

Quantifying the Directional Spatial Order of Hakka Architecture: A CNN–LSTM–Attention Framework for Heritage Floor-Plan Analysis in Gannan, China

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Abstract

The spatial organization of Hakka architecture in southern China is widely believed to embody traditional cosmological principles, notably the Later Heaven arrangement of the Eight Trigrams (Bagua) and the Five Elements; however, this relationship has rarely been examined with quantitative, reproducible methods. This study operationalizes the Bagua directional system as a nine-sector spatial coding scheme and introduces a hybrid CNN–LSTM–Attention framework that measures the correspondence between heritage floor plans and the directional reference template. Fourteen cases from the Gannan Hakka heartland—six walled dwellings (weiwu), seven public buildings documented in the Tongzhi-era Gazetteer of Ganzhou Prefecture, and the historical map of the Ganzhou prefectural city—were analysed, yielding 126 sector-level observations. For each sector, three complementary similarities (deep image features, built-density distribution, and spatial structure) were computed and fused through attention-weighted summation. All 126 sector correspondences exceeded the 0.78 matching threshold, with a mean comprehensive similarity of 0.9904 (95% CI [0.9901, 0.9907]), a mean standard deviation of 0.0018, and correspondence levels significantly above a random-guess baseline ($p < 0.001$, Cohen's $d = 6.93$). The results indicate a stable directional order shared across building types, together with systematic typological differentiation: walled dwellings exhibit pronounced “dense core–sparse periphery” density gradients concentrated in the eastern and southern sectors, whereas public buildings approach a high-density equilibrium, culminating in the Longevity Palace (mean similarity 0.9927). The proposed pipeline offers a reproducible computational approach for the quantitative study and digital documentation of vernacular architectural heritage.

Keywords: Hakka architecture; spatial configuration; Later Heaven Bagua; feng shui; deep learning; CNN–LSTM–attention; digital cultural heritage; Gannan

1. Introduction

The Hakka (Kejia, literally “guest families”) are a distinctive Han Chinese subgroup whose ancestors migrated southward from the Central Plains in successive waves beginning around the fourth century AD. Settling predominantly in the mountainous borderlands of Jiangxi, Fujian, and Guangdong—today home to the majority of an estimated 65 million Hakka worldwide—they developed a highly recognizable built culture (Luo 1933; Knapp 1999). The triangular region formed by southern Jiangxi (Gannan), eastern Guangdong, and western Fujian is commonly referred to as the “Hakka heartland” (Fig. 1). Within this region, the enclosed and defensive building types of the Hakka—including walled villages (weiwu), enclosed dragon houses (weilongwu), and rammed-earth tulou—constitute some of the most remarkable vernacular building traditions in China (Porretta et al. 2022; Hu and Yang 2023).

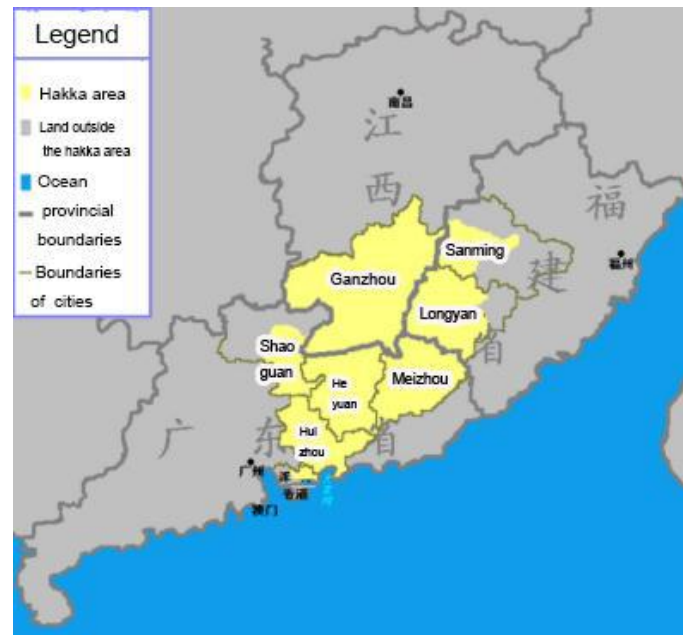


Fig. 1. The Hakka heartland at the junction of Jiangxi, Fujian, and Guangdong provinces (source: southcn.com).

A recurrent theme in the scholarship on Hakka building culture is its embeddedness in traditional Chinese cosmology. Because the Hakka historically occupied remote and environmentally harsh mountain terrain, geomantic (feng shui) principles—understood as a codified system for harmonizing settlement with topography, orientation, and climate—strongly informed site selection and spatial layout (Feuchtwang 1974; Mak and So 2009). Gannan is of particular significance in this respect: it was the principal area of activity of Yang Yunsong (ninth century), the foundational master of the Form School of feng shui, and the regional building tradition is consequently regarded as one of the most faithful materializations of geomantic doctrine (Knapp 1999; Madeddu and Zhang 2017). Central to this doctrine is the Later Heaven (King Wen) arrangement of the Eight Trigrams, which maps eight trigrams onto the cardinal and intercardinal directions and associates each direction with one of the Five Elements (Wood, Fire, Earth, Metal, Water), together with the central Supreme Ultimate (Taiji) (Needham 1956; Wilhelm and Baynes 1967).

Despite the richness of this interpretive tradition, existing research on the relationship between Hakka architecture and cosmological principles remains overwhelmingly qualitative. Ethnographic and historical studies describe how feng shui masters surveyed sites, how ideal landforms were conceptualized through the “Four Symbols” (Azure Dragon, White Tiger, Vermilion Bird, Black Tortoise), and how ritual and ethical orders shaped plan geometry (Feuchtwang 1974; Knapp 1986); yet such accounts rarely translate into measurable, reproducible spatial evidence. In parallel, quantitative studies of feng shui have emerged in

geography and planning—using GIS-based suitability modelling and multi-criteria evaluation—but these focus on site selection at the landscape scale rather than on the internal spatial organization of buildings (Cui et al. 2021; Guan et al. 2024; Wang et al. 2025). Meanwhile, deep learning has demonstrated strong capability in classifying, detecting, and documenting architectural heritage (Monna et al. 2021; Zou et al. 2023; Siountri and Anagnostopoulos 2023; Liu et al. 2026), but has not, to our knowledge, been used to test the correspondence between vernacular floor plans and traditional directional-cosmological ordering systems.

This study addresses this gap by asking three research questions. (RQ1) Can the Later Heaven Bagua directional system be operationalized as a computational spatial coding scheme for analysing heritage floor plans? (RQ2) To what degree do the internal spatial configurations of Hakka dwellings, public buildings, and the prefectural city of Ganzhou correspond to this directional order, and does the correspondence exceed chance? (RQ3) Are there systematic differences between building types in how directional correspondence and built density are distributed? To answer these questions, we construct a nine-sector directional coding scheme derived from the Later Heaven Bagua and develop a hybrid CNN–LSTM–Attention model that fuses three complementary similarity measures—deep image features, built-density distribution, and spatial structure—into a comprehensive sector-level correspondence score. Fourteen cases from Gannan (six walled dwellings, seven public buildings recorded in the Tongzhi-era Gazetteer of Ganzhou Prefecture, and the historical city map of Ganzhou) are analysed, producing 126 sector-level observations that are subjected to descriptive, inferential, and robustness evaluation.

The contributions of this study are threefold. First, methodologically, it translates a traditional cosmological ordering system into an explicit, reproducible computational workflow that couples a hybrid deep-learning architecture with a directional sector partition—an approach transferable to other heritage building traditions. Second, empirically, it provides the first quantitative, statistically evaluated evidence on the directional organization of Gannan Hakka architecture across 126 sector-level observations. Third, substantively, it identifies a typological gradient—from the strongly contrasted “dense core, sparse periphery” pattern of walled dwellings to the “high-density equilibrium” of major public buildings—that refines our understanding of how a shared directional order was adapted to different functional and institutional contexts.

2. Literature Review

2.1 The spatial culture of Hakka architecture

Hakka vernacular architecture has attracted sustained scholarly attention because it couples a defensive, collective residential form with a strongly coded ritual and cosmological order. Foundational ethnographic work established the Hakka as a distinct cultural group and documented the migration history that shaped their settlement geography (Luo 1933), while architectural surveys have catalogued the formal repertoire of walled villages, weilongwu, and tulou across the Guangdong–Fujian–Jiangxi border area (Katayama 2011; Knapp 1999). Recent morphological studies have added a comparative and quantitative dimension: Hu and Yang (2023) applied space syntax to six tulous and weilong houses, showing that tulou retain a highly integrated ritual core at the geometric centre, whereas weilong houses exhibit decentralization consistent with increasing secularization; Xu and Zhou (2025) traced the divergent evolution of Cantonese, Teochew, and Hakka settlement forms in Lingnan; and Xu and Ferretto (2024) documented how peri-urbanization is transforming Hakka village fabric in southern China. Studies of neighbouring building traditions in Jiangxi further confirm the persistence of patio-centred, cosmologically informed layouts in the region (Song and Liao 2023). Conservation-oriented research, including environmental assessment of Fujian tulou and UNESCO World Heritage listing dynamics, underscores the urgency of systematic documentation (Ueda 2012).

2.2 Geomantic principles and their quantitative study

Feng shui, or Chinese geomancy, has long been studied as an anthropological and historical phenomenon (Needham 1956; Feuchtwang 1974; Knapp 1986). Its theoretical core relevant to building layout is the Later Heaven (King Wen) sequence of the Eight Trigrams, described in the *Shuogua Zhuan* commentary of the *I Ching*: arranged clockwise, Zhen (east) → Xun (southeast) → Li (south) → Kun (southwest) → Dui (west) → Qian (northwest) → Kan (north) → Gen (northeast), with the Taiji at the centre. Each trigram carries a Five-Element attribution—Wood (Zhen, Xun), Fire (Li), Earth (Kun, Gen), Metal (Qian, Dui), Water (Kan)—embedded in cycles of mutual generation and restriction that were historically used to reason about orientation, functional placement, and seasonal rhythms (Needham 1956; Wilhelm and Baynes 1967). Until recently, assessments of such principles in the built environment were largely descriptive. A systematic review by Han and Lin (2023) shows that empirical and quantitative feng shui studies, though growing, remain scarce and methodologically heterogeneous. GIS-based approaches have evaluated geomantic suitability

for mausoleums in Nanjing (Cui et al. 2021), imperial tomb site selection (He et al. 2026), and temple complexes (Yan et al. 2025); most relevant here, Guan et al. (2024) combined geomantic theory with an AHP–GIS model to evaluate the site selection of traditional Hakka villages, providing rare quantitative evidence at the settlement scale. Urban-design research has likewise examined feng shui's imprint on urban form (Hong et al. 2007). These studies establish that geomantic principles are amenable to formal spatial analysis, but they operate on landscape variables (terrain, hydrology, aspect); the internal configuration of buildings—how rooms, halls, and courtyards distribute across directional sectors—remains essentially unexamined with quantitative tools.

2.3 Deep learning for architectural heritage and floor-plan analysis

Deep learning has rapidly entered architectural heritage research. Convolutional neural networks (CNNs) have been used to classify heritage building images (Ćosović and Janković 2020; Siountri and Anagnostopoulos 2023), to recognize regional architectural features with Faster R-CNN (Zou et al. 2023), to detect vernacular houses in satellite imagery (Monna et al. 2021), to extract historic building “genes” with Mask R-CNN (Shao and Sun 2023), to detect surface damage on traditional materials (Yan et al. 2024), and to enrich heritage BIM models (Miky et al. 2024); attention mechanisms have further improved classification and retrieval for diaspora Chinese architectural heritage (Gao et al. 2023). Reviews confirm a broader shift from photogrammetric documentation toward learning-based interpretation of heritage data (Mishra and Lourenço 2024; Liu et al. 2026). In parallel, computer-vision research has addressed architectural floor plans directly, from early parsing pipelines (Dodge et al. 2017) to large-scale recognition and reconstruction datasets (Lv et al. 2021; Pizarro et al. 2023). Methodologically, hybrid architectures that combine CNNs for local feature extraction with long short-term memory (LSTM) networks and attention mechanisms have demonstrated superior sequence-modelling performance in load forecasting, fault detection, and water-quality prediction (Yang et al. 2021; Wan et al. 2023; Borré et al. 2023), suggesting their suitability for problems in which local spatial evidence must be aggregated along an ordered sequence—precisely the structure of sector-by-sector plan analysis. What remains absent is an application of such hybrid architectures to the spatial analysis of heritage floor plans against a culturally defined reference order.

2.4 Research gap

Three gaps follow from the review. First, the relationship between Hakka building layouts

and the Bagua/Five-Elements directional system has been asserted qualitatively but never measured: no study reports sector-level, statistically evaluated correspondence for a sample of buildings. Second, quantitative geomantic research addresses site selection at the landscape scale, leaving the building scale untouched. Third, heritage deep-learning applications focus on classification and detection, not on correspondence analysis against a symbolic spatial template. The present study sits at the intersection of these gaps: it formalizes the Later Heaven Bagua as a nine-sector coding scheme, quantifies floor-plan correspondence with a hybrid CNN–LSTM–Attention model, and statistically evaluates the results across 14 cases and 126 sector observations.

3. Materials and Methods

3.1 Study area and case selection

The study area is the Gannan region of southern Jiangxi, centred on Ganzhou, the historical core of Hakka activity and of the Form School of feng shui. Fourteen cases were selected under three criteria: (i) location within the Gannan Hakka heartland; (ii) availability of a legible, geometrically reliable floor plan; and (iii) representativeness of either the residential or the public building tradition. The residential subset comprises six walled dwellings (weiwu) covering the three principal plan types—square, circular, and hybrid square–circular—including some of the oldest surviving examples dating to the Shunzhi reign of the early Qing dynasty (Fig. 3). Because most historical public buildings in Ganzhou have not survived, the public-building subset comprises seven institutional complexes—the Prefectural Office, the Commander-in-Chief's Office, the Regional Surveillance Circuit Office, the Yangming Academy, the Confucian Temple, the Guan Yu Temple, and the Longevity Palace (Wanshou Gong, the venue for receiving imperial envoys and edicts)—whose plans are preserved in the Gazetteer of Ganzhou Prefecture compiled in the Tongzhi reign (1862–1874) of the Qing dynasty (Editorial Board of Ganzhou Prefecture 1873) (Fig. 4). Finally, the contemporaneous map of the Ganzhou prefectural city (Fig. 5) was included as a fourteenth case at the urban scale, since the city represents the cumulative outcome of Hakka building practice. Table 1 summarizes the sample.

Table 1. Case sample: 14 heritage floor plans from the Gannan Hakka heartland.

ID	Category	Description	Source / date
D1–D6	Walled dwellings	Six enclosed Hakka residences covering square, circular, and hybrid square–circular plan types;	Surveyed / published floor plans

ID	Category	Description	Source / date
	(weiwu)	located in the Gannan border area; earliest examples from the Shunzhi reign (early Qing)	
P1	Public building	Ganzhou Prefectural Office (seat of the prefect)	Gazetteer of Ganzhou Prefecture, Tongzhi reign (1862–1874)
P2	Public building	Commander-in-Chief's Office (military headquarters)	idem
P3	Public building	Regional Surveillance Circuit Office	idem
P4	Public building	Yangming Academy (leading Confucian academy, associated with Wang Yangming)	idem
P5	Public building	Confucian Temple (partially extant)	idem
P6	Public building	Guan Yu Temple (military cult and training venue)	idem
P7	Public building	Longevity Palace (Wanshou Gong; reception of imperial envoys and edicts)	idem
City	Prefectural city	Historical map of the walled city of Ganzhou	idem

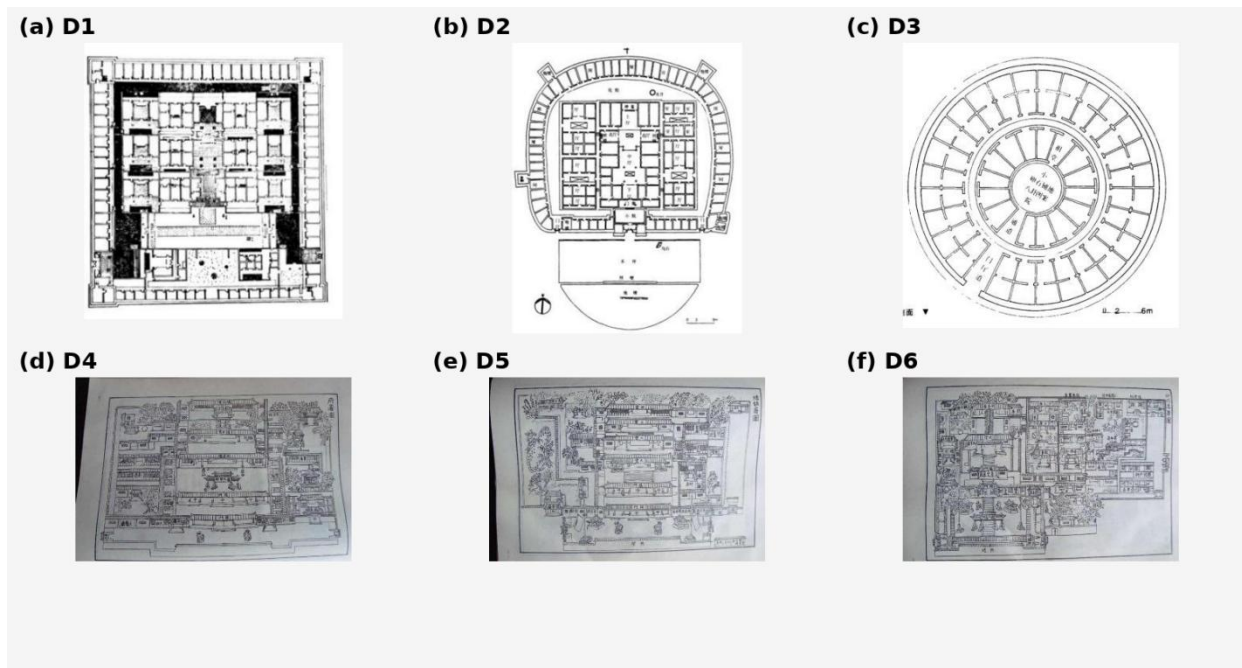


Fig. 3. Floor plans of the six Hakka walled dwellings (D1–D6): square, circular, and hybrid types.

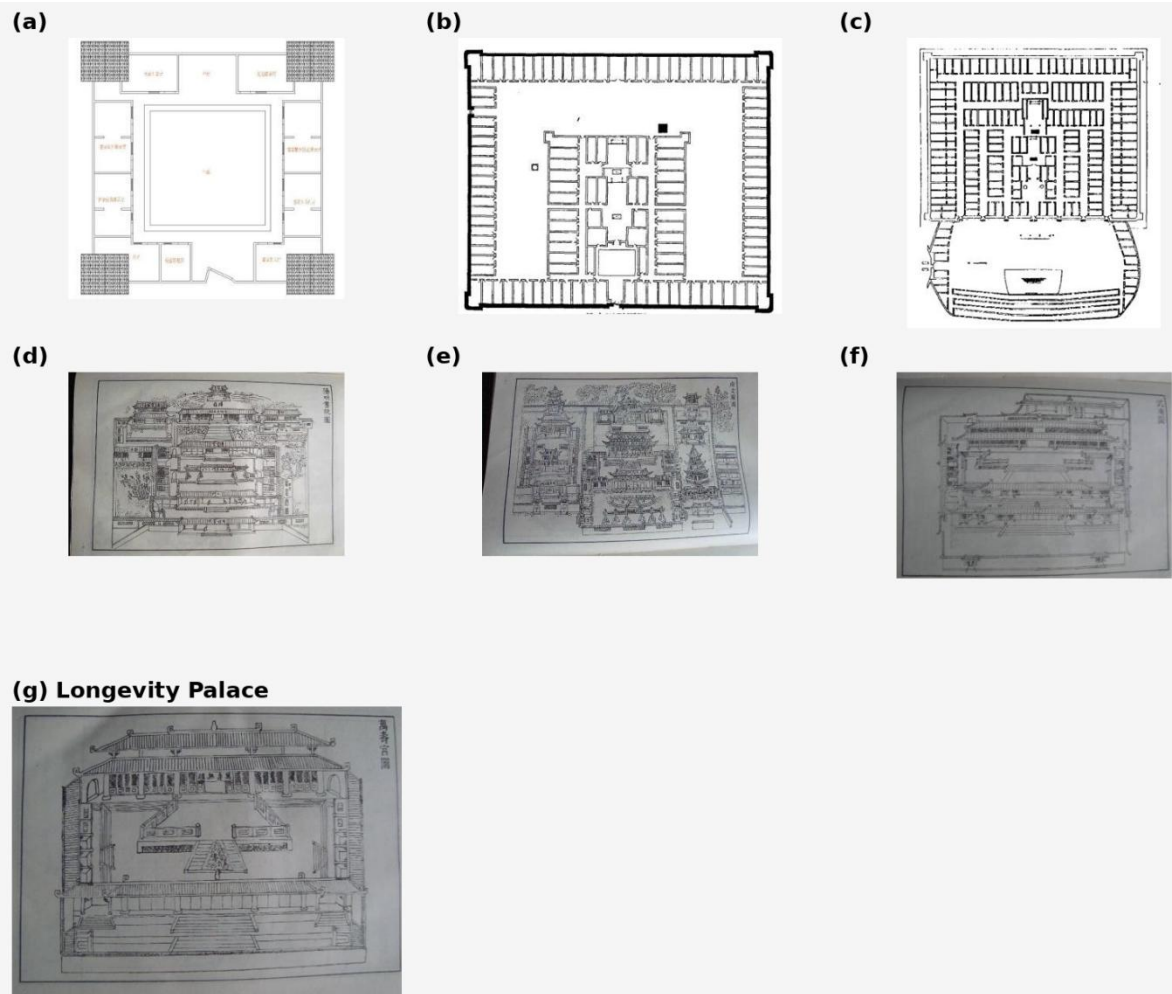


Fig. 4. Plans of the seven public buildings (P1–P7), redrawn from the Tongzhi-era Gazetteer of Ganzhou Prefecture (Editorial Board of Ganzhou Prefecture 1873); (g) Longevity Palace.

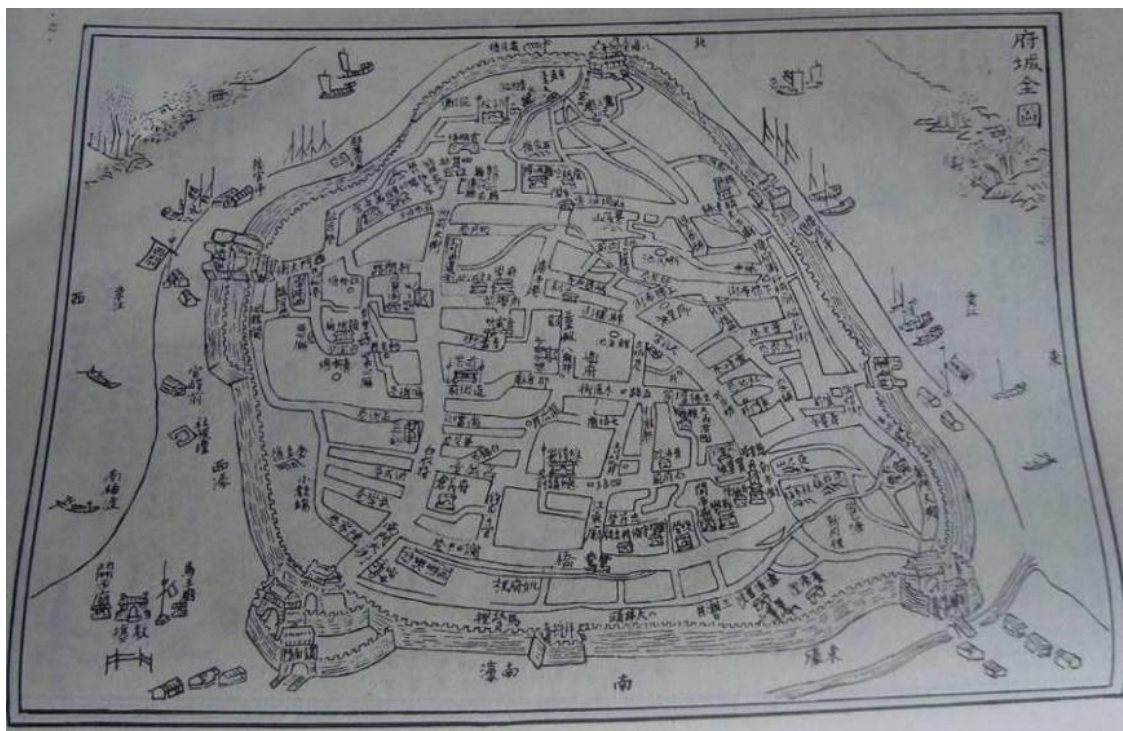


Fig. 5. Historical map of the Ganzhou prefectural city, Tongzhi-era Gazetteer of Ganzhou Prefecture (Editorial Board of Ganzhou Prefecture 1873).

3.2 The nine-sector directional coding scheme

The Later Heaven Bagua was adopted as the spatial partitioning standard (Fig. 2). Each floor-plan image and the reference template were normalized to a common square canvas and partitioned into eight 45° directional sectors—North (Kan), Northeast (Gen), East (Zhen), Southeast (Xun), South (Li), Southwest (Kun), West (Dui), Northwest (Qian)—plus a circular central zone corresponding to the Taiji. Every sector thus carries a fixed directional and Five-Element attribution (Table 2). This partition converts a symbolic ordering system into a well-defined spatial grid over which pixel-level evidence can be aggregated, answering RQ1. The ordered sequence of sectors also defines a natural cyclic sequence (N → NE → E → SE → S → SW → W → NW → centre), which is exploited by the sequence-modelling branch of the network (Sect. 3.3).

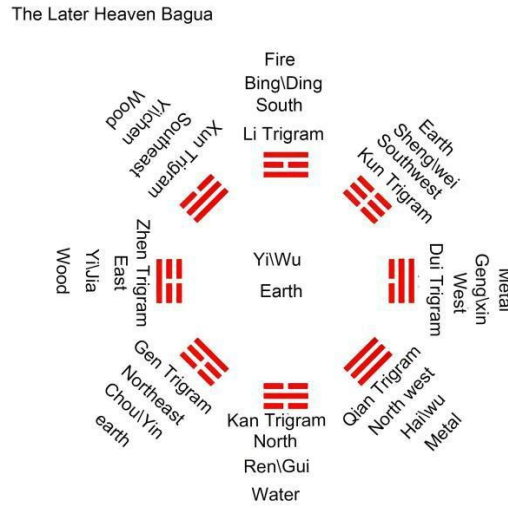


Fig. 2. The Later Heaven (King Wen) Bagua: trigram–direction–element correspondences used for the nine-sector partition.

3.3 The CNN–LSTM–Attention correspondence model

The analytical pipeline (Fig. 6) couples three components. First, a CNN (LeCun et al. 1998) extracts local spatial features from each sector image. A convolutional layer computes feature maps as

$$y(i, j) = \sigma (\sum_m \sum_n x(i + m, j + n) \cdot w(m, n) + b), \quad (1)$$

where x is the input image, w the convolution kernel, b the bias, σ a nonlinear activation, and y the output feature map; max-pooling then aggregates each pooling window R_{ij} as

$$y(i, j) = \max(x(m, n)), (m, n) \in R_{ij}. \quad (2)$$

Second, because the eight peripheral sectors form an ordered cyclic sequence, an LSTM models dependencies between neighbouring sectors (e.g., the continuous transition of density along the perimeter). The LSTM updates its gates and states as

$$i(t) = \sigma(W_i x(t) + U_i h(t-1) + b_i), \quad (3)$$

$$f(t) = \sigma(W_f x(t) + U_f h(t-1) + b_f), \quad (4)$$

$$c(t) = f(t) \odot c(t-1) + i(t) \odot \tanh(W_c x(t) + U_c h(t-1) + b_c), \quad (5)$$

$$o(t) = \sigma(W_o x(t) + U_o h(t-1) + b_o), \quad h(t) = o(t) \odot \tanh(c(t)), \quad (6)$$

where i, f, o are the input, forget, and output gates, c the cell state, h the hidden state, and $\odot$ element-wise multiplication (Hochreiter and Schmidhuber 1997). Third, an attention layer (Vaswani et al. 2017) re-weights the sector representations according to their relevance for the correspondence decision:

$$e(t) = v^T \tanh(W h(t) + b), \quad \alpha(t) = \exp(e(t)) / \sum_k \exp(e(k)), \quad h^* = \sum_t \alpha(t) h(t). \quad (7)$$

The model was implemented in MATLAB. Data augmentation (resizing, greyscale normalization) was applied to reduce sensitivity to scan quality, scale, and line-weight differences between the surveyed plans and the gazetteer woodblock prints, which differ markedly in drawing style.

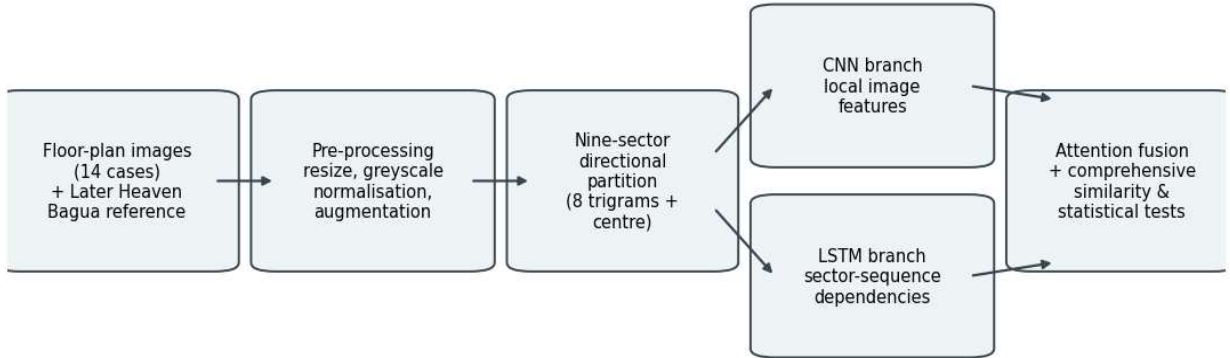


Fig. 6. Analytical workflow: pre-processing, nine-sector partition, parallel CNN/LSTM branches, and attention-weighted similarity fusion.

3.4 Similarity measures and matching criterion

For each case and each of the nine sectors k , three complementary similarities with respect to the reference template were computed: (i) CNN similarity $C(k)$, the cosine similarity of deep feature vectors; (ii) density similarity $D(k) = 1 - |\rho_{\text{ref}}(k) - \rho_{\text{case}}(k)|$, where ρ is the built-pixel (occupancy) ratio within the sector; and (iii) spatial similarity $S(k)$, a structural correspondence

measure over the sector's layout skeleton. The three measures were fused by attention-derived weights:

$$F(k) = wC \cdot C(k) + wD \cdot D(k) + wS \cdot S(k), \text{ with } wC + wD + wS = 1. \quad (8)$$

A sector is counted as a match when $F(k) \geq \tau$, with $\tau = 0.78$ set a priori; the case-level comprehensive similarity is the sector mean $\bar{F} = (1/9) \sum_k F(k)$, and the match rate is the proportion of sectors above τ . Decomposition of the learned fusion weights yielded balanced contributions of CNN features (35.84%), spatial structure (35.76%), and density (28.40%), indicating that no single channel dominates the correspondence score.

3.5 Statistical evaluation

The evaluation combined descriptive statistics (sector- and case-level means, standard deviations, coefficients of variation), inferential testing (one-sample tests of sector similarities against a random-guess baseline, reporting p-values and Cohen's d effect sizes, plus a 95% confidence interval for the overall mean), and consistency analysis (pairwise inter-sector correlation coefficients and distances). This three-tier design mirrors validation practice in applied deep-learning studies and addresses RQ2; typological contrasts between dwellings, public buildings, and the city (RQ3) are examined descriptively and through density-deviation profiles.

4. Results

4.1 Overall correspondence and model performance

Across the 14 cases, all 126 sector-level comprehensive similarities exceeded the matching threshold $\tau = 0.78$, yielding a 100% sector match rate. The overall mean comprehensive similarity was 0.9904 (95% CI [0.9901, 0.9907]). Dispersion was very small: the mean case-level standard deviation was 0.0018 and the mean coefficient of variation 0.0017, indicating stable model outputs across heterogeneous drawing styles. One-sample tests against the random-guess baseline returned $p < 0.001$ for every sector, with a mean effect size of Cohen's d = 6.93—far above the conventional 0.8 threshold for a large effect—confirming that the measured correspondence is not an artefact of chance. The mean inter-sector correlation coefficient was 0.6417 with a mean inter-sector distance of 0.0006, indicating that sectors behave consistently without collapsing into redundancy. The composite evaluation aggregated performance (99.04/100), stability (99.83/100), robustness (99.83/100), significance (100/100), application readiness (86.66/100), and interpretability (33.58/100) into an overall score of 90.40/100; the interpretability subscore is discussed as a limitation in Sect.

5.4. Figure 7 summarizes the evaluation dashboard.

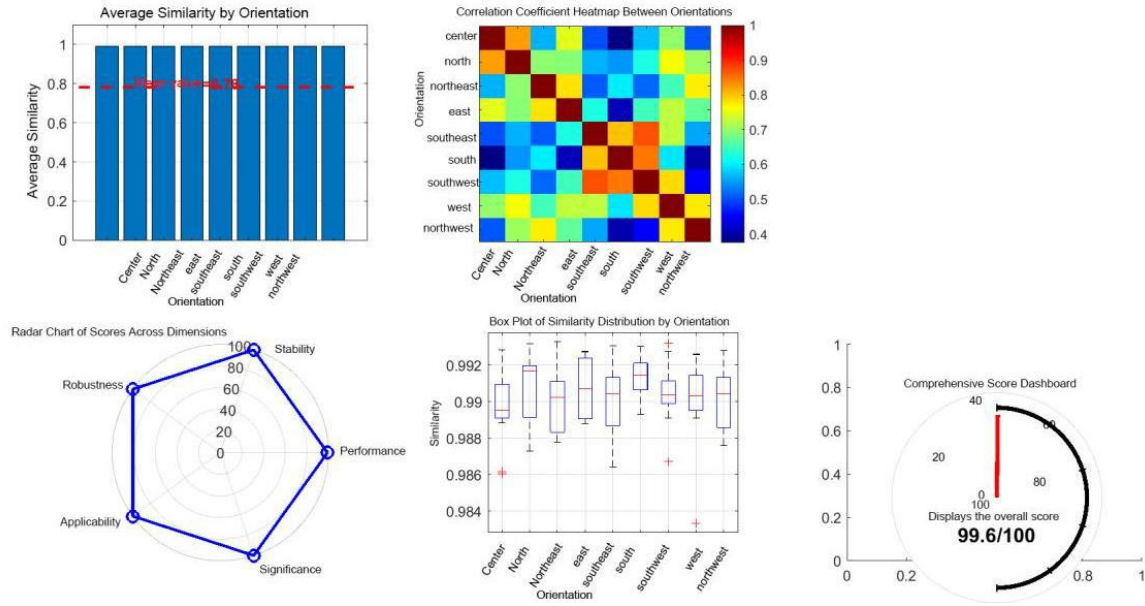


Fig. 7. Comprehensive evaluation of the CNN–LSTM–Attention correspondence model across the 126 sector observations.

4.2 Sector-level patterns

Mean comprehensive similarity varied narrowly but systematically across sectors (Table 2, Fig. 8). The South (Li) sector showed the highest mean correspondence (0.9913) and the lowest dispersion (SD 0.0012), whereas the centre (Taiji) showed the lowest mean (0.9896); the West (Dui) sector exhibited both the widest dispersion (SD 0.0022) and the single lowest observation (0.9833, in dwelling D1). These differences, though small in absolute terms, are directionally consistent with the functional geography of Hakka plans, in which principal halls, gates, and activity spaces concentrate in the southern and eastern sectors (Sect. 5.1).

Table 2. Sector-level correspondence statistics across 14 cases (n = 14 per sector).

Sector	Trigram	Element	Mean sim.	SD	Min	Max	Match rate
North	Kan	Water	0.9909	0.0018	0.9873	0.9932	100%
Northeast	Gen	Earth	0.9900	0.0018	0.9878	0.9933	100%
East	Zhen	Wood	0.9908	0.0015	0.9888	0.9927	100%
Southeast	Xun	Wind/Wood	0.9902	0.0019	0.9864	0.9931	100%
South	Li	Fire	0.9913	0.0012	0.9893	0.9930	100%
Southwest	Kun	Earth	0.9905	0.0016	0.9867	0.9932	100%

Sector	Trigram	Element	Mean sim.	SD	Min	Max	Match rate
West	Dui	Metal	0.9901	0.0022	0.9833	0.9926	100%
Northwest	Qian	Metal	0.9902	0.0015	0.9876	0.9928	100%
Centre	Taiji	Earth (centre)	0.9896	0.0019	0.9861	0.9928	100%

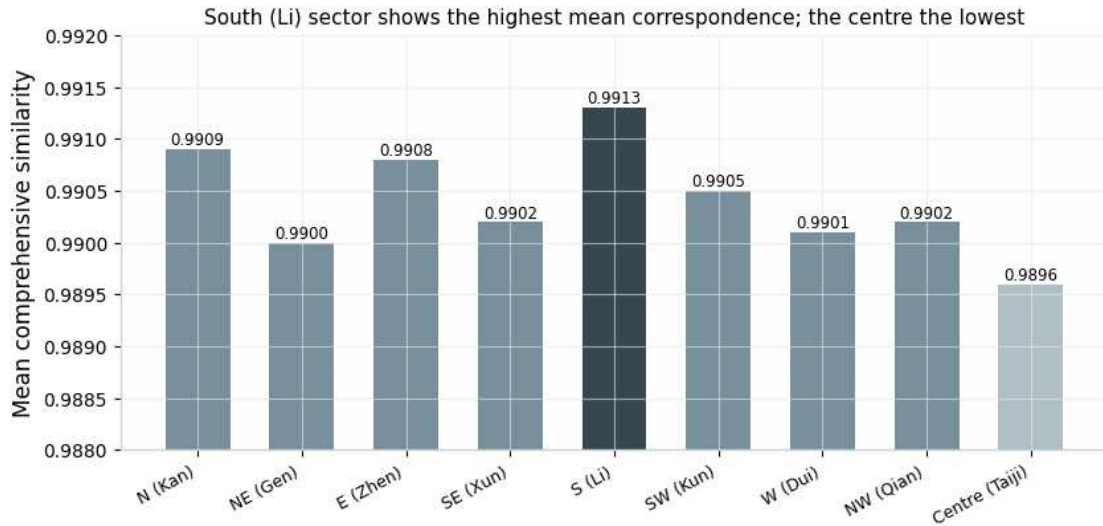


Fig. 8. Mean comprehensive similarity by directional sector (n = 14 per sector).

4.3 Case-level differentiation and building typology

Case-level means ranged from 0.9871 (dwelling D1) to 0.9927 (the Longevity Palace, P7) (Table 3, Fig. 9). Two patterns emerge. First, the two typological groups occupy distinct ranges: the six walled dwellings span 0.9871–0.9921 and the seven public buildings 0.9890–0.9927, with the public subset containing both the maximum and the most stable case (P7: SD 0.0005, CV 0.0088). Second, the density profiles diverge more strongly than the similarity means. In dwellings, per-sector density similarity dropped as low as 0.6307, with density deviations exceeding 20–35% in peripheral sectors—an expression of the “dense core, sparse periphery” layout in which a compact residential–ancestral core is wrapped by thin perimeter ranges. In public buildings, density deviations were smaller and more evenly distributed; the Longevity Palace kept every sector's density similarity above 0.925 and all deviations below 8%, approaching a “high-density equilibrium.” Directionally, high-correspondence core sectors in dwellings concentrate in the east, south, northeast, and north (entrance, lighting, and mountain-backing functions), while public buildings extend high correspondence to the southwest and northwest, indicating broader multi-directional coverage. Inter-sector correlation coefficients fluctuated widely in dwellings (0.158–0.718) but were smoother in public buildings (–0.020–

0.662), consistent with more tightly regulated institutional planning.

Table 3. Case-level results ranked by mean comprehensive similarity (D1–D6: dwellings; P1–P7: public buildings; City: prefectural city).

Rank	ID	Mean	Max	Min	SD	Centre density dev. (%)	Min density sim.	CV	Core-sector pattern
1	P7	0.9927	0.9932	0.9919	0.0005	4.44	0.9256	0.0088	SW–N dual core
2	D3	0.9921	0.9933	0.9909	0.0008	2.80	0.8744	0.0154	NE single core
3	P4	0.9903	0.9917	0.9894	0.0008	18.59	0.8232	0.0138	N–S dual core
4	D4	0.9914	0.9928	0.9898	0.0010	17.13	0.8287	0.0218	NW–E dual core
5	D5	0.9914	0.9929	0.9899	0.0012	16.59	0.8523	0.0210	SE–S–SW triple core
6	D2	0.9904	0.9926	0.9883	0.0018	20.69	0.7734	0.0294	S-facing triple core
7	P2	0.9900	0.9914	0.9879	0.0011	11.20	0.7617	0.0176	N-facing balanced
8	P3	0.9897	0.9908	0.9881	0.0009	18.08	0.7695	0.0142	S-facing dual core
9	P1	0.9896	0.9918	0.9883	0.0012	18.02	0.7732	0.0205	N-facing dual core
10	P5	0.9896	0.9918	0.9862	0.0016	29.35	0.7921	0.0240	S single core, open centre
11	D6	0.9911	0.9920	0.9892	0.0008	19.46	0.8054	0.0129	N-facing balanced
12	P6	0.9890	0.9906	0.9878	0.0008	19.68	0.7573	0.0124	E single core
13	D1	0.9871	0.9894	0.9833	0.0018	29.66	0.6307	0.0247	E single core
—	City	0.9914	0.9924	0.9900	0.0008	12.18	0.8390	0.0135	NE–E dual core

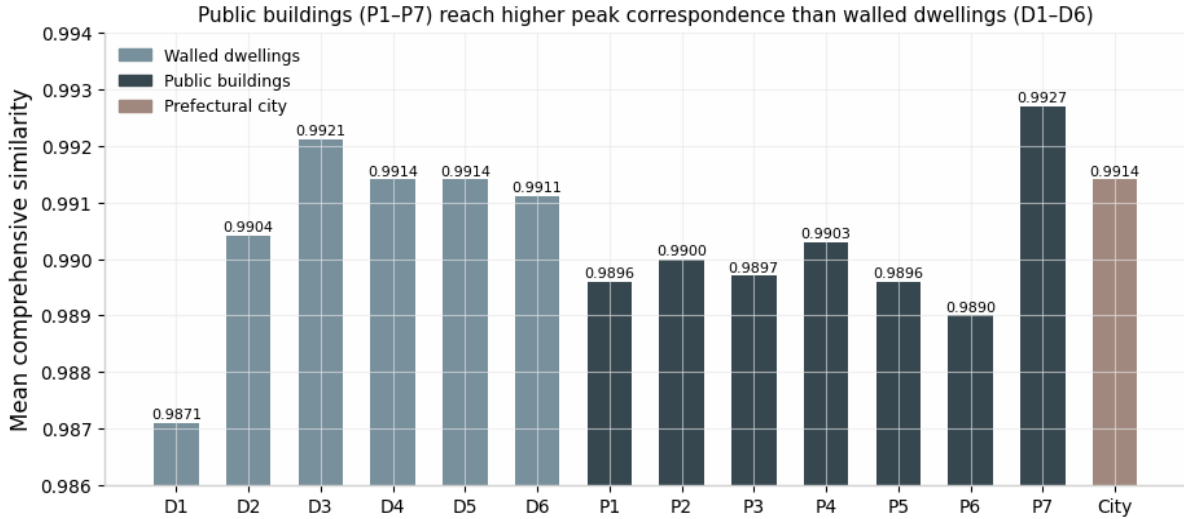


Fig. 9. Mean comprehensive similarity by case; the public-building subset reaches the sample maximum at the Longevity Palace (P7).

4.4 Representative cases: the Longevity Palace and the prefectural city

The Longevity Palace (P7), the venue for receiving imperial envoys and edicts, is the limiting case of the sample. It achieved the highest mean comprehensive similarity (0.9927), the lowest dispersion (SD 0.0005; CV 0.0088), and near-uniform density correspondence: the southwest (Kun, Earth) and north (Kan, Water) sectors reached density similarities of 0.9951 and 0.9925 (deviations of 0.49% and 0.75%), and even its lowest sectors (northwest, 0.9256; northeast, 0.9319) exceeded the best sectors of most dwellings. Its dual southwest–north core, compact central courtyard (centre deviation 4.44%), and balanced auxiliary zones illustrate the most complete alignment between institutional function and directional order in the sample.

At the urban scale, the Ganzhou prefectural city reproduced the same directional logic: a mean comprehensive similarity of 0.9914 (SD 0.0008) with a dual northeast–east core (both sectors 0.9924), density similarities of 0.9487 (Gen) and 0.9477 (Zhen) on the core axis, and a single deviation point in the southeast (0.8390). The northeast–east axis corresponds to the historical “east-facing gates, mountain-backed northeast” siting logic of the walled city, suggesting that the directional order observed at building scale scales up to the city plan—a point developed in Sect. 5.1.

5. Discussion

5.1 Directional cores and their functional interpretation

Read against the trigram–element attributions, the observed sector patterns form a coherent—though necessarily interpretive—picture. High correspondence in the east (Zhen,

Wood, “generative spring”) coincides with the position of entrances and principal lighting/ventilation zones in Hakka dwellings; the south (Li, Fire) core matches the main halls and activity areas of a north-backed, south-facing orientation; and northern (Kan, Water) correspondence aligns with the defensive “mountain-backing” perimeter. Conversely, the weakest and most variable sector, the west (Dui, Metal, “autumn storage”), is functionally auxiliary in most cases. We stress that these readings are post hoc functional interpretations of statistical patterns, not proof of causation: the evidence demonstrates that Hakka plans share a stable directional order consistent with the Later Heaven Bagua, not that builders computed layouts from trigrams. What the quantitative results add is precision: the correspondence is sector-specific, typologically differentiated, and strongest precisely where the interpretive tradition predicts (entrance/lighting east, ceremonial south, defensive north).

5.2 A stable template with adaptive density filling

The clearest substantive finding is the dissociation between layout order and density filling. Comprehensive similarity—driven jointly by image, structure, and density channels—is uniformly high, whereas density deviations vary by an order of magnitude across cases (from 0.49% in P7 to 36.9% in D1's western sector). In other words, the directional skeleton of the plans is conservative, while the intensity of occupation within each sector is adaptive: dwellings concentrate mass near the residential–ancestral core, and public institutions distribute it more evenly as ceremonial and administrative functions demand. This “invariant core layout, adaptive functional filling” reading refines earlier qualitative claims about Hakka construction wisdom (Feuchtwang 1974; Knapp 1999) and parallels space-syntax findings that Hakka building types share configurational genotypes while differing in integration profiles (Hu and Yang 2023). The gradient from the contrasted density of dwellings through the gentler profiles of public buildings to the near-equilibrium of the Longevity Palace may also track institutional hierarchy, an interpretation to be tested on larger samples.

5.3 Methodological implications

Methodologically, the study shows that a culturally defined symbolic system can be converted into an explicit spatial coding scheme and evaluated with standard statistical machinery—an approach complementary to GIS-based geomantic suitability modelling at the landscape scale (Cui et al. 2021; Guan et al. 2024; He et al. 2026) and to space-syntax quantification of plan configuration (Chen et al. 2021; Hu and Yang 2023; Zhao et al. 2025). The hybrid architecture proved appropriate to the problem structure: CNN features capture

local texture of woodblock prints and surveyed drawings alike, the LSTM respects the cyclic ordering of sectors, and the attention layer prevents any single feature channel from dominating (contributions 35.84%/35.76%/28.40%). The workflow is transferable: the reference template can be replaced by other ordering systems (e.g., the Earlier Heaven arrangement, Islamic cosmological schemes, or Renaissance ideal-city geometries), and the case images by other heritage plan corpora, opening a route to comparative, cross-cultural studies of cosmological ordering in vernacular architecture.

5.4 Limitations and future work

Four limitations qualify the findings. First, the reference template is itself derived from the Bagua scheme, so high correspondence indicates consistency with the coding framework rather than independent external validation; future work should benchmark against null templates (rotated or randomized sector attributions) and non-Bagua control buildings to sharpen falsifiability. Second, the sample of 14 cases—though yielding 126 sector observations—is small and geographically concentrated; expanding to Fujian and Guangdong Hakka corpora and to non-Hakka comparisons would test generality. Third, the density channel uses a binary occupancy proxy from scanned plans of heterogeneous provenance (woodblock gazetteer prints vs. modern surveys), and although augmentation mitigates style differences, vector re-drawings or 3D documentation would provide cleaner inputs. Fourth, the model's interpretability subscore (33.58/100) is low: feature-importance analyses (e.g., SHAP, Grad-CAM) and ablation experiments (CNN-only, LSTM-only, attention-free variants, and classical baselines such as template matching) are needed to attribute the correspondence signal to specific visual evidence. Addressing these issues is the agenda of our ongoing work, together with multimodal extensions that incorporate textual gazetteer descriptions and craft documentation.

6. Conclusions

This study set out to quantify the long-asserted but never measured relationship between Hakka architecture and the traditional Chinese directional-cosmological order. By operationalizing the Later Heaven Bagua as a nine-sector spatial coding scheme and coupling it with a CNN–LSTM–Attention correspondence model, we analysed 14 heritage cases from the Gannan Hakka heartland (126 sector observations) spanning dwellings, public institutions, and the prefectural city. Three conclusions answer the research questions.

First, the Bagua directional system can be formalized as a reproducible computational

framework: the nine-sector partition, hybrid feature extraction, and attention-weighted fusion together constitute a transferable pipeline for correspondence analysis of heritage floor plans (RQ1). Second, Hakka plans correspond to the directional order strongly and significantly: all sector correspondences exceeded the matching threshold, the mean comprehensive similarity reached 0.9904 (95% CI [0.9901, 0.9907]), and correspondence significantly exceeded the random-guess baseline ($p < 0.001$, $d = 6.93$), with sector-level heterogeneity that matches the functional geography of the plans (RQ2). Third, building types differ systematically in how the shared order is filled: dwellings exhibit “dense core, sparse periphery” density contrasts, whereas public buildings approach high-density equilibrium, culminating in the Longevity Palace—evidence of an invariant directional template with adaptive functional filling (RQ3).

For heritage practice, the pipeline offers a quantitative instrument for documenting, comparing, and monitoring vernacular plans—useful for authenticity assessment, restoration prioritization, and digital archiving. For scholarship, it demonstrates that cosmological ordering principles can be studied with the same evidentiary standards as other spatial hypotheses, helping move the field from qualitative description toward a productive combination of quantitative analysis and cultural interpretation.

References

- Borré A, Seman LO, Camponogara E, Stefenon SF, et al (2023) Machine fault detection using a hybrid CNN-LSTM attention-based model. *Sensors* 23(9):4512. <https://doi.org/10.3390/s23094512>
- Chen Y, Xu K, Liu P, Jiang R, Qiu J, Ding K, Fukuda H (2021) Space as sociocultural construct: reinterpreting the traditional residences in Jinqu Basin, China from the perspective of space syntax. *Sustainability* 13(16):9004. <https://doi.org/10.3390/su13169004>
- Ćosović M, Janković R (2020) CNN classification of the cultural heritage images. In: *Proceedings of the 19th International Symposium INFOTEH-JAHORINA*. IEEE, pp 1–6. <https://doi.org/10.1109/INFOTEH48170.2020.9066300>
- Cui J, Liu Y, Sun J, Hu D, He H (2021) Study on feng shui (geomantic) suitability evaluation of mausoleums in Nanjing city based on GIS. *ISPRS International Journal of Geo-Information* 10(11):752. <https://doi.org/10.3390/ijgi10110752>
- Dodge S, Xu J, Stenger B (2017) Parsing floor plan images. In: *Proceedings of the 15th LAPR International Conference on Machine Vision Applications (MVA)*. IEEE, pp 358–361
- Editorial Board of Ganzhou Prefecture (1873) *Ganzhou Fu Zhi [Gazetteer of Ganzhou Prefecture]*, Tongzhi reign edition, Qing dynasty (in Chinese)
- Feuchtwang SDR (1974) *An Anthropological Analysis of Chinese Geomancy*. Vithagna, Vientiane
- Gao L, Wu Y, Yang T, Zhang X, Zeng Z, Chan CKD, et al (2023) Research on image classification and retrieval using deep learning with attention mechanism on diaspora Chinese architectural heritage in Jiangmen, China. *Buildings* 13(2):275. <https://doi.org/10.3390/buildings13020275>
- Guan R, Chen Y, Chen X (2024) Scientific evaluation of fengshui from the perspective of geography: empirical evidence from the site selection of traditional Hakka villages. *Applied Spatial Analysis and Policy* 17(4):1545–1568. <https://doi.org/10.1007/s12061-024-09595-6>
- Han KT, Lin JK (2023) Empirical and quantitative studies of Feng Shui: a systematic review. *Heliyon*

9(9):e19532. <https://doi.org/10.1016/j.heliyon.2023.e19532>

He Q, Luo L, Liao M, Samson MGM, Lin H (2026) Site selection principles and geocomputational modeling for the imperial tombs of the Ming and Qing Dynasties in China. *Humanities and Social Sciences Communications*. <https://doi.org/10.1057/s41599-026-07917-2>

Hochreiter S, Schmidhuber J (1997) Long short-term memory. *Neural Computation* 9(8):1735–1780. <https://doi.org/10.1162/neco.1997.9.8.1735>

Hong SK, Song IJ, Wu J (2007) Fengshui theory in urban landscape planning. *Urban Ecosystems* 10(3):221–237. <https://doi.org/10.1007/s11252-006-3263-2>

Hu L, Yang T (2023) Landed and rooted: a comparative study of traditional Hakka dwellings (tulou and weilong houses) based on the methodology of space syntax. *Buildings* 13(10):2644. <https://doi.org/10.3390/buildings13102644>

Katayama K (2011) Spatial order and typology of Hakka dwellings. In: *Proceedings of the International Symposium on Hakka Architecture*. Southeast University Press, Nanjing

Knapp RG (1986) *China's Traditional Rural Architecture: A Cultural Geography of the Common House*. University of Hawaii Press, Honolulu

Knapp RG (1999) *China's Living Houses: Folk Beliefs, Symbols, and Household Ornamentation*. University of Hawaii Press, Honolulu

LeCun Y, Bottou L, Bengio Y, Haffner P (1998) Gradient-based learning applied to document recognition. *Proceedings of the IEEE* 86(11):2278–2324. <https://doi.org/10.1109/5.726791>

Liu S, Yuan Y, Yang G, Sheng G (2026) Machine learning in architectural heritage: a review of research trends and applications. *Journal of Asian Architecture and Building Engineering*. <https://doi.org/10.1080/13467581.2026.2725985>

Luo X (1933) *Kejia Yanjiu Daolun [An Introduction to Hakka Studies]*. Xingshan Bookstore, Guangzhou (in Chinese)

Lv X, Zhao S, Yu X, Zhao B (2021) Residential floor plan recognition and reconstruction. In: *Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition (CVPR)*, pp 16712–16721

Madeddu M, Zhang X (2017) Harmonious spaces: the influence of Feng Shui on urban form and design. *Journal of Urban Design* 22(6):709–725. <https://doi.org/10.1080/13574809.2017.1336061>

Mak MY, So AT (2009) *Scientific Feng Shui for the Built Environment: Fundamentals and Case Studies*. City University of Hong Kong Press, Hong Kong

Miky Y, Alshawabkeh Y, Baik A (2024) Using deep learning for enrichment of heritage BIM: Al Radwan house in historic Jeddah as a case study. *Heritage Science* 12. <https://doi.org/10.1186/s40494-024-01382-3>

Mishra M, Lourenço PB (2024) Artificial intelligence-assisted visual inspection of cultural heritage: state-of-the-art review. *Journal of Cultural Heritage* 66:536–550. <https://doi.org/10.1016/j.culher.2024.01.005>

Monna F, Rolland T, Denaire A, Navarro N, Granjon L, Barbé R, Chateau-Smith C (2021) Deep learning to detect built cultural heritage from satellite imagery—spatial distribution and size of vernacular houses in Sumba, Indonesia. *Journal of Cultural Heritage* 52:171–183. <https://doi.org/10.1016/j.culher.2021.10.004>

Needham J (1956) *Science and Civilisation in China, Vol. 2: History of Scientific Thought*. Cambridge University Press, Cambridge

Pizarro PN, Hitschfeld N, Sipiran I (2023) Large-scale multi-unit floor plan dataset for architectural plan analysis and recognition. *Automation in Construction* 152:104918. <https://doi.org/10.1016/j.autcon.2023.104918>

Porretta P, Pallottino E, et al (2022) Minnan and Hakka tulou: functional, typological and construction features of the rammed earth dwellings of Fujian. *International Journal of Architectural Heritage*. Taylor & Francis

Shao L, Sun J (2023) Identification of historic building “genes” based on deep learning: a case study on Chinese baroque architecture in Harbin, China. *Heritage Science* 11. <https://doi.org/10.1186/s40494-023-01091-3>

Siountri K, Anagnostopoulos CN (2023) The classification of cultural heritage buildings in Athens using deep learning techniques. *Heritage* 6(4):3673–3705. <https://doi.org/10.3390/heritage6040195>

- Song Y, Liao C (2023) Research on the architectural features and artistic elements of traditional buildings in different regions of Jiangxi, China. *Buildings* 13(7):1597. <https://doi.org/10.3390/buildings13071597>
- Ueda M (2012) A preliminary environmental assessment for the preservation and restoration of Fujian Hakka tulou complexes. *Sustainability* 4(11):3103–3119. <https://doi.org/10.3390/su4113103>
- Vaswani A, Shazeer N, Parmar N, Uszkoreit J, Jones L, Gomez AN, Kaiser Ł, Polosukhin I (2017) Attention is all you need. *Advances in Neural Information Processing Systems* 30:5998–6008
- Wan A, Chang Q, Khalil AL-B, He J (2023) Short-term power load forecasting for combined heat and power using CNN-LSTM enhanced by attention mechanism. *Energy* 282:128274. <https://doi.org/10.1016/j.energy.2023.128274>
- Wang L, Bi Y, Hu S, Yang S (2025) Interpretation of sustainable spatial patterns in Chinese villages based on AHP-GIS-FCE: a case study of Chawan Village, East Mountain Island, Taihu Lake. *Buildings* 15(17):3198. <https://doi.org/10.3390/buildings15173198>
- Wilhelm R, Baynes CF (trans) (1967) *The I Ching or Book of Changes*, 3rd edn. Princeton University Press, Princeton
- Xu X, Ferretto PW (2024) The emerging middle ground: a case study of vernacular Hakka settlements in the peri-urban areas of southern China through an architectural heritage analysis. *Journal of Chinese Architecture and Urbanism* 7(1):3649. <https://doi.org/10.36922/jcau.3649>
- Xu Y, Zhou W (2025) Comparative evolution of vernacular settlements among the Cantonese, Teochew, and Hakka ethnic groups in Lingnan. *Journal of Asian Architecture and Building Engineering*. <https://doi.org/10.1080/13467581.2024.2421240>
- Yan L, Chen Y, Zheng L, Zhang Y (2024) Application of computer vision technology in surface damage detection and analysis of shedthn tiles in China: a case study of the classical gardens of Suzhou. *Heritage Science* 12(1):72. <https://doi.org/10.1186/s40494-024-01185-6>
- Yan Y, Bai Z, Hu X, Wang Y (2025) How do environmental factors influence the spatial patterns and site selection of famous mountain temple complexes in China? Quantitative research on Wudang Mountain. *Land* 14(7):1441. <https://doi.org/10.3390/land14071441>
- Yang Y, Xiong Q, Wu C, Zou Q, Yu Y, Yi H, et al (2021) A study on water quality prediction by a hybrid CNN-LSTM model with attention mechanism. *Environmental Science and Pollution Research* 28:53329–53341. <https://doi.org/10.1007/s11356-021-14687-8>
- Zhao Y, Luo Z, Huang K (2025) Characterization of public space forms in traditional Chinese villages based on spatial syntax: Zhangli village as an example. *Journal of Asian Architecture and Building Engineering*. <https://doi.org/10.1080/13467581.2024.2366811>
- Zou H, Ge J, Liu R, He L (2023) Feature recognition of regional architecture forms based on machine learning: a case study of architecture heritage in Hubei Province, China. *Sustainability* 15(4):3504. <https://doi.org/10.3390/su15043504>