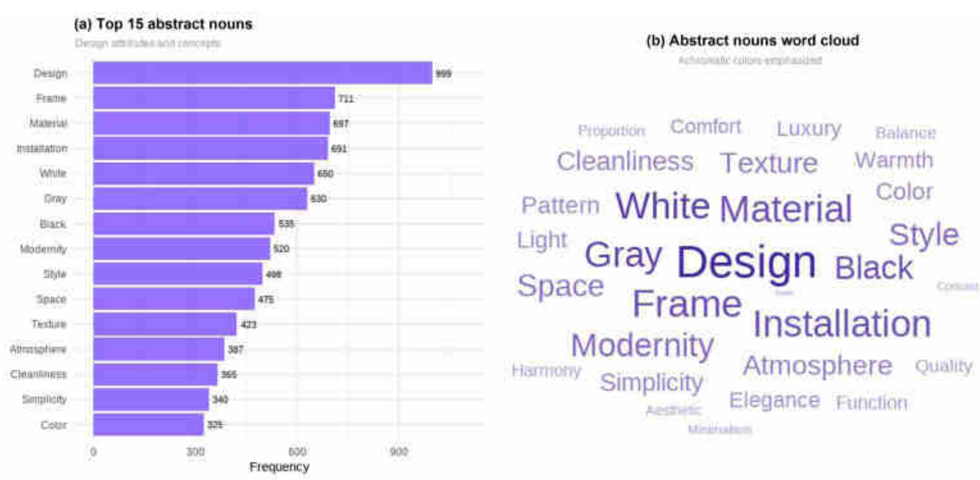


Figure 5 Top 15 abstract nouns-hierarchical bar chart and word cloud

3.3 Design language: “Sophisticated modern minimalism”

Adjective analysis revealed the establishment of a dominant design vernacular. From 11,407 total adjective occurrences (82 unique terms), the distribution followed the Pareto principle, with the top 10 terms accounting for 65% of all occurrences.

The Sophistication Paradigm: ‘Sophisticated’ (1,476 occurrences) exceeded ‘modern’ (911) by 62%, contrary to common assumptions about contemporary design priorities. This suggests evolution beyond mere modernism toward refined, nuanced aesthetics. The adjective hierarchy-sophisticated> modern> clean> minimal> elegant-defines what we term "Sophisticated Modern Minimalism" as the prevailing bathroom design language.

Figure 6　Adjective frequency word cloud with sophistication emphasis

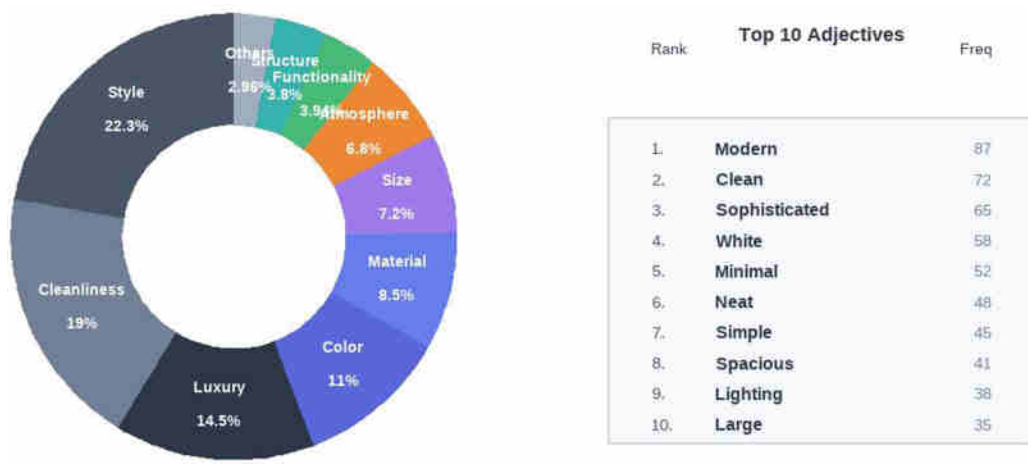
Categorical analysis of spatial attributes, classification into 10 attribute categories revealed design priorities:

Style (22.3%) and cleanliness (19.0%): Core axes forming 41.3% of descriptions.

Luxury (14.5%) and color (11.0%): Key differentiators in competitive market.

Functionality (3.94%): Lowest frequency, suggesting functionality as implicit baseline rather than differentiator.

This distribution indicates that in contemporary discourse, bathrooms are presumed functional; differentiation occurs through style and experience. This represents a significant departure from mid-20th century priorities where function was the primary consideration.



Rank	Top 10 Adjectives	Freq
1.	Modern	87
2.	Clean	72
3.	Sophisticated	65
4.	White	58
5.	Minimal	52
6.	Neat	48
7.	Simple	45
8.	Spacious	41
9.	Lighting	38
10.	Large	35

Figure 7　Spatial characteristic distribution with temporal overlay

Temporal evolution of design priorities, time-series analysis (2015-2024) revealed remarkable stability rather than dramatic shifts:

'Modern' category, dominant and stable at 31%-34% throughout the period.

'Cleanliness', consistently maintained at 25%-27%, unaffected by pandemic.

'Luxury' category, minor fluctuations around 19%-21% (+ 2 percentage points).

'Brightness', gradual decline from 15%-11% (-4 percentage points).

'Nature-related', minimal presence at 6%-8%, with negligible COVID-19 impact.

These patterns indicate a consolidation of minimalist aesthetics as the dominant paradigm, with pandemic effects proving insignificant (< 2% change across all categories). The stability suggests bathroom design preferences are driven by long-term cultural shifts rather than sudden external disruptions.

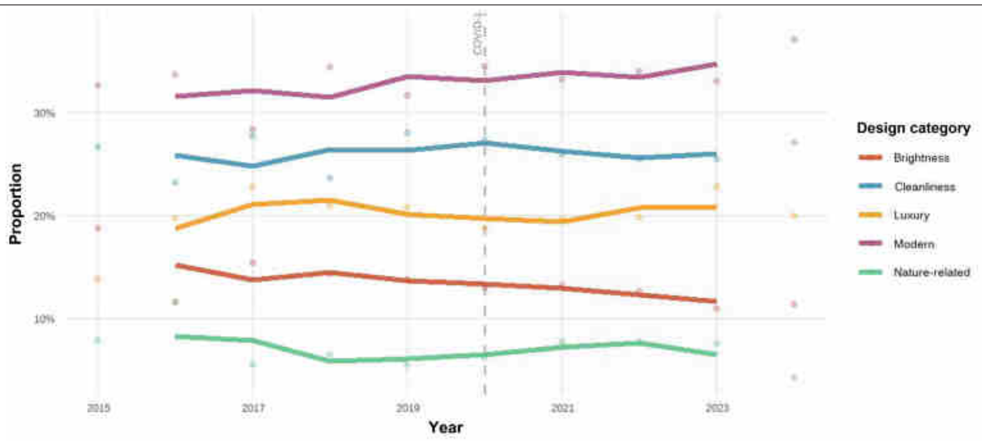


Figure 8 Design trend evolution with COVID-19 marker

3.4 Latent design themes through topic modeling

LDA analysis revealed six coherent design themes, each representing distinct aesthetic approaches:

Luxury modern (18.2%), marble, luxury, sophisticated, gold, chandelier.

• Represents premium market segment emphasizing material opulence.

• Associated with largest project sizes (median 412 m^2).

Nature-friendly (17.7%), wood, natural, plant, warm, organic, beige.

• Embodies biophilic design principles and wellness orientation.

• Represents 17.7% of topics in LDA modeling, while temporal frequency analysis shows stable presence at 6%-8% of actual descriptions across the study period.

Functional vanity space (17.0%), sink, mirror, storage, cabinet, practical.

• Focuses on utilitarian efficiency and organization.

• Popular in smaller projects (median 238 m^2).

Lighting & open-concept (14.4%), window, skylight, natural-light, spacious, airy.

• Emphasizes spatial perception and connection to exterior.

• Strongly associated with contemporary architecture.

Industrial (15.6%), concrete, metal, exposed, raw, black, urban.

• Represents alternative aesthetic challenging mainstream minimalism.

• Shows regional concentration in urban markets.

Minimalism (17.0%), white, clean, simple, zen, uncluttered.

• Classic modernist approach remaining consistently popular.

• Highest in European markets (21.1%).

3.4.1 Temporal dynamics and COVID-19 impact

The relatively even distribution (14.4%-18.2%) suggests contemporary bathroom design as pluralistic field. Topic distribution remained stable throughout 2015-2024, with all themes showing < 3% variation despite pandemic disruption. This stability indicates bathroom design aesthetics are governed by longer-term cultural preferences rather than external shocks.

3.4.2 Regional design cultures

Continental analysis revealed distinct cultural preferences:

Asia, luxury (22.8%) + Nature-Friendly (21.5%)-material richness with natural elements.

Americas, similar to Asia but more balanced distribution.

Europe, hygiene/cleanliness (21.1%) + Minimalism (18.9%)-functional pragmatism.

Oceania, lighting/Open (24.3%)-indoor-outdoor connection.

These patterns reflect deep cultural values: Asian markets balancing prosperity display with harmony principles, European emphasis on practical sustainability, and Oceanic integration with landscape.

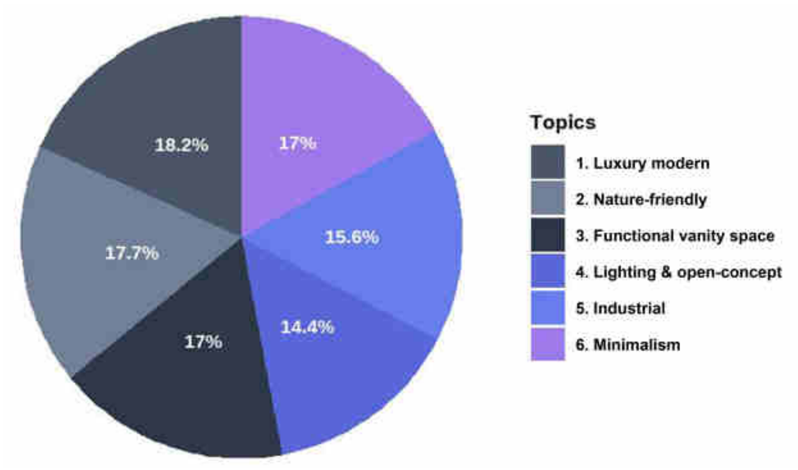


Figure 9 Topic distribution pie chart (n=1,492)

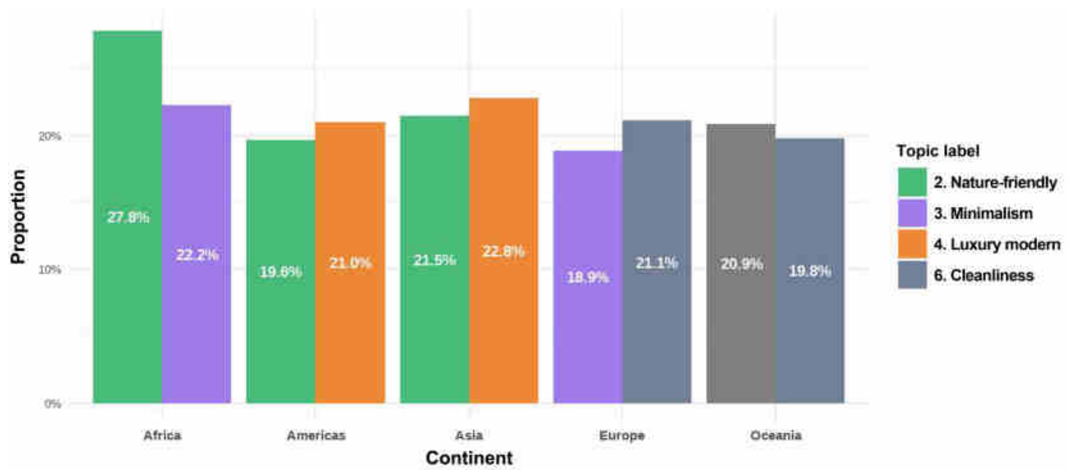


Figure 10 Regional topic preferences

4 Discussion

4.1 Key findings and theoretical implications

This research provides empirical evidence for several theoretical propositions about contemporary bathroom design:

From function to experience, the near-equal balance of material to abstract nouns (42.5% vs 40.5%) quantitatively validates bathroom's evolution from purely functional space to experiential environment. This empirical finding supports the conceptual shift from the function-first approach [5] to contemporary bathrooms as spaces of self-construction, where identity and wellness aspirations materialize through design choices. The dominance of 'sophisticated' over 'modern' suggests users seek not just contemporary aesthetics but refined, culturally resonant experiences.

Standardized pluralism, while "sophisticated modern minimalism" emerges as standard language, the even distribution of six design themes reveals paradoxical standardized pluralism. This pattern reflects the influence of global design media—as observed in architectural AI studies [2,4] —creating common vocabulary while allowing diverse interpretations within that framework.

Stability despite crisis, contrary to expectations, bathroom design aesthetic preferences showed remarkable stability during COVID-19, with all style categories showing < 2% variation. The nature-friendly theme, while comprising 17.7% of the LDA topic distribution, maintained a consistent 6%-8% frequency in actual bathroom descriptions throughout the period, demonstrating that its prominence as a latent topic did not translate to increased adoption during the pandemic. This stability suggests bathroom design aesthetics are governed by long-term cultural preferences rather than external shocks.

Design democracy limitations, despite democratizing trends in design media, correlation between certain themes and project size reveals persistent exclusivity. Luxury Modern and Lighting/Open concepts remain spatially constrained, suggesting class-based design stratification persists despite aesthetic democratization, a pattern consistent with broader observations in architectural design research [4].

4.2 Methodological contributions and validation

The dual transformation methodology-visual to linguistic to quantitative-opens new research possibilities:

Consistency and scale, AI-generated descriptions achieved 96% adequacy with perfect completeness, surpassing human analysis limitations. This validates the vision capabilities documented in recent LLM research [1,3] for architectural applications. The ability to maintain consistent analytical standards across 1,500 cases exceeds previous studies by an order of magnitude, demonstrating the scalability potential identified [4].

Discovery science validation, topic modeling revealed patterns invisible to traditional analysis. The nature-friendly surge and regional design cultures emerged from data rather than predetermined hypotheses, validating discovery science approaches in architecture consistent with inductive methodologies in computational design research [8].

Reproducibility framework, by documenting prompts, preprocessing steps, and classification criteria, we establish reproducible protocol for future studies. This addresses critical reproducibility crisis in architectural research where subjective interpretation typically dominates, extending the systematic approaches demonstrated in heritage classification and style recognition [6-8].

4.3 Limitations and future directions

Several limitations warrant acknowledgment:

Platform bias, archDaily's curatorial process favors professionally photographed, architecturally significant projects, potentially overstating luxury and sophistication prevalence. Cross-platform validation using real estate listings or social media could provide broader market representation.

Temporal concentration, data clustering around 2020-2021 provides pandemic snapshot but limits long-term trend analysis. Longitudinal studies spanning decades could reveal cyclical patterns versus permanent shifts.

Spatial resolution, using total floor area rather than bathroom-specific dimensions introduces noise. Future research should develop methods for extracting room-specific areas from architectural documentation, potentially using the spatial understanding capabilities demonstrated in recent AI research [2].

Cultural representation, western-centric bias (61.5%) limits global applicability. Targeted data collection from underrepresented regions could reveal alternative design paradigms beyond those captured in current AI training data [1].

4.4 Practical implications

For design practitioners and industry stakeholders, findings offer actionable insights:

Product development, the material-abstract balance indicates equal importance of functional performance and aesthetic experience. Product designers should consider sensory and emotional attributes alongside technical specifications. The sink's prominence as most frequent object (1,044 mentions) suggests prioritizing this as visual focal point in bathroom design compositions.

Market segmentation, six distinct themes provide framework for targeted product lines and marketing strategies. The nature-friendly theme's dual presence—17.7% weight in topic modeling yet stable 6%-8% frequency in actual descriptions—suggests a latent market opportunity: while strongly defined as a design approach, it remains underutilized in practice.

Regional customization, significant continental variations indicate need for localized strategies. European emphasis on Minimalism (18.9%) versus Asian preference for Luxury (22.8%) requires differentiated approaches despite global standardization trends.

Sustainability integration, nature-friendly theme's growth suggests sustainability messaging resonates when combined with wellness and aesthetic benefits rather than purely environmental arguments, reflecting holistic design approaches in contemporary architectural practice.

Conclusion

This study systematically analyzed design characteristics of 1,500 contemporary residential bathrooms using AI visual recognition and text mining, revealing multiple layers of insight into contemporary design culture. The research makes three primary contributions:

Methodological innovation, the dual transformation methodology combining AI image recognition with text mining overcomes traditional limitations of subjective interpretation in architectural analysis. By converting visual information to linguistic data, then to quantitative metrics, we establish reproducible protocol for large-scale design research. The 96% adequacy rate and perfect completeness validate AI as a reliable analytical instrument, building on the capabilities demonstrated in recent LLM research [1, 3] and extending applications shown in architectural AI studies [2,4].

Empirical evidence, we empirically demonstrated contemporary bathroom design's evolution from functional to experiential spaces through the near-equal balance of material and abstract nouns (42.5% vs 40.5%). The emergence of "sophisticated modern minimalism" alongside six coexisting design themes reveals a standardized pluralism in global design culture, validating the shift from the function-first paradigm [5] to contemporary multivalent design approaches.

Theoretical extension, applying discovery science approaches to architectural design validates inductive pattern discovery in aesthetic domains traditionally dominated by deductive reasoning. The divergence between topic prominence (e.g., nature-friendly at 17.7% in topics) and actual frequency (6%-8% in descriptions), combined with stability despite pandemic disruptions, provides data-driven evidence for theoretical propositions about latent versus realized design preferences, cultural resilience in aesthetic choices, and the persistent influence of socioeconomic factors on spatial decisions. This extends the analytical frameworks demonstrated in architectural classification research [6-8] to interior design analysis.

The methodology presented here extends beyond bathrooms to any architectural element amenable to visual documentation. Future research should address identified limitations through multi-platform validation, extended temporal coverage, and improved spatial resolution. The analytical capabilities demonstrated in recent AI research [2,8] suggest potential for extending this methodology to other architectural typologies and design domains.

This research fundamentally demonstrates how architectural databases—long considered passive repositories of visual documentation—can be transformed from silent archives accessible only through manual browsing into active resources for systematic knowledge discovery. The convergence of AI's visual understanding capabilities [1, 3] and analytical precision [2,8] reveals that vast architectural media collections contain untapped empirical insights about how humanity shapes and inhabits space. As AI capabilities mature and architectural documentation proliferates, we stand at the threshold of a new era where the accumulated visual history of architecture becomes a living laboratory for understanding the complex interplay between design, culture, and human experience—transforming architectural research from an interpretive art into a data-driven science without sacrificing its humanistic core.

Competing interests

The authors have no competing interests to declare that are relevant to the content of this article.

Sources of Figures and Tables

Figures 1-10: Author's own work.

Note

The analysis is based on 1,500 bathroom images sourced from ArchDaily (www.archdaily.com). A permission request was submitted to contributors.support@archdaily.com on 12 Sep 2025 and remains pending. Images used for non-commercial academic research purposes.

References

[1] Anthropic. (2024). *Claude 3 Technical Report*. Retrieved from https://www.anthropic.com.

[2] As, I., Pal, S., & Basu, P. (2018). Artificial intelligence in architecture: Generating conceptual design via deep learning. *International Journal of Architectural Computing*, 16(4), 306-327.

[3] Bubeck, S., Chandrasekaran, V., Eldan, R., Gehrke, J., Horvitz, E., Kamar, E., ... & Zhang, Y. (2023). Sparks of artificial general intelligence: Early experiments with GPT-4. *arXiv preprint arXiv*: 2303.12712.

[4] Castro Pena, M. L., Carballal, A., Rodríguez-Fernández, N., San-

tos, I., & Romero, J. (2021). Artificial intelligence applied to conceptual design: A review of its use in architecture. *Automation in Construction*, 124, 103550.

[5] Kira, A. (1976). *The Bathroom*. Viking Press.

[6] Llamas, J., Lerones, P. M., Medina, R., Zalama, E., & Gómez-García-Bermejo, J. (2017). Classification of architectural heritage images using deep learning techniques. *Applied Sciences*, 7(10), 992.

[7] Shalunts, G., Haxhimusa, Y., & Sablatnig, R. (2012). Architectural style classification of building facade windows. *In International Symposium on Visual Computing* (pp. 280-289). Springer.

[8] Yoshimura, Y., Cai, B., Wang, Z., & Ratti, C. (2019). Deep learning architect: Classification for architectural design through the eye of artificial intelligence. In *International Conference on Computers in Urban Planning and Urban Management* (pp. 249-265). Springer.

Appendix A: AI image analysis prompts and implementation

A.1 API implementation code

```
def analyze_image_with_claude(image_path, prompt):
    """
    Analyzes bathroom images using Claude 3 Haiku API.

    Parameters:
    -image_path: Path to the bathroom image file
    -prompt: Structured prompt for analysis

    Returns:
    -Structured text description of bathroom features
    """
    api_key= os.getenv('ANTHROPIC_API_KEY')
    #  … API key validation …

    client= anthropic.Anthropic(api_key= api_key)

    #  Encode image to base64
    with open(image_path, 'rb') as image_file:
        image_bytes= image_file.read()
    image_data= base64.b64encode(image_bytes).decode('utf-8')

    #  Claude API call
    message= client.messages.create(
        model= "claude-3-haiku-20240307", #  Model specification
        max_tokens= 1500, #  Maximum token limit
        messages= [
            {
                "role": "user",
                "content": [
                    {"type": "text", "text": prompt},       #  Text prompt
                    {"type": "image", "source": {          #  Image data
                        "type": "base64",
                        "media_type": "image/png",
                        "data": image_data
                    }}
                ]
            }
        ]
    )
    return message.content
```

A.2 Structured analysis prompt

```
def get_bathroom_analysis_prompt():
    """
    Returns the standardized prompt used for all bathroom image analyses.
    The prompt ensures consistent, structured output across all 1,500 images.
    """
    return (
        "Analyze the attached image and provide detailed responses to the following "
        "two questions with maximum specificity and comprehensiveness.\n\n"

        "Format all responses in Markdown with items clearly delineated using lists "
        "(• or 1. 2. etc.). Each response should be numbered (1, 2) with descriptive "
        "subheadings (e.g., 'Identifiable Objects and Characteristics', "
        "'Interior Design Features'). Use concise, descriptive statements without "
        "formal endings; employ telegraphic style where appropriate.\n\n"

        "1. Identify and describe all discernible objects in the image with their "
        "characteristics in comprehensive detail without redundancy:\n"
        " -Include material composition, color, spatial positioning, functional "
        " purpose, design features, and placement rationale for each object.\n"

        "2. Describe the interior design characteristics comprehensively without "
        "redundancy:\n"
        " -Address overall ambiance, color palette, spatial configuration, "
        " natural/artificial lighting, material harmony, visual focal points, "
        " design intent, stylistic elements, and functional considerations.\n"
        " -Present notable features as numbered lists (1. 2. 3. …) with "
        " specific details.\n"

        "While responses need not artificially reach 10 lines, provide rich, "
        "non-redundant descriptions that capture all relevant aspects."
    )
```

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Exploration of Guangdong Rural Distributed Photovoltaic Construction Model from the Perspective of "Innovative Carbon-Neutral Rural Area"

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ABSTRACT: As China is a major carbon-emitting country, low-carbon development in rural areas will play a key role in achieving the national goal of carbon peaking and neutrality. With the advancement of the rural revitalization strategy, carbon emissions in rural areas have intensified; however, these areas also demonstrate significant advantages in spatial resources for ecosystem carbon sinks and new energy development. The two national strategies of "carbon neutrality" and "rural revitalization" are intrinsically linked. Therefore, a strategic coupling mechanism combining "carbon neutrality" and "innovative rural area" should be established. This mechanism aims to promote positive interaction between urban capital, talent, and technology and the rich ecological carbon sinks and vast spatial resources of the countryside, opening up new pathways for the flow of urban-rural capital and resources.

Based on this new perspective, and leveraging Guangdong Province's abundant solar energy resources and vast stock of rural housing, this article explores the technical system, implementation path, and operation mode of rural distributed photovoltaics. The construction of this model is carried out at five levels. At the level of resource assessment and construction, it emphasizes the comprehensive investigation and evaluation of resources within a certain area (preferably at the county or town level) and establishes coordination between investment companies, multi-disciplinary teams, villagers, and governments. At the design and implementation level, it proposes combining distributed photovoltaics with the revitalization of rural landscapes in Guangdong Province to improve rural aesthetics, turning government costs into investments, and converting idle village resources into effective assets. At the commercial operation level, based on clarifying the functions and benefits of all parties, a win-win cooperation mechanism comprising "village joint-stock company-operating enterprise-government" is constructed, and three business models for the renovation of rural houses with solar panels have been designed to enhance their market promotion. At the level of operation and maintenance management (O&M), a rooftop solar energy smart management platform is built to manage the pre-development process, project approval, capital use, and O&M, promoting efficient management.

Furthermore, based on the construction of photovoltaic sun pavilions for rural houses, this paper further proposes a variety of models combining distributed photovoltaics with traditional rural construction and agriculture. It also puts forward ideas for the construction of a rural energy system featuring "source-grid-load-storage integration," to promote the iterative upgrading of power generation technology and the combined utili-

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zation of resources in rural production and living spaces. Finally, this article proposes an extended reflection on the model of "Innovative Carbon-Neutral Rural Area". It is a comprehensive concept that requires the comprehensive transformation and development of rural space, economy, and society in harmony with the environment, aiming to build a rural area developed with environmentally-friendly principles. Economically, it promotes the assetization of ecological resources and creates a new model of rural green industry and finance. Socially, it focuses on low-carbon production and lifestyle, establishing a new mechanism for smart and modern ecological governance.

KEYWORDS: rural revitalization; carbon neutrality; rural distributed photovoltaic construction model; Innovative Carbon-Neutral Rural Area

Introduction

The increasing concentration of greenhouse gases, such as carbon dioxide, has intensified the greenhouse effect, leading to global warming and a higher frequency of extreme weather events. These changes exert irreversible and severe impacts on human production,living, and ecosystems [1]. In his important speech at the ninth meeting of the Central Financial and Economic Affairs Commission, General Secretary Xi Jinping pointed out that carbon peaking and carbon neutrality should be incorporated into the overall layout of ecological civilization, signifying a broad and profound systemic socio-economic transformation [2]. The trend of low-carbon consumption driven by ecological economics, which emphasizes returning to nature, is providing a vast market and impetus for the development of China's rural ecological economy [3]. However, China has long exhibited a tendency to prioritize cities over rural areas (a phenomenon known as "urban bias"). Decision-makers have predominantly focused low-carbon economic development on cities, while rural areas are easily overlooked [4]. Standing at the new starting point of comprehensively promoting rural revitalization, we find it even more urgent to explore the transformation pathways for low-carbon development in rural areas, promote the development of rural ecological civilization, and help China achieve its carbon neutrality goal as soon as possible.

1 "Innovative Carbon-Neutral Rural Area": Comprehensive advancement and high integration of the two major national strategies

1.1 The Challenges and potentials of low-carbon development in rural areas

China's rural land area covers 5.53 million km^2, including 1.23 million km^2 of arable land, with a rural population of about 577 million. Across such a vast area, the total energy demand for rural living and production is large, widespread, and relatively dispersed [5]. In terms of rural life, in recent years, the per capita energy consumption in rural areas of China has been increasing, with a growth rate far exceeding that in urban areas, and carbon emissions have also shown an increasing growth trend. Regarding rural production, agricultural activities are not only a major source of greenhouse gas emissions, but also the sector most vulnerable to climate change [6]. As a major agricultural country, China's total agricultural carbon emissions have consistently been higher than those of European and American countries. In addition, China's agricultural production mainly relies on the application of chemical fertilizers and pesticides to achieve the goal of increasing yields [7]. The extensive use of pesticides, agricultural plastic films, and diesel fuel generates significant amounts of greenhouse gases—such as carbon dioxide, methane, and nitrous oxide—while also leading to a gradual decrease of soil organic matter. Evidently, the agricultural production sector holds significant potential for carbon emission reduction in the future.

Rural areas are not only an indispensable part of the nation's energy consumption and greenhouse gas emissions, but also an important spatial carrier for ecosystem carbon sinks and new energy development. In terms of ecosystem carbon sinks, if the soil organic matter of the country's 120 million hectares of farmland increases by 1‰, it can net absorb 3 billion tons of CO_2 from the atmosphere. Additionally, with a national forest area of 208 million hectares, the total carbon storage can reach 8.427 billion tons. If these vast carbon sink resources in rural areas can be effectively managed, they can be increased at a low cost, making a significant contribution to reducing greenhouse gas emissions. Regarding new energy development, biomass energy, solar energy, wind energy, and other renewable energy sources are decentralized and relatively evenly distributed energy sources compared to traditional fossil energy. This characteristic gives rural areas a spatial resource advantage over cities. With the rapid development of new energy technologies such as photovoltaic and wind power generation, renewable energy is more economically viable than ever before [8], providing stronger support for the low-carbon transformation of rural areas.

1.2 The Significance and value of integrating the rural revitalization strategy with the carbon neutrality strategy

Green and low-carbon development is the endogenous driving force and inevitable requirement for high-quality rural revitalization, and the emission reduction potential inherent in rural areas can be effectively stimulated through rural revitalization.

Key documents, such as the *Strategic Plan for Rural Revitalization* (2018-2022) and the No. *1* Central Document of *2021* (i.e., *Opinions of the CPC Central Committee and the State Council on Comprehensively Promoting Rural Revitalization and Accelerating the Modernization of Agriculture and Rural Areas*), have put forward specific requirements for the construction of modern rural energy systems, industrial upgrading, ecological protection and restoration, and the cultivation of low-carbon living concepts.

The concept of carbon neutrality presents both opportunities and challenges for rural development. Achieving carbon neutrality means a broad and profound transformation of the energy, socio-economic, and technological systems. In the energy system, the main approach is to promote the clean and efficient transformation of energy production and supply, while effectively integrating new energy sources with digital and intelligent technologies [9]. In the socio-economic system, the core lies in improving market mechanisms such as carbon trading and carbon emission taxes, and perfecting relevant carbon regulatory systems to open up new channels for the flow of capital and resources between urban and rural areas. In the technology system, the focus is on the innovative development of technologies such as nature-based negative emission technologies, sustainable agricultural development technologies, and carbon sequestration technologies.

Focusing on issues such as inefficient energy structure, outdated energy facilities, underutilization of resources, severe pollution and low added value in agricultural production, and the lagging development of the rural financial system, a coupling mechanism of the rural revitalization strategy and the carbon neutrality strategy should be constructed (Figure 1). By organically integrating elements such as new energy, new institutions, and new technologies, this mechanism promotes a positive interaction of urban capital, talent, and technology with the abundant ecological carbon sink resources and vast spatial resources of rural areas. This approach opens up new pathways for the flow of urban-rural capital and resources, driving rural areas to transcend the traditional low-quality, high-pollution development model and transition towards resource efficiency, increased farmer income, and environmental friendliness.

2 Exploration of a new model for guangdong rural distributed photovoltaic construction from a new perspective

Based on the Kaya Identity Theory, improving energy efficiency in rural production and living, optimizing the energy structure, and reducing the carbon intensity of energy consumption are critical pathways for building a low-carbon countryside [10]. Among these, developing clean energy stands out as the core pathway. Rural areas possess abundant renewable energy resources, such as wind, solar, hydro, biomass, and geothermal energy. These resources should be effectively developed and utilized based on the resource endowments of rural "production-living-ecological" spaces. Under the "Innovative Carbon-Neutral Rural Area" perspective, rural areas in Guangdong should specifically tailor the construction of new energy systems to local conditions, promote the modernization and upgrading of industries, foster a new low-carbon economy, and facilitate the low-carbon transformation of rural production and lifestyles.

Exploringa new model for rural distributed photovoltaic construction based on Guangdong's own resource endowment is one of the essential approaches to building a modern rural energy system in Guangdong. However, unlike those "photovoltaic poverty alleviation" projects that rely on government financial subsidies, in order to achieve widespread, large-scale construction and operation of distributed photovoltaics in rural areas, a comprehensive survey and assessment of resources within a certain area (preferably at the county or town level) is required. This should be combined with relevant urban and rural development plans to conduct scientific spatial layout and integrated design. At the same time, enterprises with long-term operational capabilities should be introduced to invest in construction in a manner that conforms to market rules, and relevant government financial funds should be used rationally. This will enable a multi-party, long-term win-win situation through a platform that links government, enterprises, villages, and professional teams.

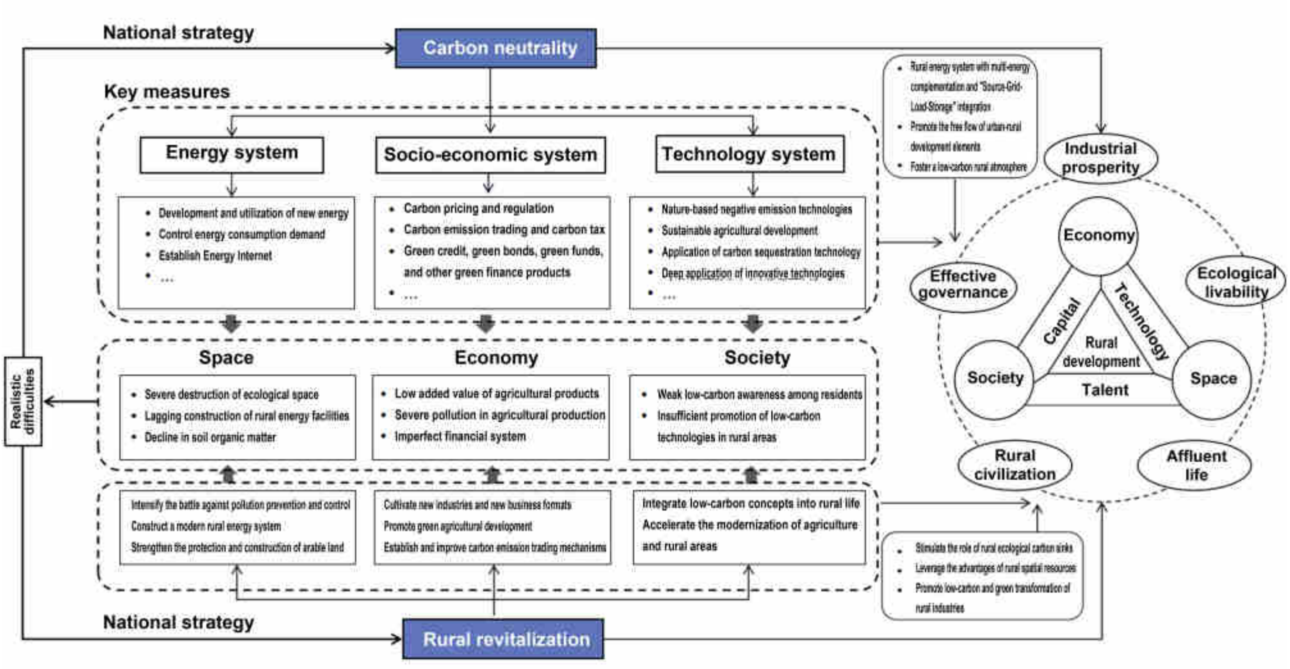

Figure 1 Strategic coupling mechanism of "Innovative Carbon-Neutral Rural Area"

In conjunction with the comprehensive improvement of rural housing appearance currently underway in Guangdong Province, the author and the research team utilized the vast number of existing rural housing rooftops to construct distributed PV systems. We explored the scientific technologies, implementation pathways, and operation models of "rural rooftop distributed photovoltaics" from multiple dimensions, achieving significant results. In addition, the author and research team took the development and construction of rooftop distributed photovoltaics as a starting point to further explore the development of rural composite distributed photovoltaics and the construction of rural new energy systems.

2.1 The Practical significance of constructing composite photovoltaic systems for Guangdong

2.1.1 Land resources in Guangdong are scarce and lack the geographical conditions for large-scale single-function photovoltaic development

From 2015 to 2020, both electricity consumption and generation in Guangdong Province continued to grow; however, the local power supply remained severely insufficient (Figure 2). With the development and construction of the Guangdong-Hong Kong-Macao Greater Bay Area, the power gap in Guangdong Province will further expand, while also providing support for the vigorous development of new energy sources. Guangdong Province is located in the East Asian monsoon region and has abundant light and heat resources, making it suitable for solar energy development. However, due to the scarcity of land resources, the province lacks the geographical conditions for developing large-scale single-function photovoltaic plants. Therefore, it is essential to utilize existing rooftop spaces of buildings—such as rural housing and public buildings—as well as production spaces involving agriculture, forestry, animal husbandry, and fishery to construct composite PV systems.

2.1.2 The Vast stock of rural houses is an ideal carrier for distributed photovoltaics

Guangdong Province possesses over 20 million rural houses. Calculated at a roof area of 80-100 m^2 per house, the total rural rooftop area exceeds 1.6 billion m^2.Although these rural houses are scattered across vast rural areas, they have similar heights and minimal mutual shading. Moreover, their property rights are clear, making them ideal carriers for the construction of distributed rooftop photovoltaic systems, from both technical and managerial-operational perspectives. Moreover, most of these houses were built after the 1990s and are unlikely to be reconstructed within the next 20 to 30 years (aligning with the lifecycle of photovoltaic systems). Furthermore, the era of large-scale new rural housing construction in Guangdong has passed. Therefore, exploring the construction of distributed photovoltaic systems on the stock of existing rural housing is a direct and effective pathway to restructure the rural new energy system in the context of the "Innovative Carbon-Neutral Rural Area." It will also contribute significantly to energy saving and emission reduction in rural buildings. This initiative coincides with the National Energy Administration's issuance of the Notice on *Submitting Pilot Schemes for Whole-County Promotion of Household and Distributed Rooftop Photovoltaic Development*, providing stronger policy support for the development of distributed photovoltaics in the rural new energy sector.

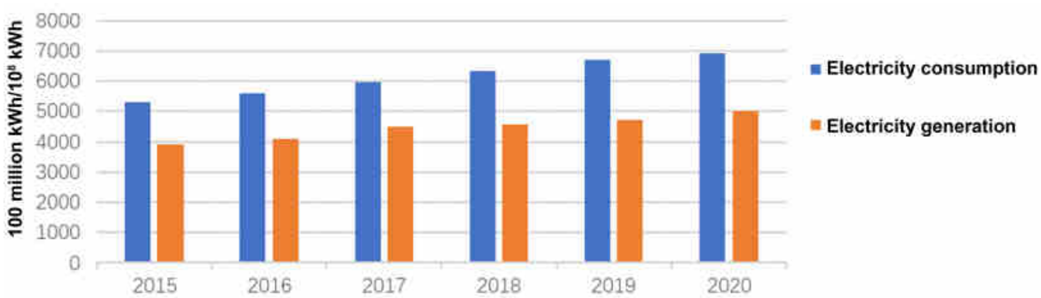

Figure 2 Statistical diagram of annual electricity consumption and power generation in Guangdong Province from 2015 to 2020

2.1.3 The ongoing renovation of rural housing appearance provides a good opportunity for the large-scale construction of rooftop photovoltaic systems

In 2020, Guangdong Province released the *Guiding Opinions of the People's Government of Guangdong Province on Comprehensively Promoting Rural Housing Control and Rural Appearance Improvement*. The document identifies rural housing control and appearance improvement as inevitable requirements and crucial levers for implementing the provincial rural revitalization strategy and strengthening rural governance.

Consequently, the renovation and beautification of the exteriors of Guangdong's distinctive "matchbox-style" rural houses have become the top priority for restoring and upgrading rural landscapes (Figure 3). In recent years, significant efforts and substantial public fiscal funds have been invested across the province to renovate and beautify the external walls and roofs of rural houses. Constructing distributed rooftop PV systems that integrate aesthetic design with power generation benefits is an effective pathway to prevent "dressing up" renovations from becoming superficial "vanity projects." Crucially, it transforms government "expense-based inputs" into "asset-based investments" and converts rural "idle resources" into "effective assets."

Figure 3 Numerous "matchbox" style farmhouses are a key focus of rural landscape improvement

2.2 Integrated design and application of distributed photovoltaics combined with rural landscape improvement

2.2.1 Providing a "beautiful, practical, and safe hat" for rural houses

The roof is an important component of a building, and its form is an important carrier for inheriting traditional culture and regional characteristics. In terms of the aesthetic effect of rural landscape, visible sloping roofs are more effective in beautifying the environment. Previously, when adding sloping roofs to rural houses in Guangdong, most projects used resin tiles to create "fake sloping roofs". These were not only impractical but also problematic due to limited funds and a lack of targeted design for rural housing. Consequently, most of these "hats" were aesthetically unpleasing and posed safety risks, such as being easily blown off by strong winds (Figure 4).

Figure 4 The lack of guidance in "flat-to-sloping" roof conversion practices does not yield satisfactory results in aesthetics and safety

In response, the joint research team combined the technical requirements of rooftop photovoltaics with the design needs of architectural appearance to develop the "Photovoltaic Sun Pavilion for Rural Housing Renovation" (Patent No.: ZL202030807781.1). This innovation effectively puts an "aesthetic, practical, and safe" hat on rural houses. Its characteristics are reflected in the following five aspects:

(1) Aesthetics. Compared to conventional photovoltaic greenhouses and metal sheet sheds built privately by farmers, photovoltaic sun pavilions are highly integrated with the overall appearance of farmhouses, resulting in higher aesthetic value. They also possess local rural characteristics, comply with farmhouse management requirements, and do not pose a risk of unauthorized construction.

(2) Practicality. Combining the functions of a photovoltaic greenhouse and a sun pavilion, it not only generates electricity but also provides farmers with more covered activity space on the roof. In addition, the sun pavilion provides heat insulation and ventilation for the interior, improves the comfort of the top floor space, and reduces energy consumption, which is in line with the practice of energy-saving renovation for existing buildings in Guangdong.

(3) Safety. Photovoltaic module technology is safe and mature. The entire process of the photovoltaic sunshine pavilion—from design and drafting to construction—is strictly supervised by relevant professionals. At the same time, it is necessary to provide villagers and maintenance workers with easy-to-understand knowledge, precautions, emergency measures, etc., so that villagers can consciously maintain and use the equipment safely.

(4) Replicability. Guangdong has a stock of rural houses, and photovoltaic sun pavilions have the potential to be promoted and applied on a large scale. From a cost control perspective, modular R&D enables the productization and mass production of sun pavilions, transforming them from single-project construction into market behavior.

(5) Carbon reduction and energy security. Photovoltaic sun pavilions provide clean energy for rural areas, effectively contributing to rural carbon emission reduction. If the pavilion is promoted on a centralized scale—taking 20,000 households as an example—it would be equivalent to constructing a PV power station with a capacity of 200 MW. Taking the western Guangdong region as an example, where the average effective annual irradiation hours are 1,100 hours/year, the power generation would reach as high as 2.2×10^8 kWh. Since coal-fired power generation emits approximately 0.997 kg of CO_2 per kWh, 2.2×10^8 kWh of electricity is equivalent to reducing CO_2 emissions by at least 200,000 tons annually. This volume is equivalent to the power generation of a thermal power plant occupying 10 hectares, yet the photovol-

taic sun pavilions utilize idle rural rooftops without occupying additional land resources.

2.2.2 Design practice of rural house renovation based on photovoltaic sun pavilions

One of the pilot sites for the photovoltaic sun pavilions was selected at the *Splendid 100-Li* Demonstration Section for Rural Revitalization in Fenjie Town, Gaozhou, Maoming City, possessing significant demonstration value. With the assistance of the government and the village, farmers in the demonstration section actively signed up to participate and were willing to provide the roofs of their farmhouses for the first batch of equipment installations.

Through visits and on-site measurements, the roof styles of farmhouses along the pilot county roads can generally be divided into two types: Type 1 is where the roof has only one stair well exit, maximizing the usable roof area; Type 2 is where a room is added next to the stairwell leading out onto the roof, with the non-accessible roof area occupying 30% to 50% of the roof area. After reserving a certain amount of open space on the roof for villagers to use for drying their laundry, the remaining space is used to create various types of sun pavilions, including double-slope, single-slope, and flat-mounted structures, depending on the available space (see Figure 5), ensuring that each household has an installed capacity of at least 10 kWp for photovoltaic modules.

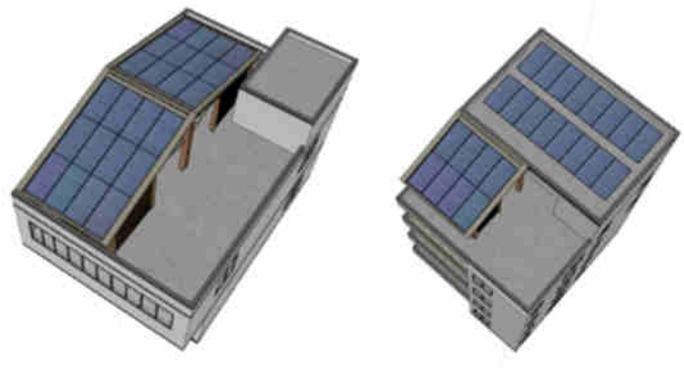

Figure 5 Construction combinations of photovoltaic sun pavilions for farmhouse renovation

In terms of appearance, the design of the photovoltaic sun pavilion is combined with the renovation design of rural houses (Figure 6). Combining local characteristics, the pilot rural housing renovation design usesa "Longan" color palette (based on the local fruit) as the main theme, with photovoltaic sun pavilions on the roof. It features uniform colors for the eaves and farmhouse tiles, uniform beige or off-white walls, a uniform gray-yellow base, and dark longan-colored metal panels. Concrete block walls and flower beds are built in the open space in front of the house, and movable flower boxes are placed to create a small garden. The unified design elements of the farmhouses, integrating the photovoltaic sunshade pavilions with the farmhouses, will significantly improve the appearance of the demonstration section.

Figure 6 Overall design effect of photovoltaic sun pavilions and rural housing facade improvement

Structurally, the photovoltaic sun pavilion's support frame retains the space for movement beneath the pavilion while employing necessary structural columns for support (Figure7). To transform the photovoltaic sun pavilion into a semi-indoor activity space, appropriate grille or railing elements are added to the design. These provide moderate visual screening, create semi-private spaces locally, and form a sense of architectural volume from the elevation view.

Figure 7 Overall construction effect of photovoltaic sun pavilions and rural housing facade improvement

In terms of materials, all frame materials are made of lightweight metals, with emphasis on anti-corrosion and anti-oxidation treatments. The photovoltaic panels use monocrystalline bifacial double-glass modules to achieve bifacial power generation, improve power generation efficiency, and increase the light transmittance of the space under the pavilion. In areas with lower energy efficiency, the design considers partially removing the backside power generation function and using colored glass or other textures instead. This approach enriches the surface texture and enlivens the atmosphere of the semi-indoor space (Figure 8).

Figure 8 Texture expression of the space under the photovoltaic sun pavilion

2.3 Establishing a co-construction and win-win development and operation model to transform rooftop space resources into long-term assets

2.3.1 Multi-Party collaborative preliminary development and construction model

Based on the construction requirements and practical experience of photovoltaic sun pavilions in rural housing renovation projects, a model for the large-scale development of distributed photovoltaic rooftops in existing rural housing has been summarized, which involves mutual consultation and assistance between village governments and investment enterprises, joint coordination among multiple professional teams, and joint construction by villagers and village collectives (Figure 9). Its specific model is as follows:

(1) Confirm villagers' willingness to install: A project team composed of members from the village committee and the investment company will carry out the work, explain to village representatives the cooperation required for rooftop photovoltaic construction and the benefits to villagers, encourage villagers to sign up for installation, and sign agreements with households who have a clear willingness to install and meet the standards, so as to form a spatial resource base map for the development of photovoltaic projects.

(2) Establish a rural housing screening mechanism: With safety as the primary criterion, rural houses must have clear property rights, stable building structure, sufficient roof load-bearing capacity, and no shading from surrounding obstacles or taller buildings. Houses that do not meet the requirements are excluded from construction.

(3) On-Site design by professional teams: First, the electrical design engineers will determine the basic structural framework of the power station and calculate the power generation efficiency based on factors such as the orientation of the house, space requirements, and building area. Subsequently, architectural or exterior design teams carry out facade improvement designs, integrating local requirements for rural appearance enhancement.

(4) Coordinate grid connection and upgrades: Understand the network structure and load rate of the medium-

and high-voltage distribution networks in the corresponding area; strengthen communication with local power supply bureaus. Prioritize compliance with existing power grid conditions to determine the scale and construction, and clarify the access plan; determine the pre-installation batches based on villagers' application status, and clarify the grid connection point, grid upgrading plan, and ownership boundaries.

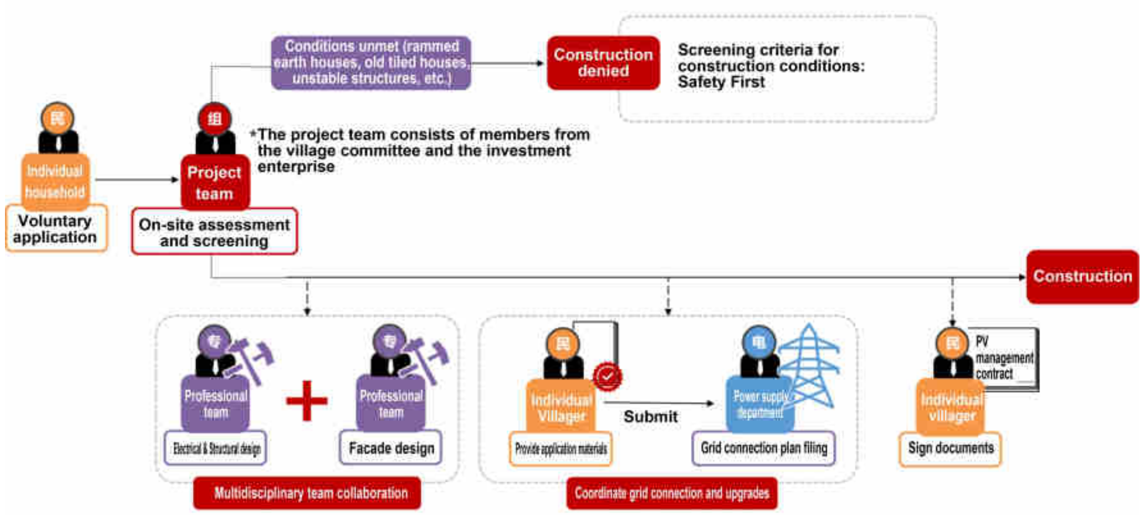

Figure 9 Multi-entity collaborative preliminary development and construction model

(5) Ensure legal validity and binding force of signed documents: Based on the needs of all parties and the installed capacity, the revenue is reasonably distributed. At the same time, the legal validity of the contract and the mutual supervision between the villagers and the project team serve as constraints to ensure the long-term operation and maintenance of the power station.

2.3.2 A Multi-party win-win commercial operation model

Currently, the market-oriented operation model for distributed photovoltaic systems in rural areas is not yet mature. The commercial models of existing domestic rural distributed photovoltaic implementation cases can be categorized intothe "Poverty alleviation model," "Loan-based model," and "Leasing-based model" (Table 1). The development of the PV industry relies heavily on policy drivers. During the "Photovoltaic Poverty Alleviation" period, the state formulated generous subsidy policies for distributed photovoltaic projects. While this stimulated a growth in installed capacity, the projects became dependent on subsidies to sustain construction, placing immense pressure on public finance. For farmers, the payback period for investing in distributed photovoltaic power stations is long, which can easily lead to financial pressure and an unclear incentive mechanism. For enterprises, distributed photovoltaic power stations are low-profit products and require a certain scale to be profitable. However, the operational difficulty of organizing farmers for centralized construction is significant.

Distinct from traditional business models, this paper proposes to introduce enterprises with long-term operational capabilities, invest in construction on a large scale in a manner that conforms to market rules, make reasonable use of relevant government fiscal funds, build a platform for multi-party collaboration among government, enterprises, villages, and professional teams, and clarify the functions and benefits of each party. Because the rural houses involved are scattered and numerous, a cooperative mechanism for centralized management based on village collectives will be established. The county and township governments coordinate the establishment of village joint-stock companies to form a contractual relationship with project companies on behalf of the village collectives. The village joint-stock companies are responsible for integrating individual construction applications from villagers and submitting overall construction applications to the operating enterprises. At the same time, it is responsible for the maintenance and management of the photovoltaic power station, obtains operation and maintenance fees, and increases the income of the village collective. The company is responsible for investing in the power generation portion and bearing the overall construction costs, while also receiving revenue from photovoltaic power generation. Villagers receive a corresponding rooftop rental fee each year and enjoy the right to use the pavilion and receive profit dividends according to their investment ratio. Local governments can match the scale of investment by enterprises in completing the renovation of rural houses with new energy resources, such as photovoltaic and wind power, to balance the revenue, and provide support in terms of rewards and incentives, low-interest loans, and financing.

By combining the government's requirements for aesthetic appeal, farmers' needs for rooftop use, and businesses' demands for power generation efficiency, the author and team ultimately developed 3 investment and benefit distribution models (Table 2): Scheme A (Pure power-Generating / Flat-Mounted), Scheme B (User-Friendly / Practical Pavilion), and Scheme C (Aesthetic / Demonstration Pavilion).

Table 1 Business models of distributed photovoltaic implementation cases in rural China

Model	Poverty alleviation model	Loan-based model	Leasing-based model
Construction form	Construction funds are comprised of government funds, social capital, and individual self-financing in certain proportions, and are mostly used for the unified construction of rooftops on public service buildings and new villages.	The company provides a full range of services for photovoltaic power plants, including product development, construction, grid connection procedures, and after-sales support. It also offers low-interest loans to individuals, forming financial products.	Individuals submit their photovoltaic power station construction requests to enterprises through a leasing agreement, while the enterprises are responsible for investing in the power station and managing its operation and maintenance throughout the entire process.
Grid connection method	The grid connection method will be determined based on the actual conditions of the power plant. The grid-connected portion will enjoy photovoltaic feed-in tariff subsidies.	Primarily, "Self-generation for self-consumption, surplus electricity fed to the grid," achieves grid parity and enjoys local household photovoltaic subsidy policies.	Primarily, "Full feed-in to the grid" achieves grid parity; enterprises do not enjoy household photovoltaic subsidy policies.
Distribution of benefits	Rooftop owners receive rent. Revenue is distributed according to the investment proportion: allocated as government rural (poverty alleviation) construction funds, enterprise investment returns, and individual dividends.	Individuals save on daytime electricity costs. Income from electricity sales is used to repay the loan. The payback period is around 8 years.	Enterprises own the rights to electricity sales revenue and provide a fixed annual subsidy (spatial compensation) to individuals based on installed capacity. Distribution is also based on the proportion of the individual's leasing fees.

2.4 Building a full-process intelligent management platform to promote digital ecological governance

The operation and maintenance (O&M) management of photovoltaic projects is gradually evolving towards an intelligent platform featuring centralized remote monitoring. By integrating high-tech applications such as "Internet+," Big Data, and the Internet of Things (IoT), it is possible to technically resolve the issues associated with the traditional O&M model caused by the scattered nature of distributed photovoltaic projects—namely, their labor-intensive nature, low efficiency, high costs, and slow decision-making.

The author and the research team have constructed a Rooftop Distributed Photovoltaic Intelligent Management Platform (Figure 10) to conduct full-cycle and full-process management—covering preliminary development, project approval, fund usage, and O&M—for the "Photovoltaic Sun Pavilions for Rural Housing Renovation".

- In the early stages of development, a series of data is collected, including residents' opinions, the suitability of rooftop photovoltaic construction for rural houses, and the current status of rural power grids. Through data consolidation, analysis, and entry, a basic database for distributed photovoltaic construction is established.

- In the project approval process, a corresponding business processing sub-platform is set up. Villagers can fill in relevant informationvia the online platform, which generates a service acceptance form. A professional team screens the applications through the backend to determine the feasible project pool, conducts on-site inspections, and finally decides on approval.

• Regarding the fund usage, the platform publicly discloses the funding sources and the allocation of economic benefits for different rooftop photovoltaic construction models, thereby improving the transparency of fund utilization.

• In terms of operation and maintenance, the platform will continuously collect data from rooftop photovoltaic modules and detect environmental variables of the sun pavilions to assess the condition of the photovoltaic modules. At the same time, it will provide visual feedback on the power generation efficiency, electricity sales revenue, and environmental benefits such as carbon emission reduction, thereby promoting intelligent decision-making and efficient management of the entire rural rooftop photovoltaic process.

Table 2 Three construction models for photovoltaic sun pavilions in farmhouse renovation projects

Specific models for rooftop photovoltaic investment and benefit distribution			
	Scheme A: Enterprise-Sole-Invested Rooftop Photovoltaic Project	Scheme B: "Enterprise + Household" Co-Invested Photovoltaic Sun Pavilion	Scheme C: "Enterprise + Government" Co-Invested Photovoltaic Sun Pavilion
Investment entities	Enterprise	Enterprises and farmers (invest in a certain proportion)	Enterprise and Government (invest in a certain proportion, or the Government allocates other higher-return new energy construction resources to the Enterprise)
Construction form	Flat-Mounted Style	Practical Pavilion Style (Prioritizing utility)	Aesthetic Demonstration Pavilion Style (Prioritizing aesthetic and demonstration benefits)
Farmer benefits	Rooftop rent	Rooftop rent and usage rights of the Sun Pavilion	Dividends (based on proportion) and usage rights of the photovoltaic sun pavilion
Government benefits	Fiscal and tax revenue	Fiscal and tax revenue; moderate improvement of local appearance	Fiscal and tax revenue; exemplary improvement of local appearance
Village collective benefits	Operation and maintenance revenue	Operation and maintenance revenue	Operation and maintenance revenue
Construction effect			

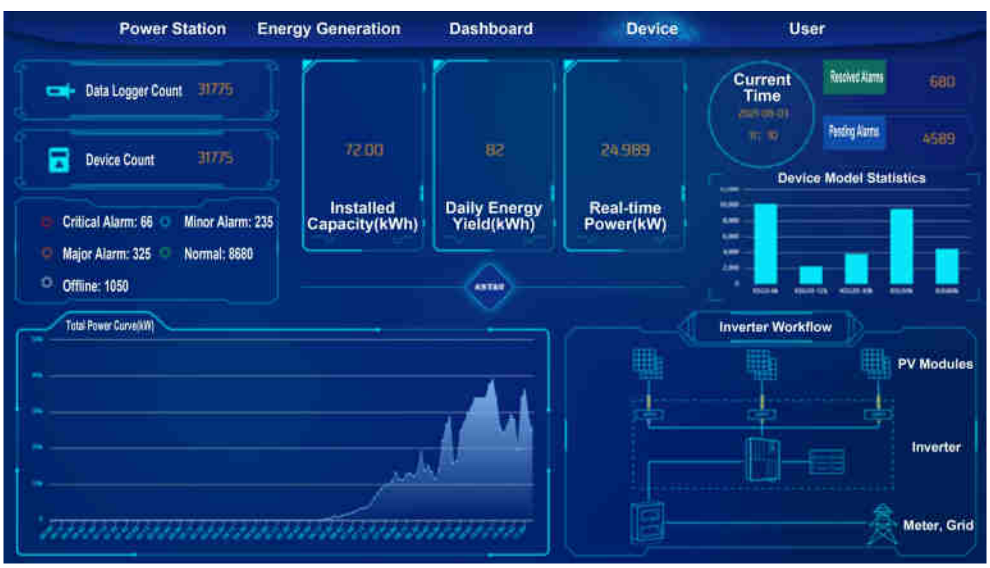

Figure 10 Smart management platform for distributed rooftop photovoltaic systems

2.5 Utilizing distributed photovoltaic construction to promote the iterative upgrading of rural electrification and comprehensive resource utilization

The development of distributed photovoltaic projects is mainly limited by factors such as land use type, space ownership, grid connection, and local power absorption conditions. Therefore, it is essential to fully respect the resource conditions of different regions and make reasonable use of various available space resources.

In terms of diverse construction forms, in addition to rooftop photovoltaic systems for rural houses, photovoltaic systems can also be integrated into traditional rural construction, such as industrial and commercial rooftops, road systems, charging piles, public facilities (such as public toilets and garbage stations), and landscape features (Figure11, 12). Furthermore, models combining photovoltaic generation with traditional agriculture are gaining increasing attention. They are widely applied in production spaces for agriculture, forestry, animal husbandry, and fishery, realizing models such as agrivoltaics, fishery-solar hybrid systems, forest-solar hybrid systems, and PV greenhouses. By integrating with technologies for breeding, irrigation, and agricultural machinery power, these systems drive the modernization of agriculture.

Figure 11 Photovoltaic landscape design of liantanghu village wetland park in Maoming City

Regarding energy system construction, rural areas face problems such as low power grid carrying capacity, limited transmission capacity, and dispersed electricity load. Planning should comprehensively consider the grid architecture and local absorption levels, rationally layout the scale and connection of power stations, and coordinate rural energy system construction with new energy storage models. The author and the research team are currently conducting research on the "Source-Grid-Load-Storage Integration" and multi-energy complementary technology systems for rural new energy. We are exploring operation technologies for multi-level "PV-Storage-Charging Integrated" energy systems (ranging from Regional to Community to Off-grid levels) and summarizing the standardization system and policy recommendations for rural distributed PV development. Increasing the proportion of green electricity use can reduce electricity costs and encourage the adoption of indoor and outdoor appliances and smart home systems. This increases investment in improving the living environment, thereby shaping low-carbon, livable spaces.

Figure 12 Photovoltaic building-integrated design of the Changshi Village Talent Station in Shaoguan City

3 Extended reflections on the "Innovative Carbon-Neutral Rural Area"

The large-scale construction of distributed PV will promote the transformation of the rural energy structure. From the perspective of the "Innovative Carbon-Neutral Rural Area," the value of rural resources is being cognitively redefined. Its development opportunities lie not only in the development of new energy but also in a comprehensive exploration across spatial, economic, and social dimensions. In the context of the new era, "Carbon Neutrality" and "Innovative Rural Area" are not two independent concepts; rather, they can achieve a high level of coupling between two major strategies. This article further proposes a new model for rural development - "Innovative Carbon-Neutral Rural Area". The key pathways to its realization lie in three dimensions: space, economy, and society.

3.1 Spatial dimension: Constructing a rural regional complex for green development and shaping low-carbon rural "New production-living-ecological spaces"

"New Rural Construction," led by rural planning and design, is the key to shaping low-carbon rural "Production-Living-Ecological Spaces." Territorial Spatial Planning emphasizes the coordinated and efficient utilization of urban and rural resource elements against the backdrop of urban-rural integration. The strategic goal of "Carbon Neutrality" essentially poses higher requirements for rural low-carbon and even negative-carbon development. The delineation of "Three Control Lines," as well as rural spatial layout, industrial planning, energy structure systems, and ecological conservation and enhancement, should all emphasize the contribution rural areas can make in the process of "urban-rural carbon value exchange." Meanwhile, more refined green and low-carbon design of rural spaces, buildings, and facilities is also key to achieving negative carbon contributions in rural areas. The realization of "Carbon Neutrality" must not be established at the cost of hindering economic development. The purpose of rural revitalization is to achieve "integrated development with urban-rural equivalence." As future criteria for distinguishing urban and rural areas will lie more in the "differences in landscape conditions"[11], this indicates that the modes of contribution towards the "Carbon Neutrality" goal differ between cities and villages. Consequently, the "Innovative Carbon-Neutral Rural Area" inevitably poses new requirements for rural planning and design.

3.2 Economic dimension: Promoting the assetization of ecological resources and creating new models for rural green industries and green finance

In order to adapt to the low-carbon development of rural production and life and the adjustment, optimization and upgrading of the industrial system, the low-carbon adaptation and innovation of economic models is particularly important. On the one hand, it can combine existing technologies with traditional agricultural development; on the other hand, it can strengthen the branding of rural green industries. At the same time, from the overall perspective of low-carbon and sustainable development of the rural economy, we should establish and improve the rural green carbon finance system. The rural carbon finance system mainly includes investment and financing for rural low-carbon project development and rural carbon trading services[12]. Investment and financing for rural low-carbon project development can include providing financial services in areas such as green rural housing, clean energy, green agriculture, and green transportation. Rural carbon trading services can include forestry and grassland carbon sink trading, clean energy carbon trading, and low-carbon agricultural carbon trading. However, given that rural resource property rights are relatively scattered, and there is a lack of institutional mechanisms to sell carbon emission reductions to the market, an interest-linked carbon trading mechanism consisting of "Enterprise-Carbon Trading Institution-Rural Professional Cooperative Organization-Farmer" should be established to broaden the pathways for rural low-carbon development [13].

In this dimension, rural carbon sink trading and the "Carbon-neutral New Agriculture" are critical. Carbon sink trading offers the concept that "lucid waters and lush mountains are invaluable assets" with broader and more profound significance. Furthermore, by adjusting agricultural planting methods and leveraging capabilities and management levels in biotechnology, digital technology, and breeding technology, it is possible to reduce carbon emissions across the entire chain of agricultural production while simultaneously increasing the yield and output value of agricultural products. Achieving such "Carbon-Neutral New Agriculture" further reinforces the significance and value of rural areas in realizing the strategic goal of carbon neutrality.

3.3 Social dimension: Establishing a new mechanism for intelligent, law-based, and modernized ecological governance in rural areas, focusing on low-carbon production and lifestyles

Under the vision of the carbon neutrality goal, rural governance regarding ecological development—such as upgrading rural energy structures, structural emission reduction in agriculture, and environmental protection and pollution control—should integrate villagers' livelihoods with existing technological levels. It is necessary to formulate scientific and rational management strategies tailored to local conditions[14]. Policies and regulations should be perfected by considering the actual needs of multiple stakeholders, including villagers, enterprises, and the government, thereby optimizing the system of co-construction and co-governance by rural multi-stakeholders. Rural carbon emission regulation and governance should further utilize digital and intelligent technologies to assist decision-making and implementation, thereby modernizing the rural governance system and governance capabilities.

At the same time, it is also necessary to build a new operating platform that links government, enterprises, villages, and professional teams to adapt to the marketization and sustainable development needs of rural areas. The construction system of the "Innovative Carbon-Neutral Rural Area" places higher demands on the overall quality of village officials and villagers. Rural construction requires "selecting talent locally," "gathering talent from various quarters," "nurturing talent through practice," and "entrusting capable talent with heavy responsibilities," so as to break the talent bottleneck in realizing rural revitalization[15]. A rural talent cultivation platform should be established to conduct training and lectures related to the "Innovative Carbon-Neutral Rural Area." This involves cultivating leaders for innovation and entrepreneurship in rural modern industries and providing multi-field thematic training for management cadres at all levels, villagers, professional technicians, and enterprise personnel. The goal is to foster a group of grassroots management talents, vocational technical service providers, and practitioners who possess new skills and are adapted to the "Innovative Carbon-Neutral Rural Area." At the same time, it is equally important to focus on cultivating and enhancing the ecological awareness of cadres at all levels in villages and towns, as well as villagers, to raise their awareness of low-carbon development and foster a sustainable consumption concept in villages and towns.

Conclusion

This article focuses on the carbon reduction potential of rural areas, taking distributed photovoltaic power as a key entry point, and takes the first step in the research and practice of the "Innovative Carbon-Neutral Rural Area". The development of new energy sources will effectively transform existing rural space resources into high-quality and long-term ecological assets, continuously bringing benefits to villagers, providing clean energy for rural areas, and promoting rural electrification. Rural landscape management and renovation have facilitated the application of the building-integrated photovoltaic (BIPV) concept in existing rural housing, while the large-scale construction trend of distributed photovoltaics highlights the potential development value of rural space resources, triggering a series of research needs such as the development, construction, and commercial operation models of new energy in rural areas, as well as policy formulation strategies related to rural new energy development. The "Innovative Carbon-Neutral Rural Area" is a novel rural development concept that highly integrates the two major national strategies of Rural Revitalization and "Carbon Peaking and Carbon Neutrality." Encompassing multiple fields such as energy, technology, and carbon finance, it demonstrates promising prospects for the future of rural areas. However, it still requires strengthened and continuous research and practice involving multiple dimensions—spatial, economic, and social—as well as the participation of multiple stakeholders.

Sources of Figures and Tables

Figure 2: Created by the authors; data source: BJX Power Grid (Bei Ji Xing).

Figure 10: Adapted from the Smart Village Management Platformof Gaozhou City,Maoming.

All other figures and tables were drawn or photographed by the authors.

References

[1] Jiang, L. (2021). Global carbon cycle: from basic scientific issues to national green responsibility.*Science*, 73(01), 39-43.

[2] Huang, C. (2021, March 25). Taking carbon peaks and carbon neutrality as a historic task in the construction of ecological civilization.*China Environmental News*, (003).

[3] Zhang, X. (2012, November 15). Development of new energy in rural China: Promote the development of China's rural ecological civilization.*Consumption Daily*, (A02).

[4] Guo, L., Liu, Y., & Li, Y. (2012). Discussion on comprehensive renovation of hollow village and low-carbon rural development strategy.*Regional Research and Development*, 31(1), 116-119.

[5] Han, Y. (2021). Analysis on the application and development of new energy in rural revitalization. *Modern Agricultural Science and Technology*, (5), 185-187.

[6] Intergovernmental Panel on Climate Change. (2007). *Climate change 2007: Synthesis report*. https://www.ipcc.ch/report/ar5/syr/. (Original work published 2007)

[7] Zhang, L., Cai, Z., & Niu, L. (2010). Low-carbon economy and rural development in my country. *Ecological Economy*, (9), 73-76.

[8] Intergovernmental Panel on Climate Change. (2018). *Special report: Global warming of 1.5 ℃*. https://www.ipcc.ch/sr15/. (Original work published 2018)

[9] Lu, H., & Xu, Y. (2021). Low carbon economy power country under the background of digital technology to promote the strategic research. *Journal of Southwest Finance*, (7), 3-13.

[10] Lin, B., & Liu, X. (2010). Carbon emissions in China's urbanization stage: Influencing factors and emission reduction strategies. *Economic Research*, 45(8), 66-78.

[11] Ye, H., Tang, S., Peng, Y., & others. (2021). Equivalence between urban and rural areas: a new era under the background of new rural development path. *Journal of Urban Planning*, (03), 44-49.

[12] Zou, X. Y.(2011). Research on the localization of carbon finance and rural financial innovation: Based on the perspective of financial industry. *China Soft Science*, 8, 21-26.

[13] Li, X.Y, & He, X.L. (2012). Basic ideas of the development of low-carbon agriculture in Sichuan - based on domestic and foreign experience for reference and enlightenment. *The Rural Economy*, (11), 48-52.

[14] Liu, J. (2021). Study on the challenges and countermeasures of rural governance in my country from the perspective of smart governance. *Bohai Economic Outlook*, (1), 81-83.

[15] Pu, S., & Sun, W. (2018). Implement the strategy of rejuvenating the country under the background of rural talent construction policy research. *China's Administrative Management*, (11), 90-93.

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Study on the Spatial Form and Elements of Huizhou Traditional Residential Courtyards Based on Clustering Analysis

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ABSTRACT: The study of traditional residential courtyards promotes the protection and renovation of traditional residences and enriches the spatial expression of new residential courtyards. As an organic component of the traditional residence, the courtyard space plays a role in improving, amplifying, and complementing the function of the main building space. This study investigated 63 Huizhou traditional residential courtyards, including those in Xidi, Hongcun, Nanping and Pingshan. The basic architectural information was first examined, and a field survey was undertaken to disclose the relationship between the courtyard and the main building space. The morphological characteristics of the courtyard were described through five dimensions: area, area ratio, aspect ratio, saturation, and boundary coefficient. Then, the courtyard space was classified through clustering analysis. Meanwhile, the courtyards' location and characteristics of elemental organization within different morphological types were considered.

The study shows that the traditional Huizhou courtyards can be classified into four types based on the quantitative clustering characteristics of spatial morphology, namely: medium-scale square, medium-scale strip, medium-scale irregular, and large-scale complex. Firstly, medium-scale square courtyards are the most common type, sharing the same proportion and form as the main building space. This type of courtyard offers a sense of stability and regularity. Moreover, they are typically located in the front and back of the residence. They include stone benches and other elements arranged with greenery, water, arches, secondary contours, and other elements, enriching the landscape levels and expanding the spatial function. Secondly, medium-scale strip courtyards mostly appear in large residential groups, which organize people's routes, depicting the spatial dynamism and directions. They mainly incorporate structures and arches, sometimes combined with greenery, plaques, stone tables, and openwork windows. Such structures weaken the sense of enclosure and insecurity generated by the long and narrow space. Thirdly, medium-scale irregular courtyards present irregular spatial forms in the front and side of the residence due to irregular land conditions and regular main building plans, often serving as a highlight of the residential space. The configuration of greenery, water, openwork windows, and their mutual combinations is mainly used to weaken the irregularity of space through spatial remediation and the creation of a visual focus. Finally, large-scale complex courtyards are predominantly located in backyards and serve as recreational areas and living spaces, enabling people to get close to nature. The configuration of spatial factors is mainly composed of natural leisure elements, such as water and stone benches. Larger-scale courtyards usually combine with greenery elements to provide the house owner with a comfortable and private living scene.

The current study clarified the typological characteristics of courtyard spatial forms through clustering analysis. It also discussed the spatial form and element organization of the traditional Huizhou courtyard. On this basis, the relationships among the courtyard, the building's main body,

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and the composition and organization of environmental elements were investigated and classified. The research conclusions can provide a theoretical basis for maintaining traditional residential courtyard forms and preserving their authenticity, as well as a reference for creating new residential courtyard spaces in Huizhou.

KEYWORDS: Huizhou traditional residence; courtyard; clustering analysis; morphological quantification; elements

Introduction

As an organic component of Huizhou traditional residences [1], the courtyard space is characterized by being "formed based on the site, adapted to the context, and following principles without fixed modes [2]", conveying the cultural characteristics of "farming-reading" and the integration of Confucian scholarship and commerce. It reflects the purpose and belief of life under the Huizhou cultural environment and plays a role in reinforcing, amplifying, and supplementing the function of the main building. Against the backdrop of changes in traditional social structure and the rise of village tourism [3], traditional culture and the "spirit of place" are gradually waning, the spatial pattern of residential courtyards is being destroyed, and the courtyard landscape is gradually being detached from traditional society [4,5]. In newly constructed residential courtyards, there are also issues where regional culture is becoming merely symbolic and superficial [6].

In the study of restoring spatial patterns and reconstructing the cultural connotations of landscapes, researchers mostly base their restoration efforts on residents' oral accounts, the regional features of courtyards, and the original building sites for restoration [7]. Previous studies on courtyard morphology have mostly focused on its relationship with the main building's orientation, form, and scale. Courtyard spaces are mostly located in the front, back, and side of Huizhou traditional residences, with free forms and variable patterns [8]. Studies on the elements of Huizhou courtyards show that the courtyards are often decorated with landscape elements such as openwork windows, arches, rocks, and plants to strengthen the connection between the courtyard space and the outside world as well as nature [9]. However, the protection and utilization of courtyard space still reveal problems such as fragmented theories and insufficient technical methods [10]. Based on the study of regional landscape features, this paper combines morphological research with element organization to explore the location and element features of residential courtyards of different morphological types. This helps to grasp the internal causes of courtyard space organization, offers quantitative reference for courtyard space research, and thereby provides guidance for the restoration and utilization of regional landscape features and cultural connotations in traditional residential space, and enriches the expression of new residential courtyard space [11, 12].

1 Overview of Huizhou traditional residential courtyards

1.1 Formation background of courtyard spaces

Huizhou villages are situated amidst picturesque mountains and rivers, with buildings and streets arranged in a staggered pattern, accompanied by abundant and beautiful flowers, trees, and vegetation. Influenced by the architectural philosophy of "suitably selecting the site and appropriately composing the garden," Huizhou traditional residential courtyard spaces have been formed within a limited space to express an emotional attachment to natural landscapes. The courtyard space serves not only as a transition connecting streets with the building interior and an outward extension of the architectural space, but also as an expression of the owner's emotions. Influenced by the overall layout of the village, the direction of the streets and alleys, and the shape of the houses, the village, within its limited space, expresses the "farming-reading" tradition of scholarly families and the idealistic pursuit of a "Peach Blossom Spring" (Utopia). Therefore, the study of the typology of Huizhou traditional residential courtyard spaces is an extension of the study of village street space and a refinement of the study of residential morphology. It also provides theoretical support for understanding the relevant aspects of the transition and connection of village residential clusters.

1.2 Case selection

The study conducted field research in Huizhou traditional villages such as Xidi, Hongcun, Nanping, and Pingshan. These villages are relatively well protected and developed, and the house layout and configuration of elements are well preserved [13]. The survey mainly focused on key protected buildings in the village and evaluated the representativeness of the buildings and courtyard spaces from the dimensions of their historical significance, integrity, artistry, and authenticity [14]. Subsequently, through on-site measurement and aerial photography, the plans of 63 representative traditional Huizhou residential courtyards were obtained (Figure 1). Basic information on the courtyard space was obtained through interviews and literature reviews (Table 1). Based on the relative relationship between the courtyard and the main hall's orientation, the courtyard space was classified into three categories: front yard, back yard, and side yard, with 37 front yards, 14 back yards, and 12 side yards.

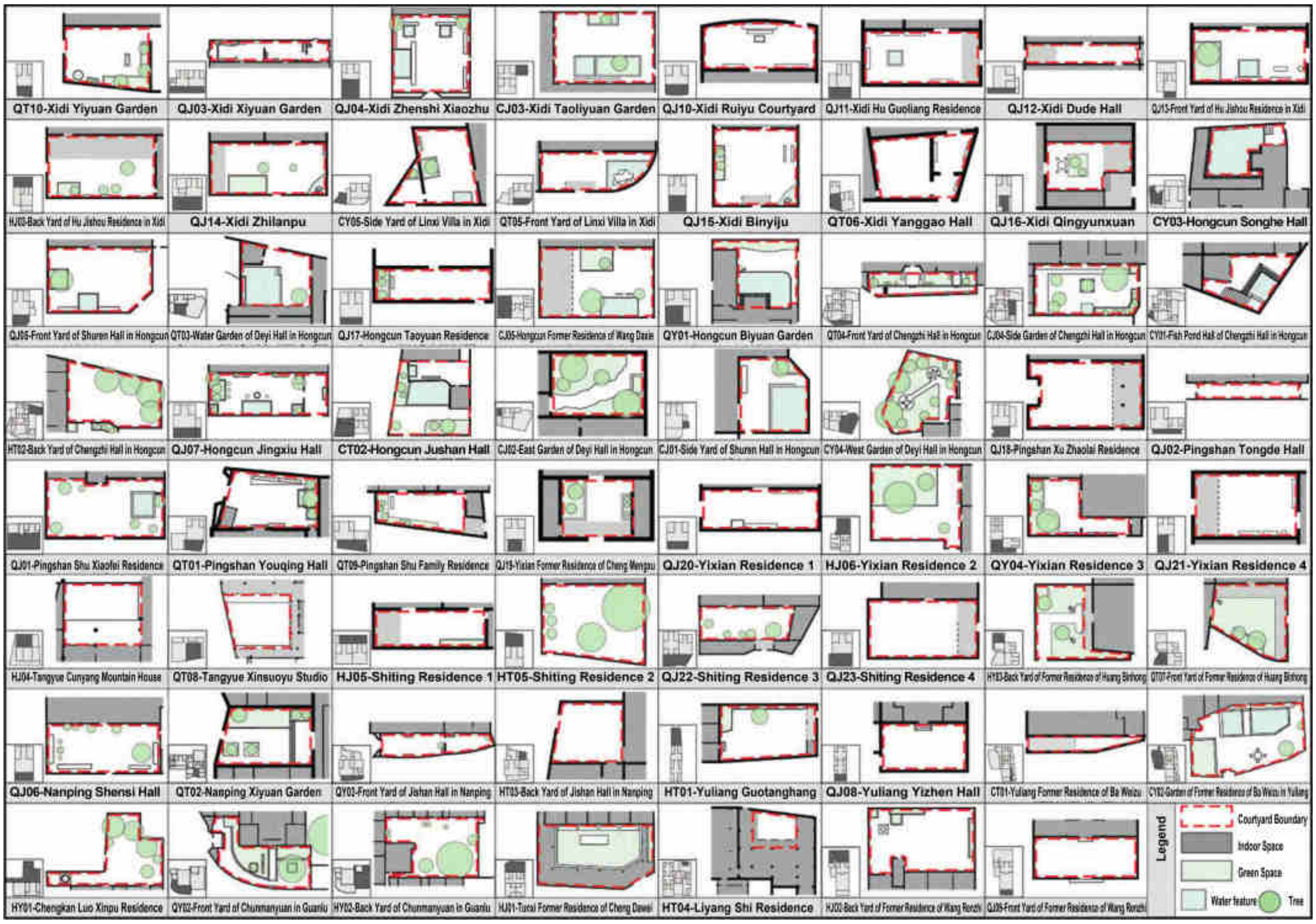


Figure 1 Selection of sample courtyards

1.3 Extraction of spatial elements

The arrangement and combination of courtyard elements greatly influence the landscape impression of the courtyard space and further serve as an organic part of cultural construction. Huizhou Traditional residences typically have small courtyards, which can create a feeling of oppression and confinement. The arrangement of spatial elements plays a role in enhancing the openness and richness of the courtyard space (Figure 2). Spatial elements are divided into two types: planar elements and vertical elements. Planar elements mainly include greenery, water, stone tables, benches, structures, and wells. Among them, structural elements include porches, bridges, and steps, which are collectively referred to as structures. Vertical elements include openwork windows, arches, plaques, and secondary contours. "Secondary contours" refer to temporary external attachments to the building [15], including lanterns, couplets, signs, and so on. These spatial elements, together with the courtyard space, constitute the unique Huizhou traditional residential courtyard, serving as a medium for ancient Huizhou literati to express their ideals and sentiments.

Table 1 Basic information of courtyard spaces

Code	Courtyard Name	Conservation Status	Era	Village	Protection Level	Current Use
QT10	Yiyuan Garden	Excellent	Qing Dynasty	Xidi	National Key Cultural Relics Protection Unit (Xidi Ancient Buildings)	Residential
QJ03	Xiyuan Garden	Excellent	Qing (Daoguang)			Tourism
QJ04	Zhenshi Xiaozhu	Excellent	Qing (Daoguang)			Residential
CJ03	Taoliyuan Garden	Excellent	Qing (Xianfeng)			Tourism
QJ10	Ruiyu Courtyard	Excellent	Qing (Xianfeng)			Tourism
QJ11	Hu Guoliang Residence	Excellent	Qing Dynasty			Residential
QJ12	Dude Hall	Excellent	Late Ming			Guesthouse
QJ13	Hu Jishou Residence (Front Yard)	Good	Qing Dynasty			Residential
HJ03	Hu Jishou Residence (Back Yard)		Qing Dynasty			Residential
QJ14	Zhilanpu	Good	Qing Dynasty			Guesthouse
CY05	Linxi Villa (Side Yard)	Excellent	Qing (Daoguang)			Guesthouse
QT05	Linxi Villa (Front Yard)	Excellent	Qing (Daoguang)			Guesthouse
QJ15	Binyiju	Good	Qing Dynasty			Guesthouse
QT06	Yanggao Hall	Excellent	Ming (Wanli)			Guesthouse
QJ16	Qingyunxuan	Excellent	Qing (Tongzhi)			Residential
CY03	Songhe Hall	Excellent	Qing (Tongzhi)	Hongcun	National Key Cultural Relics Protection Unit (Hongcun Ancient Buildings)	Guesthouse
QJ05	Shuren Hall (Front Yard)	Excellent	Qing (Tongzhi)			Residential
CJ01	Shuren Hall (Side Yard)	Excellent	Qing (Tongzhi)			Residential
QJ17	Taoyuan Residence	Excellent	Qing (Xianfeng)			Tourism
CJ05	Former Residence of Wang Daxie	Good	Qing (Daoguang)			Tourism
QY01	Biyuan Garden	Good	Late Ming			Guesthouse
QT04	Chengzhi Hall (Front Yard)	Excellent	Qing (Xianfeng)			Tourism
CJ04	Chengzhi Hall (Side Garden)	Excellent	Qing (Xianfeng)			Tourism
CY01	Chengzhi Hall (Fish Pond Hall)	Excellent	Qing (Xianfeng)			Tourism
HT02	Chengzhi Hall (Back Yard)	Excellent	Qing (Xianfeng)			Tourism
QJ07	Jingxiu Hall	Excellent	Qing (Daoguang)			Tourism
CT02	Jushan Hall	Excellent	Qing (Xianfeng)			Guesthouse
CJ02	Deyi Hall (East Garden)	Excellent	Qing (Jiaqing)			Residential
QT03	Deyi Hall (Water Garden)	Excellent	Qing (Jiaqing)			Residential
CY04	Deyi Hall (West Garden)	Excellent	Qing (Jiaqing)			Residential
HJ04	Cunyang Mountain House	Excellent	Qing (Jiaqing)	Tangyue Village	National Key Cultural Relics Protection Unit (Tangyue Ancient Residences)	Display
QT08	Xinsuoyu Studio	Excellent	Qing (Jiaqing)			Display
QJ18	Xu Zhaolai Residence	Excellent	Qing Dynasty	Pingshan Village	Anhui Provincial Cultural Relics Protection Unit (Pingshan Ancient Buildings)	Residential
QJ02	Tongde Hall	Excellent	Qing Dynasty			Residential
QJ01	Shu Xiaofei Residence	Good	Qing Dynasty			Guesthouse
QT01	Youqing Hall	Excellent	Qing (Daoguang)			Tourism
QT09	Shu Family Residence	Good	Qing Dynasty			Residential

(Continued)

Code	Courtyard Name	Conservation Status	Era	Village	Protection Level	Current Use
QJ19	Former Residence of Cheng Mengxu	Excellent	Qing Dynasty	Yixian Ancient City	Yixian County Cultural Relics Protection Unit	Residential
QJ20	Residence 1	Excellent	Qing Dynasty		Yixian Registered Immovable Cultural Relics	Residential
HJ06	Residence 2	Good	Qing Dynasty		Yixian County Cultural Relics Protection Unit	Vacant
QY04	Residence 3	Good	Qing Dynasty		Yixian Historical Architecture	Residential
QJ21	Residence 4	Excellent	Qing Dynasty		Yixian County Cultural Relics Protection Unit	Residential
HJ05	Residence NO. 1	Good	Qing Dynasty	Shiting Village	2nd Batch of Traditional Chinese Villages List	Residential
HT05	ResidenceNO. 2	Excellent	Qing Dynasty			Residential
QJ22	ResidenceNO. 3	Excellent	Qing Dynasty			Residential
QJ23	ResidenceNO. 4	Good	Qing Dynasty			Residential
HY03	Former Residence of Huang Binhong (Back)	Excellent	Qing (Kangxi)	Tandu Village	Anhui Provincial Cultural Relics Protection Unit	Exhibition
QT07	Former Residence of Huang Binhong (Front)	Excellent	Qing (Kangxi)			Exhibition
QJ06	Shensi Hall	Excellent	Qing (Kangxi)	Nanping Village	National Key Cultural Relics Protection Unit (Nanping Ancient Buildings)	Residential
QT02	Xiyuan Garden	Good	Qing (Qianlong)			Residential
QY03	Jishan Hall (Front Yard)	Excellent	Qing (Guangxu)			Residential
HT03	Jishan Hall (Back Yard)	Excellent	Qing (Guangxu)			Residential
HT01	Guotanghang	Good	Qing Dynasty	Yuliang Village	Shexian County Cultural Relics Protection Unit	Tourism
QJ08	Yizhen Hall	Excellent	Republic of China		Shexian County Cultural Relics Protection Unit	Residential
CT01	Former Residence of Ba Weizu	Excellent	Ming (Wanli)		Anhui Provincial Cultural Relics Protection Unit	Exhibition
CY02	Garden of Former Residence of Ba Weizu	Excellent	Ming (Wanli)			Exhibition
HY01	Luo Xinpu Residence	Good	Qing Dynasty	Guanlu Village	—	Residential
QY02	Chunmanyuan (Front Yard)	Excellent	Qing (Qianlong)			Residential
HY02	Chunmanyuan (Back Yard)	Excellent	Qing (Qianlong)		Anhui Provincial Cultural Relics Protection Unit	Residential
HJ01	Former Residence of Cheng Dawei	Excellent	Ming (Hongzhi)	Tunxi District	National Key Cultural Relics Protection Unit	Exhibition
HT04	Shi Residence	Excellent	Late Qing	Liyang Old Street	Huangshan Municipal Cultural Relics Protection Unit	Exhibition
HJ02	Former Residence of Wang Renzhi (Back)	Good	Early Qing	Shexian Ancient City	Shexian County Cultural Relics Protection Unit	Exhibition
QJ09	Former Residence of Wang Renzhi (Front)	Good	Early Qing		Shexian County Cultural Relics Protection Unit	Exhibition

Legend 1. Greenery 2. Water feature 3. Stone table 4. Stone bench 5. Structure 6. Well 7. Openwork window 8. Arch 9. Plaque 10. Secondary contour

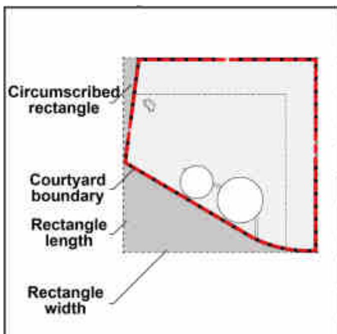
Figure 2 Extraction of courtyard space elements

2 Quantitative analysis of courtyard space form

2.1 Principles of courtyard space quantification

Quantitative indicators related to the size and morphological proportions of courtyard spaces were established to describe the courtyard spaces of traditional residences. The study analyzes five dimensions: courtyard area, area ratio, aspect ratio, saturation, and boundary coefficient, aiming to grasp the morphological characteristics of Huizhou traditional residential spaces, such as size and proportion, from a quantitative perspective.

The dimensions of the courtyard and main building were obtained through on-site measurement (Figure 3). The area of the courtyard and the ratio of the courtyard space to the building footprint were calculated toassess the scale, size and proportional relationship of the courtyard space to the main building. In graphic morphology research, the ratio of the projected area of a graphic to the area of its circumscribed rectangle is often used to define the degree to which it fills the circumscribed rectangle [16]. The study uses the ratio of the area of the courtyard to the area of the circumscribed rectangle as the saturation degree. The higher the value, the more saturated the courtyard space is. In order to supplement the saturation degree in reflecting the indentation and inclination of the courtyard outline, the ratio of the perimeter of the courtyard to the perimeter of the circumscribed rectangle is used as the boundary coefficient. The closer the value is to 1, the more regular the courtyard outline is. The aspect ratio of the circumscribed rectangle is used as the aspect ratio of the courtyard space.



$$\text{Area ratio} = \frac{\text{Courtyard area}}{\text{Building footprint}} \%$$

$$\text{Aspect ratio} = \frac{\text{Length of circumscribed rectangle}}{\text{Width of circumscribed rectangle}} \%$$

$$\text{Saturation} = \frac{\text{Courtyard area}}{\text{Area of circumscribed rectangle}} \%$$

$$\text{Boundary coefficient} = \frac{\text{Courtyard perimeter}}{\text{Perimeter of circumscribed rectangle}} \%$$

Courtyard Code	QJ01	QJ02	QJ03	QJ04	QJ05	QJ06	QJ07	QJ08	QJ09	QJ10	QJ11	QJ12	QJ13	QJ14	QJ15
Area(m²)	192.2	81.7	126.5	61.7	63.1	25.2	71.2	54.5	33.1	21.9	23.2	30.3	24.5	78.5	78.0
Area ratio	0.62	0.22	0.32	0.52	0.11	0.18	0.22	0.2	0.09	0.21	0.34	0.29	0.11	0.42	0.46
Aspect ratio	1.96	5.96	5.35	1.01	1.62	2.24	2.74	1.74	2.44	2.41	2.07	5.02	2.05	2.17	1.09
Saturation	0.97	1	1	1	0.97	1	1	1	1	0.96	1	1	1	1	1
Boundary coefficient	1.04	1	1	1	0.96	1	1	1	1	0.97	1	1	1	1	1
QJ16	QJ17	QJ18	QJ19	QJ20	QJ21	QJ22	QJ23	QT01	QT02	QT03	QT04	QT05	QT06	QT07	QT08
19.9	22.2	59.5	12.6	24.2	22.4	96.0	63.7	51.3	32.2	80.8	111.1	35.2	18.7	93.4	29.5
0.24	0.28	0.25	0.24	0.28	0.33	0.28	0.32	0.24	0.06	0.17	0.1	0.13	0.17	0.21	0.32
1.81	3.23	1.74	1.2	2.98	1.57	2.83	1.85	1.77	1.63	1.07	4.28	2.81	1.52	1.08	1.23
0.77	1	0.95	1	1	1	0.96	1	0.88	0.93	0.89	0.93	0.77	0.68	0.85	0.91
1	1	1.1	1	1	1	0.98	1	0.94	0.95	0.95	0.97	0.93	0.91	0.9	0.95
QT09	QT10	QY01	QY02	QY03	QY04	HJ01	HJ02	HJ03	HJ04	HJ05	HJ06	HT01	HT02	HT03	HT04
50.6	38.9	58.1	137.8	43.2	44.9	141.0	126.1	78.6	48.3	18.2	150.4	117.5	142.6	24.0	29.1
0.37	0.35	0.42	0.22	0.15	0.32	0.31	0.31	0.33	0.24	0.29	0.41	0.42	0.12	0.09	0.03
2.03	1.44	1.24	1.41	4.18	2	1.81	1.59	1.7	1.24	2.78	1.08	1.68	1.37	1.19	1.82
0.81	1	0.76	0.6	0.85	0.59	0.94	0.94	1	1	1	0.92	0.95	0.81	0.93	0.89
0.94	0.99	0.98	0.94	0.95	1	0.95	1.09	1	1	1	1	0.98	0.93	0.96	0.97
HT05	HY01	HY02	HY03	CJ01	CJ02	CJ03	CJ04	CJ05	CT01	CT02	CY01	CY02	CY03	CY04	CY05
197.2	145.6	272.2	76.4	16.4	27.1	78.9	146.2	186.5	25.9	119.0	38.0	252.7	99.3	225.6	34.7
0.4	0.51	0.37	0.17	0.11	0.06	0.19	0.12	0.38	0.04	0.27	0.04	0.29	0.21	0.47	0.22
1.27	1.61	1.64	1.25	1.08	1.38	1.4	2.03	1.62	6.57	1.11	1.6	1.54	1.47	1.11	1.28
0.92	0.53	0.8	0.64	0.96	1	1	0.99	1	0.86	0.92	0.69	0.8	0.77	0.71	0.64
0.97	0.99	1.14	0.99	0.96	1	1	0.98	1	0.96	0.96	0.86	0.93	0.98	0.87	0.93

Figure 3 Quantitative description of the sample courtyard

2.2 Quantification of the morphological characteristics of courtyard spaces

By conducting statistical analysis on five aspects of the sample courtyards—area, area ratio, aspect ratio, saturation, and boundary coefficient—the general rules of the courtyard spatial arrangement can be grasped as a whole (Figure 4).

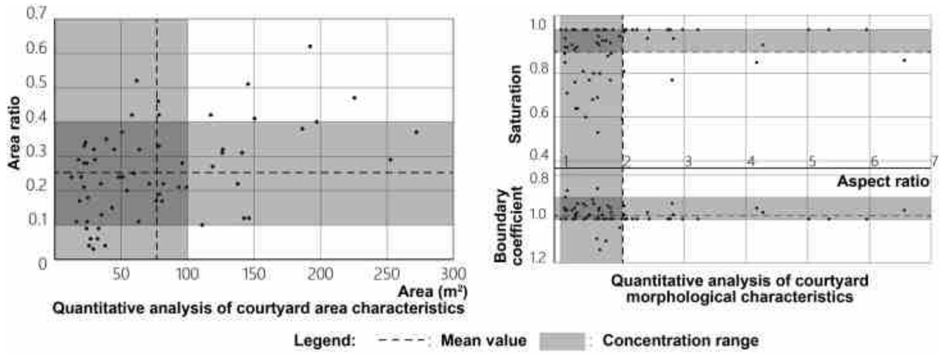


Figure 4 Analysis of the quantitative coefficients of the courtyard

In terms of area, the average area of the sample courtyards is 78.2 m^2, and most of them are under 100 m^2. Courtyards within 50 m^2 account for 42.9% of the sample courtyards, and courtyards between 50 m^2 and 100 m^2 account for 30.2%. It can be seen that, as a supplement to the main building, the courtyard space is generally smaller in scale, and its spatial scale is intimate and human-scaled. There are also some large courtyard spaces. These courtyards have a weaker sense of enclosure, are closer to nature, and can serve as places for viewing, rest, and daily life, enriching the lifestyle of the homeowners. In terms of area ratio, Huizhou traditional residences vary in size, and the constraints on courtyard construction are different, thus showing considerable variation. The average area ratio of courtyard space was 0.26, with 73% of the sample courtyards having an area ratio between 0.1 and 0.4. Among these, the ratio between 0.2 and 0.3 accounted for the largest proportion (31.7%).

A percentage higher than 0.4% or lower than 0.1% is less common. The analysis shows that, in courtyard construction, designers not only made use of limited residual spaces but also deliberately reserved moderately sized courtyards that are proportionate to the main building, thereby enriching the rhythm of the spatial sequence. However, outside of this general pattern, the survey found a small number of samples with a small building footprint but a large courtyard area, or a large building footprint but a small courtyard space. For these types of courtyards, it is necessary to consider the special land use conditions and the living background of the homeowner.

In terms of aspect ratio, the average aspect ratio of the sample courtyards is 2, and most of them are between 1 and 2, accounting for 68.3% of the sample courtyards. Those with an aspect ratio greater than 2 are relatively few. The results indicate that rectangular courtyard spaces ensure a strong sense of centrality and provide relatively uniform viewing distances for resting and strolling, contributing to a stable and comfortable spatial perception.

In terms of saturation, the mean value is 0.9, and 65.1% of the sample courtyards are concentrated between 0.9 and 1. It can be observed that, influenced by the traditional construction concepts of regularity and stability, and by introducing the regular order of traditional architectural space into the courtyard, most courtyard spaces areregular and full. From the perspective of the boundary coefficient, courtyards with a value less than 1 account for 52.4% of the sample courtyards, of which 49.2% are in the range of 0.9 to 1. The findings suggest that most courtyards adopted inclined or bent boundary treatments to adapt to land-use constraints during construction, although these adjustments were generally controlled within a limited range.

3 Courtyard feature analysis based on clustering analysis

3.1 Classification and analysis of courtyard forms

Clustering analysis, as a multivariate statistical method, splits or aggregates data according to the data connection rules to find natural groups in the dataset [17]. The distance between any two points within the same group is less than the distance between any two points in different groups; data within a group are similar, while data in different groups are dissimilar. The study provides a quantitative description of the courtyard space of Huizhou traditional residences from five dimensions: area, area ratio, aspect ratio, saturation, and boundary coefficient. In the clustering analysis, the quantification coefficients of the selected 63 Huizhou traditional residential courtyard samples were first standardized using a standard deviation of 1 to eliminate the influence of different units of measurement. Subsequently, Ward's method was employed for cluster analysis. The classification was determined by observing the clustering results, and the types were named according to the distribution characteristics of the initial variables within each classification result (Figure 5).

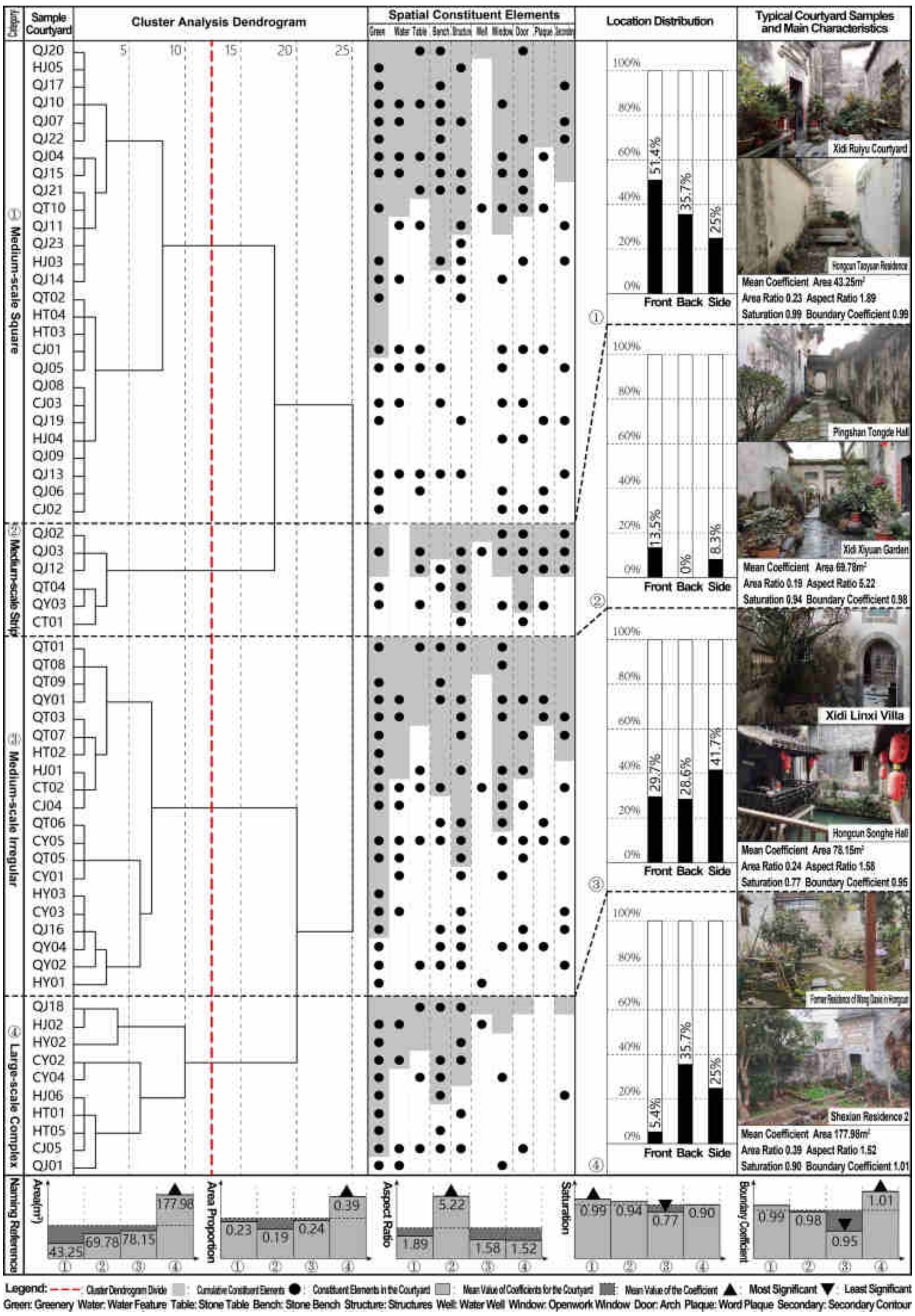


Figure 5 Comparison of planar morphological clustering and spatial organization

The courtyard spaces of traditional Huizhou residences can be broadly categorized into four types:

Type1, represented by Ruiyu Courtyard in Xidi and Taoyuan Residence in Hongcun, has the highest average saturation (0.99) and a relatively low average area (43.25 m^2) among the four types, and is therefore named "medium-scale square" courtyards. This type of courtyard appeared most frequently in the sample, accounting for 42.9% of the courtyards.

Type2, represented by Tongde Hall in Pingshan and Xiyuan Garden in Xidi, has the highest average aspect ratio (5.23) and a relatively low average area (69.78 m^2) among the four types, and is therefore named "medium-scale strip" courtyards. This type of courtyard appeared least frequently in the sample, accounting for 9.5% of the courtyards.

Type3, represented by the side yard of Xidi Linxi Villa and Songhetang in Hongcun, have the lowest average saturation (0.77), average boundary coefficient (0.95), and relatively low average area (78.15 m^2) among the four types of courtyards. Therefore, they are named "medium-scale irregular" courtyards, accounting for 31.7% of the sample.

Type4, represented by the former residence of Wang Daxie in Hongcun and Shexian Folk House 2, have the highest average area (177.98 m^2), average area ratio (0.39), and average boundary coefficient (1.01) among the four types of courtyards. Therefore, they are named "large-scale complex" courtyards, which are less common in the sample, accounting for 15.9%.

Courtyard design in Huizhou traditional residences demonstrates an emphasis on human-scaled spaces and the use of regularity to enhance spatial order. Due to land constraints, many irregular courtyard spaces have emerged. By cleverly utilizing these spaces and seeking variations within the balanced and symmetrical form of traditional residences, these spaces often become focal points of the living environment. Large-scale complex courtyards often have high requirements for land conditions. In addition to organizing circulation, they can also serve as places for viewing and relaxation, providing a place for homeowners to enjoy the natural scenery. Medium-scale strip courtyards generally serve to organize and connect circulation, but because their narrow and long spaces can easily create a sense of insecurity, they are generally less common.

3.2 Correlation analysis between morphological type and location

In Huizhou traditional residences, courtyard spaces are generally divided into front yards, back yards, and side yards according to their relative position and orientation to the main hall. The front yards appeared most frequently, accounting for 58.7% of the sample courtyards, followed by the back yards, accounting for 22.2%, while the side yards appeared the least frequently, accounting for 15.9%. As the starting point and transition of the architectural spatial sequence, the front yard is the focus of courtyard space creation. The axial relationship of the main building extends to the courtyard space, playing a role in highlighting the family status and symbolizing lineage. In addition, the front yard can block wind and sand, welcome sunlight, form a comfortable climate, and satisfy the feng shui pursuit of "gathering wind and accumulating *qi*"[18]. Because the back yard is located at the end of the building's flow, it is a more private space and serves less as a circulation area and more as a space for rest and daily life. There are two common types of side yards. One type involves creating a landscape design for the empty space within the site, transforming it into a scenic courtyard. Another type is arranged on one side of the main building, and these courtyards serve both as scenic attractions and circulation hubs.

In terms of the location distribution of courtyards in the four categories, the front yard is the most common in medium-scale square courtyards, followed by the back yard, while the side yard is less common. Among these, the front yard had the largest distribution in this type of yard, accounting for 51.4% of the total front yards sampled. In the medium-scale strip courtyard samples, the front yard was the most common, followed by the side yard, and no back yards were found. Among the samples of medium-scale irregular courtyards, the front yard appeared the most, followed by the side yard, and the back yard appeared the least. Specifically, the distribution of side yards in this category accounts for 41.7% of the total side yard sample, which is the highest proportion for side yards across all categories and exceeds the proportional representation of front and back yards within this category relative to their respective total samples. In large-scale complex courtyards, the back yard appears most frequently, followed by the side yard, and the front yard appears least frequently. These types of courtyards are mostly residential courtyards with relatively simple space requirements, resulting in complex boundary forms. Therefore, they are mainly distinguished from the other three categories by area metrics.

The analysis reveals that medium-scale square courtyards are predominantly used as introductory spaces, supplementing the outdoor area in front of the main building. Their human-scaled spatial dimensions and square spatial layout provide an opportunity to appreciate and get close to nature, while also providing a comfortable spatial experience. Medium-scale strip courtyards, due to their long and narrow spatial characteristics, often express directionality and give the courtyard space a sense of dynamism. They are suitable for use as front yard spaces in larger residential complexes for circulation organization. Due to the strict land use conditions in Huizhou, side yards are often located at the corners of the land. Compared with courtyards in other locations, they are more affected by the terrain and present a low-saturation form. This unsaturated spatial form breaks the rigidity of the architectural composition, making the overall space more dynamic and lively. Due to the private spatial attributes of the back yard and its functions of viewing, resting, and living, the space requirements are relatively large, which is more in line with the concept of "emulating heaven and earth, and imitating the four seasons". However, under the condition of tight land use, it is not easy to create such a large-scale complex courtyard in the front yard.

3.3 Correlation Analysis between morphological types and environmental Factors

From the overall distribution of elements, greenery elements appeared most frequently in the sample courtyards. The creation of courtyard spaces emphasizes the concepts of "learning from nature" and "harmony between man and nature". Through the observation of natural scenery and phenomena in the courtyard, people can feel the vitality of all things, think about the connection between life and nature, and express their moral ideals and life pursuits through images such as "serene bamboo" and "orchid in an empty valley". In addition, in a space rich in natural elements, people's attention is easily diverted, which can foster positive emotions [19]. Thus, the courtyard space can also play a role in mutual nourishment between people and nature. As the main source of drinking water for villagers, wells are mostly located in the village center or nearby streets and alleys combined with open spaces, so they rarely appear in the courtyards of residential houses [20]. The distribution and combination patterns of elements differ in the four types of courtyards. The proportion of each type of courtyard containing various environmental elements is used as the distribution ratio of the elements to express the distribution of elements in each type of courtyard (Figure 6).

Among medium-scale square courtyards, those with water features, structures, or wells accounted for 37%, 40.7%, and 3.7% of the sample, respectively, which is a relatively low proportion. These results indicate that medium-scale square courtyards, due to their relatively limited spatial scale, show less need for additional structures to reinforce territorial definition or enrich spatial layering and enclosure. In fact, they may even exacerbate the feeling of crampedness in the courtyard space. In addition, these courtyards have fewer living functions and are mostly front yards that serve more functions of circulation organization and display. As a result, elements of water wells and water features are less common.

In medium-scale strip courtyards, those with structures, stone tables, arches, plaques, or secondary contours accounted for 83.3%, 50%, 83.3%, 50%, and 50% of the sample, respectively, which is a relatively high proportion.

Because the narrow and long space of medium-scale strip courtyards can easily create a sense of oppression and insecurity, it is necessary to introduce arches and structural elements to increase their spatial layering. Since these courtyards often connect several building entrances, the secondary contour additions that are often arranged at the building entrance and the wall facing the entrance are also more numerous. Among them, elements such as lanterns and couplets are in line with the traditional style and can effectively enhance the courtyard landscape. However, some modern signs have caused interference to the courtyard space due to the confusion in their design [21]. In addition, courtyards with greenery or stone benches accounted for 50% and 33.3% of the courtyard sample, respectively, which is a relatively low proportion, and water features were not found in them. The results show that medium-scale strip courtyards, characterized by strong directionality and spatial dynamism, primarily serve circulation functions; consequently, elements intended for viewing or resting appear less frequently.

Among medium-scale irregular courtyards, those with greenery, water features, or openwork windows accounted for 90%, 40%, and 55% of the sample courtyards, respectively, which is a relatively high proportion. Courtyards with stone tables accounted for 25% of the sample courtyards, which is a relatively low proportion. It can be seen that when designing medium-scale irregular courtyards, the irregular spaces are often arranged in a rich way, with greenery and water features used to mask and remedy the irregular parts of the courtyard, thereby weakening the irregular shape of the space. Furthermore, using the courtyard wall as the "ground" and the openwork window as the "figure", the openwork window becomes a visual focal point of the courtyard space, which can effectively reduce the feeling of irregularity of the courtyard space under the "spotlight effect" [22]. Simultaneously, in the Huizhou region, where literature and art flourish, these elements possess rich artistic value and scholarly aesthetic, enhancing the spatial level recognition. Stone tables are often placed in courtyards in conjunction with building entrances to follow or support the building axis. However, in medium-scale irregular courtyards, the alignment with the building axis is weaker, so the placement of stone tables is correspondingly less frequent.

In large-scale complex courtyards, those with water features or stone benches accounted for a relatively high proportion of 40% and 60% of the sample, respectively. These findings suggest that this type of courtyard is generally more open and closely connected to nature, functioning primarily as a space for viewing and rest. The arrangement of more water features, stone benches, and other rest elements enriches the spatial layers and circulation paths of the courtyard. Based on the concepts of "a residence with water possesses spirit" and "accumulating water gathers wealth", and given that the courtyard is large enough to accommodate water features, these courtyards often incorporate water features to serve purposes such as fire prevention, cooling, and irrigation. At the same time, the leisurely swimming fish in the water express the desire for a free and unrestrained life, roaming between heaven and earth. In addition, courtyards with openwork windows or arches accounted for 20% and 10% of the sample courtyards, respectively, which is a relatively low percentage. The results indicate that these courtyards place greater emphasis on creating a peaceful and comfortable living atmosphere and, due to their private and introverted spatial attributes, rarely establish visual connections with the external environment through arches or openwork windows.

Overall, the analysis reveals that the arrangement of spatial elements varies significantly among courtyard spaces with different morphological characteristics. The arrangement and combination of these elements either enhance the spatial characteristics or mitigate shortcomings. Medium-scale square and irregular courtyards have a high degree of element richness. Among them, medium-scale square courtyards have more elements such as greenery, water features, stone tables, and stone benches. Medium-scale irregular courtyards are mainly characterized by greenery, water features, and openwork windows. Medium-scale strip courtyards and large-scale complex courtyards have a low degree of element richness. Medium-scale strip courtyards are mainly composed of structures, arches, plaques, stone tables, and secondary contours, with fewer planar elements. Large-scale complex courtyards are mainly composed of greenery, water features, and stone benches, with fewer vertical elements.

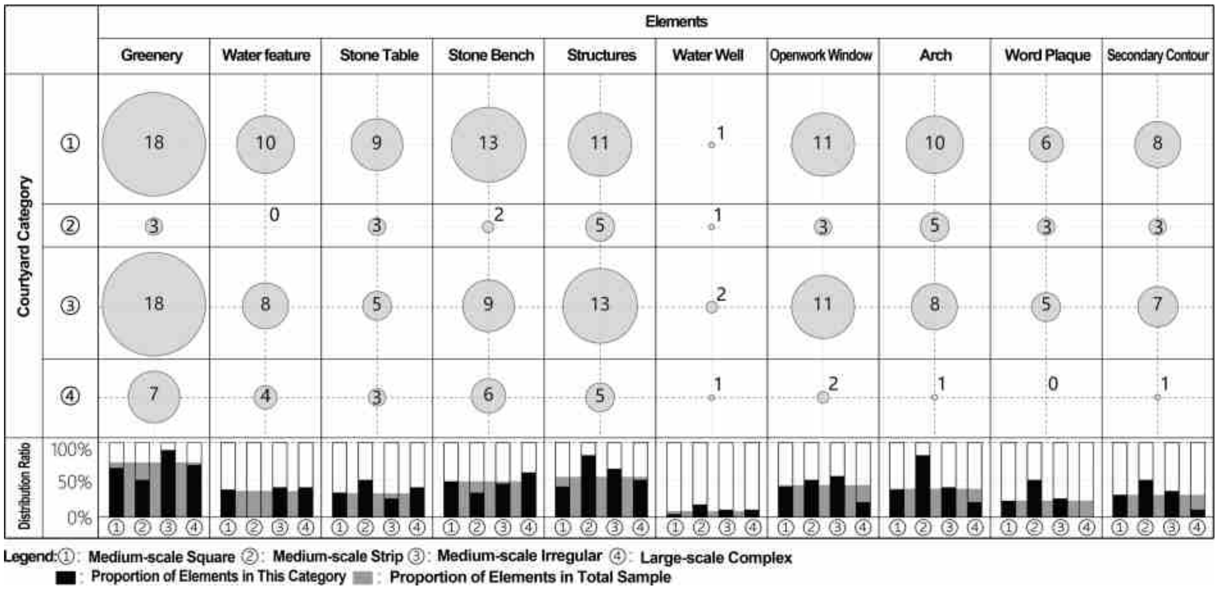


Figure 6 Statistical analysis and comparison of element distribution

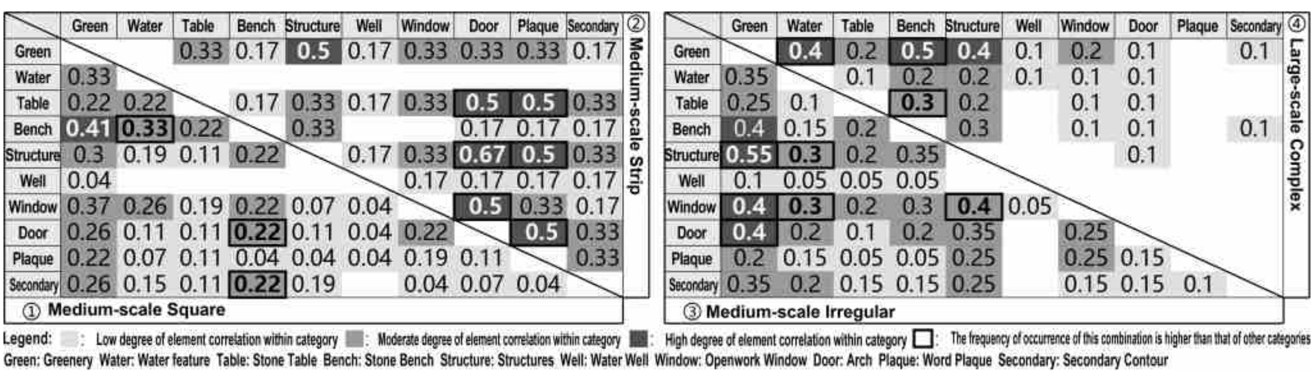


Figure 7 Statistics and comparison of element combinations

3.4 Correlation analysis between elements

The combination patterns of elements in courtyards are complex and exhibit strong individual characteristics. By statistically analyzing the distribution of element combinations in various types of courtyards, the correlation between elements is analyzed (Figure 7), thus providing a reference for the combination of elements in residential courtyards. The proportion of courtyards with various combinations of elements in a given category of courtyards is used as the frequency of occurrence of element combination patterns to express the degree of correlation between elements in each category of courtyards. If the frequency is below 0.2, the correlation between the elements is considered low; if the frequency is between 0.2 and 0.4, the correlation is considered moderate; and if the frequency is above 0.4, the correlation between the elements is considered high. Overall, the greening elements are highly correlated with elements such as water features, stone benches, structures, or openwork windows, indicating that while introducing natural landscapes, the embellishment of artificial elements is more conducive to creating a spatially permeable, comfortable, and leisurely courtyard space. Looking at the combination distribution in various types of courtyards, they are mostly arranged around the main constituent elements. The combination patterns are most abundant in medium-scale square courtyards and medium-scale irregular courtyards, followed by medium-scale strip courtyards, while the combination of elements is less abundant in large-scale complex courtyards.

In medium-scale square courtyards, the "greenery-bench" element combination had the highest frequency of 0.41, indicating the highest correlation. Meanwhile, the frequencies of combination patterns such as "water-bench", "bench-door", and "bench-contour" are 0.33, 0.22, and 0.22, respectively, which are more frequent than in other types of courtyards, reflecting that the correlation between elements such as water features, arches, secondary contours, and stone benches is relatively higher in this type of courtyard. Combining and arranging these elements can serve to connect the axis, enrich the landscape layers, and optimize the rest space within a relatively small and regular space.

In medium-scale strip courtyards, the common combination patterns are mainly "greenery-structure", "door-table", "door-structure", "door-window", "plaque-table", "plaque-structure", and "plaque-door", with frequencies of 0.5, 0.5, 0.67, 0.5, 0.5, 0.5, and 0.5, respectively. These patterns appear more frequently than in other types of courtyards, indicating a high degree of correlation between elements such as greenery, plaques, stone tables, openwork windows, arches, and structures. The arrangement of these elements, while increasing spatial layers and reducing the sense of depth, ensures that every section of the courtyard is appropriately sized and exudes an elegant atmosphere.

In medium-scale irregular courtyards, the combination patterns of "green-structure", "green-window", "green-door", "water-structure", "water-window", and "structure-window" appear relatively frequently, with frequencies of 0.55, 0.4, 0.4, 0.3, 0.3, and 0.4, respectively. At the same time, these combination patterns are relatively more common in other courtyards, reflecting the high correlation between elements such as greenery, water features, structures, and openwork windows. It can be seen that while individual elements can cover and repair irregular spaces, combining these elements can strengthen the reduction of spatial irregularity, enhance the spatial quality, and transform the courtyard into a highlight of the architectural space.

For large-scale complex courtyards, common combination patterns are mainly "green-water", "green-bench", "green-structure", and "table-bench". These combination patterns have a combination frequency of 0.4, 0.5, 0.4, and 0.3, which is higher than that of other types of courtyards. In these types of courtyards, elements such as water features and stone benches are often combined with greenery to create a space that feels close to nature, while providing a richer environment for relaxation.

Conclusions

By introducing spatial quantitative indicators to describe the spatial form of courtyards, and summarizing the location characteristics and element distribution patterns of courtyard spatial types based on clustering analysis (Figure 8), the study found that:

(1) Overall, the courtyard area of Huizhou traditional residences is mostly within 100 m^2. with a suitable spatial scale, which is suitable for construction under the tight land use conditions in Huizhou; the courtyard area is mostly 10% to 40% of the building area, which is in appropriate proportion to the main building and serves as an outdoor supplement to the main building; the aspect ratio can be divided into two categories: between 1 and 2 and greater than 2. The aspect ratios of most of them are between 1 and 2, reflecting traditional design principles emphasizing regularity and stability. Their regular spatial form can give people a comfortable and stable spatial experience. For courtyards with an aspect ratio greater than 2, the space often exhibits a strong sense of dynamism and has more circulation attributes. Regarding the distribution of location, front yards are the most common, followed by backyards, with side yards being the least common. As the

starting point of the architectural sequence, the front yard is often the focus of courtyard design. In terms of element arrangement, greenery elements are the most numerous overall, with structures, water features, openwork windows, and arches also appearing frequently. In terms of element combination, greenery elements are often combined with water features, stone benches, structures, and openwork windows. While introducing natural landscape imagery, this arrangement expresses the ideals of the literati, and the rich elements embellish and enhance the spatial atmosphere that combines the artificial and the natural.

(2) Medium-scale square courtyards are the most common, reflecting that even under the tight land use conditions in Huizhou, there is an enduring priority placed on the creation of courtyard space. The square and stable spatial order is well reflected in the courtyard space, and the form and proportion are consistent with the main body. These types of courtyards are mostly located in the front yard and back yard. As important circulation organization spaces and extensions of living spaces, the front and back yards require square and comfortable spaces. Therefore, when conditions permit, building medium-scale square courtyards is more conducive to maintaining consistency with the main form and to functional use. In terms of spatial configuration, small and medium-scale square courtyards often combine elements such as stone benches with greenery, water features, arches, and secondary contours to extend spatial functions, enrich landscape layers, and enhance spatial interest. Therefore, when creating courtyard spaces for residential buildings, the primary consideration should be to create a courtyard with a square shape and moderate size, and to embellish and enhance it with spatial elements, thereby forming a comfortable and pleasant courtyard space that extends the building space outdoors.

	Spatial attributes	Ranking of location distribution	Ranking of element edistribution	Design strategies
Medium-scale square	Spatial transition, outdoor supplement	Front>back>side	Green>Bench>Structure=Window>Door=Water>Table>Secondary>Plaque>Well	Maintain the historical landscape pattern of Huizhou traditional residential courtyard spaces
Medium-scale strip	Circulation organization for large residential complexes	Front>side>back	Structure=Door>Green=Table=Window=Plaque=Secondary>Bench>Well>Water	Guide the spatial sequence by creating a sense of directionality in the courtyard, and mitigate the uncomfortable spatial feeling through element arrangement
Medium-scale irregular	Sightseeing, circulation	Side>front>back	Green>Structure>Window>Bench>Water=Door>Secondary>Table>Plaque>Well	Rationally utilize different terrains to create courtyards, and weaken the sense of spatial irregularity through element arrangement
Large-scale complex	Daily living, close to nature	Back>front>side	Green>Bench>Structure>Water>Table>Window>Well=Door=Secondary>Plaque	Construct larger-scale courtyards where conditions permit, to better get close to and dwell in nature

Legend: Green: Greenery Water: Water feature Table: Stone table bench: Stone bench structure: Structures Well: Water well Window: Openwork window Door: Arch Plaque: Word plaque Secondary: Secondary contour

Figure 8 Summary of the regular characteristics of courtyards

(3) Medium-scale strip courtyards are mainly front yards. As the circulation space at the front of the building, the front yard requires convenient circulation access. Because of the spatial dynamism and directionality embodied by the strip courtyard, it is often used as the front yard for circulation organization in larger residential complexes. In terms of element configuration, the main elements are structures and arches, which are combined with greenery, plaques, stone tables, and openwork windows to reduce the sense of oppression and insecurity caused by the narrow space. Therefore, when faced with a long and narrow courtyard space due to land constraints, the sense of constriction can be reduced by using structures, arches, and other elements to divide and add layers.

(4) Medium-scale irregular courtyards are mainly front yards and side yards. Under the combined effect of irregular land conditions and the regular main building plan, these courtyards present an irregular spatial form. In addition to being arranged as a viewing space, they also undertake certain circulation functions. Because it seeks variation within a regular planar shape,this type becomes a highlight in the architectural space. In terms of element configuration, greenery, water features, openwork windows, and their combinations are the most common elements. The irregularity of the space is reduced by remedying the space and placing a visual center. Therefore, when

faced with restrictions on land use conditions or irregular shapes of residential land, the impression of spatial irregularity can be mitigated by using elements to shield or correct them, or by arranging eye-catching elements to form a visual center.

(5) Large-scale complex courtyards are mainly back yards, which are mostly living and resting spaces. If the land conditions permit, it is more conducive to building a larger courtyard to create a courtyard space that incorporates more landscape and pastoral imagery and is close to nature, so as tofoster relaxation and spiritual tranquility in a courtyard environment full of natural charm. In terms of spatial configuration, the layout mainly features natural leisure elements such as water features and stone benches, and often combines them with greenery to provide residents with a comfortable and private living environment. Therefore, where land conditions permit, a large-scale courtyard space can be created by combining natural landscapes and recreational facilities to satisfy the pursuit of living in nature.

In conclusion, by studying the spatial organization patterns of courtyards based on typological analysis, we can underst and the general rules of different courtyard spatial arrangements, thus providing a basis for the protection and restoration of Huizhou traditional residential courtyard spaces [23, 24]. Meanwhile, when constructing courtyard spaces for new Huizhou-style residences, attention should be paid to creating regular and square courtyard spaces that provide human-scaled and outdoor spaces that are in harmony with the building's proportions. When land conditions permit, a large-scale courtyard space can be built at the rear of the building, and the natural and private spatial atmosphere can provide a variety of supplements to residential life. The relatively long and narrow courtyard can be used to guide the spatial sequence, and the spatial comfort can be increased by dividing the space through structures and arches. In addition, irregular land use can be used to carry out diversified designs, and spatial elements can be inserted to remedy defects or form a visual center to soften the impression of irregular space [25, 26].

Sources of Figures and Tables

All figures and tables in this article were drawn and photographed by the authors.

References

[1] Shan, D. Q. (2009). *Anhui folk houses*. Beijing, China: China Architecture & Building Press.

[2] Ji, C. (2013). *Horticulture*. Hangzhou, China: Zhejiang People's Fine Arts Publishing House.

[3] Yang, G. Q., Dai, T. X., Wang, Z., & et al. (2016). Reflections on the renewal of historical and cultural villages from the perspective of social change. *Journal of Urban Planning*, (3), 45-54.

[4] Chen, L. K. (2018). Embedding-disembedding: Landscape changes of ethnic communities in suburban tourist destinations. *Social Scientist*, (10), 98-104.

[5] Yang, H. Z., & Zhang, J. J. (2011). Research on cultural inheritance in "transformational" new rural construction: A case study of Dihua Town, Danfeng County, Shaanxi Province. *Journal of Architecture*, (4), 31-34.

[6] Peng, J. Y., & Lu, S. M. (2017). Reconstruction of ethnic minority dwellings from the perspective of critical regionalism: A case study of Lisu dwellings in Ganqia Village, Nujiang, Yunnan Province. *South Architecture*, (5), 109-115.

[7] Zhao, X. F., Jin, H. C., & Xiao, X. K. (2019). Research on courtyard space restoration and protection strategies of ancient villages in Huaxian County. *Industrial Construction*, 49(2), 38-43.

[8] Wang, Q., Li, Z., Gao, X., & et al. (2019). Construction method and characteristic analysis of semantic system of regional residential style elements: A case study of Huizhou area. *Decoration*, 2019 (6), 94-97.

[9] Zhai, Y.(2016). Analysis on the constituent elements of Chinese traditional courtyard space. *Chinese Landscape Architecture*, 32 (9), 58-62.

[10] He, Y., & Sun, L. (2017). Research on traditional village courtyard unit based on clan structure: a case study of conservation planning of historic and cultural village in Walking Matang, Ningbo. *Journal of Architecture*, (2), 90-95.

[11] Wei, S., & Liu, H. (2015). A quantitative study on the spatial characteristics of gardening elements in Humble Administrator's Garden. *Chinese Garden*, 31(7), 78-82.

[12] Wu, Y., He, L., & Fang, W. (2012). Research methods and inspiration of landscape character of Japanese historical and cultural districts. *Journal of Architecture*, (6), 44-49.

[13] Bao, J., & Lin, M. (2014). Study on the control of tourism commercialization in historical villages and towns. *Journal of Geography*, 69(2), 268-277.

[14] Zhu, X. (2001). Experimental evaluation criteria of ancient villages.*Ancient Garden Technology*, (4), 53-55, 28.

[15] Ashihara, Y. (2006).*The aesthetics of the street* (Y. Peitong, Trans.). Tianjin, China: Baihua Wenyi Publishing House, 55-64.

[16] Ye, M., & Li, Z. (2018). Research on the spatial plane morphology types of traditional villages based on cluster analysis. *Industrial Architecture*, 48(11), 50-55, 80.

[17] Wang, J., Wang, S., & Deng, Z. (2012). Some issues in cluster analysis research.*Control and Decision Making*, 27(3), 321-328.

[18] Wang, X., & Cao, Y. (2012). Study on the wind environment of traditional villages and towns: the example of the ancient town of Yiyan, Chongqing. *Journal of Architecture*, S2, 21-23.

[19] Ulrich, R. S., Simons, R. F., Losito, B. D., Fiorito, E., Miles, M. A., & Zelson, M. (1991). Stress recovery during exposure to natural and urban environments. *Journal of Environmental Psychology*, 11(3), 201-230.

[20] Wang, Z., & Yang, J. (2001). Ecological reflections on the relationship between water and villages. *Journal of Ecology*, 2001 (5), 69-72.

[21] Zuo, H., Li, Z., Yu, X., & others. (2019). The visual quantification of "secondary contours" of building facades in historical districts: the case of Tunxi Old Street in Anhui Province. *Modern Urban Research*, (1), 88-93.

[22] Liu, B., & Fan, R. (2014). Experiment and analysis of visual attraction mechanism of landscape space.*China Garden*, 30(9), 33-36.

[23] Xu, H., & Tang, Z. (2021). Research on the temporal and spatial law of settlement distribution along Dongjiang-Hanjiang Ancient Post Road based on big data. *South Architecture*, (4), 67-73.

[24] Tang, S., & Tan, G. (2021). Inheritance and protection of vernacular architecture and settlements in a contemporary perspective: Review of academic research on Chinese vernacular architecture. *South Architecture*, 2021 (4), 112-117.

[25] Wang, Y., & Shen, J. (2020). Exploration of multi-scale spatial process in the characteristics and evolution of rural landscape pattern: A case study of Wuzhen. *Landscape Architecture*, 27(4), 62-68.

[26] Kong, Y., Zhang, B., & Hu, Y. (2020). Research on construction of traditional settlement spatial schema language system: A case study of Minjiang River Basin in Fujian Province. *Landscape Architecture*, 27(6), 100-107.

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A Discussion on Livability Issues of Rural Dwellings in the Context of Rural Revitalization

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ABSTRACT: Ecological livability is one of the five overarching goals of rural revitalization, and this study focuses on issues concerning the livability of rural dwellings. It proposes a "Hierarchical Reference Framework for Evaluating the Livability of Rural Dwellings", and analyzes and evaluates the livability of both traditional and newly built rural dwellings in China. Three representative rural dwelling projects conducted by the authors over the years are examined to evaluate improvements in livability, followed by reflections on the problems revealed. The discussion focuses on three key aspects: The setting of livability goals and standards, the challenges and special policies related to livability in impoverished areas, and the tensions between the conservation of rural dwellings as "immovable cultural relics" and livability requirements. Particular attention is given to discussions and recommendations regarding regulatory, policy, and conservation requirements concerning such protected dwellings.

KEYWORDS: rural revitalization; traditional rural dwellings; newly built rural dwellings; livability; immovable cultural relics

Introduction

Ecological livability, as one of the five overarching goals of rural revitalization, has a direct bearing on our research on rural dwellings. The authors strongly concur with Professor LIU Shouying's view: "The primary indicator of successful rural revitalization is dignity—dignified living conditions, public services, and people...[1)]" Living in peace and working happily has long been the greatest aspiration of both urban and rural life in China, and building a house has traditionally been the foremost priority of rural families [1].

The livability of rural dwellings currently faces two direct challenges: first, how can the conservation and restoration of traditional dwellings be enhanced to meet contemporary standards of livability? Second, how can newly built rural dwellings achieve a high level of livability? These issues involve many specific aspects. Below, we discuss these issues from three perspectives: Evaluation of the current state, reflections on practical experiences, and exploration of the problems.

1 Current conditions of rural dwellings in China and their livability assessment

The inclusion of "ecological livability" in the central government's rural revitalization strategy, along with the requirements issued by the Ministry of Housing and Urban-Rural Development regarding rural housing and vil-

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lage construction [2], clearly reflects farmers' aspirations for stable and comfortable living. However, how should livability be evaluated? What is the current status of livability in traditional and newly built rural dwellings, and what challenges do they encounter? These questions constitute the basis for this discussion.

1.1 Reflections on evaluation criteria for livability of rural dwellings

According to Maslow's hierarchy of needs, human needs are divided into five ascending levels: Physiological needs, safety needs, social needs, esteem needs, and self-actualization [3]. Naturally, this involves the concept of "dwelling."

In 2009, while researching the core values of traditional rural dwellings, the authors proposed a "Five-Level Hierarchy of Dwelling Needs" based on this theory. Given that no formal standard currently exists for evaluating the livability of dwellings, this framework may serve as a reference. After slight revisions, it has been transformed into the "Hierarchical Reference Framework for Evaluating the Livability of Rural Dwellings" (Figure 1 [4]). In the framework, E, D, C, B, and A represent five levels from low to high, with each level further subdivided into three grades—3, 2, and 1 (low, medium, high). The meanings of the five levels are clearly defined in the diagram. Although the framework does not provide a quantitative assessment of dwelling livability, it can at least offer a relatively intuitive qualitative classification.

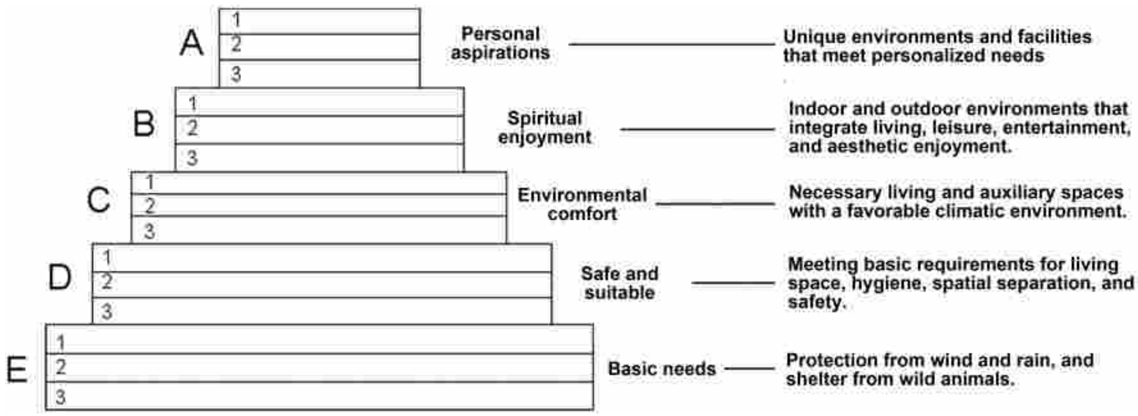

Figure 1 Hierarchical reference framework for evaluating the livability of rural dwellings

1.2 Analysis of the livability of current traditional rural dwellings in China

China's rural areas are vast and economically diverse, and the conditions and problems of traditional rural dwellings vary greatly. This analysis focuses primarily on rural areas in the less-developed western regions of China.

Traditional rural dwellings are inseparable from agriculture. Functions such as grain storage and the keeping of farm tools are essential, but they also lead to problems such as space occupation, cluttered storage, rodent and insect infestation, and negative impacts on hygiene. Different regions and ethnic groups have their own customs regarding agricultural routines, sideline production, and agricultural-related festivals and rituals, and these customs in turn shape their specific livability needs.

Traditional rural dwellings are also closely tied to livestock. Cattle and horses serve as primary labor, while poultry and livestock are important supplements to the rural subsistence economy. They require substantial space, and human-animal cohabitation is common, resulting in significant sanitation challenges.

"Once fire was introduced into human dwellings, the hearth gradually took shape, strengthening the bond between humans and fire [5]12-13." The less economically developed an ethnic group or region is—especially those in the southwestern mountainous areas—the more central the role of fire becomes in traditional dwellings. The hearth serves multiple functions—cooking, heating, smoking meat, and repelling insects—and also holds symbolic significance as a focal point for family gatherings. However, prolonged smoke accumulation darkens the interior, and fire hazards remain among the greatest risks associated with such dwellings.

Adequate spatial separation is the minimum requirement for livability, yet this issue persists in many traditional rural dwellings. In the past, some ethnic minority groups had certain problematic residential arrangements (e.g., prior to the 1990s, Dai bamboo dwellings in Xishuangbanna featured undivided sleeping areas) [6]76-116. In some impoverished minority areas (such as the Yi in the Liangshan region and the Hani in Honghe Prefecture), all domestic functions are concentrated in a single space, with sleeping areas minimally demarcated around the hearth. Situations such as growing household size, economic poverty, insufficient floor area in existing dwellings, and difficulties in creating interior partitions are still commonly observed today.

Timber-and-earth traditional rural dwellings commonly exhibit long-term disrepair—decaying structural timbers, cracked walls, and leaking roofs—a widespread condition across rural regions. The lack of maintenance funds and rural hollowing accelerates structural deterioration and eventual collapse, posing direct and severe challenges to livability.

The conservation of traditional built form and the continuity of associated cultural practices represent core intrinsic and extrinsic dimensions of livability. Few traditional dwellings in rural areas are well preserved; most are severely damaged, and many have already disappeared.

Traditional rural dwellings can generally be categorized into three types based on economic conditions: Low-income, moderate-income, and high-income dwelling typologies [7] (Figure 2). Because economic conditions vary widely across regions, it is difficult to quantify the proportion of each type. Overall, based on our fieldwork in the Southwest in recent years: Low-income dwellings are numerous, with livability generally corresponding to E1-D3 levels; moderate-income dwellings are the most common, with livability generally in the D2-C3 range; high-income dwellings are fewer in number, with livability mostly at the C2-C1 levels.

Figure 2 Classification of traditional dwellings by economic status (2a: Low-income type; 2b: Moderate-income type; 2c: High-income type)

Figure 3 A self-built new rural dwelling in Jingmai Mountain, Lancang, Yunnan (3a: Exterior; 3b: Kitchen; 3c: Bedroom; 3d: Bathroom)

Figure 4 Two conditions of current new rural dwellings (4a: Well-constructed unified housing; 4b: Self-built housing that detracts from environmental character)

1.3 Livability analysis of newly built rural dwellings

Many newly built rural dwellings have been built in recent years. Most are self-built by villagers, while some are built through coordinated development. In more economically developed areas, the proportion of the latter is higher.

Overall, the construction quality of newly built rural dwellings has improved considerably: Structural safety has increased, and earlier problems of crude structures and materials have largely been overcome; functional performance has improved: Room divisions generally meet basic standards, kitchens and bathrooms have been added, and human and livestock are separated; the indoor environment has improved significantly, with larger daylighting areas and enhanced facilities and interior finishes (Figure 3). However, many problems remain in newly built rural dwellings: Planning lags behind, spatial layouts are often poorly conceived, and the overall environment is substandard; despite a relatively large floor area, the functional layout remains inadequate; the exterior appears unrefined, with disparate forms, materials, and colors that compromise traditional rural character; construction quality is often substandard, and some structural elements and materials lack adequate safety performance. Accordingly, as stated in a joint document issued by the Ministry of Housing and Urban-Rural Development, the Ministry of Agriculture and Rural Affairs, and the National Rural Revitalization Administration, "the design and construction standards of rural housing in China urgently need improvement, 'and it is necessary to' enhance housing functions and improve housing quality [2]."

Overall, newly built rural dwellings (Figure 4) show some improvement in livability compared with low-income and moderate-income traditional dwellings, but most remain of relatively low quality and generally correspond to Levels D2-C1. The reasons for the generally low quality of newly built rural dwellings include: A lack of planning vision—construction is dispersed, prioritizing individual dwellings over the communal environment; a lack of quality consciousness—emphasis is placed on imposing height and scale while interior functionality is neglected, with attention paid to façade at the expense of internal detailing; a lack of aesthetic discernment—local traditions are disregarded, creativity is absent, imitation is uncritical, and formal expression is disordered; and a lack of professional design input—the role of design is misunderstood, investment in design is deemed unnecessary, and construction execution often lacks technical competence.

2 Reflections on three successive projects involving ethnic minority dwellings and their livability issues

The following section examines three projects the authors have engaged in over the past twenty years to reflect on livability-related issues in both traditional dwelling restoration and various forms of newly built rural dwelling development.

2.1 Experimental newly built Dai Dwellings in Xishuangbanna (1999) [8]

The issues to be addressed at the time included: Improving functional layouts (dividing sleeping areas, adding kitchens and bathrooms, and utilizing raised floors); changing construction materials (replacing timber with reinforced concrete due to timber scarcity); preventing the loss of traditional architectural character of Dai bamboo houses (as villagers began constructing flat-roofed brick houses, placing this heritage at risk of disappearance); and accommodating economic constraints (each self-built house had to remain within an 80,000-yuan budget). The research began in 1997. It was easy to develop proposals, but the implementation proved difficult. The first experimental "bamboo house" was constructed from January to April 1999. Its functional layout was significantly improved, and its architectural character retained the traditional hipped roof and part of the raised floor. To reduce costs, a monolithic prestressed precast reinforced concrete structure was adopted.

The aim of this experimental project was to conduct an individual exploration into the modernization of Dai bamboo houses from traditional forms [9]137-143. Upon completion, it was well received by villagers and hailed as the advent of the "third-generation bamboo house" (Figure 5), achieving the intended transition from second-generation timber-frame "bamboo houses" to third-generation reinforced-concrete ones. In terms of livability, this experimental "bamboo house" was assessed as having improved from Level D1—typical of villagers' newly built dwellings at the time—to Level C1.

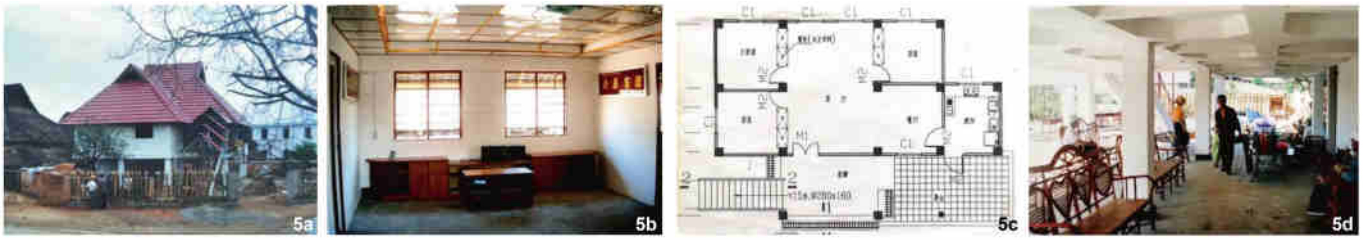

Figure 5 The first experimental newly built rural dwelling of the Dai in Xishuangbanna
(5a: Exterior; 5b: Interior; 5c: Floor plan of the first experimental building (200.25 m^2); 5d: Partially elevated ground floor)

In retrospect, after the project was widely implemented in numerous Dai villages, new problems arose: Dense clusters of new "bamboo houses" emerged; although their livability had improved compared to traditional bamboo houses, the overall village environment regressed, becoming far less picturesque than before. While population growth, land scarcity, and increased building density were contributing factors, the primary causes were the lack of comprehensive planning, neglect of environmental quality, ad hoc construction practices, and inadequate regulatory oversight. "Ecological livability" inherently encompasses the rural environment, spatial organization, and built form in an integrated manner. Therefore, the document jointly issued earlier by the Ministry of Housing and Urban-Rural Development and other departments, which states that "rural housing construction should proceed in parallel with environmental improvement, with attention to enhancing supporting services and the village environment", is entirely correct.

2.2 Conservation and restoration of Hani Mushroom houses in Yuanyang (2017-2019)

The issues to be addressed at the time included the needs of poverty alleviation and dilapidated-house renovation, strong demands for functional improvement, and the constraints imposed by cultural-heritage conservation regulations. Since the authors carried out the first pilot maintenance and renovation project on a Hani mushroom house [10] in 2015 in Azheke Village, located in the core zone of the Honghe Hani Rice Terraces World Heritage Site, the research team continued on-site conservation and restoration work in Azheke from 2017 to 2019, from September 2018 to the end of 2019, on-site guidance was provided for the restoration of 33 traditional residential buildings (this project was shortlisted for the Architectural Achievement Award of the WAACA in 2025) [11]. Following restoration, structural safety—particularly in walls and roofs—was significantly enhanced, yet the exterior appearance was preserved unchanged. Indoor functions and environmental quality were enhanced, and residents expressed general satisfaction (Figure 6). These severely deteriorated timber-and-earth mushroom houses represented the low-income type of traditional dwellings and were still inhabited by residents. The residents had high expectations for improvement. However, because Azheke Village is one of the key villages in the core zone of the World Heritage site, the houses were designated as "immovable cultural relics," their repair was subject to numerous restrictions on form, size, height, materials, and so on, which led to many conflicts. Upon completion of the restoration, the self-assessed livability level improved from Level D3 to Level D1, but it still fell short of residents' expectations and remained far from true livability.

Figure 6 Conservation and restoration of Hani mushroom houses in Azheke Village, Yuanyang
(6a: Exterior before restoration; 6b: Exterior after restoration; 6c: Interior before restoration; 6d: Interior after restoration)

Reflecting on the project, the entire restoration process was fraught with intractable tensions: These low-income type traditional dwellings had very poor livability and the residents had strong demands for improvement, yet the status of the houses as "immovable cultural relics" imposed numerous constraints. How should such contradictions be resolved? (The issues raised here and below will be further discussed in the next section.)

2.3 Implementation of newly built Yi Dwellings in Sanhe New Village, Zhaojue, Sichuan (2018-2019)

The issues to be addressed at the time were as follows: Sanhe Old Village, a severely impoverished Yi village in the Liangshan Mountains of Sichuan, was designated for relocation and reconstruction following a personal inspection by General-Secretary Xi Jinping on February 11, 2018. This relocation was necessary for poverty alleviation and carried special political significance. The newly built rural dwellings were required to substantially enhance living functionality while embodying a distinctive new architectural character of Yi housing. Due to land constraints, the new village was divided into two sections, with a total of 29 newly built rural dwellings (Figure 7) constructed along with tourism and public facilities. Owing to the previous extreme poverty and the special construction conditions, the self-evaluated livability of the newly built Yi dwellings improved markedly from Level E1 (old village) to Level C2 (new village). Moreover, the construction of Sanhe New Village, from planning to design, integrated newly built rural dwellings with the overall village environment, resulting in simultaneous improvement of both individual houses and the broader settlement environment (Figure 8).

Figure 7 Newly built rural dwellings of the Yi in Sanhe Village, Zhaojue County, Sichuan (7a: Exterior; 7b: Interior)

Figure 8 Interior view of Point No. 2 in Sanhe New Village, Zhaojue County, Sichuan

In retrospect, both projects were situated in impoverished regions. The former was in a key village within a World Heritage core zone, and the latter benefited from the special opportunity of a visit by the General Secretary. Both received certain funding, which helped address livability issues to varying degrees. Yet how can livability challenges in other impoverished villages and dwellings be effectively addressed? And how should appropriate livability targets be established?

3 Discussion of several issues related to livability of dwellings

3.1 Setting livability goals and establishing standards

From the three cases discussed above, it is clear that although all achieved improvements in livability, the extent of improvement and the final targets differed significantly. Without clear goals set in advance, improvements could only be made on an ad hoc basis. This is partly due to differences in baseline conditions, objective constraints, and funding levels, and partly because no formal livability goals or standards have yet been established; localities remain in an exploratory phase. Without established goals and standards, rural housing construction cannot be properly regulated, which is also a key problem in current rural development.

When it comes to the goals of rural dwellings, they are of course primarily constrained by economic capacity, but they are also shaped by people's aspirations and cultural influences. Since the pursuit of livability cannot usually be achieved in a single step, nor can it be frequently adjusted, it is advisable to propose a range of target levels. Moreover because current baseline conditions vary greatly, this range should be relatively broader. We recommend that, in the context of rural revitalization, the long-term livability target for rural dwellings should reach the C-B level, specifically C3-B1 (Figure 9). This represents a substantial improvement over the current E1-C1 levels of traditional dwellings and the D2-C1 levels of newly built rural dwellings. Given that low-income type dwellings exhibit a significant gap from livability standards, each improvement cycle should strive for a larger improvement step.

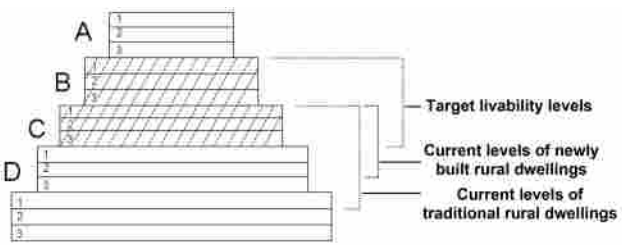

Figure 9 Recommended long-term livability target levels

As rural revitalization progresses, relatively unified standards for the livability of dwellings should be established. Such standards should undoubtedly address both the overall village environment and the quality of individual dwellings. The former includes adequate infrastructure, complete public facilities, and an attractive environment; the latter includes sufficient floor area, well-designed functional layouts, good spatial quality, and a pleasingarchitectural character. The indicator system for rural dwellings should include land area, building area, functional spaces, physical indicators such as sunlight, ventilation, and daylighting, as well as the surrounding environment and architectural character requirements. Quantitative requirements for these indicators should be differentiated by region (developed, moderately developed, and under-developed areas), by dwelling type (traditional or newly built), and by time frame.

3.2 Livability challenges and special policies in impoverished areas

In low-income rural areas, a small number of villages have been relocated to towns under major national projects, where livability issues are primarily addressed through state investment and coordinated urban-level planning. Another small number of villages have undergone consolidation, full relocation, or construction of new settlements (such as Sanhe Village in Zhaojue County), and these projects generally receive dedicated funding, enabling livability issues to be addressed to varying degrees. The most challenging cases are the numerous low-income type villages that remain in their original locations. Although these villages are poor due to their remote mountainous locations, some possess good ecological environments, distinctive ethnic cultures, and relatively intact traditional settlement patterns despite deterioration. Many are highly valuable (such as rare ethnic-minority settlement relics or scarce examples of unique dwelling types), and some have been designated as national-level traditional villages (such as Azheke Village in Yuanyang). These villages continue to exist naturally in their original locations, yet their situation is the most precarious: Economic decline has led to partial abandonment and increasing village hollowing. Abandonment is neither feasible nor acceptable; preservation suffers from inadequate awareness and, more critically, insufficient funding—even national-level traditional village subsidies fall short of conservation needs. Development faces a shortage of skilled personnel and no clear direction, with only a few able to leverage tourism. Livability improvements in dwellings of these villages rely primarily on residents' own investment: Low-income households cannot afford repairs, resulting in deterioration and haphazard construction; wealthier households often demolish old houses and construct new ones at will, thereby damaging traditional village character.

Such low-income type villages are fairly numerous in certain provinces and represent the most challenging component of rural revitalization: Preservation is difficult, development is difficult, and achieving both simultaneously is even more so. They are farthest from achieving livability, making the attainment of livability goals particularly arduous. For such low-income type villages, the authors have long recommended the establishment of special policies with focused government support [12]. As demonstrated in recent years, without the policies and measures of the national poverty-alleviation campaign, poverty issues would have been extremely difficult to resolve. Special policies include: Targeted support (distinctive designation, dedicated archives, and institutional pairing); tailored measures (mobilizing internal capacity, providing external assistance, and ensuring goal implementation); and dedicated funding (special-purpose funds, social contributions, and strictly earmarked use).

3.3 The Contradiction between livability and the restoration of dwellings as "Immovable cultural relics"

In recent years, China has designated a number of traditional villages and dwellings as "immovable cultural relics" in accordance with the *Guidelines for the Determination of Immovable Cultural Relics* (*Trial*) (the "*Guidelines*" hereinafter) [13]. Some have even been classified as national- or provincial-level cultural heritage protection units (such as Wengding Wa Village in Cangyuan). This is entirely appropriate and necessary for former residences of notable figures or dwellings associated with historical events. However, for traditional dwellings still inhabited by residents, it creates numerous problems that arise from the fundamentally different attributes of "dwelling" and "cultural relics."

A "dwelling" is, by definition, "the residence of the people."[14] This is its essence and core. Its culture emerges from habitation: A courtyard inhabited by a family becomes a vessel of family culture, and a village inhabited by an ethnic group becomes a carrier of ethnic culture. "Dwelling" is dynamic and changing. Living spaces inevitably evolve with demographic shifts, economic development, and environmental improvement. Traditional dwellings themselves have developed through continuous change and will continue to do so. In contrast, "cultural heritage" must preserve historical authenticity and therefore should not change. The two concepts are theoretically contradictory.

In practice, this contradiction manifests as the tension betwe en residents' demands to improve livability during the restoration of "immovable cultural relics" dwellings and the restrictions imposed by heritage-protection regulations. In rural areas, beyond addressing structural safety, material reinforcement, and roof repair, villagers often request expanded functions, increased floor area, higher ceiling heights, or improved appearance. Some of these requests are reasonable from the perspective of enhancing livability. Particularly in low-income type dwellings, where houses are rudimentary, functions are mixed, locally sourced and opportunistic materials are used, and construction lacks standardized methods or norms, the gap between "tradition" and contemporary livability is substantial, leading to strong demands for improved living conditions. Yet some of these dwellings, due to their "distinctive form and style," "representativeness," or "typicality," or because they form part of a World Cultural Heritage site, have been designated as "immovable cultural relics" or even "cultural relics protection units." The Law of the People's Republic of China on Protection of Cultural Relics stipulates: "The use of immovable cultural relics must adhere to the principle of preserving their original condition, ensuring the safety of the building and its affiliated relics, and prohibiting damage, alteration, additions, or demolition."[15] As a result, disagreements—and even sharp confrontations—often arise between residents and heritage-management or design personnel. When participating in the restoration of 33 mushroom houses in Azheke Village, Yuanyang, we encountered such conflicts every day and often had to adopt compromise solutions to control the major issues while letting the minor ones go. It can be said that every restored house was the result of mutual compromise; otherwise, restoration would not have been possible.

In response to the theoretical and practical contradictions in restoring "immovable cultural relics" dwellings, we propose the following three areas for discussion and recommendation.

(1) Can relevant regulations be appropriately revised?

Traditional dwellings, as tangible cultural heritage, require serious protection, but their designation as "immovable cultural relics" should be approached with caution. It is recommended that the *Guidelines for the Determination of Immovable Cultural Relics* (*Trial*) (2018) issued by the National Cultural Heritage Administration be appropriately revised. In Article 7, concerning traditional dwellings, wording such as "designation may be permitted only under exceptional circumstances" and "generally subject to strict control" should be added.

If traditional dwellings remain within the scope of "immovable cultural relics", it is recommended that Article 26 of the *Law of the People's Republic of China on Protection of Cultural Relics* (*2017 Revision*)—which states that "...prohibiting damage, alteration, additions, or demolition"—be supplemented with: "For traditional dwellings still in residential use, necessary alterations or additions that respond to livability needs and do not impair the integrity of core protected elements may be permitted, provided that the proposed interventions undergo rigorous review and formal approval, followed by strict oversight."

(2) Can protection and utilization policies be appropriately adjusted?

For traditional dwellings already designated as "protected heritage units," it is recommended that they should, in principle, no longer serve residential functions (with a few original residents allowed to remain as caretakers). Their conservation and restoration should strictly follow heritage-protection requirements, and the funding should primarily be provided by the government.

For traditional dwellings designated as "immovable cultural relics" but still in residential use, it is recommended that policy be adjusted to "safeguard cultural traditions and relic values while enabling incremental improvements in livability"—that is, protection takes precedence, but limited, incremental development is permissible.

The concepts and policies for "immovable cultural relics" dwellings and "cultural relics protection units" should be clearly distinguished and differentiated. It is recommended that cases previously misclassified due to conceptual ambiguity be re-evaluated and adjusted as appropriate.

(3) Should restoration requirements be moderately relaxed?

Restoration requirements for "immovable cultural relics" dwellings should be based on practical realities and appropriately relaxed. In principle, exterior-appearance protection should remain strict, while interior development and modifications may be more flexible. Regarding height, scale, materials, and form, "minor changes," "gradual adjustments," and "progressive relaxation" should be allowed when required for livability. Exterior restoration should strive to maintain original appearance while distinguishing traces of different periods.

For low-income type dwellings with substantial livability gaps, it is recommended that requirements be further relaxed. The *Guidelines* should provide overarching principles, while specific restoration content and methods are determined through on-site assessment, with post-completion documentation and archiving. Strict adherence to "no alteration from the original" or "approval of drawings prior to construction, followed by rigid compliance" is not advisable.

Conclusion

"Livability" is both a core goal of rural revitalization and an inherent aspiration of rural dwellings. Studying rural dwelling livability not only strengthens the policy framework for rural revitalization but also addresses the practical demands of contemporary rural housing construction.

A standard for evaluating dwelling livability is necessary. Building on prior research, we propose a "Hierarchical Reference Framework for Evaluating Rural Dwelling Livability," which serves as the basis for analyzing the current state and challenges of traditional and newly constructed rural dwellings in China. This forms the foundation of the present study.

Three prior projects led by the authors (covering both traditional dwelling restoration and explorations of newly built rural dwelling types) are briefly presented to critically reflect on livability-related issues, among which three key issues constitute the focus of this paper.

Without defined goals and standards for livability, rural housing construction cannot be regulated, which is a major problem in current rural development. Therefore, the paper first discusses "the setting of livability goals and the establishment of standards" and presents our recommendations.

The greatest challenge to livability lies in low-income type areas. This is the most significant insight from our research, and we therefore propose that targeted policy support is essential to address this issue.

The contradiction between livability and the restoration of "immovable cultural relics" has been a frequent, widespread, and pressing issue in recent practice—particularly for low-income type dwellings. This paper therefore focuses on analyzing these theoretical and practical tensions and presents focused discussions and specific recommendations concerning regulatory frameworks, policy adjustments, and restoration standards.

Addressing real issues, analyzing contradictions, solving problems, and promoting rural revitalization constitute the purpose of this study. Preserving traditional character and transmitting traditional culture amid development is not only a timeless principle for improving the livability of traditional dwellings but also a high-quality pursuit for the livability of newly built rural dwellings.

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Source of Figures and Tables

Figure 6: Courtesy of Li Liping;

All other images were created or captured by the authors.

Note

1) Liu Shouying. Nine Perspectives on Rural Revitalization [Z/OL]. Planning China, (2021-06-23) [Accessed 2022-04-12]. https://baijiahao.baidu.com/s? id= 1703270335155875007&wfr= spider&for= pc.

References

[1] Xia, Q., Luo, Y., & Zhang, B. (2021). Rural construction for farmers: The preservation of traditional villages. *Planners*, (10), 26-33.

[2] Ministry of Housing and Urban-Rural Development, Ministry of Agriculture and Rural Affairs, & National Rural Revitalization Administration. (2021, June 8). *Guidelines on accelerating the modernization of rural housing and village construction*. https://www.mohurd.gov.cn/gongkai/fdzdgknr/tzgg/202106/20210621_250525.html.

[3] Maslow, A. H. (1943). A theory of human motivation. *Psychological Review*, 50(4), 370-396. https://doi.org/10.1037/h0054346.

[4] Zhu, L. W. (2010). Avoid the restriction of form, trace back to the origin of residence: On the key values of traditional folk residence. *China Ancient City*, (6), 12-16.

[5] Yang, F. Q., & Zheng, X. Y. (1991). *Huotang culture record*. Kunming, China: Yunnan People's Publishing House.

[6] Zhu, L. W. (1992). *The DAI or the Tai and their architecture & customs in South China*. Bangkok, Thailand: D D Books.

[7] Zhu, L. W. (2017). Considerations on some questions of traditional villages research. *Southern Architecture*, (1), 4-9.

[8] Zhu, L. W. (2000). A note of Dai people's new housing test. *New Architecture*, (2), 12-15.

[9] Zhu, L. W. (2011). *The value and inheritance of traditional dwellings*. Beijing, China: China Construction Industry Press.

[10] Zhu, L. W. (2016). The reflection and exploration of poverty-stricken traditional dwellings maintenance and renovation: An experiment of Hani traditional dwellings. *New Architecture*, 2016 (4), 40-45.

[11] Cheng, H. f., & Zhang, P. (2025) *Local design research*: 2011-2023, (8),112- 113. Wuhan: Huazhong University of science and technology press.

[12] Zhu, L. W. (2020). Reconsideration of traditional villages under the rural revitalization strategy. *Southern Architecture*, (2), 62-67.

[13] National Cultural Heritage Administration. (2018, June 27). *Guidelines for the recognition of immovable cultural relics* (for trial implementation). http://www.ncha.gov.cn/.

[14] Zhu, L. W. (2015). Discussion on the activation of traditional folk house. *China Ancient City*, (11), 4-9.

[15] National People's Congress. (2017, November 4). *The Law of the People's Republic of China on Protection of Cultural Relics*.

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Spatio-temporal Evolution of Spatial Accessibility of Traditional Chinese Villages in Guangdong Province and Its Determinants

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ABSTRACT: Taking 263 traditional Chinese villages in Guangdong Province as the study sites and spatial accessibility as the core focus, this study employs ArcGIS, the GWR model, web-crawling techniques, and other modern geographical analytical tools to provide an in-depth analysis of the spatio-temporal evolution, processes, and determinants of spatial accessibility in traditional villages to conduct an integrated qualitative-quantitative analysis. Furthermore, the GWR model is applied to examine the local effects and spatial spillovers of these determinants. The findings indicate that: (1) From the Song to the Qing dynasties, the point-axis progressive development pattern of historical accessibility and historical routes is distinct. It generally extends outward from Guangzhou along six major axes. (2) At present, spatial accessibility shows a concentric, stepwise decline from the Pearl River Delta toward the surrounding areas. (3) The traditional settlement concepts of "living with mountains and waters" and the practical needs of "transportation and commerce" have become key determinants of spatial accessibility. (4) GWR regression analysis shows that among the determinants, the effect of elevation on accessibility weakens in concentric layers from the Pearl River Delta toward the surrounding areas; river density shows clear inter-municipal clusters of positive and negative values; and the influence of road-network density varies considerably across municipalities, and the regression coefficients increase outward from central Guangdong. Differences in spatial accessibility thus shape divergent pathways for preservation and revitalization.

KEYWORDS: traditional villages; spatial accessibility; Guangdong Province; determinants; GWR model

Introduction

From December 2012 to June 2019, the Ministry of Housing and Urban-Rural Development, the Ministry of Culture and Tourism, and other authorities designated five batches totaling 6,819 traditional Chinese villages, of which 263 are located in Guangdong Province (hereinafter referred to as "traditional villages in Guangdong Province"). The traditional villages in Guangdong are primarily composed of settlements associated with the Guangfu, Hakka, and Chaoshan Han Chinese cultural groups, accounting for about 88% of the total, reflecting the deep integration of Central Plains culture and Lingnan culture. In addition, a small number of minority villages are found in areas such as Lianzhou City, Qingyuan.

Research on traditional villages in China initially focused on topics such astypical architecture, folk customs,

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and organizational systems. In recent years, the application of theories and methods from cultural anthropology, cultural geography, cultural ecology, and spatial sociology has substantially expanded and deepened research into the spatial dimensions of traditional villages. Major areas of focus include [1-15]: spatial morphology and regional reconstruction (XI Jianchao et al., 2014; LI Hongbo et al., 2015), spatial distribution and driving mechanisms (FENG Yafen et al., 2017; KANG Jingyao et al., 2016), spatial production and social change (ZHANG Jingxiang et al., 2014; GUO Wen et al., 2015; YANG Guiqing et al., 2016), production-living-ecological space and human settlements (WANG Yuncai et al., 2011; LI Bohua et al., 2018), and spatial memory and cultural revitalization (LÜ Long et al., 2018; QIAN Lili et al., 2015; HU Zui et al., 2015). As a result, the holistic nature of village-space research has become increasingly prominent. However, in-depth analysis and interpretation of particular spatial characteristics remain insufficient. Regarding research methodology, there is a growing trend to integrate qualitative and quantitative approaches to analyze and interpret complex spatial phenomena and underlying mechanisms. Among these, space syntax and ArcGIS surface statistical analysis have been widely applied in studies of traditional villages (TAO Wei et al., 2013; LI Bohua et al., 2015). Yet they are insufficient to fully explain the multidimensional human-environment spatial coupling. The geographically weighted regression (GWR) model, a key tool in spatial statistics, is a key tool for the quantitative analysis of spatially varying relationships (SONG Weixuan et al., 2017; ZHANG Yaojun et al., 2012) and offers strong explanatory power for spatial patterns. Building on this research context and trend, this study adopts accessibility as a focal spatial attribute, and employs ArcGIS, web-crawling techniques, and other modern geographical analytical tools to conduct an in-depth analysis of the spatio-temporal evolution, processes, and determinants of spatial accessibility for 263 traditional villages in Guangdong Province. Moreover, it uses the GWR model to examine the local effects and spatial spillovers of the determinants. On one hand, this approach offers a new analytical perspective on traditional villages in Guangdong Province and deepens research on their spatial characteristics. On the other hand, as accessibility is crucial to the formation of traditional villages, the preservation of their traditional features, and the formulation of future protection strategies, accessibility research can thus provide a critical foundation for classifying, protecting, and revitalizing traditional villages.

1 Data sources and research methods

1.1 Data sources

The list of 263 traditional villages in Guangdong Province, covering the first to fifth batches, was obtained from the website of the Ministry of Housing and Urban-Rural Development (MOHURD) of the People's Republic of China. The latitude and longitude coordinates of these villages were obtained by geocoding village names in Baidu Map, followed by coordinate correction. Historical road data were sourced from the *Historical Atlas of Guangdong* [16]. River-network and road-network spatial data were obtained from the latest vector datasets provided by the National Geomatics Center of China (NGCC). Current accessibility was measured using the shortest real-time driving time obtained from Baidu Map. The primary data were processed, quantified, and analyzed using spatial tools in ArcGIS 10.2, including raster mosaicking, table joining, and data extraction.

1.2 Research methods

A quantitative analysis of traditional Chinese villages in Guangdong Province was conducted, employing kernel density estimation, nearest neighbor analysis, and the geographic concentration index to characterize their spatial distribution patterns. The spatio-temporal evolution of historical accessibility was analyzed using cost-distance modeling and raster overlay techniques. Current accessibility levels of individual traditional villages were assessed using real-time travel time data from Baidu Map and an accessibility assessment model. To analyze the determinants of spatial accessibility, line density was employed to represent river and road network densities, and their associations with accessibility were examined; raster-based reclassification was used to examine how terrain elevation and slope relate to accessibility; finally, the geographically weighted regression (GWR) model was adopted to identify the key determinants of spatial accessibility in traditional villages and quantify their spatially varying effects.

2 Spatial distribution characteristics of the traditional villages in Guangdong Province

2.1 Spatial distribution density of the traditional villages

The 263 traditional villages in Guangdong Province were abstracted as point features and visualized using kernel density estimation (KDE), a method that estimates the spatial intensity of geographic phenomena across a region. After iterative adjustment, a bandwidth of 180 km was selected to generate the kernel density map of the traditional villages (Figure 1). The analysis indicates that the spatial distribution is uneven, with two primary clusters—northeastern Meizhou and the Guangzhou-Foshan border region—and two secondary clusters—the Chaozhou-Shantou border region and northwestern Qingyuan. In contrast, areas such as Maoming, Yangjiang, and Yunfu contain only a few sparsely scattered villages. Overall, the traditional villages display a dumbbell-shaped pattern, with major concentrations in the central Pearl River Delta and northeastern Guangdong.

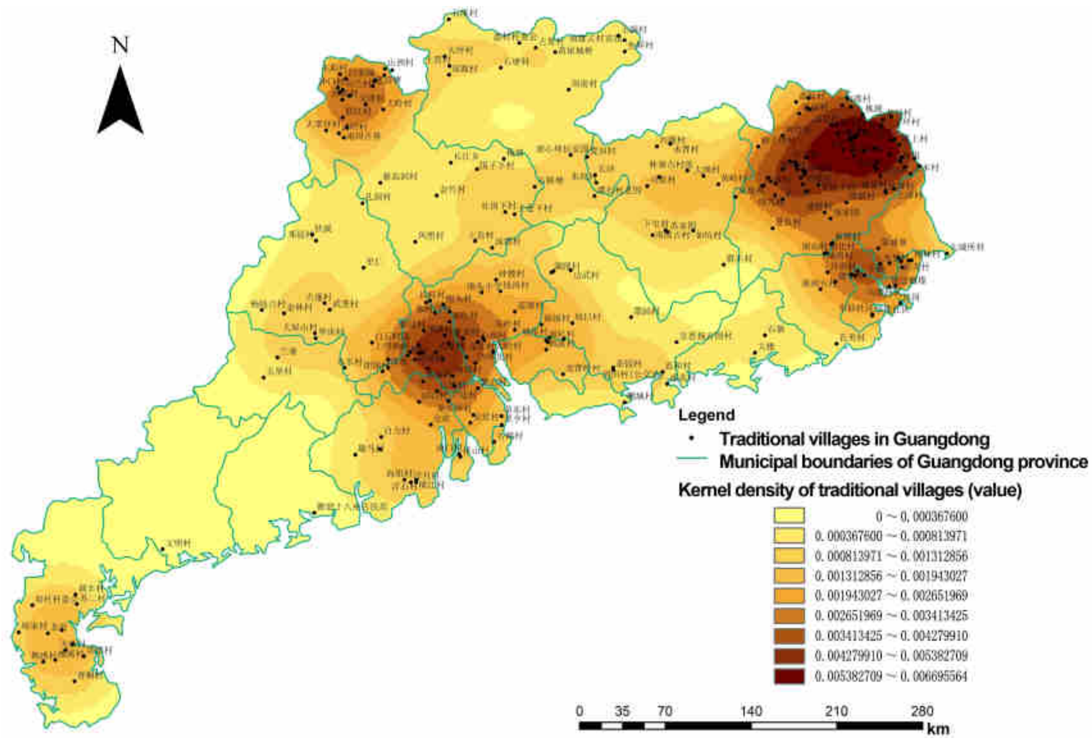

Figure 1 Kernel density analysis of traditional villages in Guangdong Province

2.2 Types and degrees of spatial distribution of the traditional villages

The spatial distribution type of the traditional villages was determined using nearest-neighbor analysis, a geographic measure reflecting the proximity of point features in space. Calculations show that the theoretical nearest-neighbor distance (i.e., expected under random distribution) is 18.66 km, while the observed distance is 16.97 km, yielding a nearest-neighbor index of ($R= 0.90$). Since ($R< 1$), this indicates a clustered spatial distribution.

A municipal-level statistical analysis was conducted for the traditional villages (Figure 2). With 263 traditional villages ($T= 263$) across 21 prefecture-level cities ($n= 21$), the calculated geographic concentration index is ($G= 35.94$), whereas the expected index under even distribution is ($G_0= 10.45$). As ($G> G_0$), this confirms that, at the municipal scale, the villages aresignificantly concentrated, mainly in Meizhou, Qingyuan, and Foshan.

3 Spatio-temporal evolution of spatial accessibility in the traditional villages

Accessibility research in traditional villages assesses the ease of access to villages. On one hand, historical spatial analysis helps reveal the relationship between accessibility and village siting. On the other hand, accessibility influences the socio-economic development of villages and the preservation of traditional culture: Villages with high accessibility are more susceptible to urbanization and industrialization, whereas villages with limited transport connectivity experience fewer external influences, facilitating cultural preservation and continuity. By conducting a spatial analysis of current spatial accessibility, the study provides an overall understanding of present conditions and ranks all 263 villages according to accessibility, thereby supporting tailored strategies for their protection and revitalization.

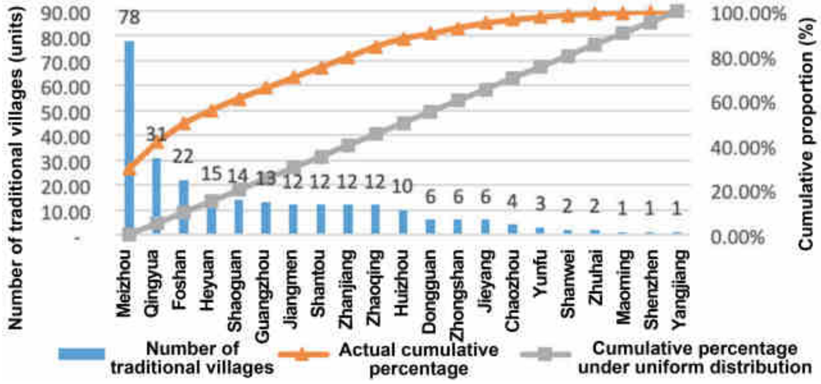

Figure 2 Municipal-level statistics of traditional villages in Guangdong Province

3.1 Analysis of the evolution of historical spatial accessibility

Based on the founding years of each traditional village, the study examines the spatio-temporal evolution of historical accessibility. In assessing spatial accessibility, some scholars argue that roads, riverbanks, water bodies, and land-use types are key factors influencing travel costs [17]. Considering the characteristics of the study area, this study adopts the principle that accessibility increases with proximity to historical land and water routes and with lower elevation and gentler slopes. Accordingly, three evaluation factors—historical land and water routes, terrain elevation, and terrain slope—were selected to analyze historical accessibility. Accessibility associated with historical routes was determined based on the distance from the raster cell representing each village to historical routes. In ArcGIS 10.2, multiple buffer zones of 5 km, 10 km, 20 km, 40 km, and 100 km were created and raster values were reclassified, with scores assigned from 5 (lowest accessibility) to 1 (highest accessibility). Elevation and slope were evaluated using a similar scoring method (Table 1). For comparison, accessibility values were normalized and classified into five levels, from Level 1 (highest) to Level 5 (lowest).

The analysis demonstrates that from the Song to the Qing dynasties, historical accessibility and historical routes exhibited a clear point-axis progressive development pattern, with accessibility having gradually expanded outward from Guangzhou along six primary axes (Figure 3): Guangzhou-Dongguan-Huizhou-Chaozhou; Guangzhou-Huizhou-Heyuan-Meizhou; Guangzhou-Shaoguan; Guangzhou-Qingyuan; Guangzhou-Foshan-Zhaoqing-Yunfu; and Guangzhou-Foshan-Jiangmen-Zhanjiang. Accessibility had expanded along these axes across successive dynasties, accompanied by the continuous enlargement of core high-accessibility zones. From the Song to the Qing dynasties, Level 1 (highest) accessibility areas expanded significantly, evolving from linear belts into planar regions. By the Ming dynasty, Level 1 (highest) areas had already covered most of Guangzhou, Foshan, Dongguan, and Zhongshan, while low-accessibility regions continued to recede. Historically, Guangzhou and Foshan featured dense road networks and have long served as major commercial corridors; consequently, they exhibited comparatively high village accessibility. In the Song dynasty, low-accessibility zones were primarily located in the mountainous regions of Qingyuan, Heyuan, and Huizhou. By the Qing dynasty, most of these areas had been incorporated into Level 1 (highest) to Level 3 accessibility zones. However, due to rugged terrain, the areas around Qingyun and Jiulian Mountains in Heyuan, Qiwei and Luoke Mountains in Qingyuan, and Yunwu Mountain in Yunfu remained persistent low-accessibility zones, where traditional villages are sparsely distributed.

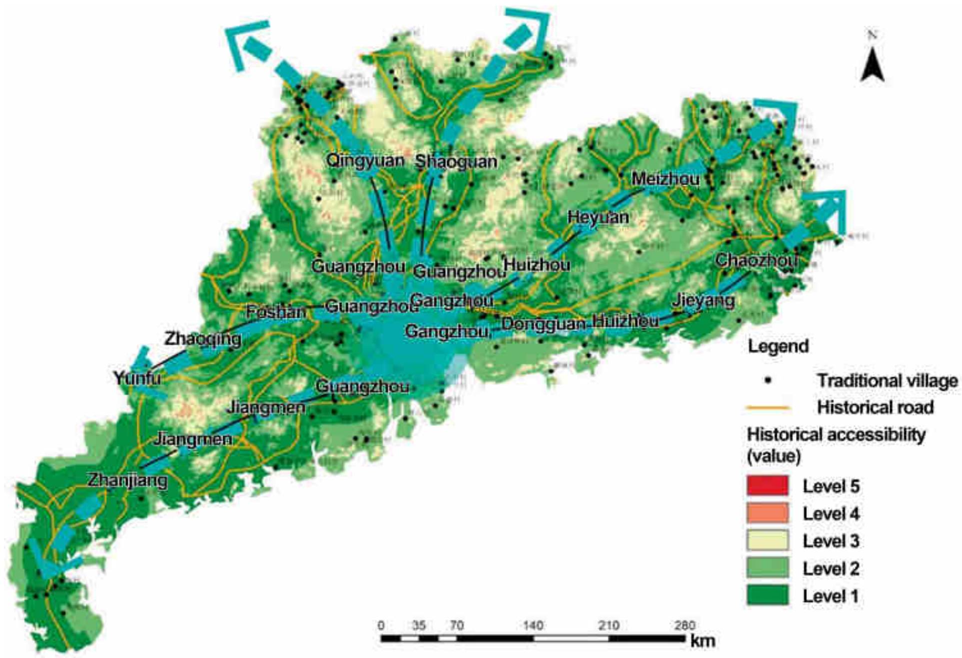

Figure 3 Six-axis expansion and evolution of spatial accessibility in traditional villages in Guangdong Province

Table 1 Evaluationfactors, classification, and scoring for historical spatial accessibility of traditional villages in Guangdong Province

Evaluation Factor	Classification	Score
Historical land/ water routes	Distance at 0-2 km	5
	Distance at 2-5 km	4
	Distance at 5-10 km	3
	Distance at 10-20 km	2
	Distance at 20-50 km	1
Terrain elevation	Elevation below 100 m	5
	Elevation at 100-200 m	4
	Elevation at 200-400 m	3
	Elevation at 400-800 m	2
	Elevation above 800 m	1
Terrain slope	Slope at 0°-7°	5
	Slope at 7°-15°	4
	Slope at 15°-30°	3
	Slope at 30°-40°	2
	Slope above 40°	1

The study further reveals that historical accessibility exerted a leading effect on the establishment of traditional villages. From the Song to the Qing dynasties, accessibility continuously improved, and a significant construction boom of traditional villages in Guangdong occurred during the Ming dynasty. As a result, the enhancement of regional accessibility served as a strong attractor for village siting and establishment. This leading effect is particularly evident in Hakka traditional villages in parts of Meizhou, Heyuan, and Qingyuan (Figure 4).

3.2 Analysis of current spatial accessibility

Current spatial accessibility of Guangdong's traditional villages was assessed using real-time shortest travel times from each village to all prefecture-level cities, extracted via the web-crawling tool "Octoparse" from Baidu Maps. Given real-world constraints—including real-time traffic conditions, road infrastructure quality, traffic signal delays, and congestion—this real-time approach yields a more accurate and realistic estimate of village accessibility [18].

Accessibility values for all 263 traditional villages were computed using Formulas (1) and (2) [19] and subsequently standardized to a 0-1 scale (Table 2). The results show that the mean travel time is 256.18 minutes, indicating overall low accessibility with substantial inter-city disparities. The accessibility ranking reveals that the top ten villages are all located in Guangzhou and Foshan—for instance, Langjin Village (Foshan), Zhonglou Village (Guangzhou), and Daqitou Village (Foshan)—demonstrating that the Guangzhou-Foshan metropolitan region exhibits the highest accessibility. In contrast, villages in Zhanjiang generally show the poorest accessibility, followed by those in Meizhou; notably, the six lowest-ranked villages are all situated in Zhanjiang, including Zhoujia, Tiaoming, and Qingtong Villages.

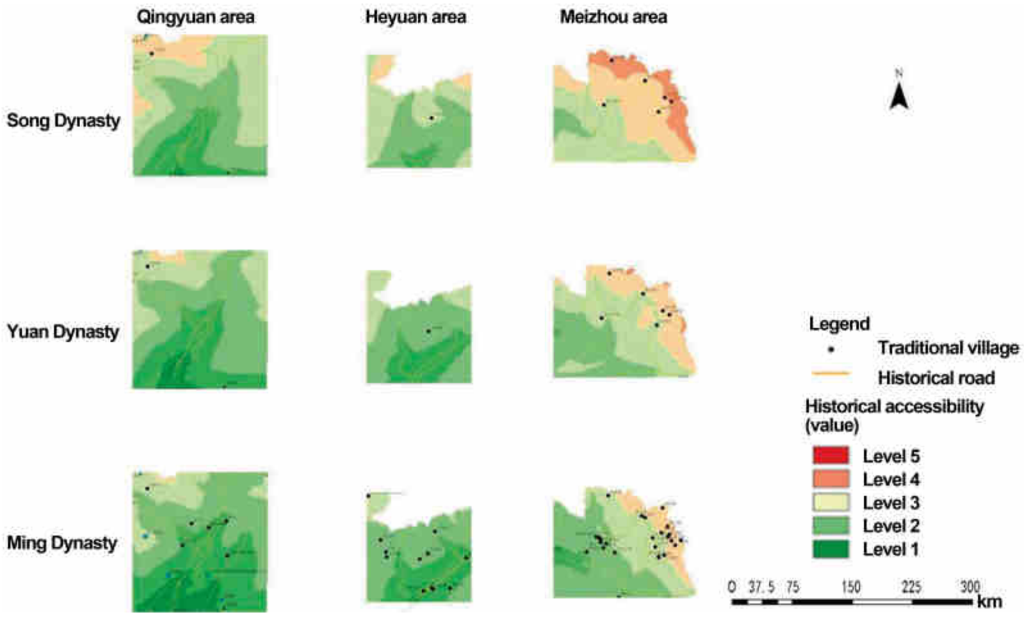

Figure 4 Historical accessibility and the development of traditional villages

Table 2 Current spatial accessibility ranking of traditional villages in Guangdong Province

Ranking	Name	Spatial Accessibility	Ranking	Name	Spatial Accessibility
1	Langjin Village, Foshan	1.0000	254	Shangmu Village, Meizhou	0.1612
2	Zhonglou Village, Guangzhou	0.9922	255	Shangzhang Village, Meizhou	0.1608
3	Daqitou Village, Foshan	0.9883	256	Guanxin Village, Zhanjiang	0.1419
4	Xinwei Village, Guangzhou	0.9875	257	Gongxia Village, Meizhou	0.1170
5	Julong Village, Guangzhou	0.9845	258	Chaoxi Village, Zhanjiang	0.1080
6	Huangpu Village, Guangzhou	0.9845	259	Egan Village, Zhanjiang	0.0769
7	Gualing Village, Guangzhou	0.9804	260	Donglin Village, Zhanjiang	0.0698
8	Tangnan Village, Foshan	0.9720	261	Qingtong Village, Zhanjiang	0.0550
9	Langtou Village, Guangzhou	0.9687	262	Tiaoming Village, Zhanjiang	0.0207
10	Gangtou Village, Guangzhou	0.9648	263	Zhoujia Village, Zhanjiang	0.0000

Kriging interpolation was further applied to examine the overall spatial pattern of current accessibility across Guangdong's traditional villages (Figure 5). The results reveal a concentric, stepwise decrease in accessibility radiating outward from the Pearl River Delta. High-accessibility zones are concentrated in central regions, including Guangzhou, Foshan, Dongguan, Zhongshan, and Huizhou; whereas peripheral and border areas such as Zhanjiang, Meizhou, Qingyuan, and Shaoguan exhibit markedly lower accessibility. Notably, the current spatial accessibility pattern closely resembles that of historical accessibility.

$$K_j = \frac{1}{n} \sum_{i=1}^{n} E_{ij} \quad (1)$$

$$K = (\max_{1 \leq j \leq m} K_j - K_j)/(\max_{1 \leq j \leq m} K_j - \max_{1 \leq j \leq m} K_j) \quad (2)$$

Where K_j denotes the raw accessibility of traditional village j, n is the number of prefecture-level cities, and E_{ij} represents the shortest travel time from village j to city i. The standardized accessibility value is also denoted as K_j. m represents the "number of traditional villages" in the study area.

4 Analysis of factors influencing spatial accessibility of the traditional villages

4.1 Village site selection and spatial accessibility

4.1.1 Landscape pattern

For traditional villages, the residential environment and local landscape patterns are critical factors in site selection. They influence geomantic principles and play decisive roles in production, daily life, defense, and mitigating natural hazards. The dominant ethnic groups in Guangdong—Guangfu, Hakka, and Chaoshan—are descendants of Han migrants from the Central Plains. Fleeing prolonged warfare, they undertook arduous southward migrations into remote frontier regions, carving out settlements through immense hardship. Their primary goal was to secure stable livelihoods by adapting to and leveraging local natural conditions. The micro-geographic ideal of “living with mountains and waters” has become a shared guiding principle for traditional village siting in Guangdong. Consequently, landscape pattern is regarded as the primary factor influencing spatial accessibility. To preliminarily explore its spatial mechanisms, three proxy variables—elevation, slope, and river density—were selected.

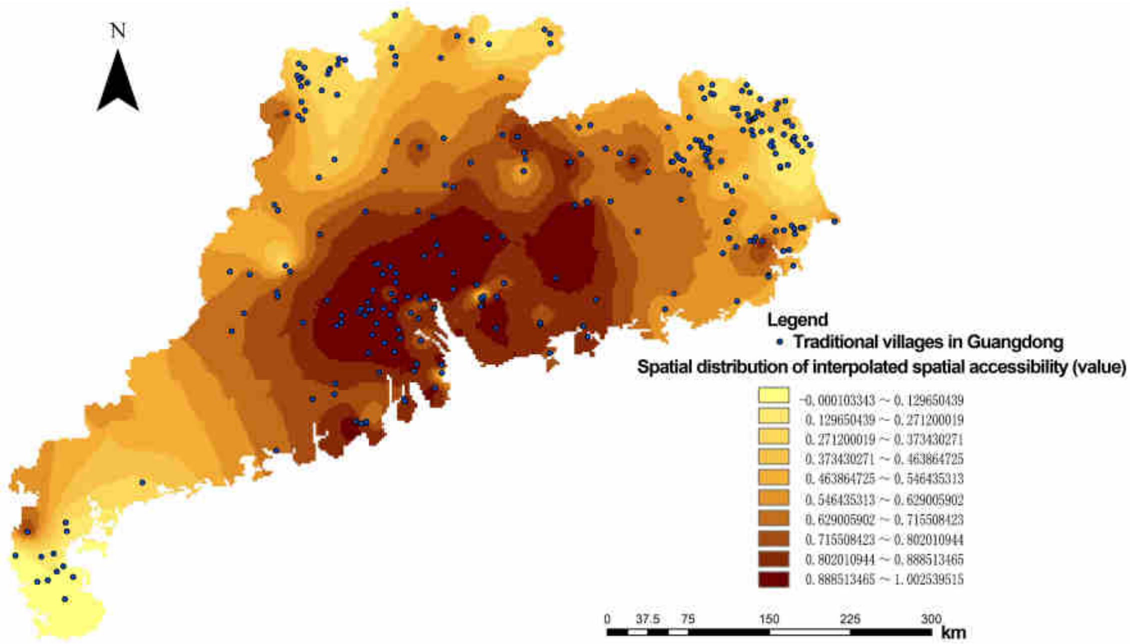

Figure 5 Kriging interpolation map of current spatial accessibility for traditional villages in Guangdong Province

Elevation (Figure 6) was first used to assess topographic influence. The analysis indicates that northern and eastern Guangdong feature higher terrain, where villages are nestled within mountainous areas and relatively isolated from external interference, resulting in lower spatial accessibility. In contrast, traditional villages in the Pearl River Delta occupy low-lying terrain and generally exhibit higher accessibility. Using raster extraction techniques, elevation values were obtained for all villages: The highest (753.98 m) occurs at Dazhang Village, Daping Town, Liannan Yao Autonomous County, Qingyuan; the lowest (-12.22 m) is recorded at Donglin Village, Nanxing Town, Leizhou City, Zhanjiang—a substantial elevational range. Subsequently, slope values were extracted, ranging from 0° to 21° (mean = 2.30°). Dazhang Village again registers the steepest slope, while Huayao Community, Longtian Town, Chaonan District of Shantou, exhibits the gentlest. Cross-referencing these metrics with accessibility rankings reveals that villages with higher elevation and steeper slopes tend to have lower accessibility, indicating that topography partially constrains access [20].

Traditional village siting in Guangdong exhibits a pronounced dependence on river systems. Line-density analysis of major rivers (Figure 7) shows that areas with high village density often coincide with regions of high river density—particularly in Foshan, Zhongshan, Meizhou, Qingyuan, and Shantou. Notably, traditional villages in the Tanjiang Basin (in Zhongshan), Meijiang Basin (in Meizhou), Rongjiang Basin (in Shantou), and Lianjiang Basin (in Qingyuan) demonstrate strong spatial coupling with their respective river networks. Integrating this finding with the Kriging-based accessibility map (Figure 5), both the density and proximity of nearby rivers areassociated with higher village accessibility.

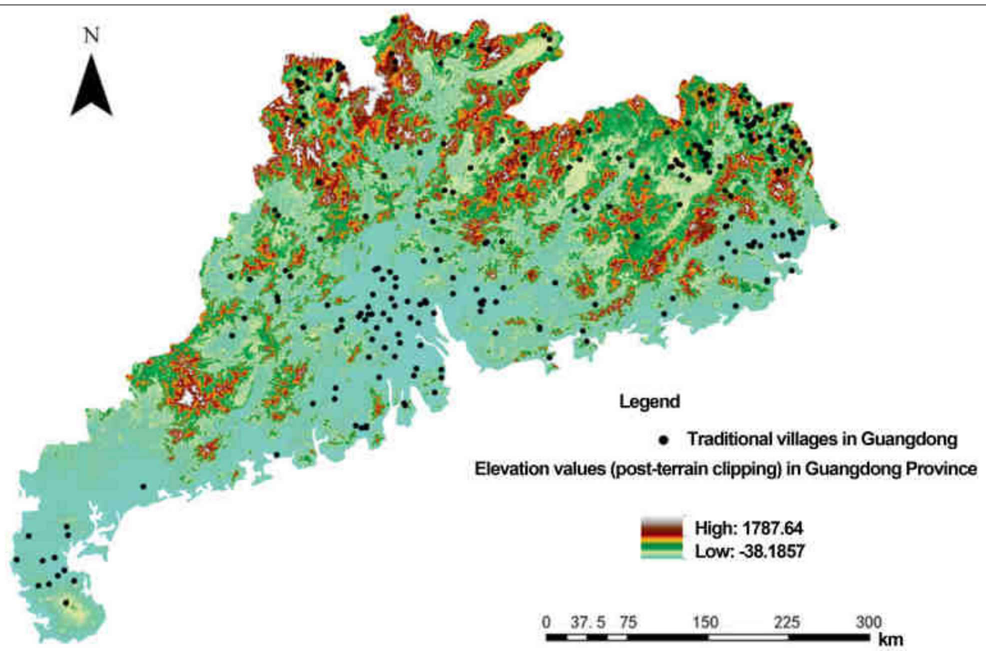

Figure 6 Overlay of traditional villages and elevation in Guangdong Province

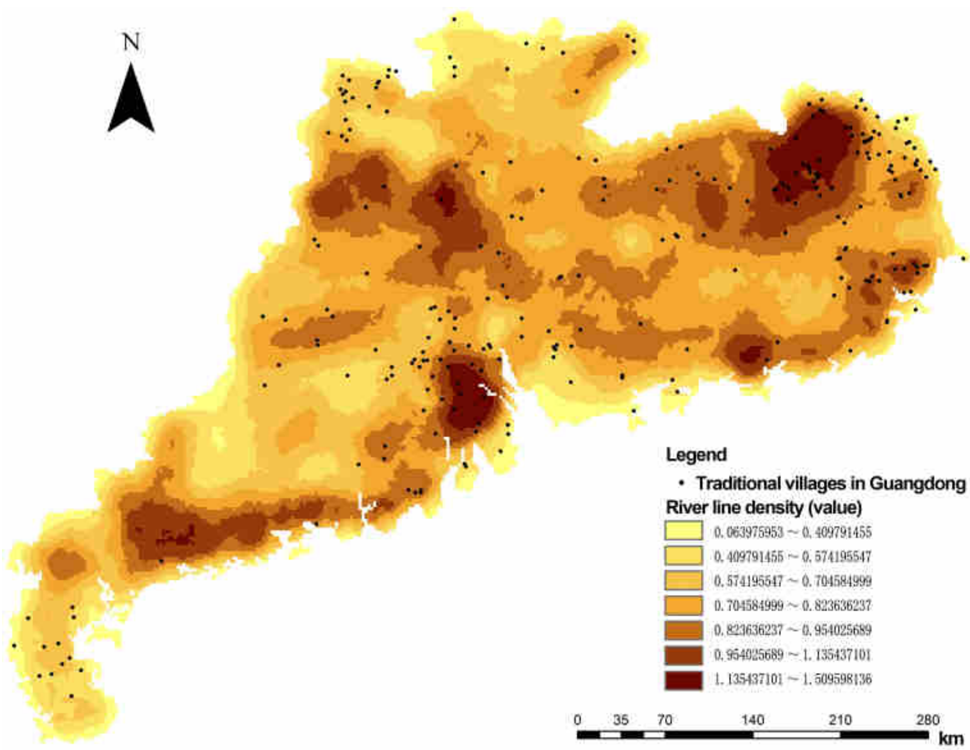

Figure 7 Overlay of traditional villages and river density in Guangdong Province

4.1.2 Transportation and commerce

Over time—particularly since the Ming and Qing dynasties—regional economies in Guangdong have steadily developed, accompanied by continuous improvements in both land and water transportation infrastructure. Settlements situated along major routes gradually flourished, giving rise to a distinct category of transportation-and commerce-oriented villages. In the Pearl River Delta, the dense road network contributes to generally high spatial accessibility of traditional villages. By contrast, in the mountainous regions of northern and eastern Guangdong—where arable land is scarce—many villages emerged along key historical post roads and rural thoroughfares, leveraging transport advantages to "engage in trade widely despite limited farmland." This pattern aligns closely with the previously analyzed spatial association between traditional villages and historical road networks.

A line-density analysis of major roads was performed, and road density was classified into five levels using the Jenks natural breaks classification method, with Level 1 denoting the highest density and Level 5 the lowest. Village distribution across these levels reveals a clear gradient: 7 villages in Level-5 areas, 13 in Level-4, 38 in Level-3, 77 in Level-2, and 128 (48.67%) in Level-1 zones. Notably, nearly half of all traditional villages are located in the highest road-density areas. Overlaying this classification with the village accessibility map confirms a strong correspondence between road-network density and spatial accessibility: Villages in better-connected areas consistently exhibit higher accessibility levels.

4.2 Analysis of accessibility determinants based on the GWR model

4.2.1 Classical OLS linear regression

The accessibility score (Y) of each traditional village was specified as the dependent variable, with five explanatory variables: Elevation ($X1$), river density ($X2$), minimum distance to the nearest water body ($X3$), road-network density ($X4$), and slope ($X5$). An ordinary least squares (OLS) regression model was constructed (Table 3). All variance inflation factor (VIF) values were well below the common threshold of 7.5, indicating no serious multicollinearity, and the Jarque-Bera test for residual normality yielded non-significant results. The regression results indicate that elevation, river density, and road-network density significantly influence village accessibility, with elevation and road-network density significant at the 1% level. To further investigate the spatially varying impacts of terrain, hydrological networks, and transportation infrastructure on accessibility, a (GWR) model is employed in the following section to capture local parameter heterogeneity and potential spatial spillover effects.

4.2.2 Parameter estimation of the GWR model

(1) Basic GWR model

The GWR model extends the conventional OLS regression framework by explicitly accounting for spatial heterogeneity in regression coefficients. Grounded in a solid theoretical foundation, GWR relaxes the global stationarity assumption of traditional linear regression and enables the estimation of location-specific relationships. It is particularly effective at capturing local spatial non-stationarity and potential spillover effects of explanatory variables [19]. The basic formulation is as follows:

$$y_i = \beta_0(u_i, v_i) + \sum_m \beta_m(u_i, v_i)x_{im} + \varepsilon_i \quad (3)$$

where (Y_i) denotes the spatial accessibility value of the traditional village at location (i); (X_{im}) represents the value of the (m)-th explanatory variable at location (i); (u_i, v_i) are the projected coordinates of location (i); ($\beta_0(u_i, v_i)$) is the location-specific intercept; ($\beta m(ui, vi)$) denotes the local regression coefficient for the (m)-th explanatory variable; and (εi) is the random error term at location (i).

Table 3 OLS regression results for spatial accessibility levels of traditional villages in Guangdong Province

Model parameter	Coefficient	T-value	P-value	Standard deviation	VIF
Intercept	0.479262	8.327723	0.000000*	0.05755	—
Elevation	-0.000584	-4.460519	0.000015*	0.000131	1.873205
River density	0.135372	2.146143	0.032799*	0.063077	1.088187
Minimum distance to nearest water body	-0.00005	-1.137354	0.256459	0.000044	1.14038
Road-network density	0.77827	6.354451	0.000000*	0.012248	1.280014
Slope	0.007715	1.156613	0.248515	0.00667	1.707599
R^2	—	—	0.3099586	—	—
Adjusted R^2	—	—	0.295995	—	—
Jarque-Bera Test	—	—	4.996988	—	—
AICc	—	—	-59.816308	—	—

For spatially autocorrelated data, the GWR model typically yields smaller residuals than the classical OLS model. By assigning a unique set of coefficients to each observation, GWR captures local spatial non-stationarity, which can be visualized through coefficient maps in ArcGIS.

(2) Parameter regression analysis of the GWR model

The results show that the GWR model yields an AICc value of-318.552 (Table 4), which is substantially lower than that of the OLS model (-59.816). The overall goodness-of-fit (R) increases markedly from 0.295995 under the OLS model to 0.759459 under the GWR model—an improvement of nearly 46%. These results demonstrate the superiority and necessity of the GWR model in the present spatial accessibility analysis.

Local regression results for factors influencing the spatial accessibility of traditional villages in Guangdong (Table 5) show that the median and mean coefficients for elevation, river density, and road-network density share consistent signs and comparable magnitudes, suggesting broadly uniform effects on spatial accessibility. The mean coefficients reflect average marginal contributions, ranked as: Road-network density> river density> elevation. However, the marginal effects of the explanatory variables exhibit directional differences under different spatial conditions. These local variations are illustrated through the visualization of regression results (Figure 8).

Table 4 GWR model parameter estimates for spatial accessibility levels of traditional villages in Guangdong Province

Model parameter	Parameter value
Bandwidth	80110.30368
AICc	-318.552267
Sigma	0.124056
R	0.795724
Adjusted R	0.759459

Table 5 Quintile summary of GWR coefficients for spatial accessibility levels

Determinant	Minimum	Upper quartile	Median	Lower quartile	Maximum	Mean	Test
Elevation	-0.00285	-0.00136	-0.00063	-0.00020	0.00033	-0.00080	0.00
River density	-0.35982	-0.00476	0.02870	0.14940	0.43465	0.06582	0.01
Road-network density	-0.34248	0.02153	0.12167	0.21037	0.94143	0.12743	0.00

① Influence of elevation on spatial accessibility

The influence of elevation on the spatial accessibility of traditional villages in Guangdong generally exhibits a concentric weakening pattern radiating outward from the Pearl River Delta, showing an inverse coupling with the regional topography that rises progressively toward eastern, western, and northern Guangdong. Except in peripheral areas of northern and eastern Guangdong, elevation is predominantly negatively associated with accessibility—indicating that mountainous terrain generally impedes village accessibility across most of the province. However, the magnitude of this effect is relatively weak. The negative impact of elevation on accessibility is weaker in Guangzhou, Foshan, Dongguan, and Zhongshan (regression coefficients close to zero), whereas in northwestern Qingyuan, northern Shaoguan, and northeastern Meizhou, the coefficients are close to zero or marginally positive. When considered alongside the spatial clustering of traditional villages, elevation shows directional differences in its impact between the densely populated Pearl River Delta and Meizhou regions, with strong internal homogeneity and spatial autocorrelation within each. A similar spatial pattern is observed in the analysis of road-network density. Overall, the influence of elevation on accessibility is spatially non-uniform.

② Influence of river density on spatial accessibility

River density influences the spatial accessibility of traditional villages in Guangdong through a clear intermunicipal division of positive and negative effects. Positive associations are observed in Qingyuan and Shaoguan (northern Guangdong) and in Meizhou, Jieyang, and Shantou (eastern Guangdong), whereas negative associations occur in western Guangdong, the southern coastal cities of the Pearl River Delta, Foshan, and Heyuan. The highest regression coefficients are concentrated along the provincial border areas of eastern, western, and northern Guangdong.

③ Influence of road-network density on spatial accessibility

The influence of road-network density on the spatial accessibility of traditional villages varies markedly across municipalities, with regression coefficients generally increasing from central Guangdong toward the periphery. Negative coefficients are primarily observed in Heyuan and Zhaoqing. High positive impacts are concentrated along the western and northern border regions. Notably, in the northern border area, elevation, river density, and road-network density exhibit concurrent high positive coefficients—reflecting a spatial coupling of their positive influences. In the western border region, road-network density is the primary determinant among the three: A one-unit increase in road-network density raises the normalized accessibility score by approximately 0.94143, indicating a substantial improvement in accessibility. By contrast, Guangzhou, Foshan, and Jiangmen exhibit low absolute regression coefficients, suggesting that accessibility in these well-connected areas is relatively insensitive to further increases in road-network density.

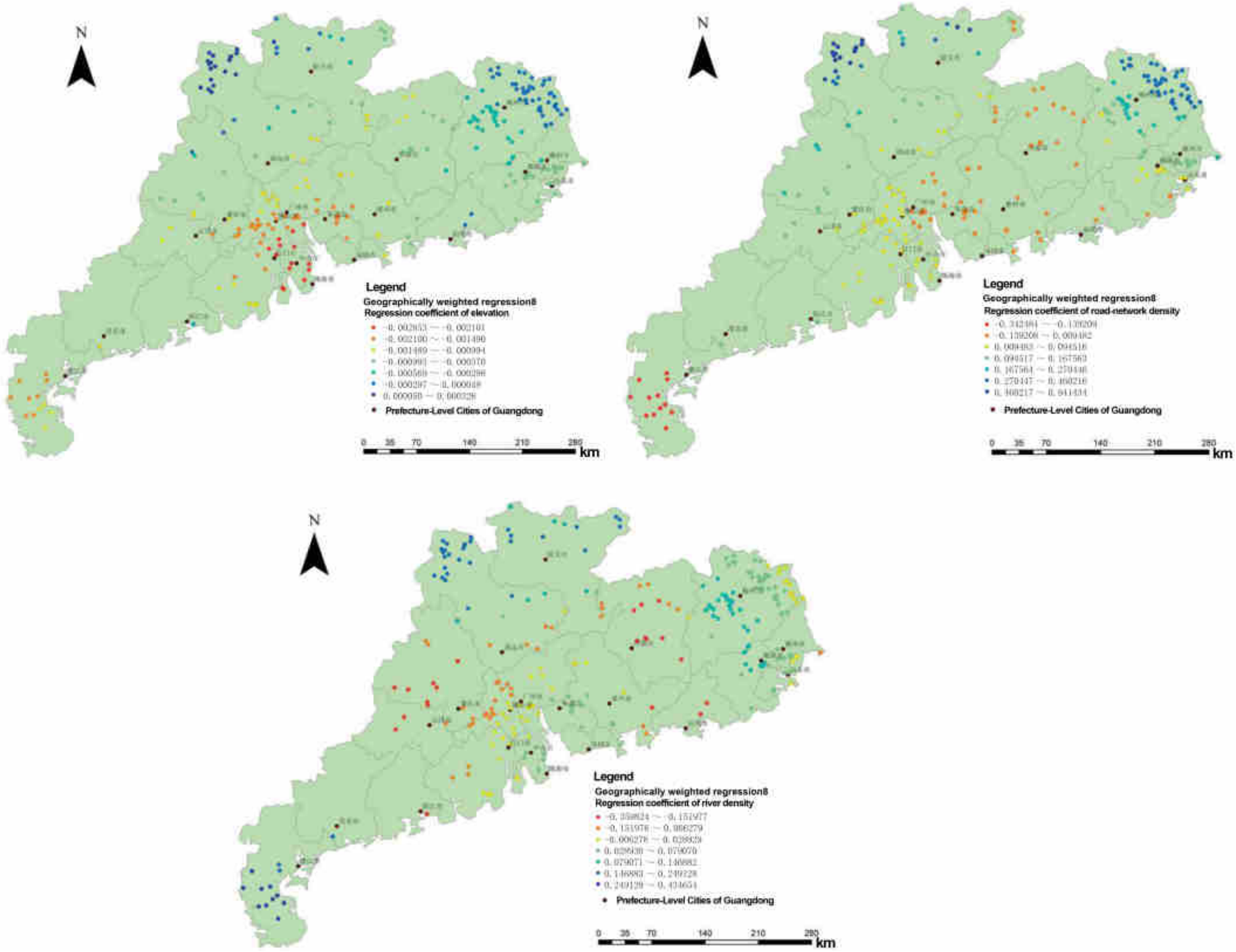

Figure 8 Spatial distribution of GWR regression coefficients for elevation, river density, and road-network density

5 Conclusions and discussion

5.1 Conclusions

As of June 2019, 263 traditional villages in Guangdong Province were listed in the officially published national register. At the provincial scale, their spatial distribution is uneven, forming a dumbbell-shaped concentration pattern between central Pearl River Delta and northeastern Guangdong. At the municipal scale, the villages are primarily concentrated in Meizhou, Qingyuan, and Foshan. This study employs modern geographic analytical tools and methods to conduct an in-depth analysis of the spatio-temporal evolution, processes, and determinants of spatial accessibility for these 263 traditional villages, and applies the GWR model to investigate local effects and spatial spillovers of accessibility-related factors. The analysis reveals that:

(1) From the Song to the Qing dynasties, historical accessibility and historical road networks exhibited a clear point-axis progressive development pattern, radiating outward from Guangzhou along six major axes. By the Ming dynasty, Level-1 accessibility areas already covered most of Guangzhou, Foshan, Dongguan, and Zhongshan.

(2) The average shortest travel time from each traditional village to all prefecture-level cities is 256.18 minutes, indicating generally low spatial accessibility with significant inter-municipal variation. Villages in the Guangzhou-Foshan area exhibit the highest spatial accessibility, whereas those in Zhanjiang and Meizhou rank lowest. Current spatial accessibility displays a concentric, stepwise decline from the Pearl River Delta toward surrounding regions, closely resembling the historical spatial accessibility pattern.

(3) In analyzing the determinants of spatial accessibility, the dominant Guangfu, Hakka, and Chaoshan populations—descendants of Han migrants from the Central Plains—share settlement ideals such as "living with mountains and waters" and practical demands for "transportation and commerce," both of which significantly influence spatial accessibility. Coupling these factors with village spatial distribution using ArcGIS 10.2 further confirms the associations between spatial accessibility and elevation, slope, river density, and road-network density.

(4) Finally, local regression analysis using the GWR model reveals that elevation, river density, and road-network density exert broadly consistent effects on spatial accessibility, with their relative contributions ranked as: Road-network density>river density>elevation. However, the marginal effects of each factor exhibit directional heterogeneity across space. Specifically, the influence of elevation on spatial accessibility weakens concentrically from the Pearl River Delta toward surrounding regions; river density displays distinct inter-municipal zones of positive and negative effects; and road-network density shows marked inter-municipal variation, with regression coefficients increasing from central Guangdong toward peripheral areas.

5.2 Discussion

Under China's national rural revitalization strategy, traditional villages face unprecedented opportunities and challenges. Villages with high spatial accessibility, such as those in the Guangzhou-Foshan area, benefit from convenient living conditions and strong social vitality, enabling them to leverage cultural tourism for socio-economic revitalization. However, their traditional cultures are more vulnerable to modern production and lifestyle pressures, intensifying the tension between preservation and development. In contrast, villages with low spatial accessibility, such as those in Zhanjiang and Meizhou, experience less impact from urbanization and industrialization, which helps preserve agrarian culture and traditional rural life. Yet, poor transportation access and inadequate infrastructure contribute to severe depopulation, aging, and low vitality. Revitalization in these areas should prioritize improving residents' living conditions while safeguarding traditional living landscapes. Differences in spatial accessibility thus shape divergent pathways for preservation and revitalization.

This study assesses current spatial accessibility using real-time driving data and does not consider newer transport modes such as high-speed rail. As China's transport network continues to evolve, the spatial accessibility of traditional villages will change dynamically—a key direction for future research.

Sources of Figures and Tables

All figures and tables in this paper are prepared by the authors.

References

[1] Xi, J. C., & Wang, S. K. (2016). Reconstruction and optimization of production-life-ecological space in rural settlements: A case study of Gougezhuang Village, Yesanpo Tourist Scenic Area, Hebei Province. *Journal of Natural Resources*, 31(3), 425-435.

[2] Li, H. B., & Zhang, X. L. (2015). Characteristics and mechanism of spatial restructuring of rural settlements in developed areas: A case study of southern Jiangsu. *Journal of Natural Resources*, 30(4), 591-603.

[3] Kang, J. Y., & Zhang, J. H. (2016). Analysis on the spatial distribution characteristics of Chinese traditional villages. *Progress in Geography*, 35(7), 839-850.

[4] Feng, Y. F., Yu, W. Y., & Lei, R. L. (2017). Spatial distribution features and controlling factors of traditional villages in Guangdong

Province. *Scientia Geographica Sinica*, 37(2), 236-243.

[5] Zhang, J. X., Hu, Y., & Sun, D. Q. (2014). The physical space change and social variation in urban village from the perspective of space production: A case study of Jiangdong Village in Nanjing. *Human Geography*, 29(2), 1-6.

[6] Guo, W. (2016). Production and analysis of space: A new perspective of tourism space research and practice. *Tourism Tribune*, 31(8), 29-39.

[7] Yang, G. Q., & Dai, T. X. (2016). Regeneration of historical cultural village under the perspective of social change. *Urban Planning Forum*, (3), 45-54.

[8] Wang, Y. C., Miller, P., & Katen, B. (2011). The traditionality evaluation of culture landscape space and its holistic conservation pattern: A case study of Qiandeng-Zhangpu region in Jiangsu Province. *Acta Geographica Sinica*, 66(4), 525-534.

[9] Li, B. H., & Zeng, C. (2018). Change of human settlement environment and driving mechanism in traditional villages based on living-production-ecological space: A case study of Lanxi Village, Jiangyong County, Hunan Province. *Progress in Geography*, 37(5), 677-687.

[10] Lü, L., Huang, Z. F., & Chen, X. Y. (2018). Progress in culture studies of rural tourism destination and research framework from the perspective of cultural memory. *Human Geography*, 33(2), 35-42.

[11] Qian, L. L., & Zhang, J. (2015). A review of studies on collective memory from the perspective of geography. *Human Geography*, 30(6), 7-12.

[12] Tao, W., Chen, H. Y., & Lin, J. Y. (2013). Spatial form and spatial cognition of traditional village in syntactical view: A case study of Xiaozhou Village, Guangzhou. *Acta Geographica Sinica*, 68(2), 209-218.

[13] Fischer, M. M., & Getis, A. (2010). *Handbook of Applied Spatial Analysis: Software Tools, Methods and Applications*. Springer.

[14] Fotheringham, A. S., Brunsdon, C., & Charlton, M. (2002). *Geographically weighted regression: The analysis of spatially varying relationships*. John Wiley & Sons, Ltd.

[15] Brunsdon, C., Fotheringham, S., & Charlton, M. (1998). Geographically weighted regression. *Journal of the Royal Statistical Society: Series D*, 47(3), 431-443.

[16] Editorial Committee of Guangdong Historical Atlas. (1995). *Historical atlas of Guangdong Province*. Guangdong Map Publishing House.

[17] Zhu, B., Yin, X., & Zhang, X. L. (2015). Spatial pattern and accessibility of rural settlements: A case study on Sheyang County in Jiangsu Province. *Scientia Geographica Sinica*, 35(12), 1560-1567.

[18] Ma, Y., & Huang, Z. X. (2017). Research on spatial distribution and accessibility of the traditional villages in the urban agglomeration on the middle reaches of the Yangtze River based on GWR model. *Human Geography*, 32(4), 78-85.

[19] Li, L. L., Bai, J. J., & Song, B. J. (2014). A study of comprehensive accessibility of Xi'an transport networks. *Human Geography*, 29(5), 88-93.

[20] Zhang, P., Li, J., & Zhang, Z. H. (2020). Spatial-temporal distribution characteristics and influencing factors of traditional villages in Qinling-Daba Mountains. *Journal of Human Settlements in West China*, 35(3), 116-124.

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A Measurement Model of Green Construction Finance Adoption in Kenya

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ABSTRACT: This study investigates the determinants of Green Construction Finance (GCF) adoption within Kenya's construction sector, addressing the significant implementation gap between sustainable policy and actual practice. Utilizing a survey design, data were collected from 55 registered property developers and analyzed through Confirmatory Factor Analysis (CFA) and Partial Least Squares Structural Equation Modelling (PLS-SEM). The results reveal an infant GCF ecosystem, with actual adoption at a mere 1.03% despite high conceptual willingness (98%) among developers. The measurement model evaluates eight key determinants: Awareness, accessibility, institutional, financial, environmental, technical, risk, and socio-cultural factors. Critically, the analysis identifies a lack of discriminant validity among these constructs, suggesting they function as an interconnected "barrier bundle" rather than independent drivers. The low explanatory power of the model ($R^2 = 0.06$) indicates that adoption is currently constrained by systemic market failures or factors beyond traditional linear determinants. The study concludes that piecemeal policy interventions are insufficient; instead, a holistic strategy is required to address the monolithic obstacles formed by regulatory, financial, and risk-related hurdles. Methodologically, it recommends that future research adopt higher-order constructs to better capture the complex reality of sustainable finance in emerging economies.

KEYWORDS: confirmatory factor analysis, determinants, green construction finance, Kenya

Introduction

The global construction and built environment sectors are at a critical juncture in the pursuit of the United Nations' 2030 Agenda for Sustainable Development. As of 2024, the building sector remains a primary driver of the climate crisis, accounting for approximately 32% of global energy consumption and contributing to 34% of global CO_2 emissions [62]. Despite a record-high $8.2 trillion in global sustainable finance in 2024, a 17% increase from the previous year, a stark geographical imbalance persists; over 90% of clean energy investment since 2021 has occurred in advanced economies, while Africa continues to capture only 3% of sustainable investment flows [61].

In Kenya, the transition toward a green economy is supported by a robust legal framework, including the Green Building Code (2022) and the Climate Change Green and Resilient Buildings Regulations 2023, which aim to establish a specialized unit to oversee green building certification and rating systems[14] Furthermore, the Finance Act 2023 has introduced incentives such as zero-rated import duty and the removal of VAT on renewable energy components to de-risk green adoption for developers [47].

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However, a significant "implementation gap" exists. Recent empirical evidence [42] indicates that GCF uptake in Kenya is extremely low, averaging only 1.06% of projects among architects and developers. Based on that study, while 98% of developers express a willingness to recommend GCF, the actual adoption is stifled by high investment costs and a lack of domestic capital. This study seeks to bridge this gap by establishing a measurement model that evaluates the determinants of GCF adoption and addresses the systemic "barrier bundles" that characterize the Kenyan construction landscape.

1 Literature review

1.1 Concept of green finance

The discourse on green financing is presently vigorous. 'Financing green' and 'greening finance' are two more terminology now employed to describe this concept. The former pertains to the funding of initiatives that either contribute to or aim to enhance the conservation, restoration, and sustainable utilization of biodiversity and its services for humanity [57]. Simultaneously, 'greening finance' aims to redirect financial resources from projects detrimental to biodiversity and ecosystems into initiatives that either reduce adverse effects or achieve positive environmental outcomes as an ancillary benefit. These principles are interrelated and facilitate a response to the climate challenge by offering a chance for enhanced coherence and depth in endeavors to restore ecosystems [15].

A precise and universally accepted definition of green finance does not exist. Most papers on the issue either fail to provide a definition or present significantly divergent definitions [38], Hohn et al. (2022) [22] define green finance as a comprehensive phrase encompassing financial investments aimed at sustainable development initiatives, projects, goods, and policies. Zadek and Flynn (2014) [77] contended that green finance and green investment are interchangeable terms, albeit the former encompasses a broader range, including operating expenses related to green investments. In the banking sector, green finance refers to financial products and services that incorporate environmental considerations in lending decisions, post-implementation monitoring, and risk management, aimed at promoting environmentally responsible investments and supporting low-carbon technologies, industries, projects, and enterprises [59]. Green finance refers to financial activities that foster improved environmental and sustainable results through the utilization of diverse financial instruments, including loans, debt structures, and varied investments [37]. Green financing refers to an investment or loan that supports environmentally beneficial activities, like the acquisition of sustainable products and services or the development of green infrastructure [33, 66].

Green finance can be delineated into three components: (i) the funding of private and public green investments, (ii) the financing of public policies that promote the execution of environmentally sustainable projects and initiatives, and (iii) elements of the financial system that specifically address green investments, encompassing their distinct legal, economic, and institutional frameworks.

1.2 Green construction project financing

Notwithstanding the favorable reports on green buildings, the construction research community has yet to comprehensively design, examine, and advocate for optimal financing methods that correspond with this revolutionary building paradigm [5]. The authors contend that green construction continues to rely on conventional project financing models, which are misaligned with the fundamental principles of green building, alongside various legislative and practical constraints [4]. Moreover, the green building model is still in its developmental stages in vast parts globally, and research on it remains limited, including the suitable financing models such as green finance tailored for green buildings [75].

1.2.1 Global perspective

Persefoni (2024) [49] reports that from 2012 to 2021, worldwide green financing increased over 100 times, rising from $ 5.4 billion to $ 540 billion. This expansion is somewhat ascribed to the increasing acknowledgment of several environmental concerns, particularly the climate catastrophe. Both foreign and domestic private capital is progressively being directed towards green development worldwide. Between 2017 and 2021, green loan finance experienced a twentyfold increase, rising from approximately $ 10 billion to a peak of $ 230 billion [70]. Green bonds constituted approximately 70 percent of that financing; Yet, certain developing debt instruments, like green sustainability bonds and loans, have been witnessing more rapid growth [27].

Equity instruments are rarely utilized, while Real Estate Investment Trusts (REITs) provide the capacity to enhance the financing of sustainable construction and operations [23]. Innovative green finance instruments, such carbon retirement portfolios and transition bonds, are almost absent in developing nations [69]. These countries are mostly excluded from the increasing influx of private green finance for sustainable construction initiatives. Since 2017, they have accounted for merely 10 percent of the overall global green debt finance [74]. Nonetheless, optimism persists. As per IFC (2022), private green financial financing for sustainable building is expanding rapidly in Sub-Saharan Africa, albeit remaining significantly low [26].

In 2021, over 90 percent of global green construction financing was allocated to green buildings, rather than to "hard-to-abate" construction materials like cement and steel, which contribute roughly 19 percent of world carbon emissions [73]. The World Economic Forum (2022a) reports that 54 percent of the total private green debt financing for green buildings in poor nations was allocated to the Caribbean and Latin America, followed by the Pacific and East Asia at 19 percent, and Central Asia and Europe at 12 percent. The Middle East, South Asia, North Africa, and Sub-Saharan Africa collectively accounted for merely 15 percent [28]. In Sub-Saharan Africa, South Africa constitutes around 75 percent of this funding [72].

In 2021, investment for green construction projects reached a record $27 billion worldwide, with 70 percent allocated to the decarbonization of construction materials. Steel and cement each accounted for around 50 percent of the total green finance allocated for construction materials, with the proportion of steel increasing more swiftly since 2019 [72] Green loans are the predominant vehicles for funding the decarbonization of construction materials, accounting for around 86 percent of overall financing; yet, green bond issuance surged seven-fold from 2019 to 2021. 208 [73].

1.2.2 Kenyan perspective

The development of Kenya's green construction market has advanced consistently. In 2020, the certified green building sector constituted 3 percent of new constructions [25]). Most of these certified buildings were offices and high-income housing. As of 2020, there were several Real Estate Investment Trusts (REITs), but the market did not record any green building construction loans or mortgage products. Though the government has a green economy strategy, the implementation and impact of these green building targets on market development are yet to be seen [25].

In Kenya, sources of green funding predominantly consist of external grants and loans from international public organizations; yet, the national government allocates billions of shillings from its revenue to climate and green-related initiatives [65]. Analysis of national budget data indicates that for the fiscal years 2017-2018 and 2019-2020, the government allocated KShs 414.23 billion and KShs 427.24 billion, respectively, to climate change sectors. On average, 40% of these funds were sourced domestically, while 60% originated from outside sources. Of these monies, the actual investment in green initiatives amounted to KShs 103 billion in 2017-2018 and KShs 120 billion in 2018-2019. The magnitude of private sector contributions to green finance remains uncertain; it is tentatively expected to average KShs 100 billion per year. Of this investment, it is projected that KShs 30 billion is derived from domestic sources and KShs 70 billion from international organizations.

Acorn Holding Limited was the inaugural private entity to capitalize on the green bond issuance in 2019, successfully raising KShs. 4.3 billion ($ 40.5 million) to establish affordable, eco-friendly student accommodations [45]. The Qwetu Hostels are constructed with climate-resilient designs, are environmentally sustainable and resource-efficient, and comply with EDGE standards.

The IFC, in partnership with International Housing Solutions (IHS), created the IHS Green Housing Fund to offer financial assistance to investors in green affordable housing [45]. The residences must comply with the IFC's EDGE requirements, which promote the efficient utilization of energy, water, and building materials. The fund aims to invest in 5,000 freshly constructed, eco-friendly, affordable dwellings, first concentrating on Nairobi County and other designated counties in Kenya.

1.2.3 Challenges facing GCF

The insufficient amounts of international and domestic private capital for green construction in developing nations may be partially attributed to market failures within the green finance and construction value chains [70]. These problems are frequently more pronounced and pervasive in low-income nations. The fragmented nature of the construction industry, informational disparities between industry segments and policymakers, highly localized regulations, and the dominance of small and medium-sized construction firms impede financing for green construction[69]. Financial decisions predominantly entail various stakeholders, including developers, owners, investors, construction specialists, and materials producers, each having divergent interests. Moreover, without green laws, regulations, and standards, investors encounter challenges in recognizing investment prospects in green construction [68]. Small and medium-sized developers, especially in economies marked by significant informality, encounter financial limitations for sustainable development. The deficiency of proficient labor in green construction methodologies further limits investment opportunities in this sector [72].

Green construction alternatives may seem disproportionately costly since existing market prices do not account for the social costs associated with emissions from traditional construction processes and materials, consequently diminishing anticipated profits for green construction projects [71]. Consumers and investors may be reluctant or unable to pay an initial extra cost of 1 to 5 percent for green buildings compared to traditional ones, especially in affordable housing intended for lower income households. This is even more challenging in low-income countries that have a few commercially viable green construction investments [74].

The absence of extensive data regarding default rates and the financial advantages of green construction investment portfolios contributes to diminished investment in green construction [68]. Financial markets frequently undervalue climate risk, encompassing economic losses attributable to climate disasters [63]. Residential property valuations often neglect the dangers associated with extreme climatic events, even when such information is publicly available[67]. This elevates the capital expenditures for green buildings compared to conventional options. This issue may be exacerbated in developing nations that are geographically vulnerable to recurrent catastrophic events and lack robust financial and insurance markets [72].

Private investors may face substantial expenses related to assessing and tracking environmental performance in green construction initiatives, particularly for "hard-to-abate" materials like cement and steel [27]. In underdeveloped nations, these costs are typically elevated due to diminished transparency, insufficient governance and disclosure standards, lax regulations, and inadequate technical capabilities for the issuance and regulation of green financial instruments [24]. Developing nations may encounter limitations in supplies. In these areas, the availability of feasible green construction projects for financing is frequently restricted [29]. This may be due to a deficiency in innovation, insufficient economies of scale, restricted green technical capabilities for execution, and limited availability of concessional financial resources [30]. Regulatory, currency, macroeconomic, and political risks, together with volatility, can elevate costs, hence diminishing the profitability of green construction investments [60].

1.3 Determinants of green construction project finance adoption

The adoption of Green Construction Finance (GCF) is influenced by a multi-dimensional array of factors that range from individual stakeholder awareness to systemic institutional frameworks. Based on the literature review, these determinants are categorized into eight key domains:

Extent of Awareness, awareness serves as a critical cognitive driver for adoption [11]. While general awareness of green building exists, many developers and construction firms—particularly smaller players—lack a detailed understanding of available green finance products, eligibility criteria, and specialized application processes [55].

Availability and accessibility, even when green finance products exist, their practical uptake is often hindered by accessibility barriers. These include complex application processes, high transaction costs, and strict eligibility requirements that may exclude smaller developers [18]. Furthermore, the limited geographical reach of green finance providers remains a significant constraint [16].

Institutional and regulatory factors, the regulatory environment provides the structural foundation for GCF. Supportive policies such as green building codes, tax incentives, and green procurement regulations are essential to encourage adoption [1]. However, gaps in institutional capacity and poor coordination among government agencies, such as the Central Bank and Ministries of Environment and Housing, can impede the effective implementation of these policies [39].

Financial and cost-related factors, high initial capital costs remain a primary barrier, as green construction typically requires a larger upfront investment compared to traditional methods [19]. This is often exacerbated by "split incentives," where the developer bears the high initial cost while the long-term benefits (e.g., lower utility bills) accrue to the tenant, creating a financial disincentive for the project owner [16].

Environmental factors, environmental concerns and sustainability awareness act as motivating drivers. Key indicators include a project's commitment to pollution prevention, resource efficiency (energy and water), material reuse, and safe waste disposal methods [12]. These factors are often driven by global climate change urgency and national environmental regulations [35].

Technological and technical factors, the availability of technological innovations, such as on-site renewable energy and digital tools (e.g., BIM), improves project feasibility and reduces implementation risks [58]. However, the lack of a standardized knowledge database and a shortage of skilled human resources can weaken the positive impact of technical readiness [63].

Risk-related factors, perceptions of risk—including financial, operational, and regulatory uncertainties—permeate all decision-making processes [12]. Developers often cite economic variability, potential technology failures, and supply chain vulnerabilities as major deterrents. Risk mitigation instruments, such as loan guarantees, are critical to bolstering financier and developer confidence[32].

Social and cultural factors, adoption is also influenced by market demand, social legitimacy, and peer influence within the industry [52]. Building trust and demonstrating the broader social benefits of green buildings (e.g., occupant well-being) are essential for fostering a cultural shift toward sustainable construction practices [53].

2 Methodology

2.1 Research design

This study employed a survey research design. This involves the gathering of quantitative data from multiple cases at a particular time point, concerning two or more variables, which are subsequently analyzed to identify patterns of association and other relationships[9]. Upon identifying the target demographic, a suitable sample was selected for data collection. After determining the level of GCF adoption and its drivers from the sample, a generalization was drawn for the overall population.

2.2 Target population and sampling procedures

The study targeted registered property developers in Kenya, who constituted the unit of analysis. Developers were selected because they serve as primary decision-makers and implementers of construction projects, positioning them as key demand-side actors in GCF. According to the Kenya Property Developers Association (KPDA) (2025) [36] online register, 69 developers were registered as of 12 March 2025 [36]. Given this relatively small population, the study adopted a census approach, distributing questionnaires to all 69 firms. A total of 55 responses were received, yielding a response rate of 79.7%, which was considered adequate for analysis. Although some missing values in responses were observed, their impact was minimal. Of the 68 questions, 62 had complete responses ($n=55$), three had one missing value ($n=54$), and another three had two missing values ($n=53$). Consequently, no imputation or corrective measures were undertaken.

2.3 Data collection

Data was collected using questionnaires administered to registered property developers in June 2025. The questionnaire was divided into two parts. The first part requested demographic data regarding the years of existence and the total number of projects undertaken by participating firms. The second part measured the following determinants of green construction uptake: Extent of awareness, availability and accessibility, institutional and regulatory related factors, financial and cost-related factors, environmental-related factors, technological and technical-related factors, risk-related factors, as well as social and cultural-related factors. A total of 68 indicators were used to measure the eight determinants based on the following 7-point Likert scale: 1 = Strongly Disagree, 2 = Disagree, 3 = Somewhat Disagree, 4= Neutral, 5= Somewhat Agree, 6= Agree, and 7 = Strongly Agree. Based on the provided scale, the developers were requested to indicate their level of agreement with a series of statements.

2.4 Data analysis

The Partial Least Squares Structural Equation Modelling (PLS-SEM) method was selected as the analytical tool for the inferential statistics. This choice was well-justified given the nature of the research, which aims to investigate a complex model with multiple constructs and indicator variables. PLS-SEM is a component-based approach that is particularly suitable for exploratory research where the theoretical framework is still developing or is based on an underdeveloped theory[17]. Unlikecovariance-based SEM (CB-SEM), PLS-SEM is a predictive causal approach that prioritizes prediction over model fit[13]. The adoption of PLS-SEM was adopted because the issue of green construction finance is relatively new, and not much has been written about its determinants and interrelationships. A key advantage of PLS-SEM is its robustness to data that does not conform to normal distribution assumptions and its ability to provide reliable results even with small sample sizes [6]. The study adopted ADANCO software, which uses a consistent PLS-SEM algorithm according to-Henseler (2016). The algorithm computes measurement and structural relationships separately and iteratively, a process that is well-suited for the complexity of the research model under consideration [41].

2.5 Ethical considerations

First, a letter of introduction was obtained from the Jomo Kenyatta University of Agriculture and Technology (JKUAT). The researcher then obtained a research permit from the National Commission for Science, Technology & Innovation (NACOSTI). These two documents were used by the researcher and research assistants for identification purposes. The study participants were informed that their participation in the study was voluntary, anonymous, and confidential, and that non-participation would not affect them in any way. Furthermore, they were informed that even when they consented to participate, they were free to withdraw their participation at any time during the study without any consequences. All aspects of the research were explained to the participants. Further, the information obtained during this research was treated with confidentiality. To help achieve anonymity of the data gathered during the survey, personal data such as names was omitted from the data collection instruments.

3 Findings and discussion

3.1 Developers' profile

3.1.1 Professional Experience

To evaluate the duration of developer firms in Kenya's construction sector, respondents were requested to provide the operational period of their firms. Figure 1 displays the results. Significantly, the sample had no enterprises with fewer than 11 years of operational experience. This is due to the absence of recorded replies in both the 1-5 years and 6-10 years groups. As a result, all participating firms possessed more than ten years of expertise in the Kenyan construction sector. The experience profile of the sample is predominantly biased towards long-established development organizations. Sixty-seven point three percent of the enterprises have been in operation for over 15 years, while thirty-two point seven percent have exceeded 25 years in the industry. This distribution signifies a seasoned respondent demographic with considerable experience in market cycles, regulatory environments, and established business practices.

Older firms are more inclined to possess substantial institutional knowledge, strong financial resources, and the ability to assimilate new innovations, including the adoption of GCF[76, 78] Their comments are anticipated to demonstrate substantial operational and sectoral understanding. Although stability can promote investment in green initiatives, established firms may adhere to conventional financing and construction methods, potentially demonstrating reluctance to adopt innovative mechanisms unless motivated or coerced by market or regulatory changes[31,48].

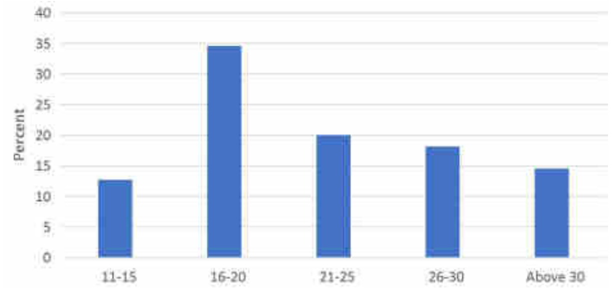

Figure 1 Developer firms' professional experience

The lack of organizations founded in the past decade indicates that the dataset fails to encompass the viewpoints or obstacles specific to newer, potentially more agile or creative enterprises.Zuo et al. (2012) [7] propose that such enterprises may exhibit enhanced flexibility and a propensity to experiment with novel financial instruments, and their removal could restrict the generalizability of findings across the whole industry. Since established firms frequently serve as industry leaders and trendsetters, their endorsement is essential for the widespread adoption of green finance techniques. Nonetheless, strategies designed to promote GCF adoption must also account for the requirements and possible contributions of new enterprises, which are absent from this sample.

Prior studies highlight the benefits and obstacles related to organizational maturity in the implementation of novel industry practices.Osei-Kyei et al. (2018) discovered that established enterprises typically possess superior resource capacity and are more adept at executing sustainable innovations. Yin et al. (2018) indicated that larger and older enterprises exhibit more receptivity to green finance; yet, inertia within established practices may hinder swift transformation. Zuo et al. (2012) noted that nascent and younger enterprises disproportionately drive innovation adoption and industry transformation owing to their receptiveness to novel concepts.

3.1.2 Number of green financed construction projects

A significant majority of developers have not utilized green finance instruments for any of their projects. Figure 2 indicates that 83.6% ($n=46$) of developers had not engaged in any green-financed initiatives, while 10.9% ($n=6$) had finished one project and 3.6% ($n=2$) had completed two projects. Merely 1.8% ($n=1$) had engaged in three green-financed projects throughout that period. Consequently, the respondents completed 13 green-financed building projects over the past five years. Figure 3 illustrates that the proportion of green-financed buildings among the total projects executed by developers ($n=1{,}265$) is 1.03%.

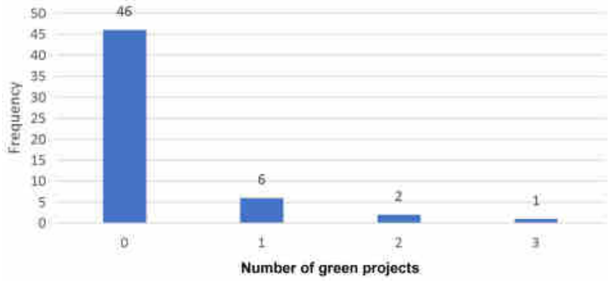

Figure 2 Total Number of green-financed projects undertaken by developers

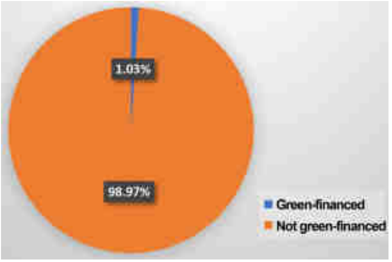

Figure 3 Proportion of green financed building projects undertaken by developers

The GCF adoption rate of 1.03% signifies that the utilization of green financial instruments in construction projects in Kenya is exceedingly restricted, with the overwhelming majority of developers and architects lacking direct expertise. This discovery aligns with overarching patterns in Kenya and several emerging nations, where the green financing ecosystem, particularly within the real estate sector, is nascent and underdeveloped. The findings indicate a nascent green finance ecosystem inside Kenya's building sector. As per Afriwise (2025) [3] Kenya is in the nascent phase of green finance implementation in construction, with pilot bonds and specialized banking products having only recently emerged in the market. Prior research [45] indicates that, despite heightened policy focus and the development of instruments like green bonds and green mortgages, actual market penetration remains constrained. Numerous studies have revealed significant obstacles to this restricted adoption. Initially, there exists a paucity of awareness and knowledge. Darko et al. (2017) assert that developers in the majority of African and developing market environments possess inadequate understanding regarding the availability, prerequisites, and advantages of green financial products. Secondly, there exists perceived complexity alongside uncertain returns. [7] assert that green finance alternatives are often regarded as intricate, with ambiguous short-term financial advantages, resulting in risk aversion among developers. The third obstacle is an inadequately developed product market. Until recently, Kenya had a limited number of green bonds issued and few prominent financial institutions actively advocating for green loans aimed at property development. Ngare (2025) [43] asserts that the challenge of securing substantial access to green financing arises from various obstacles, including intricate legal frameworks, restricted availability of different financial instruments, and insufficient capacity to create viable investment projects.

Though the early adopters of GCF are rare, they're significant, and their experiences may help drive broader market acceptance. The presence of even a few green-financed projects indicates that market structures, however limited, do exist and can be leveraged with further support. Early adopters can showcase feasibility and help reduce perceived risk among peer firms, supporting the "demonstration effect" described in adoption literature. To enhance uptake, concerted efforts are needed to address informational, financial, and regulatory barriers.

3.1.3 Likelihood of recommending adoption of GCF to other developers

Developers were requested to evaluate the likelihood of recommending green finance solutions to peers in the construction sector using a 7-point Likert scale ranging from "extremely unlikely" to "extremely likely." Contrary to the findings regarding GCF uptake, the replies indicated a predominantly favorable attitude towards endorsing green financing. Only one respondent (1.8%) indicated neutrality, while the remaining respondents (98.2%) selected options ranging from likely to extremely likely, as illustrated in Figure 4.

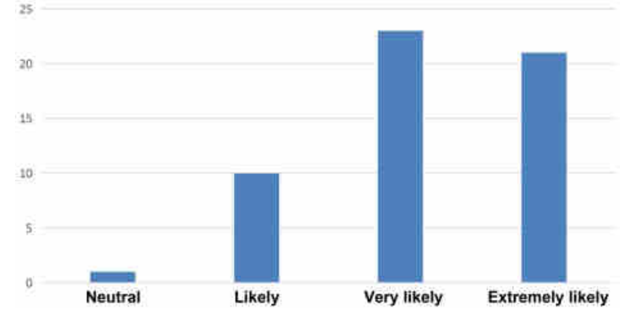

Figure 4 Likelihood of recommending adoption of GCF

Approximately 98% of developers expressed a favorable disposition ("likely," "very likely," or "extremely likely") toward endorsing green financing options, indicating robust confidence and contentment among participants in green finance initiatives. This enthusiasm indicates a responsive and optimistic stakeholder base that may be utilized to expedite the implementation of green finance solutions in Kenya's building sector. The propensity to recommend is essential for fostering peer influence and the broader dissemination of innovative financial solutions [51]. Developers who advocate for green financing can enhance demand among industry participants, financial institutions, and investors, thereby broadening the green finance ecosystem. This corresponds with findings from emerging market research, which emphasize the significance of word-of-mouth and peer recommendations in surmounting initial market inertia in green building finance [10].

The positive developer attitude corresponds with Kenya's growing institutional support for green finance. Initiatives such as the IFC's Green Housing Fund, Kenya's Green Bond programme, and the Guarantee Facility under the Environment Facility (EEF) provide critical technical assistance, credit enhancement, and risk mitigation that increase developer confidence [34,46]. Although the actual uptake remains very low, as demonstrated in this study, the strong positive recommendation sentiment signals that where green finance is experienced, it is valued, making education, capacity building, and risk-sharing mechanisms crucial to broaden access.

3.2 Confirmatory factor analysis results

Since research on Green Construction Finance (GCF) is relatively new, the current study aimed to investigate potential relationships among all the variables. This was achieved through a measurement model (Figure 5) executed via the Confirmatory Factor Analysis (CFA) function in ADANCO software. The measurement model comprises nine latent constructs, all interacting with each other as dependent (endogenous) and independent (exogenous) variables. The operationalization of these constructs and their associated indicators is detailed in Table 1.

Table 1 Construct operationalization

Code	Construct	Indicators	Indicators (Measured attributes)
EA	Extent of Awareness of GCF	7	EA1, EA2, EA3, EA4, EA5, EA6, EA7
AA	Availability and Accessibility of GCF	6	AA1, AA2, AA3, AA4, AA5, AA6
IRF	Institutional and Regulatory Factors	9	IRF1, IRF2, IRF3, IRF4, IRF5, IRF6, IRF7, IRF8, IRF9
FCF	Financial and cost-related Factors	7	FCF1, FCF2, FCF3, FCF4, FCF5, FCF6, FCF7
EF	Environmental Factors	9	EF1, EF2, EF3, EF4, EF5, EF6, EF7, EF8, EF9
TTF	Technological and Technical Factors	10	TTF1, TTF2, TTF3, TTF4, TTF5, TTF6, TTF7, TTF8, TTF9, TTF10
RF	Risk Factors	11	RF1, RF2, RF3, RF4, RF5, RF6, RF7, RF8, RF9, RF10, RF11
SCF	Social and Cultural Factors	9	SCF1, SCF2, SCF3, SCF4, SCF5, SCF6, SCF7, SCF8, SCF9
GCF	Adoption of GCF	1	GCF

3.2.1 Goodness of model fit

The ADANCO output provides the Standardized Root Mean Square Residual (SRMR) as the key indicator of model fit. The SRMR measures the average discrepancy between the observed and the model-implied correlation matrices, whereby a lower value indicates a better fit [8] The measurement model achieved an SRMR (Standardized Root Mean Squared Residual) of 0.0867 (Table 2), which is below the specified threshold of 0.1 [6,13,21], indicating an acceptable model fit, suggesting the model adequately reproduces the observed data relationships. The second SRMR value was for the modified measurement model after the three problematic indicators (those with low factor loadings) were removed.

Table 2 Goodness of model fit (saturated model)

Index	Initial model	Modified model	Threshold
SRMR	0.0867	0.0850	≤0.1

Since the SRMR value falls within the acceptable range, it provides initial evidence that the model adequately represents the empirical data. This suggests that the measurement model is a valid representation of the relationships among the constructs and their indicators.

3.2.2 Construct reliability and internal consistency

Construct reliability evaluates the internal consistency of the indicators measuring each latent variable. Three metrics were used to measure the construct reliability. These are: Dijkstra-Henselers rho, Joreskog's rho (also known as composite reliability), and Cronbach's alpha. While a general threshold of > 0.70 is recommended for all three, values between 0.60 and 0.70 are considered acceptable in exploratory research, and those exceeding 0.95 suggest multicollinearity or indicator redundancy [13,17]. As seen on Table 3, all the values were within the acceptable limits, indicating very good internal consistency. The only exception was for the GCF adoption variable, which had a value of 1.0 because it was only measured using a single indicator.

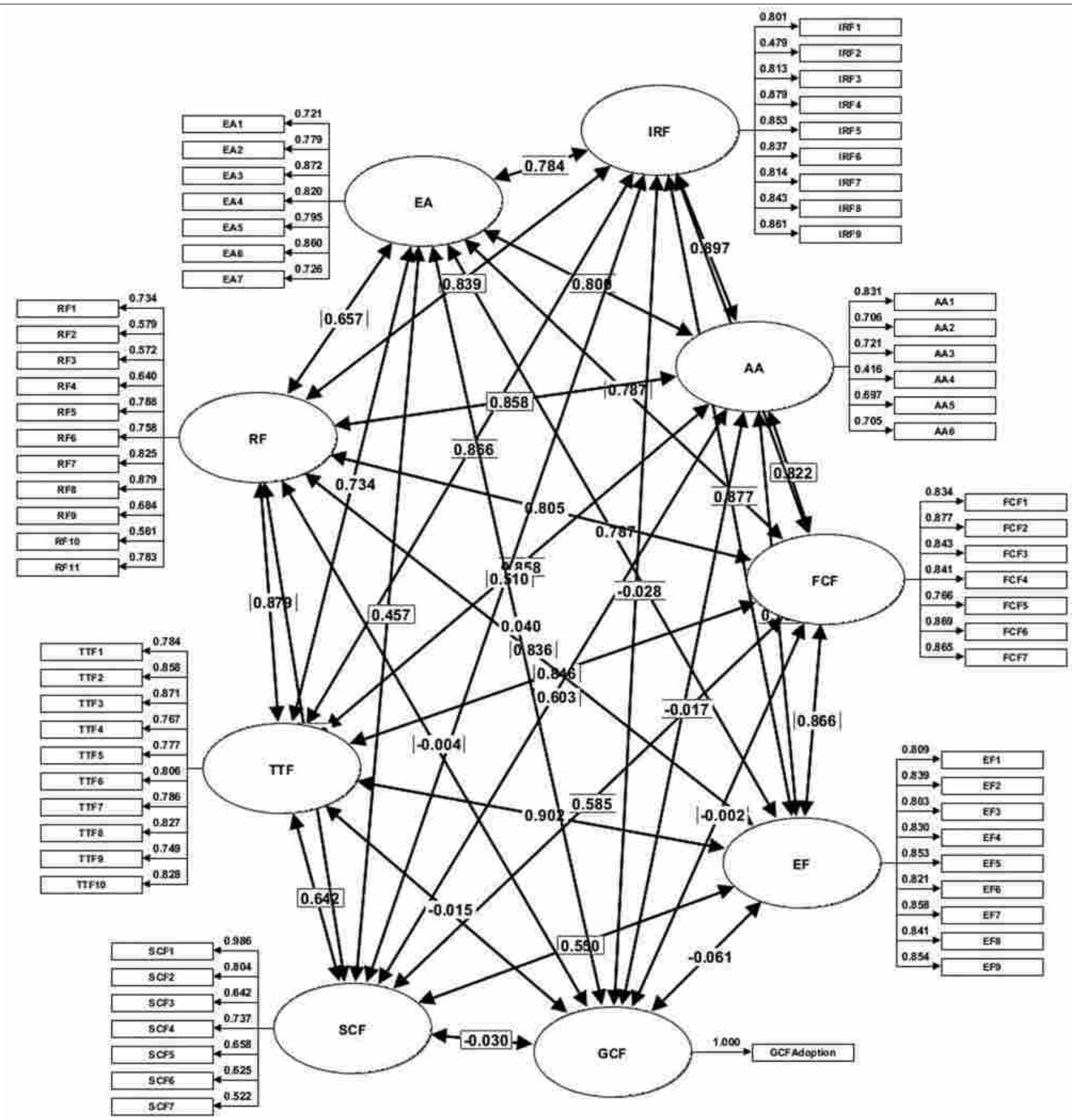

Figure 5 Graphical representation of the modified measurement model (CFA output)

Table 3 Construct reliability

Construct	Dijkstra-Henseler's rho (ρ_A)	Jöreskog's rho (ρ_c)	Cronbach's alpha(α)
Extent of awareness of GCF	0.9270	0.9243	0.9251
Availability and accessibility of GCF	0.8582	0.8414	0.8439
Institutional and regulatory factors	0.9490	0.9424	0.9393
Financial and cost-related factors	0.9457	0.9449	0.9451
Environmental factors	0.9540	0.9538	0.9538
Technological and technical factors	0.9497	0.9488	0.9486
Risk factors	0.9273	0.9194	0.9203
Social and cultural factors	0.8975	0.8414	0.8453
Adoption of GCF	1.0000	1.0000	—

3.2.3 Indicator reliability and factor loadings

Indicator reliability assesses the extent to which a construct explains the variance of its individual indicators. This is determined by the outer loadings, with a preferred threshold of > 0.70 [54]. Loadings between 0.40 and 0.70 may be acceptable in some cases, provided their removal does not negatively impact other validity metrics [20,50]. Indicators with loadings below 0.40 should be removed (Hair et al., 2022). The results of the factor loadings (Appendix Ⅰ) revealed significant issues with several constructs. In availability and accessibility (AA), indicator AA4 has a loading of 0.4159, falling below the ideal 0.70 threshold. Among the institutional and regulatory factors (IRF), indicator IRF2 has a low loading of 0.4807. Among the risk factors (RF), indicators RF2 (0.5812), RF3 (0.5741), RF4 (0.6376), and RF10 (0.5638) all fail to meet the 0.70 threshold. Lastly, it is important to point out that social and cultural factors (SCF) were the most problematic, with a majority of the indicators failing to meet the threshold. SCF3 (0.6334), SCF5 (0.6487), SCF6 (0.6174), SCF7 (0.5160), SCF8 (0.3133), and SCF9 (0.0918) all have inadequate loadings, with the last two being extremely poor and falling well below the 0.40 threshold for removal. The two indicators were removed from the model accordingly. Figure 5 thus presents the modified measurement model, while the initial model is presented in Appendix Ⅱ. The factor loadings for the modified measurement model are presented in Appendix Ⅳ.

3.2.4 Convergent validity

Convergent validity ensures that a construct is effectively capturing the variance of its indicators [21]. This was assessed using the Average Variance Extracted (AVE), with a recommended threshold of>0.50 [41,44] An AVE value above this threshold signifies that the construct explains more than 50% of the variance of its indicators [17]. As shown in Table 4, all the AVE values were> 0.5, except for availability and accessibility (AA= 0.4777) and social and cultural factors (SCF= 0.4088), indicating acceptable convergent validity with some weaknesses. These findings are a direct consequence of the low indicator loadings identified in the previous section. The poor performance of the individual indicators for AA and SCF collectively pulls down the AVE for their respective constructs. Once the two problematic indicators were deleted, all the AVE values were more than 0.5, as shown in the added column in Table 4, indicating that convergent validity had been achieved.

Table 4 Convergent validity

Code	Construct	AVE (Initial model)	AVE (Modified model)
EA	Extent of awareness of GCF	0.6368	0.6369
AA	Availability and accessibility of GCF	0.4777	0.5142
IRF	Institutional and regulatory factors	0.6498	0.6499
FCF	Financial and cost-related factors	0.7104	0.7104
EF	Environmental factors	0.6963	0.6963
TTF	Technological and technical factors	0.6498	0.6498
RF	Risk factors	0.5143	0.5139
SCF	Social and cultural factors	0.4088	0.5240
GCF	Adoption of GCF	1.0000	1.0000

3.2.5 Discriminant validity

Discriminant validity ensures that a construct is conceptually distinct from other constructs in the model [20]. This was evaluated using two key criteria: The Heterotrait-Monotrait Ratio (HTMT) and the Fornell-Larcker criterion. Based on the HTMT criterion, the HTMT values should be below the conservative threshold of 0.85, or below 0.90 for conceptually similar constructs[21]. As seen in Table 5, the HTMT correlation values between IRF and FCF (0.9092), EF and TTF (0.9013), IRF and TTF (0.8698), and AA and IRF (0.8902) exceeded the recommended thresholds, indicating a lack of discriminant validity between these pairs of constructs.

Table 5 Discriminant validity: Heterotrait-monotrait ratio of correlations (HTMT)

Construct	EA	AA	IRF	FCF	EF	TTF	RF	SCF	GCF
EA	—	—	—	—	—	—	—	—	—
AA	0.7718	—	—	—	—	—	—	—	—
IRF	0.7821	0.8902	—	—	—	—	—	—	—
FCF	0.7831	0.8038	0.9092	—	—	—	—	—	—
EF	0.7855	0.7788	0.8787	0.8654	—	—	—	—	—
TTF	0.7281	0.8527	0.8698	0.8446	0.9013	—	—	—	—
RF	0.6431	0.8460	0.8363	0.7966	0.8269	0.8717	—	—	—
SCF	0.4108	0.6256	0.4807	0.5413	0.5430	0.6173	0.7223	—	—
GCF	0.0433	0.0255	0.0313	0.0000	0.0617	0.0156	0.0062	0.0747	—

According to the Fornell-Larcker criterion, the square root of a construct's AVE (its diagonal value in the table) must be greater than its correlation with all other constructs in the row and column[41]. As presented in Table 6, the AVE for AA (0.4777) is lower than its correlations with IRF (0.8044), FCF (0.6764), EF (0.6208), TTF (0.7359), and RF (0.7365). Also, the AVE for IRF (0.6498) is lower than its correlation with FCF (0.8327). Lastly, the AVE for FCF (0.7104) is lower than its correlation with IRF (0.8327).

Table 6 Discriminant validity: Fornell-larcker criterion

Construct	EA	AA	IRF	FCF	EF	TTF	RF	SCF	GCF
EA	0.6368	—	—	—	—	—	—	—	—
AA	0.6402	0.4777	—	—	—	—	—	—	—
IRF	0.6140	0.8044	0.6498	—	—	—	—	—	—
FCF	0.6188	0.6764	0.8327	0.7104	—	—	—	—	—
EF	0.6194	0.6208	0.7686	0.7504	0.6963	—	—	—	—
TTF	0.5390	0.7359	0.7504	0.7150	0.8141	0.6498	—	—	—
RF	0.4308	0.7365	0.7033	0.6484	0.6987	0.7717	0.5143	—	—
SCF	0.2082	0.3848	0.2625	0.3407	0.3141	0.4186	0.5193	0.4088	—
GCF	0.0016	0.0003	0.0008	0.0000	0.0037	0.0002	0.0000	0.0021	1.0000

The failure of both discriminant validity tests suggests a fundamental conceptual problem. The respondents likely do not perceive these factors (institutional/regulatory, financial, environmental, and risk) as distinct concepts. This is not just a statistical issue; it reflects the real-world complexity of a nascent market. In such an environment, an underdeveloped institutional framework (IRF) directly translates into higher financial costs (FCF) and increased risk perceptions (RF) for potential investors. The lack of conceptual distinction is a reflection of this interconnected reality, where a "barrier bundle" [56] of intertwined challenges exist rather than a set of isolated determinants.

3.2.6 Indicator multicollinearity

Multicollinearity is a statistical phenomenon where two or more predictor variables in a multiple regression model are highly correlated [17]. In reflective measurement models like the one in this study, it is assessed using Variance Inflation Factors (VIFs), with a VIF> 5 being a common threshold for concern, and a VIF> 10 indicating a serious problem [54]. The results presented in Appendix Ⅲ reveal the presence of multicollinearity at the indicator level. Indicators IRF4 (8.8924), IRF5 (6.4703), EF2 (7.5346), EF8 (6.2283), TTF2 (9.0448), TTF3 (10.8928), RF5 (6.1900), and SCF4 (6.2259) were all above 5, though only one indicator had severe multicollinearity exceeding 10. These high VIFs are a direct consequence of the lack of discriminant validity. When constructs are not distinct, their underlying indicators will be highly correlated, leading to inflated VIFs. This compromises the stability and reliability of the regression coefficients in the structural model, making their interpretation unreliable [50]. The collinearity indicates that the model is statistically fragile and that the conceptualization of the determinants as separate variables is problematic in this context.

These multicollinearity findings align with the strong determinants' interrelationships findings from the bivariate correlation analysis and the lack of discriminant validity and multicollinearity among the constructs. This means that respondents do not conceptually differentiate between these factors. The data does not support the idea that these are distinct drivers of GCF adoption. This empirical finding aligns with a significant body of literature on green finance barriers in developing countries. Research has repeatedly identified that obstacles like financial constraints, weak policy structures, and high-risk perceptions do not exist in isolation [2]. Instead, they are part of a larger, interconnected "barrier bundle" that must be addressed systemically [40]. An insufficient institutional framework, for example, makes it challenging to provide clear financial incentives and leads to a higher perception of risk, as earlier shown by the strong correlation between IRF, FCF, and RF in this study's data.

4 Conclusions and recommendations

4.1 Conclusions

The most profound conclusion from the CFA is the complete failure of discriminant validity across both the Fornell-Larcker and Heterotrait-Monotrait (HTMT) criteria. The extremely high correlations (often exceeding 0.90) between constructs such as institutional and regulatory factors (IRF), financial and cost-related factors (FCF), and risk-related factors (RF) indicate that Kenyan developers do not perceive these as distinct, independent drivers of adoption. Instead, they function as a single, interconnected "barrier bundle" where a deficiency in one area (e.g., poor regulation) is indistinguishable from its impact on another (e.g., increased financial risk).

The presence of significant multicollinearity at the indicator level, evidenced by Variance Inflation Factors (VIF) exceeding 5.0 and 10.0 for several items, suggests that the measurement model is statistically fragile. This implies that the current first-order conceptualization of these eight determinants as independent variables is problematic and leads to unreliable path coefficients in the structural model.

The CFA results culminate in an exceptionally low R-squared value for GCF adoption (0.0595), meaning that the eight theorized determinants collectively explain only 6% of the variance in actual uptake. This leads to the conclusion that adoption is currently driven by factors outside the traditional theoretical domains or that the current first-order model is too simplistic to capture the complex, nonlinear reality of the Kenyan construction market.

4.2 Recommendations

The study offers the following recommendations for future research and practice.

4.2.1 Recommendations for policy and market strategy

Adoption of a systemic intervention approach, because the CFA proves that determinants are part of an inseparable "barrier bundle," piecemeal policy interventions (e.g., focusing only on awareness or only on tax incentives) are unlikely to succeed, policymakers and financial institutions must adopt a holistic strategy that simultaneously addresses the regulatory, financial, and risk-related components of the bundle to achieve a meaningful shift in adoption.

De-risking through institutional reform, since the model shows that institutional frameworks (IRF) and risk perceptions (RF) are statistically intertwined, strengthening the regulatory environment is identified as the primary lever for lowering perceived financial risk. Streamlining project approval timelines and clarifying green codes should be prioritized as direct "risk-reduction" mechanisms to unlock private capital.

4.2.2 Methodological recommendations for future research

Transition to higher-order constructs, given the lack of discriminant validity, future studies should abandon first-order models that treat determinants as independent.

Instead, researchers should employ second-order (or higher-order) latent constructs that consolidate these overlapping factors into broader, systemic dimensions such as "integrated market barriers" or "systemic institutional drivers".

Development of context-ppecific measurement scales, the CFA indicates that existing indicators (often adapted from developed-market literature) are not effectively distinguishing between constructs in the Kenyan context. There is an urgent need to develop and validate new, context-aware measurement instruments that better reflect the unique sociocultural and economic nuances of the African construction industry.

Competing interests

The authors have no competing interests to declare that are relevant to the content of this article.

Sources of Figures and Tables

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References

[1] Abdullah, M. S., & Keshminder, J. S. (2020). What drives green sukuk? A leader's perspective. *Journal of Sustainable Finance & Investment*, 12(3), 985-1005. https://doi.org/10.1080/20430795.2020.1821339.

[2] Addy, J. O., Kofie, J. O., & Gyamfi, P. (2020). Obstacles to green building project financing: An empirical study in Ghana. *Annual Conference on Information Technology and Management*.

[3] Afriwise. (2025). *Walking the Talk on Climate Action: Kenya's Green Finance Taxonomy*. https://www.afriwise.com/blog/walking-the-talk-on-climate-action-kenyas-green-finance-taxonomy.

[4] Agliardi, E., & Agliardi, R. (2019). Financing environmentally-sustainable projects with green bonds. *Environment and Development Economics*, 24(6), 608-623. https://doi.org/10.1017/S1355770X19000020.

[5] Akomea-Frimpong, I., Kukah, A. S., Jin, X., Osei-Kyei, R., & Pariafsai, F. (2022). Green finance for green buildings: A systematic review and conceptual foundation. *Journal of Cleaner Production*, 356, 131869. https://doi.org/https://doi.org/10.1016/j.jclepro.2022.131869.

[6] Benitez, J., Henseler, J., Castillo, A., & Schuberth, F. (2020). How to perform and report an impactful analysis using partial least squares: Guidelines for confirmatory and explanatory IS research. *Information & Management*, 57(2), 103-168. https://doi.org/10.1016/j.im.2019.05.003.

[7] Chang, R., Zillante, G., Zhao, Z., & Zuo, J. (2015). Research on Sustainability and Construction Firms: Current Status and Future Agenda. *ICCREM 2015-Environment and the Sustainable Building-Proceedings of the 2015 International Conference on Construction and Real Estate Management*, 310-317. https://doi.org/10.1061/9780784479377.036.

[8] Cheah, J. H., Memon, M. A., Chuah, F., & Ting, H. (2018). HTMT for discriminant validity. *Journal of the Academy of Marketing Science*, 43(1), 115-135.

[9] Czaja, R., & Blair, J. (1996). *Designing surveys: a guide to decisions and procedures*. Pine Forge Press. London.

[10] Darko, A., Zhang, C., & Chan, A. P. C. (2017). Drivers for green building: A review of empirical studies. *Habitat International*, 60(1), 34-49.

[11] Debrah, C., Chan, A. P. C., Darko, A., Ries, R. J., Ohene, E., & Tetteh, M. O. (2024). Driving factors for the adoption of green finance in green building for sustainable development in developing countries: The case of Ghana. *Sustainable Development*, 32(6), 6286-6307. https://doi.org/10.1002/sd.3022.

[12] Debrah, C., Darko, A., Chan, A. P. C., Owusu-Manu, D. G., & Edwards, D. J. (2022). Green finance in green building needs under the Paris agreement. *IOP Conference Series: Earth and Environmental Science*, 1085(1), 012033.

[13] Dijkstra, T. K., & Henseler, J. (2015). Consistent partial least squares path modeling. *MIS Quarterly*, 39(2), 297-316.

[14] FSD Africa. (2024). *Green Finance*. FSD Africa. https://fsdafrica.org/our-work/green-finance/# :~ :text= Africa, one of the most,on the green finance boom.

[15] Global Landscapes Forum. (2021). *Greening Finance and Financing Green: Opportunities and Challenges for a Holistic Approach to Boosting Finance for Nature*. https://events.globallandscapesforum. org/agenda/climate-2021/07-november-2021/greening-finance-financing-green-opportunities-and-challenges-for-a-holistic-approach-to-boosting-finance-for-nature.

[16] Gulzar, R., Bhat, A. A., Mir, A. A., Athari, S. A., & Al-Adwan, A. S. (2024). Green banking practices and environmental performance: navigating sustainability in banks. *Environmental Science and Pollution Research*, 31(15), 23211-23226. https://doi.org/https://doi.org/10.1007/s11356-024-32418-7.

[17] Hair, J. F., Hult, G. T. M., & Ringle, C. M. (2022). *A primer on partial least squares structural equation modeling (PLS-SEM)*

(3rd ed.). SAGE Publications. Los Angeles.

[18] Haque, M. S., & Murtaz, M. (2018). Green Financing in Bangladesh. In M. S. Jahur & S. M. S. Uddin (Eds.), *Proceedings of the International Conference on Finance for Sustainable Growth and Development*. *Department of Finance, Faculty of Business Administration, University of Chittagong*.

[19] Hayee, R. (2025). Determinants of Green Finance Adoption in Emerging Economies: The Role of Regulations, Management Commitment, and Technology Competence. *Qlantic Journal of Social Sciences*, 6(1), 454-470. https://doi.org/10.55737/qjss.vi-i.25340.

[20] Henseler, J. (2016). New developments in PLS path modeling. *Industrial Management & Data Systems*, 116(9), 1842-1848. https://doi.org/10.1108/IMDS-09-2016-0366.

[21] Henseler, J., Ringle, C. M., & Sarstedt, M. (2015). A new criterion for assessing discriminant validity in variance-based structural equation modeling. *Journal of the Academy of Marketing Science*, 43(1), 115-135. https://doi.org/10.1007/s11747-014-0403-8.

[22] Höhne, N., Khosla, S., Fekete, H., & Gilbert, A. (2012). *Mapping of Green Finance Delivered by IDFC Members in 2011*. Ecofys.

[23] IEA. (2023). *Scaling Up Private Finance for Clean Energy in Emerging and Developing Economies (IEA, Paris)*. https://www.iea. org/reports/scaling-up-private-finance-for-clean-energy-in-emerging-and-developing-economies.

[24] IFC. (2021a). *Ctrl Alt Del. A Green Reboot For Emerging Markets Key Sectors For Post-Covid Sustainable Growth*. https://documents1. worldbank. org/curated/en/560761621495404959/pdf/Ctrl-Alt-Delete-A-Green-Reboot-for-Emerging-Markets-Key-Sectors-for-Post-COVID-Sustainable-Growth.pdf.

[25] IFC. (2021b). *Kenya Green Building Market Snapshot 2020*. Market Accelerator for Green Construction (MAGC) program, funded by the UK Government.

[26] IFC. (2022). *IFC provides US$ 60 million loan to BBVA Perú to finance green buildings and fight climate change*. International Finance Corporation, Washington D.C.

[27] IFC. (2023a). *Building Green: Sustainable Construction in Emerging Markets*. International Finance Corporation (World Bank Group). New York, NY. https://www.ifc.org/en/insights-reports/2023/building-green-in-emerging-markets.

[28] IFC. (2023b). *Capturing the Value of Green Steel*. International Finance Corporation, Washington D.C.

[29] IMF. (2021). Investment Funds: Fostering the Transition to a Green Economy. In *Global Financial Stability Report*. International Monetary Fund, Washington D.C.

[30] IMF. (2022). *World Economic Outlook: Countering the Cost-of-Living Crisis*. International Monetary Fund, Washington, D.C.

[31] Jørgensen, B., & Messner, M. (2010). User innovation in sustainable building. *Building Research & Information*, 38(5), 631-645.

[32] Kariuki, J. (2023). *Determinants of Green Financing Adoption By Small and Medium Sized Enterprises in Manufacturing Sector at Nairobi City County, Kenya*. Unpublished Thesis, KCA Universisty.

[33] Kelkar, G. (2023). *How Does Green Finance Benefit Organizations and the World?* https://emeritus.org/blog/finance-what-is-green-finance.

[34] KGBS. (2025). *Sustainable Affordable Housing Pocket Guide. Nairobi: KGBS*. https://www.kgbs.co.ke/wp-content/uploads/2025/05/KGBS-SAH-Pocket-Guide-[19] 2025.pdf.

[35] Khan, N. A., Hassan, S., Pravdina, N., & Akhtar, M. (2023). Drivers of sustainability: technological and relational factors influencing young consumers' green buying intentions and green actual consumption behavior. *Young Consumers*, 24(6), 686-703. https://doi.org/https://doi.org/10.1108/YC-09-20221610.

[36] KPDA. (2025). Registered members. https://www.kpda.or.ke/documents/MEMBERS IN GOOD STANDING 2024.pdf.

[37] Kripa, E., & Ilollari, O. (2023). Green Finance Management Challenges in Developed and Developing Countries. *CUKUROVA 10th International Scientific Researches Conference*, 533-540.

[38] Lindenberg, N. (2014). Definition of Green Finance. *German Development Institute*, 4(1), 1-4. https://www.cbd.int/financial/gcf/definition-greenfinance.pdf.

[39] Macharia, C. M., Obulinji, H. W., & Karanja, A. M. (2024). Determinants of adoption of green technologies in the construction of buildings in Nakuru city, Kenya. *Open Access Research Journal of Science and Technology*, 11(1), 125-134. https://doi.org/10.53022/oarjst.2024.11.1.0078.

[40] Mensah, C., Addy, J. O., & Addo, A. (2024). Green building project financing in Ghana: A systematic review. *International Journal of Construction Management*.

[41] Müller, T., Schuberth, F., & Henseler, J. (2018). PLS path modeling: A confirmatory approach to study tourism technology and tourist behavior. *Journal of Hospitality and Tourism Technology*, 9(3), 249-266. https://doi.org/10.1108/JHTT-09-2017-0106.

[42] Musingi, D. M., Simon, S. M., & Okaka, J. O. (2025). Extent of Green Construction Finance Adoption in Kenya's Construction Industry. *Journal of Building Construction and Planning Research*, 13(4), 174-201. https://doi.org/10.4236/jbcpr.2025.134008.

[43] Ngare, P. (2025). *Counties Struggle to Tap Green finance for Sustainable Development*. Big3Africa. https://big3africa.org/2025/05/19/counties-struggle-to-tap-green-finance-for-sustainable-development/.

[44] Nitzl, C., Roldan, J. L., & Cepeda, G. (2016). Mediation analysis in partial least squares path modeling. *Industrial Management &*

Data Systems, 116(9), 1849-1864. https://doi.org/10.1108/IMDS-07-2015-0302.

[45] Odhiambo, Y., & Amayo, S. (2024). *Leveraging on Green Housing to Promote Sustainable Housing in Kenya*. KIPPRA. https://kippra. or. ke/leveraging-on-green-housing-to-promote-sustainable-housing-in-kenya/.

[46] Ollerenshaw, C. (2025). *Advancing Green, Affordable Homes in Kenya: Insights from Reall's Climate Engagement*. Reall. https://reall. net/blog/advancing-green-affordable-homes-in-kenya-insights-from-realls-climate-engagement/.

[47] Osano, E. (2024). *How green bonds can fund development*. FSD Africa. https://fsdafrica.org/blog/how-green-bonds-can-fund-development/.

[48] Osei-Kyei, R., Chan, A. P. C., Javed, A. A., & Ernest, C. (2018). Critical success criteria for public-private partnership projects: International experts' opinion. *International Journal of Strategic Property Management*, 22(2), 116-125.

[49] Persefoni. (2024). *Green Finance Explained*. https://www.persefoni.com/blog/green-finance.

[50] Rodriguez-Entrena, M., Schuberth, F., & Gelhard, C. (2018). Assessing statistical differences between parameters estimates in partial least squares path modeling. *Quality and Quantity*, 52(1), 57-69. https://doi.org/10.1007/s11135-016-0400-8.

[51] Rogers, E. M. (2003). *Diffusion of Innovations* (5th ed.). Free Press. New York, NY, US.

[52] Russo, A., Mariani, M., & Caragnano, A. (2021). Exploring the determinants of green bond issuance: Going beyond the long-lasting debate on per-formance consequences. *Business Strategy and the Environment*, 30(1), 38-59.

[53] Sangiorgi, I., & Schopohl, L. (2021). Why do institutional investors buy green bonds: Evidence from a survey of European asset managers. *International Review of Financial Analysis*, 75(1), 101738.

[54] Sarstedt, M., Henseler, J., & Ringle, C. M. (2011). Multi-group analysis in partial least squares (PLS) path modeling: alternative methods and empirical results. *Advances in International Marketing*, 22(1), 195-218. https://doi.org/10.1108/S1474-7979(2011)0000022012.

[55] Sossou, M. L. A., & Moyeyegue, J. (2024). Factors Favoring the Adoption of Green Finance by Financial Institutions In Dakar: An Exploratory Study. *International Business Research*, 17(6), 34. https://doi.org/10.5539/ibr.v17n6p34.

[56] Tarkhanova, E., Tsyganov, A., & Ryzhov, M. (2020). Green finance development in Russia. *Journal of Reviews on Global Economics*, 9(1), 76-88.

[57] The World Bank. (2025). *Global Economic Prospects* 2024. Unlocking Private Finance for Nature.

[58] Tran, Q., Nazir, S., Nguyen, T. H., Ho, N. K., Dinh, T. H., Nguyen, V. P., Nguyen, M. H., Phan, Q. K., & Kieu, T. S. (2020). Empirical examination of factors influencing the adoption of green building technologies: The perspective of construction developers in developing economies. *Sustainability (Switzerland)*, 12(19), 1-28. https://doi.org/10.3390/su12198067.

[59] Turner, B. (2016). *Exploring Green Finance Incentives in China*. Pricewaterhouse Coopers.

[60] Ul Haq, I., & Doumbia, D. (2022). *Structural Loopholes in Sustainability-Linked Bonds*. Policy Research Working Paper Series, 10200. World Bank., Washington, D.C. https://repec.org/p/wbk/wbrwps/10200.html.

[61] UNEP. (2021). *2021 Global Status Report for Buildings and Construction: Towards a zero-emissions, efficient and resilient buildings and construction sector*. https://globalabc.org/sites/default/files/2021-10/GABC_Buildings-GSR-2021_BOOK.pdf.

[62] United Nations. (2024). *Sustainable Development*. Sustainable Development Goals. https://sdgs.un.org/goals# history.

[63] Wang, W., Zhang, S., Su, Y., & Deng, X. (2018). Key Factors to Green Building Technologies Adoption in Developing Countries: The Perspective of Chinese Designers. *Sustainability*, 10(1), 4135.

[64] WBCSD/Arup Group Limited. (2021). *Net-zero buildings Where do we stand?* https://www.wbcsol.org/Cities/Transforming-the-Built-Environment/Decarbonization/Resources/Net-zero-buildings-Where-do-we-stand.

[65] Were, A., Olum, O., & Makunda, L. G. (2022). Green finance in Kenya. In *FSD Kenya Blogs*. FSD Kenya. https://www.fsdkenya.org/blogs-publications/publications/green-finance-in-kenya/.

[66] Wire, S. (2024). *What is green finance?* https://www.lloydsbankinggroup.com/insights/green-finance.html.

[67] World Bank. (2020). *Capital Markets Development: A Primer for Policymakers*. World Bank, Washington, D.C.

[68] World Bank. (2021). *State and Trends of Carbon Pricing* 2021. World Bank, Washington, D.C. https://worldbank.org/handle/10986/35620.

[69] World Bank. (2022). *Carbon Pricing Dashboard*. https://carbonpricingdashboard.worldbank.org/.

[70] World Economic Forum. (2021). *Carbon retirement portfolio: a faster and fairer way to retire carbon-emitting assets*. https://www.weporum.agenda/agenda/2021/09/a-better-way-to-retire-carbon-emitting-assets/ .

[71] World Economic Forum. (2022a). *Green Public Procurement: Catalysing the Net-Zero Economy*. https://www.weforum.org/.

[72] World Economic Forum. (2022b). *Massive shortfall in green financing for region's emerging markets: Asean chair*. https://www.weforum.org/.

[73] World Green Building Council. (2022). *What are green mortgages & how will they revolutionize home energy efficiency?* https://www.worldgbc.org.

[74] World Steel Association. (2021). *Climate change and the production of iron and steel*. https://uploads/Climate-change-and-the-production-of-iron-and-steel.pdf.

[75] Wuni, I. Y., Shen, G. Q. P., & Osei-Kyei, R. (2019). Scientometric review of global research trends on green buildings in construction journals from 1992 to 2018. *Energy and Buildings*, 190, 69-85. https://doi.org/10.1016/j.enbuild.2019.02.010.

[76] Yin, S., Shen, G. Q., & Tang, B. S. (2018). Barriers to Improving the Social Sustainability of Urban Renewal Projects: A Case Study of Hong Kong. *Sustainability*, 10(5), 13-42.

[77] Zadek, S., & Flynn, C. (2014). *South-Originating Green Finance: Exploring the Potential*. https://www.iisd.org/publications/report/south-originating-green-finance-exploring-potential.

[78] Zhou, D., Wang, Q., & Liu, Y. (2013). The impact of firm age on innovation: The moderating effect of knowledge intensity. *International Journal of Innovation Management*, 17(4), 1350014.

[79] Zuo, J., Zhao, Z Y., & Wu, G. (2012). Green building research-current status and future agenda: A review. *Renewable and Sustainable Energy Reviews*, 21(1), 593-601.

Appendices

Appendix Ⅰ: Factor loadings (Initial measurement model)

Indicator	EA	AA	IRF	FCF	EF	TTF	RF	SCF	GCF
GCFAdoption	—	—	—	—	—	—	—	—	1.0000
EA1	0.7207	—	—	—	—	—	—	—	—
EA2	0.7786	—	—	—	—	—	—	—	—
EA3	0.8728	—	—	—	—	—	—	—	—
EA4	0.8195	—	—	—	—	—	—	—	—
EA5	0.7951	—	—	—	—	—	—	—	—
EA6	0.8595	—	—	—	—	—	—	—	—
EA7	0.7262	—	—	—	—	—	—	—	—
AA1	—	0.8292	—	—	—	—	—	—	—
AA2	—	0.7062	—	—	—	—	—	—	—
AA3	—	0.7216	—	—	—	—	—	—	—
AA4	—	0.4159	—	—	—	—	—	—	—
AA5	—	0.6976	—	—	—	—	—	—	—
AA6	—	0.7067	—	—	—	—	—	—	—
IRF1	—	—	0.8028	—	—	—	—	—	—
IRF2	—	—	0.4807	—	—	—	—	—	—
IRF3	—	—	0.8121	—	—	—	—	—	—
IRF4	—	—	0.8788	—	—	—	—	—	—
IRF5	—	—	0.8521	—	—	—	—	—	—
IRF6	—	—	0.8374	—	—	—	—	—	—
IRF7	—	—	0.8136	—	—	—	—	—	—
IRF8	—	—	0.8423	—	—	—	—	—	—
IRF9	—	—	0.8613	—	—	—	—	—	—
FCF1	—	—	—	0.8331	—	—	—	—	—

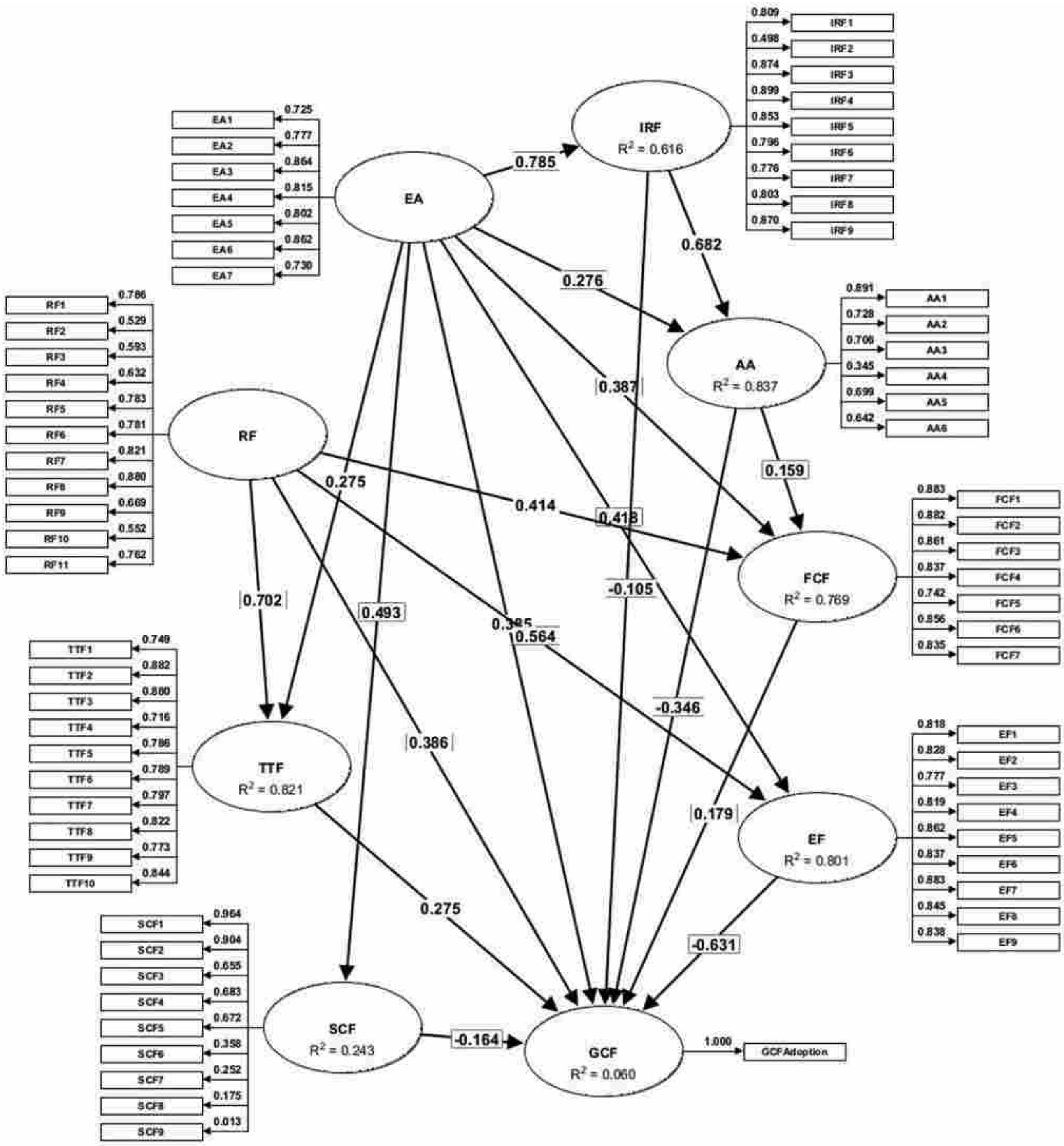
(Continued)

Indicator	EA	AA	IRF	FCF	EF	TTF	RF	SCF	GCF
FCF2	—	—	—	0.8754	—	—	—	—	—
FCF3	—	—	—	0.8447	—	—	—	—	—
FCF4	—	—	—	0.8401	—	—	—	—	—
FCF5	—	—	—	0.7671	—	—	—	—	—
FCF6	—	—	—	0.8690	—	—	—	—	—
FCF7	—	—	—	0.8656	—	—	—	—	—
EF1	—	—	—	—	0.8084	—	—	—	—
EF2	—	—	—	—	0.8378	—	—	—	—
EF3	—	—	—	—	0.8020	—	—	—	—
EF4	—	—	—	—	0.8311	—	—	—	—
EF5	—	—	—	—	0.8535	—	—	—	—
EF6	—	—	—	—	0.8211	—	—	—	—
EF7	—	—	—	—	0.8585	—	—	—	—
EF8	—	—	—	—	0.8419	—	—	—	—
EF9	—	—	—	—	0.8539	—	—	—	—
TTF1	—	—	—	—	—	0.7829	—	—	—
TTF2	—	—	—	—	—	0.8576	—	—	—
TTF3	—	—	—	—	—	0.8712	—	—	—
TTF4	—	—	—	—	—	0.7678	—	—	—
TTF5	—	—	—	—	—	0.7759	—	—	—
TTF6	—	—	—	—	—	0.8054	—	—	—
TTF7	—	—	—	—	—	0.7856	—	—	—
TTF8	—	—	—	—	—	0.8276	—	—	—
TTF9	—	—	—	—	—	0.7494	—	—	—
TTF10	—	—	—	—	—	0.8288	—	—	—
RF1	—	—	—	—	—	—	0.7340	—	—
RF2	—	—	—	—	—	—	0.5812	—	—
RF3	—	—	—	—	—	—	0.5741	—	—
RF4	—	—	—	—	—	—	0.6376	—	—
RF5	—	—	—	—	—	—	0.7844	—	—
RF6	—	—	—	—	—	—	0.7598	—	—
RF7	—	—	—	—	—	—	0.8262	—	—
RF8	—	—	—	—	—	—	0.8792	—	—
RF9	—	—	—	—	—	—	0.6840	—	—
RF10	—	—	—	—	—	—	0.5638	—	—
RF11	—	—	—	—	—	—	0.7817	—	—
SCF1	—	—	—	—	—	—	—	0.9723	—
SCF2	—	—	—	—	—	—	—	0.7930	—
SCF3	—	—	—	—	—	—	—	0.6334	—
SCF4	—	—	—	—	—	—	—	0.7272	—

(Continued)

Indicator	EA	AA	IRF	FCF	EF	TTF	RF	SCF	GCF
SCF5	—	—	—	—	—	—	—	0.6487	—
SCF6	—	—	—	—	—	—	—	0.6174	—
SCF7	—	—	—	—	—	—	—	0.5160	—
SCF8	—	—	—	—	—	—	—	0.3133	—
SCF9	—	—	—	—	—	—	—	0.0918	—

Appendix Ⅱ: Initial structural model



Appendix Ⅲ: Indicator multicollinearity/variance inflation factors (VIF)

Indicator	EA	AA	IRF	FCF	EF	TTF	RF	SCF	GCF
GCFAdoption	—	—	—	—	—	—	—	—	1.0000
EA1	4.6279	—	—	—	—	—	—	—	—
EA2	5.6821	—	—	—	—	—	—	—	—
EA3	3.7815	—	—	—	—	—	—	—	—
EA4	2.4533	—	—	—	—	—	—	—	—
EA5	6.6726	—	—	—	—	—	—	—	—
EA6	7.0089	—	—	—	—	—	—	—	—
EA7	3.7237	—	—	—	—	—	—	—	—
AA1	—	2.5032	—	—	—	—	—	—	—
AA2	—	2.0729	—	—	—	—	—	—	—
AA3	—	2.4302	—	—	—	—	—	—	—
AA4	—	1.6321	—	—	—	—	—	—	—
AA5	—	1.6057	—	—	—	—	—	—	—
AA6	—	2.2245	—	—	—	—	—	—	—
IRF1	—	—	2.8479	—	—	—	—	—	—
IRF2	—	—	1.7054	—	—	—	—	—	—
IRF3	—	—	3.2812	—	—	—	—	—	—
IRF4	—	—	8.8924	—	—	—	—	—	—
IRF5	—	—	6.4703	—	—	—	—	—	—
IRF6	—	—	4.2381	—	—	—	—	—	—
IRF7	—	—	3.7953	—	—	—	—	—	—
IRF8	—	—	4.4108	—	—	—	—	—	—
IRF9	—	—	5.0756	—	—	—	—	—	—
FCF1	—	—	—	4.0866	—	—	—	—	—
FCF2	—	—	—	5.1558	—	—	—	—	—
FCF3	—	—	—	3.2911	—	—	—	—	—
FCF4	—	—	—	5.9357	—	—	—	—	—
FCF5	—	—	—	4.2771	—	—	—	—	—
FCF6	—	—	—	4.6377	—	—	—	—	—
FCF7	—	—	—	1.9738	—	—	—	—	—
EF1	—	—	—	—	4.9952	—	—	—	—
EF2	—	—	—	—	7.5346	—	—	—	—
EF3	—	—	—	—	4.3284	—	—	—	—
EF4	—	—	—	—	3.5527	—	—	—	—
EF5	—	—	—	—	4.9538	—	—	—	—
EF6	—	—	—	—	4.5951	—	—	—	—

(Continued)

Indicator	EA	AA	IRF	FCF	EF	TTF	RF	SCF	GCF
EF7	—	—	—	—	5.3242	—	—	—	—
EF8	—	—	—	—	6.2283	—	—	—	—
EF9	—	—	—	—	5.4041	—	—	—	—
TTF1	—	—	—	—	—	4.8776	—	—	—
TTF2	—	—	—	—	—	9.0448	—	—	—
TTF3	—	—	—	—	—	10.8928	—	—	—
TTF4	—	—	—	—	—	3.5201	—	—	—
TTF5	—	—	—	—	—	5.4301	—	—	—
TTF6	—	—	—	—	—	5.3569	—	—	—
TTF7	—	—	—	—	—	2.4162	—	—	—
TTF8	—	—	—	—	—	4.3221	—	—	—
TTF9	—	—	—	—	—	3.2532	—	—	—
TTF10	—	—	—	—	—	5.3660	—	—	—
RF1	—	—	—	—	—	—	5.1631	—	—
RF2	—	—	—	—	—	—	2.3645	—	—
RF3	—	—	—	—	—	—	3.2422	—	—
RF4	—	—	—	—	—	—	5.3807	—	—
RF5	—	—	—	—	—	—	6.1900	—	—
RF6	—	—	—	—	—	—	6.2314	—	—
RF7	—	—	—	—	—	—	4.2042	—	—
RF8	—	—	—	—	—	—	3.6682	—	—
RF9	—	—	—	—	—	—	2.2365	—	—
RF10	—	—	—	—	—	—	3.0604	—	—
RF11	—	—	—	—	—	—	2.3639	—	—
SCF1	—	—	—	—	—	—	—	1.5408	—
SCF2	—	—	—	—	—	—	—	1.6283	—
SCF3	—	—	—	—	—	—	—	3.9536	—
SCF4	—	—	—	—	—	—	—	6.2259	—
SCF5	—	—	—	—	—	—	—	4.9269	—
SCF6	—	—	—	—	—	—	—	4.3680	—
SCF7	—	—	—	—	—	—	—	4.8926	—
SCF8	—	—	—	—	—	—	—	2.5354	—
SCF9	—	—	—	—	—	—	—	2.1943	—

Appendix Ⅳ: Factor loadings (Modified measurement model)

Indicator	EA	AA	IRF	FCF	EF	TTF	RF	SCF	GCF
GCFAdoption	—	—	—	—	—	—	—	—	1.0000
EA1	0.7213	—	—	—	—	—	—	—	—
EA2	0.7787	—	—	—	—	—	—	—	—
EA3	0.8720	—	—	—	—	—	—	—	—
EA4	0.8196	—	—	—	—	—	—	—	—
EA5	0.7953	—	—	—	—	—	—	—	—
EA6	0.8596	—	—	—	—	—	—	—	—
EA7	0.7260	—	—	—	—	—	—	—	—
AA1	—	0.8309	—	—	—	—	—	—	—
AA2	—	0.7064	—	—	—	—	—	—	—
AA3	—	0.7211	—	—	—	—	—	—	—
AA4	—	0.4157	—	—	—	—	—	—	—
AA5	—	0.6971	—	—	—	—	—	—	—
AA6	—	0.7054	—	—	—	—	—	—	—
IRF1	—	—	0.8015	—	—	—	—	—	—
IRF2	—	—	0.4794	—	—	—	—	—	—
IRF3	—	—	0.8134	—	—	—	—	—	—
IRF4	—	—	0.8787	—	—	—	—	—	—
IRF5	—	—	0.8526	—	—	—	—	—	—
IRF6	—	—	0.8373	—	—	—	—	—	—
IRF7	—	—	0.8136	—	—	—	—	—	—
IRF8	—	—	0.8432	—	—	—	—	—	—
IRF9	—	—	0.8610	—	—	—	—	—	—
FCF1	—	—	—	0.8337	—	—	—	—	—
FCF2	—	—	—	0.8765	—	—	—	—	—
FCF3	—	—	—	0.8432	—	—	—	—	—
FCF4	—	—	—	0.8410	—	—	—	—	—
FCF5	—	—	—	0.7662	—	—	—	—	—
FCF6	—	—	—	0.8693	—	—	—	—	—
FCF7	—	—	—	0.8653	—	—	—	—	—
EF1	—	—	—	—	0.8095	—	—	—	—
EF2	—	—	—	—	0.8391	—	—	—	—
EF3	—	—	—	—	0.8027	—	—	—	—
EF4	—	—	—	—	0.8296	—	—	—	—
EF5	—	—	—	—	0.8533	—	—	—	—
EF6	—	—	—	—	0.8213	—	—	—	—

(Continued)

Indicator	EA	AA	IRF	FCF	EF	TTF	RF	SCF	GCF
EF7	—	—	—	—	0.8576	—	—	—	—
EF8	—	—	—	—	0.8415	—	—	—	—
EF9	—	—	—	—	0.8538	—	—	—	—
TTF1	—	—	—	—	—	0.7840	—	—	—
TTF2	—	—	—	—	—	0.8583	—	—	—
TTF3	—	—	—	—	—	0.8712	—	—	—
TTF4	—	—	—	—	—	0.7669	—	—	—
TTF5	—	—	—	—	—	0.7768	—	—	—
TTF6	—	—	—	—	—	0.8056	—	—	—
TTF7	—	—	—	—	—	0.7856	—	—	—
TTF8	—	—	—	—	—	0.8270	—	—	—
TTF9	—	—	—	—	—	0.7486	—	—	—
TTF10	—	—	—	—	—	0.8284	—	—	—
RF1	—	—	—	—	—	—	0.7336	—	—
RF2	—	—	—	—	—	—	0.5795	—	—
RF3	—	—	—	—	—	—	0.5716	—	—
RF4	—	—	—	—	—	—	0.6399	—	—
RF5	—	—	—	—	—	—	0.7876	—	—
RF6	—	—	—	—	—	—	0.7578	—	—
RF7	—	—	—	—	—	—	0.8254	—	—
RF8	—	—	—	—	—	—	0.8786	—	—
RF9	—	—	—	—	—	—	0.6844	—	—
RF10	—	—	—	—	—	—	0.5606	—	—
RF11	—	—	—	—	—	—	0.7834	—	—
SCF1	—	—	—	—	—	—	—	0.9860	—
SCF2	—	—	—	—	—	—	—	0.8044	—
SCF3	—	—	—	—	—	—	—	0.6415	—
SCF4	—	—	—	—	—	—	—	0.7372	—
SCF5	—	—	—	—	—	—	—	0.6583	—
SCF6	—	—	—	—	—	—	—	0.6247	—
SCF7	—	—	—	—	—	—	—	0.5219	—

Aim & Scope

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