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A PATTERN LANGUAGE FOR BUILDING MORPHOLOGY IN TRADITIONAL VILLAGES OF WESTERN GUANGDONG UNDER TYPHOON DISTURBANCE RISK: CASE STUDIES OF BAYI AND ZHOUJIA VILLAGES

LiHao Yao
College of Coastal Agricultural Sciences, Guangdong Ocean University, Zhanjiang, Guangdong 524088, China.

Abstract: Villages in western Guangdong face an extremely high risk from typhoons, and the resulting impacts vary with village morphology. Existing research has focused largely on describing settlement form, and few studies have linked disturbance risk to morphological types. Using Bayi Village and Zhoujia Village, two nationally designated traditional villages in western Guangdong, as case studies, this study measures typhoon disturbance risk using the tree-fall rate derived from pre- and post-typhoon imagery. High-resolution orthophotos produced by UAV oblique photogrammetry were sampled in 30 m grid cells, morphological elements were delineated by combining the orthophotos with DSM-derived canopy height, and relationship indicators along three dimensions—building–courtyard, building–road, and building–vegetation—were computed following the character–word–phrase–context hierarchy of pattern language; high- and low-risk samples were then clustered separately into morphological types. The high-risk group yielded three phrase types: a dispersed-open type with no distinct courtyard, weak road adjacency, and interstitial vegetation; a clustered courtyard-enclosure type with partial road adjacency and interstitial vegetation; and a dense courtyard-enclosure type with partial road adjacency and sparse vegetation. The low-risk group likewise yielded three phrase types: a dispersed-open type with partial road adjacency and peripheral vegetation; a clustered courtyard-enclosure type with multi-sided road adjacency and interstitial vegetation; and a dense courtyard-enclosure type with partial road adjacency and sparse vegetation. These results provide a typological basis for morphological control, risk-stratified management, and differentiated disaster-prevention planning for traditional villages in typhoon-prone regions.
Keywords: Traditional villages; Typhoon disturbance risk; Tree-fall rate; Building morphology; Pattern language; Morphological atlas

1 INTRODUCTION

The southeastern coast of China is among the regions most severely affected by tropical cyclones worldwide. Historical typhoon hazard zoning places the western Guangdong coast in a high-risk zone [1], and traditional villages there have long been exposed to typhoon-related disturbances. In recent years, intense typhoons such as Yagi and Ragasa have made successive landfalls along the Hainan–Guangdong coast. The area affected by a typhoon and the severity of the resulting damage depend directly on geographic location, terrain, and land use [1], while tree fall is directly related to species characteristics, location, and the surrounding built environment; accordingly, a rational spatial layout can reduce disaster losses [2]. This implies that differences in damage between villages and among spatial units within a village are shaped by morphological characteristics such as building layout, degree of enclosure, road adjacency, and vegetation configuration. Traditional villages are both living cultural heritage and basic units of human-settlement safety in typhoon-prone regions, and systematically documenting their adaptive building forms is fundamental to both heritage conservation and disaster-prevention planning. Studying the pattern language of traditional-village building morphology in relation to typhoon disturbance risk can theoretically extend the character–word–phrase–context descriptive hierarchy of pattern language to disaster-risk contexts and provide an operational framework for typological research on risk–form relationships. In practical terms, it can provide a typological basis for morphological control, risk-stratified management, and differentiated disaster-prevention planning for traditional villages in typhoon-prone regions.

Relevant research falls into three streams. The first stream concerns the measurement and assessment of typhoon disasters, with research focusing mainly on cities. Post-disaster field surveys have established systematic damage-recording methods, and field investigations of building damage in several East Asian wind disasters have quantified damage grades and their relationships with wind fields, terrain, and building attributes [3]. Research on wind damage to trees has developed damage-grading systems and methods for evaluating species-level wind resistance based on tree-fall and stem-snapping rates. An international scoping review of predictors of tropical cyclone-induced urban tree failure has identified vulnerable species, factors contributing to wind-induced damage, and the influence of the surrounding environment [2]. In remote-sensing assessments, studies of Typhoon Meranti on Xiamen Island and urban vegetation damage in Haikou both used differences between pre- and post-typhoon NDVI values to characterize vegetation damage patterns and found that built-environment factors such as building height and landscape pattern were significantly associated with damage severity [4-5]. This stream provides well-established wind-damage metrics and remote-sensing assessment methods, but it focuses on urban green spaces, street trees, or ecosystems as assessment units and rarely examines rural building morphology. The second stream concerns the typology and mapping of traditional-village morphology. The landscape-gene approach has established methods for identifying and extracting the landscape genes of traditional settlements and mapping their adaptation to the environment [6]. Originating in Alexander's theory, the pattern-language approach organizes settlement space into a hierarchy of nameable and combinable vocabulary elements and has produced, for example, a morphological typology pedigree of centripetal spatial schemas [7-8]. This stream offers tools for describing form through nameable and combinable elements, but it focuses on the interpretation and conservation of cultural landscapes, usually examines only a few typical villages, and largely omits the disaster-risk dimension. The third stream concerns rural disaster resilience and disaster-prevention adaptation. Research on urban–rural differences in disaster resilience points out that the characteristics of rural resilience are often obscured by urban-focused studies and that rural preparedness and absorptive capacity require dedicated attention [9]. At the settlement level, studies have revealed form–hazard adaptation mechanisms, such as the climate-adaptive design of historic villages and dwellings in typhoon-prone regions and the optimization of wind environments in the spatial forms of coastal villages in western Guangdong [10-11]. This stream brings a disaster perspective to rural research, but it emphasizes socioeconomic evaluation or explanations of case-specific mechanisms and has not yet incorporated pattern-language methods.

In summary, typhoon-disaster measurement has focused on cities and has rarely addressed traditional villages, while morphological pattern-language research and disaster-risk assessment have proceeded separately rather than within a single framework. To address this gap, this study examines two nationally designated traditional villages in western Guangdong and measures village-scale typhoon disturbance risk using the tree-fall rate derived from pre- and post-typhoon imagery. Drawing on the character–word–phrase–context hierarchy of pattern language, it then induces building-morphology phrase types separately within the high- and low-risk sample pools and identifies their typical forms and organizational rules [7-8]. The study thus integrates risk measurement and morphological patterns within a single research framework.

2 RESEARCH DESIGN

2.1 Study Areas, Data Sources, and Sampling

The study areas are two traditional villages in western Guangdong, Bayi Village and Zhoujia Village. Both lie in the typhoon-prone region of western Guangdong; within each village, buildings, courtyards, roads, and vegetation are interspersed, while the degree of enclosure, mode of road adjacency, and vegetation configuration vary markedly. The diversity of building morphologies makes the two villages suitable cases for a pattern-language analysis stratified by typhoon disturbance risk. Two types of source data were used. The first dataset comprised high-resolution orthophotos and digital surface model (DSM) data generated by unmanned aerial vehicle (UAV) oblique photogrammetry using a DJI Mavic 3 Pro, with ground resolutions of approximately 0.05 m for Bayi Village and 0.07 m for Zhoujia Village; these data were used to delineate morphological elements. The second comprises NDVI composite imagery: NDVI composites for the month before and the month after each typhoon were produced from Landsat 8/9 on the Google Earth Engine platform—centered on Typhoon Ragasa (24 September 2025) for Bayi Village and on Typhoon Yagi (6 September 2024) for Zhoujia Village—and the pre-/post-typhoon NDVI difference was used to represent the tree fall rate as a grid-scale measure of typhoon disturbance risk.

The core areas of the two villages covered by the imagery were sampled using a 30 m × 30 m grid, yielding 111 samples from Bayi Village and 445 from Zhoujia Village, for a total of 556. Two image extents were generated for each sample: a GeoTIFF corresponding exactly to the 30 m grid cell and a contextual GeoTIFF extending 10 m beyond the cell on each side, for a total width of 50 m. The latter was used to assess courtyard, road, and vegetation relationships that extended beyond the grid boundaries. Risk classification used the tertile method: the raw risk values from all grid cells in both villages were pooled, and common thresholds were calculated by linear interpolation at the 33.33rd and 66.67th percentiles. Samples with risk values at or below the first tertile cutoff were classified as low risk; those above the first cutoff and at or below the second were classified as medium risk; and those above the second cutoff were classified as high risk. After classification, medium-risk samples were retained in the overall risk classification but excluded from morphological typology induction, whereas high- and low-risk samples formed two separate, non-overlapping pools for independent within-group typological analyses.

2.2 Construction of the Morphological Pattern Language

The morphological typology was organized according to the character–word–phrase–context hierarchy of pattern language: the four elements—buildings, courtyards, roads, and vegetation—served as characters, each measured using computable indicators; the categorized states of the three relationships—building–courtyard, building–road, and building–vegetation—constituted words; the types derived from within-group clustering constituted phrases, with each type named by combining its three relational words; and typhoon disturbance risk stratification constituted the context (Table 1) [7-8].

Table 1 Correspondence between Pattern-Language Levels and the Operational Objects of This Study

Pattern-language level	Operational object in this study	Indicators	Method
Character (vocabulary)	Four basic elements and their measurement	Buildings (coverage ratio, cluster count); courtyards (area ratio, enclosure ratio); roads (proportion, road-adjacency ratio); vegetation (proportion, green-adjacency ratio, peripheral ratio)	Building-enclosure morphology is defined as a planar composition in which buildings form the main body, courtyards the inner core, roads the external interface, and vegetation the infill and boundary. Building candidates were screened primarily by local relative elevation from the DSM, assisted by RGB color and texture; vegetation was identified through ExG and HSV conditions; roads were identified through low-saturation bright or reddish-soil color rules combined with connectivity to grid boundaries.
Word (relational word)	State assignment of relationships	Enclosure candidate / no distinct courtyard; weak / partial / multi-sided road adjacency; sparse / interstitial / peripheral vegetation	The three groups of relationship candidates were merged into state words by thresholds; the relational grammar comprises enclosure, openness, adjacency, setback, separation, and surrounding.
Phrase (type)	Combined naming of relational words	Determined by the computed results	Mean Gower dissimilarities were computed within each of the three feature blocks and averaged with equal weights into a distance matrix [12]; PAM clustering was performed separately within the high- and low-risk groups [13]. For k = 2–6, the silhouette coefficient, the adjusted Rand index from 80% resampling, and a minimum type size (no fewer than 5 samples) were diagnosed group by group, and the number of classes was determined together with the interpretability of typical samples.
Context	Typhoon disturbance risk stratification	Independently numbered H types (high-risk pool) and L types (low-risk pool)	Types are named in a three-part structure: courtyard dominant-type word – road word – vegetation-position word.

3 RESULTS

3.1 Spatial Distribution of Typhoon Disturbance Risk in the Two Villages

Tertiles of the risk values of the 556 samples from both villages were computed: samples with values ≤ Q1 = 0.042 were classified as low risk, those between Q1 and Q2 as medium risk, and those > Q2 = 0.069 as high risk, yielding 186 low-risk, 185 medium-risk, and 185 high-risk samples in total. At the village scale, Zhoujia Village and Bayi Village exhibit the same spatial pattern: typhoon disturbance risk is lower in the village core and higher at the periphery (Figure 1).

Figure 1 Spatial Distribution of Typhoon Disturbance Risk in Bayi Village (Left) and Zhoujia Village (Right)
Source: http://bzdt.ch.mnr.gov.cn/

3.2 Morphological Characteristics and Pattern-Language Construction

Because the objective was to construct pattern languages for high- and low-risk building morphologies, the 185 medium-risk samples were excluded from morphological induction. The 371 high- and low-risk samples were further processed; 328 of them contained the minimum identifiable building(s), while 43 samples had no identifiable buildings, or only scattered and very small ones, and were excluded. Specifically, 151 high-risk samples entered the analysis and 34 were excluded; 177 low-risk samples entered and 9 were excluded. Exclusion indicates neither missing imagery nor a lack of spatial value; it only means that the grid cell does not meet the object conditions for studying building-enclosure morphology.

3.2.1 Low-Risk Morphological Characteristics and Pattern-Language Construction

The 177 low-risk cells were clustered separately into three morphological types, L01–L03. Cluster diagnostics showed that the three-class solution met the requirements on silhouette coefficient, adjusted Rand index from 80% resampling, and minimum type size, while clearly expressing the internal hierarchy of courtyard, road, and vegetation relationships. Ordered by building organization from dispersed to dense, L01 is the dispersed-open type, L02 is the clustered courtyard-enclosure type, and L03 is the dense courtyard-enclosure type, together forming a dispersed-to-dense phrase sequence within the low-risk context (Table 2).

Table 2 Relational Characteristics of the Three Candidate Morphological Types in the Low-Risk Group (Medians)

Type	Sample size (Bayi/Zhoujia)	Building coverage	Buildings (n)	Courtyard ratio	Mean enclosure	Road proportion	Road-adjacency ratio	Vegetation proportion	Green-adjacency ratio	Peripheral vegetation
L01	56 (12/44)	0.181	3	—	—	0.022	0.039	0.210	0.121	0.179
L02	53 (4/49)	0.301	3	0.056	0.799	0.102	0.118	0.167	0.086	—
L03	68 (17/51)	0.420	3	0.040	0.644	0.017	0.015	0.078	0.072	0.091

In terms of phrase composition, the low-risk context takes the dense courtyard-enclosure phrase (L03) as its most common construction, followed by the clustered courtyard-enclosure phrase (L02), while the dispersed-open phrase (L01) is the smallest. This distribution is consistent with the spatial pattern described in Section 3.1: low-risk cells are concentrated in the built-up village core, where contiguous buildings, enclosed courtyards, and limited vegetation are common. The low-risk context is therefore characterized by dense enclosure: along the building-organization axis, forms progress from dispersed (L01) through clustered (L02) to dense (L03); vegetation shifts from peripheral (L01) through interstitial (L02) to sparse (L03); and courtyard enclosure is consistently present in phrases at the clustered level and above, constituting a shared feature of this context (Table 3).

Table 3 Morphological Phrase Types and Typical Characteristics in the Low-Risk Group

Level / element		L01	L02	L03
Phrase		Dispersed open, no distinct courtyard – partial road adjacency – peripheral vegetation	Clustered courtyard enclosure (candidate) – multi-sided road adjacency – interstitial vegetation	Dense courtyard enclosure (candidate) – partial road adjacency – sparse vegetation
Sample size (Bayi/Zhoujia)		56 (12/44)	53 (4/49)	68 (17/51)
Word	Courtyard (building–courtyard)	Dispersed and open, no distinct courtyard: coverage 0.181, 3 buildings, no distinct courtyard within the cluster	Clustered courtyard enclosure: coverage 0.301, courtyard ratio 0.056, enclosure ratio 0.799; nearly closed courtyards	Dense courtyard enclosure: coverage 0.420, courtyard ratio 0.040, enclosure ratio 0.644; continuous dense buildings enclosing semi-open courtyards
	Road (building–road)	Partial road adjacency: road proportion 0.022, road-adjacency ratio 0.039; locally not directly abutting	Multi-sided road adjacency: road proportion 0.102, road-adjacency ratio 0.118; multiple boundaries close to roads	Partial road adjacency: road proportion 0.017, road-adjacency ratio 0.015
	Vegetation (building–vegetation)	Peripheral vegetation: vegetation proportion 0.210, peripheral ratio 0.179; located along the outer edges of buildings	Interstitial vegetation: vegetation proportion 0.167; located in gaps within and along the edges of building clusters	Sparse vegetation: vegetation proportion 0.078, peripheral ratio 0.091; limited to scattered small patches
Type comparison		Less distinct courtyard candidates and fewer road adjacencies than L02	More road adjacencies and lower building coverage than L03	Fewer road adjacencies, higher coverage, and less vegetation than L02
Typical sample				
Morphological schema				

3.2.2 High-Risk Morphological Characteristics and Pattern-Language Construction

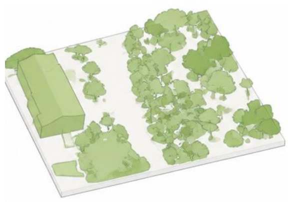
The 151 high-risk samples were classified independently within the group into three candidate morphological types, H01–H03, and the cluster diagnostics (silhouette coefficient, adjusted Rand index from 80% resampling, and minimum type size) likewise supported the three-class solution. Ordered by building organization from dispersed to dense, the three types form a dispersed-to-dense phrase sequence within the high-risk context (Table 4).

Table 4 Relational Characteristics of the Three Candidate Morphological Types in the High-Risk Group (Medians)

Type	Sample size (Bayi/Zhoujia)	Building coverage	Buildings (n)	Courtyard ratio	Mean enclosure	Road proportion	Road-adjacency ratio	Vegetation proportion	Green-adjacency ratio	Peripheral vegetation
H01	87 (15/72)	0.103	1	0.000	—	—	0.000	0.470	0.175	0.399
H02	31 (9/22)	0.220	2	0.037	0.648	0.021	0.013	0.358	0.192	—
H03	33 (7/26)	0.275	3	0.039	0.715	—	0.036	0.171	0.105	0.155

The dispersed-open phrase (H01) predominates, accounting for more than half of the high-risk samples; it is characterized by a small number of buildings scattered among extensive vegetation and open land, with no courtyard core and limited road contact. The clustered and dense courtyard-enclosure phrases (H02 and H03) together account for 64 samples. This composition is consistent with Section 3.1: high-risk cells occur mainly along village peripheries, where sparse buildings are distributed in open settings surrounded by vegetation. The high-risk context is therefore characterized by dispersed-open forms: as building organization progresses from dispersed (H01) through clustered (H02) to dense (H03), vegetation proportion decreases progressively while courtyard enclosure increases (Table 5).

Table 5 Morphological Phrase Types and Typical Characteristics in the High-Risk Group

Level / element		H01	H02	H03
Phrase		Dispersed open, no distinct courtyard – weak road adjacency – interstitial vegetation	Clustered courtyard enclosure (candidate) – partial road adjacency – interstitial vegetation	Dense courtyard enclosure (candidate) – partial road adjacency – sparse vegetation
Sample size (Bayi/Zhoujia)		87 (15/72)	31 (9/22)	33 (7/26)
Word	Courtyard (building–courtyard)	Dispersed and open, no distinct courtyard: coverage 0.103, 1 building, courtyard ratio 0; discontinuous cluster boundary, no distinct courtyard	Clustered courtyard enclosure: coverage 0.220, courtyard ratio 0.037, enclosure ratio 0.648; nearly closed courtyards	Dense courtyard enclosure: coverage 0.275, courtyard ratio 0.039, enclosure ratio 0.715; relatively continuous building boundaries
	Road (building–road)	Weak road adjacency: road-adjacency ratio close to 0; limited contact between buildings and road candidates	Partial road adjacency: road proportion 0.021, road-adjacency ratio 0.013; limited local abutment	Partial road adjacency: road-adjacency ratio 0.036
	Vegetation (building–vegetation)	Interstitial vegetation: vegetation proportion 0.470, green-adjacency ratio 0.175, peripheral ratio 0.399; both gap-embedded and periphery-surrounding	Interstitial vegetation: vegetation proportion 0.358, green-adjacency ratio 0.192; scattered in building gaps and cluster edges	Sparse vegetation: vegetation proportion 0.171, green-adjacency ratio 0.105, peripheral ratio 0.155
Type comparison		Buildings are dispersed and courtyards are absent; fewer courtyards and buildings than in H02	More clearly defined internal courtyards and clusters than in H01; lower density and more vegetation than in H03	Higher coverage and less vegetation than in H02
Typical sample		 	 	 
Morphological schema				

4 DISCUSSION

In this study, typhoon disturbance risk in two nationally designated traditional villages in western Guangdong was measured using the tree-fall rate derived from pre- and post-typhoon imagery. Following the character–word–phrase–context hierarchy of pattern language, three building-morphology phrase types were identified separately within the high- and low-risk contexts and organized into a risk-stratified pattern language of village building morphology. Previous city-scale wind-damage research has shown that built-environment factors such as building height and landscape pattern are significantly associated with vegetation damage [5], while village spatial forms have also been shown to influence the near-ground wind environment [11]. The pattern identified here—lower disturbance risk in village cores and higher risk at their peripheries—is consistent with both findings and with field-survey evidence that built-environment factors influence wind-damage patterns in East Asia [3]. The character–word–phrase–context approach used in this study further shows that the hierarchical organization of pattern language and methods for extracting morphological typologies can be applied to risk-stratified samples [7-8]. The dense courtyard-enclosure phrase is the most common type in the low-risk context, whereas the dispersed-open phrase dominates the high-risk context; this contrast is consistent with previous findings on form–hazard adaptation in traditional settlements [10-11].

The findings extend previous research in three respects. First, spatial variation in typhoon disturbance can be resolved at the intra-village scale: whereas the cited remote-sensing wind-damage assessments were conducted at the city scale [4-5], both villages studied here have a low-risk core and a high-risk periphery. Second, the risk–form relationship can be quantified through the frequencies of phrase types: clustered and dense courtyard-enclosure phrases together account for about two-thirds of the low-risk samples, whereas dispersed-open phrases account for more than half of the high-risk samples. Third, this study extends the notion of context in pattern language. The cited settlement-morphology studies did not incorporate a hazard dimension [6-8], whereas this study treats risk stratification as the context that defines the sample pools within which phrase types are identified. Pattern language therefore serves as an organizing framework for disaster-risk analysis rather than merely as a descriptive tool.

The pattern of lower risk in village cores and higher risk at village peripheries, together with the differences in phrase composition, describes a spatial association between morphology and risk strata. Pattern language describes spatial form; by itself, it cannot explain why that form occurs [7]. Whether and to what extent dense enclosure reduces typhoon disturbance remains to be evaluated using wind-speed observations, building-damage records, and field-survey data. This paper makes no claim about the disaster-mitigation effectiveness of any morphological type.

5 CONCLUSIONS

Using the tree-fall rate derived from pre- and post-typhoon imagery, this study classified 556 samples from Bayi and Zhoujia Villages into high-, medium-, and low-risk categories. Following the character–word–phrase–context hierarchy of pattern language, it then identified three building-morphology phrase types within each of the low- and high-risk contexts and used them to construct a risk-stratified pattern language of village building morphology. The results show that both villages have lower typhoon disturbance risk in their cores and higher risk at their peripheries. The dense courtyard-enclosure phrase is the most common type in the low-risk context, whereas the dispersed-open phrase dominates the high-risk context; this contrast corresponds spatially to the observed risk pattern. By integrating risk measurement and morphological patterns within a single analytical framework, this study provides a typological basis for morphological control, risk-stratified management, and differentiated disaster-prevention planning for traditional villages in typhoon-prone regions.

COMPETING INTERESTS

The author has no relevant financial or non-financial interests to disclose.

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