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Adaptive spatial genotypes in Thai Lue houses across rural–town–urban contexts: A space syntax study in Xishuangbanna, China

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Abstract

Rapid urbanization in Xishuangbanna has transformed Thai Lue dwellings from traditional timber stilt houses to reinforced concrete structures, raising questions about the continuity of cultural identity. This study investigates the possibility of persistence of the spatial genotype, the deep social logic governing space, by analyzing 24 contemporary houses distributed across rural, town, and urban contexts relative to two traditional prototypes. Using space syntax methodology to quantify spatial sequence, functional integration, and privacy levels, the research reveals that while the architectural phenotype has shifted, the underlying configurational order remains resilient. Analysis of the relative difference factor demonstrates that contemporary dwellings maintain a degree of structural differentiation comparable to the traditional baseline. Furthermore, the study identifies three specific adaptation mechanisms that sustain this logic: topological compression, where the family shrine retains sacred depth through layered segmentation despite morphological compression; functional substitution, where the gatekeeping role shifts from traditional courtyards to transitional interfaces; and vertical displacement, where the social center in urban high-rises decouples from the infrastructure-dominated syntactic core to be re-established in rooftop spaces. These findings suggest that Thai Lue identity persists through a dynamic topological logic capable of inhabiting new typologies, offering a new perspective for assessing vernacular continuity beyond material preservation.

Keywords: Thai Lue; Vernacular architecture; Urbanization; J-graph; Cultural continuity; Spatial genotypes

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1. Introduction

Xishuangbanna Thai Lue (Dai) Autonomous Prefecture is located in southern Yunnan province, China. The Thai Lue (or Dai) are one of the major ethnic groups in the region. This study collectively refers to them as Thai Lue. In terms of building type, Thai Lue dwellings in Xishuangbanna are commonly represented by stilt houses, characterized by timber-and-bamboo structural frames and envelopes, and by spatial organization adapted to a tropical–subtropical climate and everyday living practices.

Previous research has provided relatively systematic accounts of the historical origins of Thai Lue vernacular housing and the formal and spatial composition of its typical styles. Zhu (1992) examined Thai Lue architecture in relation to customs and its broader

social context. Ai (2016) discussed how residential spatial structure relates to cognitive logic and local knowledge. Guo (2025) summarized typological characteristics and generative principles of Thai Lue vernacular architecture in Xishuangbanna from the perspectives of environmental adaptation and cultural origins. These studies form a foundation for understanding how traditional prototypes emerged and how typical forms were composed.

However, under urbanization constraints and material modernization, the replacement of traditional materials and the transformation of structural systems not only change external appearance but also reshape the flexibility of interior space and everyday patterns of use, raising concerns about whether cultural identity may be weakened as forms change (L. Chen, 2014; Zhu, 2020). Many contemporary houses are still largely self-built by Thai Lue residents. Under new structural and construction conditions, how residents continue to express and reproduce cultural identity and everyday social order through contemporary dwelling forms remains insufficiently addressed, particularly with respect to interpretive frameworks and empirical evidence focused on "transformed" contemporary houses.

Heritage and conservation approaches often prioritize the continuity of façades or visual style, while providing limited guidance on the ongoing adaptation of interior spaces. This can create tension between preservation goals and residents' practical and cultural needs (Xian et al., 2024; Tabatabaei Malazi et al., 2020). For this reason, the house needs to be understood as a material carrier of deeper cultural logic. In traditional Thai Lue dwellings, space is not only a floor plan but also an order linked to social rules (Guo & Zhang, 2020), which is translated into specific spatial strategies and interfaces through ideas such as generational hierarchy, reverence for ancestral spirits, and distinctions between insiders and outsiders (Das *et al.*, 2021). A key gap in current research is that, when urbanization brings major changes in land use, structural systems, and living facilities, it is still unclear how Thai Lue residents adapt their spatial use and how Thai Lue identity continues to shape spatial configuration.

2. The cultural genotype: Theoretical framework

This study utilizes the concept of spatial genotype to analyze the dwelling not as a static physical object, but as a dynamic system of social relationships. Originating from Hillier and Hanson's (1984) Social Logic of Space theory, the genotype is defined not by the surface appearance of a building (the phenotype), but by the abstract "deep structure" of social rules that govern how space is organized (Bafna, 2012). It represents the invariant cultural logic that persists even as architectural forms evolve. To rigorously identify this genotype within the changing forms of Thai Lue architecture, this section establishes a theoretical framework that bridges sociocultural insights with quantitative spatial analysis. The framework proceeds in three logical steps: describing the sociocultural basis of the traditional dwelling, extracting the specific cultural imperatives through a literature review, and operationalizing these cultural rules into measurable space syntax metrics.

2.1. Theoretical basis: From social rules to spatial forms

Thai Lue domestic space is repeatedly described as being regulated by a stable set of social rules, such as hierarchy, insider/outsider distinction, and ritual propriety, which become legible through spatial organization, extending beyond the mere use of room labels. At the settlement scale, an "inside/outside" cognitive schema is reinforced through boundary-making practices and graded domains, in which the protected "inside" is associated with order and legitimacy, and the "outside" with exposure and potential risk (Y. Chen & Yu, 2009). At the dwelling scale, this schema is translated into tangible spatial differentiation and controlled access (Ai, 2016).

Figure 1 summarizes how these social rules are embedded in the traditional house prototype. The stilt-house form institutionalizes a vertical hierarchy: the ground level commonly accommodates storage and livestock, while the raised living level concentrates everyday life and key domestic rituals, producing a clear socio-symbolic separation between "lower" and "upper" realms (Zhu, 1992). This domestic hierarchy is also positioned within a broader religious order, for example, through vernacular constraints that keep domestic rooflines lower than the village temple, linking household form to community-scale status and ritual precedence. On the raised level, spatial organization typically follows an outer-to-inner progression consisting of three zones: the semi-open entry or veranda, the shared living zone centered on the hearth, and the deepest inner domain. Lineage and spirit-related elements (e.g., family shrine and symbolic columns) tend to be placed in the most protected zone, ensuring that ritual authority is spatially buffered from the public interface (Oranratmanee, 2018). The transition between shared and inner domains functions as a boundary and access filter: guests may be received in semi-public areas, while movement into the inner room is socially conditioned, translating kinship distance and host–guest relations into configurational constraints (Guo & Zhang, 2024). Furthermore, this traditional spatial logic is not entirely

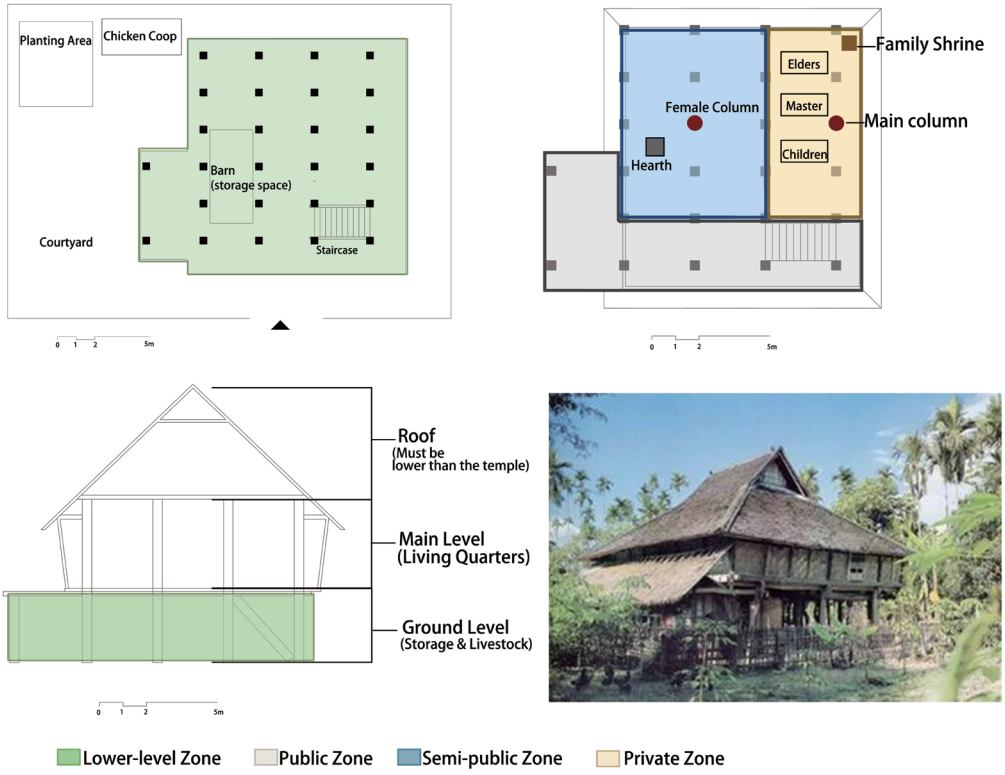


Figure 1. Traditional Thai Lue house. Source: Upper panel: Adapted from Zhu (1992); Lower panel: Adapted from Sun (2013)

static. Even prior to the shift to reinforced concrete, traditional stilt houses exhibited early evolutionary stages, defined in this study as the Transitional Prototype, which incorporated modern functional demands such as independent kitchens, ground-floor parking, and bathrooms positioned on peripheral balconies to separate sanitation from living areas, retaining the original timber framework.

Thai Lue dwelling is maintained not solely by specific objects or labels, but by a consistent spatial logic, such as hierarchy and access rules. This consistency makes the genotype approach ideal for this study. Since materials and functions often change over time, relying on appearance alone can be misleading. Instead, spatial genotype treats the dwelling as a system defined by social relations. This method provides a consistent lens for identifying stable structural principles and quantitatively testing them, even as the houses' physical forms evolve.

2.2. Spatial genotype: Three factors

Building on the preceding evidence that Thai Lue domestic space materializes stable social rules through patterned differentiation and controlled access, this study conceptualizes the Thai Lue dwelling as a spatial genotype governed by three invariant sociocultural imperatives: spatial sequence, key functional spaces, and privacy level. Instead of treating rooms as fixed functional containers, this perspective highlights how everyday movement, co-presence, and restriction are patterned through recurrent spatial relations. Figure 2 schematically illustrates how these three factors integrate to form a cohesive spatial system that physically inscribes social order into the dwelling.

2.2.1. Spatial sequence

Spatial sequence governs the hierarchical ordering of relationships within the household. In Thai Lue society, social interaction is structured by a strict stratification between "elders and juniors" and a spiritual distinction between the "sacred and the secular" (Y. Chen & Yu, 2009; Fan, 2008). This hierarchy is not merely conceptual but requires a spatial translation that prioritizes a linear progression of status.

In the traditional dwelling, this linear progression manifests as a deliberate "outer-to-inner" topological sequence. Movement begins at the public exterior,

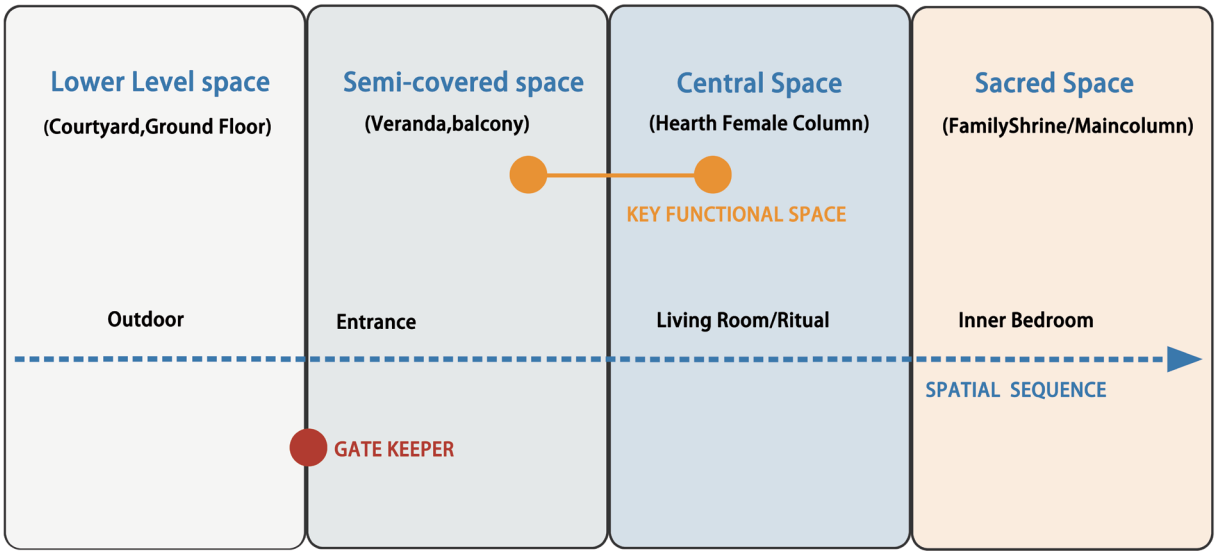


Figure 2. Conceptual diagram of the traditional Thai Lue spatial genotype: spatial sequence, key spaces, and privacy control. Source: Diagram by the authors

transitions through the semi-open veranda or courtyard, proceeds into the communal living area centered around the hearth, and ultimately terminates at the most protected, sacred domain—the family shrine (Zhu, 1992). This sequential deepening ensures that ritual authority and elder privacy are physically shielded from everyday secular activities and outsider intrusion. Consequently, the spatial genotype demands a configuration in which the most sacred or high-status nodes are positioned at the greatest topological depth from the entrance, thereby creating a measurable access hierarchy.

2.2.2. Key functional spaces

Key functional spaces necessitate a spatial focus for collective identity. The concept of a "center" is fundamental to Thai Lue family life, serving as the locus where the household acts as a unified entity (Song et al., 2023). This requirement goes beyond mere functional utility; it demands a space that fosters high-frequency interaction and co-presence among family members.

In Figure 2, these spaces are depicted as linked nodes bridging the semi-covered area and the central hearth zone. Spatially, this cultural rule dictates the need for a "syntactic nucleus"—a convergence point where the paths of individual members naturally intersect. Whether the physical structure is large or small, the genotype requires a configuration that resists fragmentation, ensuring that these specific nodes actively promote the solidarity of the family unit by minimizing segregation among its members.

2.2.3. Privacy level

Privacy level regulates the interaction between the household and the wider community. The boundary between "public" and "private" is not a fixed spatial given but is culturally mediated and can be organized through a range of intermediate interfaces, avoiding absolute separation (Madanipour, 2003). Cultural variation is also reflected in everyday domestic control behaviors, such as users' motivations for shading control, which shape exposure and interaction in the home environment (Abdelwahab, 2023). Thai Lue culture enforces a sharp distinction between "insiders," including family and clan members, and "outsiders," meaning guests or strangers, with strict norms governing access (Guo & Zhang, 2024). This distinction requires a spatial mechanism that filters permeability without blocking it entirely.

The genotype, therefore, demands the existence of "transitional interfaces"—zones that possess the structural capacity to regulate the flow of movement from the public exterior to the private interior. In Figure 2, this is explicitly identified as the gatekeeper at the boundary separating the outdoor level from the semi-covered entrance. These interfaces allow the household to control social contact and preserve the sanctity of the domestic core without resorting to total isolation, ensuring that the boundary between the public and private realms remains distinct, controllable, and socially codified.

2.3. Factors of space syntax

To quantitatively verify whether modern dwellings encode traditional cultural rules, this study establishes a theoretical mapping between the three extracted cultural factors and specific space syntax metrics. This selection is not arbitrary but is grounded in the socio-spatial theories of Hillier and Hanson (1984), ensuring that the mathematical indicators reflect specific social functions and extend beyond mere descriptions of physical geometry. By translating abstract cultural logic into measurable topological properties, this study creates a testing instrument to assess the persistence of the genotype without assuming a priori which specific rooms fulfill these roles. Recent applications of the justified graph (J-graph) method have successfully extracted evolving spatial genotypes in other ethnic minority contexts, such as the transition of Tibetan rural houses toward circulation-dominated layouts under modernization (Lei & Li, 2025). Building on this proven approach, as illustrated in Figure 3, this methodological framework translates the abstract Social Logic of Space theory into a quantifiable J-graph, subsequently mapping specific cultural factors, namely spatial sequence, key functional spaces, and privacy level, to their corresponding syntactic indicators to define the overall spatial genotype. Each factor and its corresponding syntactic indicator are outlined below.

(i) Spatial sequence and depth values: In configurational theory, social hierarchy is often realized through "depth," defined as the topological isolation of space. Mean depth (MD) quantifies this property by calculating the average topological distance of a node from all other nodes in the system. A higher MD value signifies a space that is topologically segregated. To complement MD, step depth (shortest topological path) is utilized to trace the exact sequence of intermediary nodes from the root (entrance area [EA]) to the deepest cultural node (family shrine). While MD identifies which zones are systematically segregated to reflect high status or sanctity, step depth empirically maps the specific access hierarchy and the exact number of topological steps required to breach the sacred domain. This dual-metric approach enables the research to objectively examine whether this hierarchical "deepening" persists across different urbanization contexts.

(ii) Key functional spaces and integration: Syntactically, for a space to function as a "social nucleus," it must facilitate co-presence by being easily accessible from all other spaces in the network. Integration measures this quality of global accessibility or "shallowness." A high Integration value indicates a space that sits at the convergence of movement paths, making it a natural locus for interaction. Consequently, integration is used to locate the mathematical "syntactic core" of the dwelling. By identifying the space with the highest Integration value, this study can assess the nature of the dwelling's center. By determining whether the most integrated point coincides with communal living areas or shifts to purely circulatory infrastructure, the analysis investigates how the spatial structure mediates social solidarity, specifically, whether the mathematical core continues to underpin the functional heart of the home.

(iii) Privacy level and control value (CV): In spatial configurations, privacy is not merely about isolation but about regulating permeability. CV quantifies the degree to which a space controls access to its

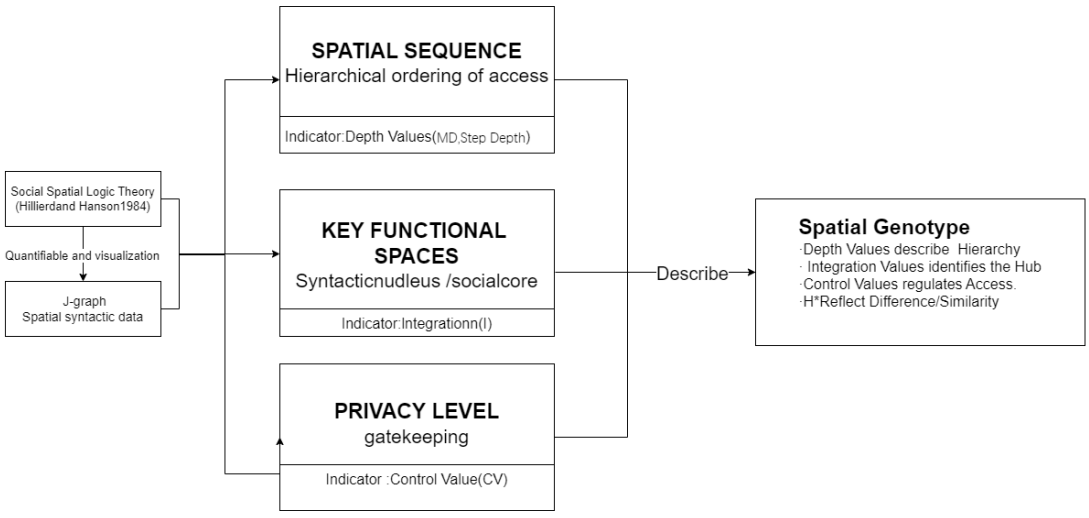


Figure 3. Factors of space syntax. Source: Diagram by the authors
Abbreviation: MD: Mean depth

immediate neighbors; a space with a high CV connects to neighbors that have few other connections, effectively acting as a structural valve. Therefore, the CV is the appropriate metric for identifying the system's "gatekeepers." By analyzing the distribution of high CV scores, this study can locate where the control interface is situated within the graph—whether it remains at the transitional boundary between exterior and interior, or if this regulatory mechanism has effectively disappeared or undergone significant alteration within the modern configuration. This allows for an assessment of how the "insider/outsider" distinction is mechanically enforced by the spatial structure.

In addition to identifying role locations through depth value, integration, and CV, in this study, the relative difference factor H* serves as a global descriptor to quantify the degree of configurational order. Unlike local metrics that describe individual spaces, the H* entropy-based summary is computed from a three-point summary of real relative asymmetry (RRA) values (max/mean/min), allowing for a structural comparison of logic across dwellings regardless of their varying room counts (Ostwald, 2011). Substantively, interpreting H* follows the standard established by Hanson (1998) and Ostwald (2011): a lower H* value (closer to 0) indicates a "structured" or strongly differentiated configuration, where a clear hierarchy of integration exists. Conversely, a higher H* value (closer to 1) suggests a "homogenized" or weak differentiation, implying that integration values are distributed more evenly across the spatial network. Tracking H* across the rural–town–urban gradient thus provides a critical lens for determining whether the Thai Lue spatial genotype is undergoing structural mutation (becoming significantly more homogeneous or polarized) or maintaining its configurational stability amidst physical transformation.

Synthesizing these local indicators with the global measure of configurational logic establishes a methodology for decoding the underlying structure of the dwelling. This quantitative framework examines how traditional spatial rules are preserved, adapted, or eroded within the built environment of urbanizing Xishuangbanna, capturing both the changing roles of individual spaces and the continuity of the overall system.

Consequently, this study is driven by two primary research objectives:

(i) Describing the Thai Lue spatial genotype: To define the core organizational properties of the Thai Lue spatial genotype—specifically its spatial sequence, key functional spaces, and privacy controls—and to examine how these characteristics manifest across differing rural, town, and urban contexts.

(ii) Investigating adaptation strategies: To explore how the underlying social logic interacts with modern architectural constraints, and to identify the specific spatial strategies residents employ to resolve conflicts between traditional cultural requirements and contemporary living environments.

3. Case, data, and methods

This study is structured into three primary stages: case selection, data collection and processing, and a multi-stage analytical framework designed to decode and compare the spatial genotype of Thai Lue houses.

3.1. Case selection

This study employs a purposive, stratified multiple-case study design to examine how the spatial logic of Thai Lue domestic space evolves alongside urbanization. Six settlements in Xishuangbanna, China, were selected to represent distinct development contexts: Mandou and Manla (urban), Mane and Manzhang (town), and Mansailong and Manxiu (rural). In the urban context, land scarcity has driven a shift to high-rise private housing, in which rental units are located on lower floors, with owner-occupied residences confined to upper levels. The town context, located closer to the city, has fully transitioned to multi-story reinforced concrete structures, whereas the rural context retains a hybrid landscape in which traditional timber dwellings coexist with modern forms. Accordingly, these categories define three distinct study contexts based on administrative status (State Council, 2014) and prevailing built-form typologies. This stratified structure enables systematic cross-context comparison while holding ethnic and regional conditions constant.

Within each settlement, dwellings were selected using strict inclusion criteria to ensure analytical comparability. The study targeted reinforced concrete houses built after 2000 to reflect current construction practices. Crucially, to address the research objective on social hierarchy, the sampling focused on multigenerational households, typically comprising three generations living in the same household. This demographic criterion ensures that spatial analysis captures the full complexity of inter-generational interaction and ritual practice. Consequently, continuous occupation by Thai Lue families was required to verify that the layouts reflect ongoing sociocultural norms, unaffected by temporary rental use.

A total of 24 contemporary cases were selected, comprising four per settlement and eight per context. This

sample follows Yin's (2018) replication logic for analytical generalization to validate theoretical propositions through recurring spatial patterns. To assess architectural evolution, two traditional references were established as diachronic benchmarks. The Pure Prototype represents the historical Thai Lue timber stilt house layout that remained stable over a very long historical period. As documented by Zhu (1992), factors including geographic isolation, adaptation to the local climate, and a self-sustaining agricultural economy enabled these traditional spatial patterns to persist across centuries. Derived from the models recorded by Zhu (1992) and Guo (2025), this prototype establishes the original configurational baseline characterized by a unified central hearth and a protected inner shrine. Following this, the Transitional Prototype captures the morphological changes prior to the adoption of reinforced concrete structures. This prototype is derived from cases documented in *Yunnan Vernacular Dwellings* (Yunnan Provincial Design Institute, 2018), established specifically through records of independent kitchen extensions and field surveys of bathroom addition locations, alongside cases analyzed by Guo (2025). It illustrates how early modern functional demands, including independent kitchens, balcony bathrooms, and ground-floor parking, were initially integrated into the traditional topological logic. Consequently, this dual-baseline approach provides a framework to measure configurational deviations in the contemporary adaptations.

3.2. Data collection and processing

Based on field surveys and data collection, each surveyed plan is translated into a J-graph. Circles represent spatial units. Lines represent direct walkable connections (doorways, open passages, stairs, or elevator links). The entrance node is used as the root. Vertical order indicates depth, defined as the number of access steps from the entrance.

The outdoor space is organized as a courtyard system. The courtyard core is coded as C. Stable outdoor destinations are coded as separate nodes when they are clearly identifiable and used repeatedly. In Figure 4, these nodes are PA (planting area), SC (semi-covered area), and CC (chicken coop). Links follow observed accessibility. Nodes typically connect to C, while direct links are retained where present.

Indoor space is coded primarily by rooms and circulation spaces. Fixed ritual/spiritual loci are coded as independent nodes when they are stable and consistently used. In Figure 5, the family shrine is coded as FS within EB (elders' bedroom), so FS connects only to EB. LR (living room) connects directly to IE (indoor entrance) and to key domestic nodes, including SG (second generation bedroom), BR (bathroom), and S (staircase). To prevent topological redundancy, multiple rooms with identical socio-functional properties and access levels, such as several bedrooms for the same generation, are aggregated into a single node, focusing the analysis on structural relations rather than room quantities.

Multi-story houses are encoded with a vertical spine and floor distribution nodes. The elevator is coded as EL. The entry sequence is E (entrance)–L (lobby)–EL. Lower-level non-residential space is compressed as CO (commercial area). In Figure 6, the residential floors are represented by 13thTGF, 14thSGF, and 15thEF, each of which links to sampled key spaces such as LR (living room) and B (bedroom). The kitchen and bathroom are combined as FA (facility space: kitchen + bathroom). When ritual activity is integrated into the living room, it is noted as LR (RA).

3.3. Analytical framework

Grounded in the theoretical and quantitative principles of space syntax (Hillier & Hanson, 1984), this study employs an analytical framework designed to capture both the measurable properties and the underlying cultural logic of spatial organization. The analysis proceeds along two complementary comparison axes: first, a primary cross-contextual examination of the 24 contemporary houses across the rural–town–urban gradient to identify patterns

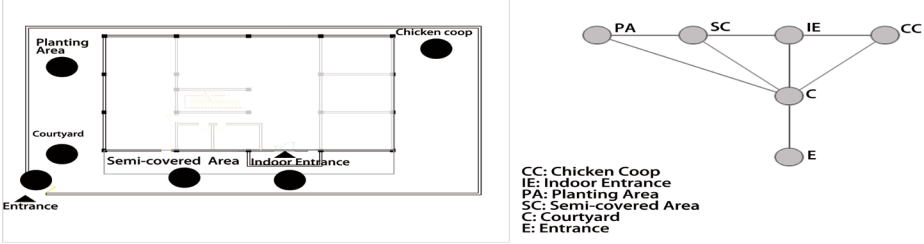


Figure 4. Protocols for J-graph construction: Outdoor. Source: Drawing by the authors

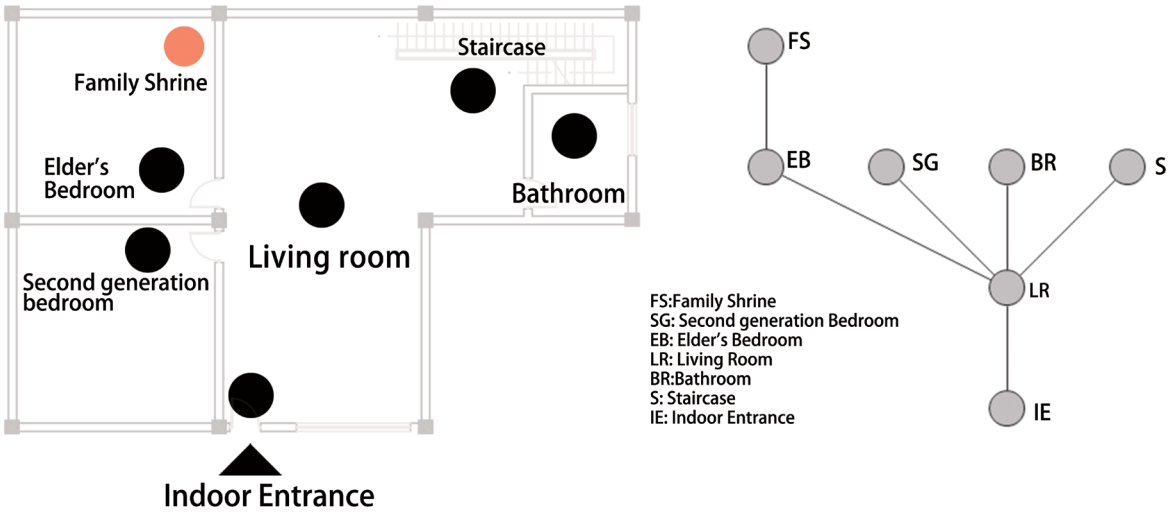


Figure 5. Protocols for J-graph construction: indoor. Source: Drawing by the authors

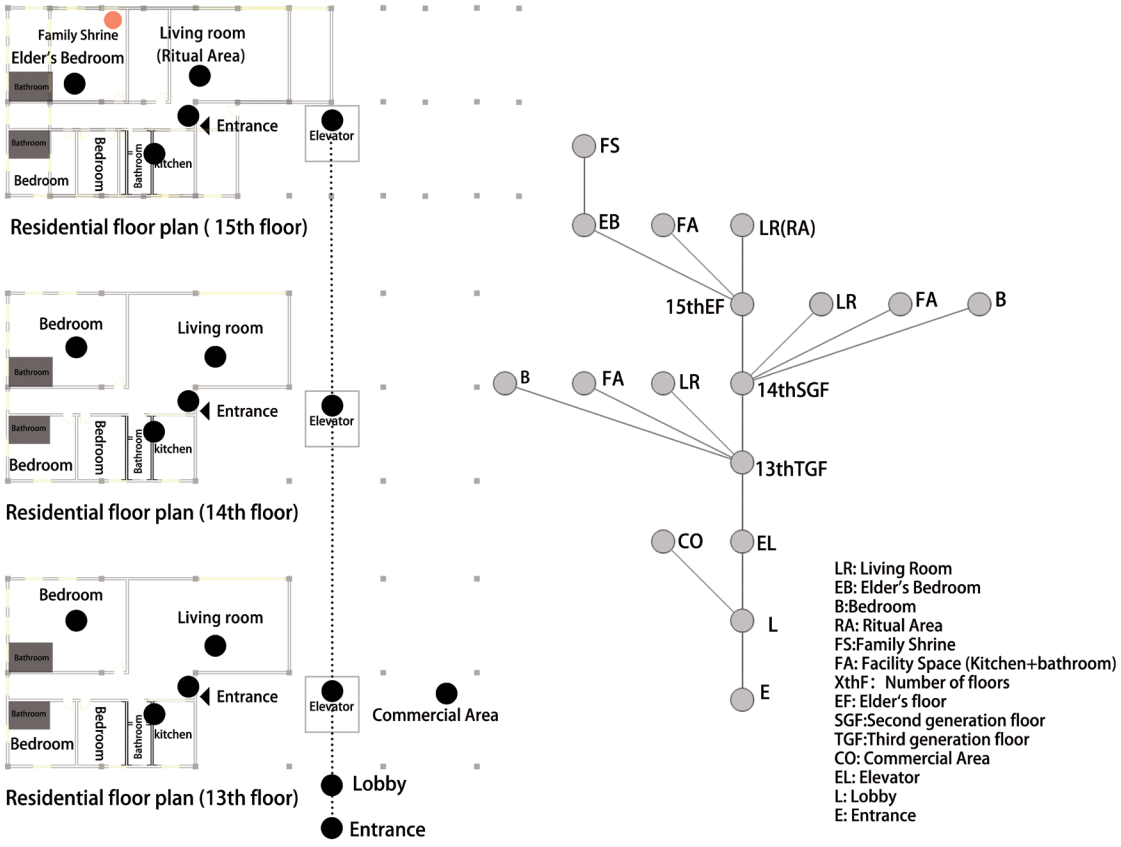


Figure 6. Protocols for J-graph construction: vertical spatial. Drawing by the authors

of configurational continuity and adaptation under modern constraints; and second, a diachronic benchmarking against the traditional prototypes. In this latter axis, traditional cases function not as a distinct context but as a baseline, allowing contemporary genotypes (spatial sequence, key functional spaces, and privacy level) to be interpreted specifically in terms of their deviation from the historical prototype. To ensure rigorous comparability across these axes, all syntactic metrics, Depth Values (MD, step depth), integration, CV, and difference factor (H/H*), were computed using identical graph definitions and normalization procedures for both contemporary and traditional datasets.

3.3.1. Component analysis: Decoding the genotype elements

This initial stage focuses on deconstructing each house's spatial organization into the three core components of the genotype by translating the theoretical concepts into measurable space syntax metrics.

The spatial sequence is operationalized through MD and step depth. MD calculates the average topological steps from all other nodes to map the gradient from shallow, public zones to deep, segregated sectors. This metric is calculated using **Equation 1**:

$$MD_i = \frac{\sum_{j=1}^{k} d(i,j)}{k-1} \quad (1)$$

where i represents the original space being analyzed, j represents any destination space, k is the total number of spaces in the system, and $d(i, j)$ denotes the shortest distance (number of steps) from i to j. Consequently, the step depth from the EA to the deepest spatial nodes is isolated as $d(EA, Max)$, representing the longest shortest-path sequence in the system. This specific metric maps the exact sequence of boundary-regulating nodes required to access the most restricted domains, allowing us to intuitively observe the spatial sequence from the exterior to the interior.

Key functional spaces are evaluated using RRA and its inverse, integration (I). Because raw depth measures vary with system size, the MD is normalized by the diamond-graph constant D_k (i.e., the RRA value of a diamond-shaped graph with k spaces) to yield RRA_i. Integration is then defined as the inverse of RRA_i, so that higher values indicate higher global accessibility. This is calculated using **Equation 2**:

$$I_i = \frac{1}{RRA_i} = \frac{D_k(k-2)}{2(MD_i-1)} \quad (2)$$

where MD_i is the MD of space i, k is the total number of spaces (nodes), and D_k is the size-normalizing constant. In this study, the syntactic core is defined as the space with the maximum I (equivalently, the minimum RRA), representing the highest potential for movement and accessibility in the configuration. By comparing the location of this syntactic core with the observed functional center, the analysis assesses the convergence or divergence between the building's configurational "efficiency logic" and the household's everyday "living logic."

The privacy level is evaluated using the CV, which identifies high-influence nodes that act as "gatekeepers." This value measures the degree to which a space controls access to its immediate neighbors and is calculated using **Equation 3**:

$$CV_i = \sum_{j=1}^{n} \frac{1}{C_j} \quad (3)$$

where n is the number of immediate neighbors of space i, and C_j represents the connectivity (total number of connections) of neighbor j.

3.3.2. Genotype analysis

This stage synthesizes the component findings from Stage 1 into a holistic genotype to enable systematic comparison. For each dwelling, the computed measures are integrated into a representative spatial genotype profile, which summarizes the relational structure by jointly identifying the syntactic core, the depth-based hierarchical sequence, and the primary "gatekeepers."

Comparative analysis is conducted along two complementary axes. First, the 24 contemporary profiles are compared across the three urbanization contexts (rural, town, and urban) to identify patterns of continuity and adaptation. This cross-context comparison employs a dual method: (i) comparative structural analysis examines whether key syntactic roles (core, deep domains, and gatekeepers) remain associated with comparable space types or shift toward circulation-only nodes; and (ii) quantitative metric analysis compares the values of key syntactic measures for syntactically corresponding spaces to quantify the magnitude of spatial adaptation.

Furthermore, two traditional reference sets (the Pure Prototype and the Transitional Prototype) are incorporated as external benchmarks to contextualize the contemporary findings. The traditional cases are not treated as an additional urbanization context; rather, they provide a baseline range of configurational tendencies associated with the traditional evolution. See **Section S2** for the traditional sample plans and the corresponding

J-graphs. Accordingly, contemporary genotype profiles are interpreted in terms of the degree and direction of deviation from these benchmarks for each genotype element (spatial sequence, key functional spaces, and privacy level). All metrics are computed using the same J-graph construction rules and normalization procedures for both contemporary and traditional plans, ensuring that observed differences reflect configurational variation without the interference of coding inconsistencies.

Finally, to assess the coherence of the cultural pattern, this study employs the difference factor (H) and its normalized form, the H*. Grounded in Hillier and Hanson's (1984) notion of structured inequality, H and H* summarize the overall differentiation of syntactic values within a configuration, representing how unevenly values are distributed across spaces. In this study, these indices are used as global descriptors to support cross-case comparison among dwellings of different sizes and are interpreted alongside the role-based genotype profile, functioning as comparative tools distinct from direct measures of cultural rules. Accordingly, H quantifies differentiation through an entropy-based summary of syntactic values, while H* provides a size-normalized form of H for rigorous comparability across systems. Following Hillier and Hanson (1984) and consistent with a recent residential space application (Song et al., 2023), H is computed using a three-point summary of RRA values—namely the maximum (a), mean (b), and minimum (c)—with t = a + b + c as shown in **Equations 4** and **5**:

$$H = -\left[\frac{a}{t}\ln\left(\frac{a}{t}\right)+\frac{b}{t}\ln\left(\frac{b}{t}\right)+\frac{c}{t}\ln\left(\frac{c}{t}\right)\right] \quad (4)$$

$$H^{*} = \frac{H-\ln 2}{\ln 3-\ln 2} \quad (5)$$

4. Results

This section presents the quantitative results from the spatial syntactic analysis of the expanded dataset, comprising 24 contemporary Thai Lue dwellings across urban, town, and rural contexts, alongside two traditional reference baselines (the Pure Prototype and the Transitional Prototype). To address previous methodological limitations and ensure robust comparative analysis, all 26 layouts were translated into J-graphs using identical root-node definitions (EA) and coding protocols.

The findings are structured around the four primary syntactic metrics that operationalize the spatial genotype: MD and step depth (spatial sequence), integration (key functional spaces), CV (privacy control), and the H* (global differentiation). The full set of floor plans and corresponding J-graphs for the 24 contemporary cases is provided in Section S1, while the traditional prototypes are detailed in Section S2.

4.1. Spatial sequence and depth hierarchy

Spatial sequence, which reflects the hierarchical ordering of domestic and sacred domains, is evaluated using MD and the specific step depth from the EA to the deepest space. As summarized in Table 1, the MD data identify the nodes occupying the deepest topological positions across the 24 analyzed cases and 2 traditional samples. The maximum MD values consistently correspond to the most private, terminal, or restricted spaces within the home.

4.1.1. Topological sequence from the entrance to the deepest spatial nodes

To present the spatial order and access hierarchy from the public boundary to the deepest domestic domains, Table 2 details the shortest topological sequences from the EA at Depth 0 to the nodes located at the maximum depth for each case. This approach maps the complete structural layering of the dwellings without pre-selecting a specific functional destination.

The data shows a structural alignment with the traditional "outer-to-inner" spatial progression across all contexts. In the traditional prototypes, the sequence systematically transitions from the public boundary through semi-open entry zones to shared living spaces, culminating in the deepest inner domain at Depth 5. In contemporary cases, this spatial rhythm, progressing from transitional buffers to communal or distributive nodes, and finally to terminal spaces, is structurally maintained. The absolute maximum depth ranges from 5 to 8 steps, consistently housing restricted or private domains, including ritual spaces, private bedrooms, and terminal auxiliary areas (such as specific roof zones or private bathrooms).

Regarding the specific intermediary nodes composing these sequences, rural and town contexts generate a maximum depth of 6 to 8 steps primarily through horizontal and transitional spaces (e.g., courtyards → semi-covered areas/indoor entrances → living rooms → staircases). Conversely, in the Urban context, the sequence reaches a maximum depth of 5 to 7 steps through vertically extruded infrastructural nodes (e.g., lobbies → elevators/stairs → floor halls) before connecting to the deepest internal rooms.

4.2. Key functional spaces and the syntactic core

The syntactic core, representing the natural locus for social

Table 1. Maximum mean depth (MD) across 24 contemporary cases and 2 traditional prototypes

Context	Case ID	Node with maximum MD	Max MD value
Traditional	Pure Prototype	FS	6.07
	Transitional Prototype	FS	5.65
Rural	Mansailong 01	FS	4.94
	Mansailong 02	FS	4.74
	Mansailong 03	FS	4.89
	Mansailong 04	FS	4.00
	Manxiu 01	FS/R	4.78
	Manxiu 02	FS/BR2	4.82
	Manxiu 03	BR2 (FS is 5.10)	6.05
	Manxiu 04	SR (FS is 4.68)	5.18
Town	Mane 01	FS	5.00
	Mane 02	FS	5.27
	Mane 03	FS	4.33
	Mane 04	FS	4.92
	Manzhang 01	FS/BR2	5.06
	Manzhang 02	CO (FS is 4.00)	4.36
	Manzhang 03	FS/BR2	4.62
	Manzhang 04	BR2 (FS is 5.27)	6.22
Urban	Mandou 01	FS	4.15
	Mandou 02	FS	4.38
	Mandou 03	FS	4.27
	Mandou 04	FS/R gathering	4.58
	Manla 01	FS	3.61
	Manla 02	EA/CO	3.54
	Manla 03	FS	3.83
	Manla 04	FS	4.00

Abbreviations: BR: Bathroom; CO: Commercial area; EA: Entrance area; FS: Family shrine; R: Roof; SR: Storeroom

convergence, is identified by the node with the maximum integration value. As shown in Table 3, comparing the 24 contemporary cases against the traditional baselines reveals a distinct configurational divergence driven by urbanization.

In the traditional prototypes, the syntactic core coincides with the communal living spaces (the courtyard, semi-covered area, or living room). This functional unity persists in the rural context, where 7 out of 8 cases (Mansailong 01–04; Manxiu 01–03) locate their highest integration values within the LR or IE. Here, the mathematical center aligns perfectly with the social heart of the home.

The town context represents a transitional phase. While half of the cases (Mane 01–02; Manzhang 01) maintain the Living Room as the syntactic core, the other half (Mane 03; Manzhang 02–04) see the core shift or split towards vertical circulation (staircase) and corridors, reflecting the growing influence of multi-story distribution.

In the urban context, a complete structural inversion occurs. Across all eight urban cases (Mandou and Manla series), the most integrated nodes are exclusively infrastructural—elevators (EL), staircases (S), or floor landings (e.g., 6thF, 7th SGF). The mathematical core is entirely decoupled from the communal living spaces, dictated instead by the necessity of vertical movement in high-rise typologies.

To visualize this structural inversion, Figure 7 illustrates the shifting trajectory of mean Integration values between communal spaces (e.g., living rooms, courtyards) and circulation infrastructure (e.g., staircases, elevators)

Table 2. Topological sequence from the entrance area to the deepest spatial nodes

Context group	Case ID	Max depth	Deepest node(s)	Shortest path sequence to the deepest node(s)
Traditional baselines	Pure Prototype 1	5	FS	EA → C → LR → SG → EB → FS
	Transitional Prototype 2	5	FS	EA → C → LR → SG → EB → FS
Urban context	Mandou 01	7	FS	EA → L → EL → 13thTGF → 14thSGF → 15thEF → EB → FS
	Mandou 02	6	CA, FG, LC, FS	EA → L → S → 7thSGF → 8thEF → [TF(9th) → CA/FG/LC, EB → FS]
	Mandou 03	5	PL, LK, SR, FS	EA → S → 5thSGF → 6thEF → [TF(7th) → PL/LK/SR, LR(RA) → FS]
	Mandou 04	6	PA, LK, SR, FS	EA → EL → 6thTGF → 7thSGF → 8thEF → [S → PA/LK/SR, EB → FS]
	Manla 01	5	FS	EA → S → 6thF → LR(RA) → EB → FS
	Manla 02	5	FS, K, BR	EA → S → 5thF → LR(RA) → [EB → FS, B → K/BR]
	Manla 03	5	FS	EA → S → 7thF → LR → EB → FS
	Manla 04	5	FS	EA → S → 6thF → LR(RA) → EB → FS
Town context	Mane 01	7	FS	EA → SC → IE → LR → S → LR(RA) → EB → FS
	Mane 02	7	FS	EA → SC → IE → LR → S → LR(RA) → EB → FS
	Mane 03	6	FS	EA → SC → S → IE → LR(RA) → EB → FS
	Mane 04	8	FS	EA → C → SC → LR → S → V(RA) → LR → EB → FS
	Manzhang 01	7	FS, BR	EA → SC → IE → LR → S → LR(RA) → [EB → FS, B → BR]
	Manzhang 02	6	FS	EA → S → B → IE → LR(RA) → EB → FS
	Manzhang 03	7	FS, BR	EA → C → IE → LR → S → LR(RA) → [EB → FS, B → BR]
	Manzhang 04	8	FS	EA → C → SC → IE → LR → S → LR(RA) → EB → FS
Rural context	Mansailong 01	8	FS	EA → C → SC → IE → LR → S → RA → EB → FS
	Mansailong 02	8	FS	EA → C → SC → IE → LR → S → LR(RA) → EB → FS
	Mansailong 03	8	FS	EA → C → IE → LR → S → B → RA → EB → FS
	Mansailong 04	6	FS	EA → C → SC → IE → LR(RA) → EB → FS
	Manxiu 01	7	FS, R	EA → SC → IE → LR → S → CD → [EB → FS, S → R]
	Manxiu 02	7	FS, BR, B	EA → C → IE → LR → S → LR(RA) → [EB → FS, B → BR/B]
	Manxiu 03	8	BR, FS	EA → C → SC → LR → S → CD → [K → B → BR, LR → EB → FS]
	Manxiu 04	7	FS	EA → C → SC → S → CD → LR(RA) → EB → FS

Abbreviations used in the topological sequences: B: Balcony; BR: Bathroom; C: Courtyard; CA: Cultivation area; CD: Corridor; EA: Entrance area; EB: Elder's bedroom; EF: Elder's floor hall; EL: Elevator; FG: Family gathering; FS: Family shrine; IE: Indoor entrance; K: Kitchen; L: Lobby; LC/LK: Large kitchen; LR: Living room; PA/PL: Planting area; R: Roof; RA: Ritual area; S: Staircase; SC: Semi-covered area; SG: Second generation bedroom; SGF: Second generation floor hall; SR: Store room; TF: Top floor; TGF: Third generation floor hall; V: Verandah. Brackets [...] indicate branching paths to multiple deepest nodes.

Table 3. Shift of the syntactic core (maximum integration [Max I]) across contexts

Context	Dominant syntactic core location (Max I)	Interpretive typology
Traditional	LR/SC	Communal interior/threshold ensemble
Rural	LR/IE	Communal interior nucleus
Town	Mixed: LR, IE, S, or B	Transitional (communal + vertical distribution)
Urban	EL/S/floor landings (with isolated exception in LR)	Purely infrastructural/vertical circulation

Abbreviations: B: Balcony; EL: Elevator; IE: Indoor entrance; LR: Living room; S: Staircase; SC: Semi-covered area.

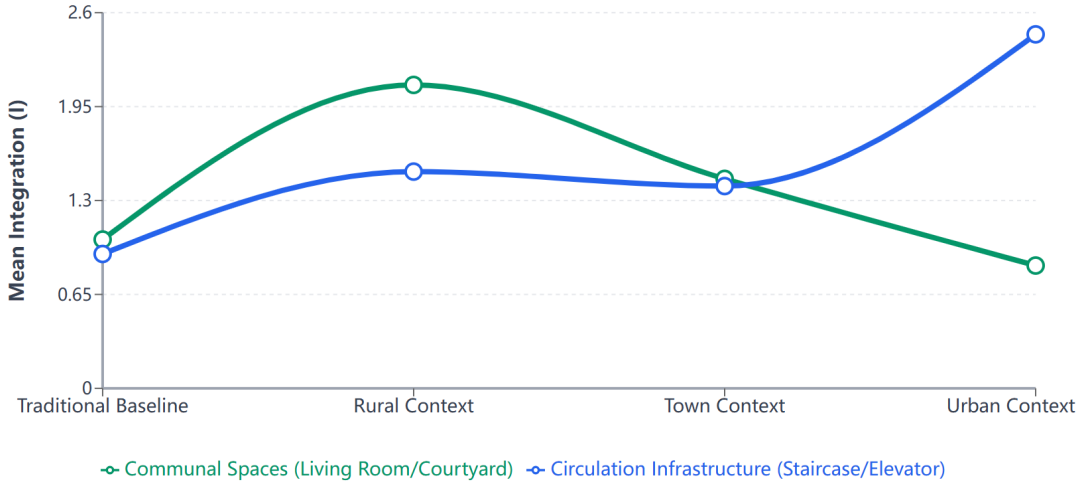


Figure 7. The shift of the syntactic core: mean integration (I) values of communal spaces versus circulation infrastructure across urbanization contexts. Source: Graph by the authors

across the four contexts. The resulting "scissors difference" quantitatively confirms the vertical displacement strategy, wherein the mathematical core explicitly decouples from the social heart of the home as urbanization intensifies.

4.3. Privacy control and transitional interfaces

The capacity of space to regulate permeability and act as a "gatekeeper" between insiders and outsiders is measured by the CV. The distribution of peak CV scores in Table 4 illustrates how residents adapt boundary regulation mechanisms to changing spatial constraints.

In both the Pure and Transitional Prototypes, the courtyard (C) acts as the primary gatekeeper (highest CV). This logic is robustly maintained in the rural context, where the Courtyard or the adjacent Living Room retains the highest CVs (e.g., CV = 5.50 in Mansailong 01 and 03), functioning as the primary filter for social reception.

As land becomes constrained in the town context, the outdoor courtyard shrinks or disappears. Consequently, the gatekeeping function undergoes a functional substitution. In 5 out of 8 town cases (Mane 01–04; Manzhang 01), the peak CV shifts to the semi-covered area (SC), intensifying its role as a transitional buffer to compensate for the loss of the courtyard. In the remaining three cases, the primary gatekeeping role is either maintained by a retained courtyard (Manzhang 03, 04) or distributed between the balcony and living room (Manzhang 02), reflecting an ongoing structural transition in boundary regulation.

In the Urban context, where individualized outdoor or semi-outdoor buffers are structurally impossible, control is relocated to shared architectural infrastructure. The highest CVs in the Mandou and Manla cases are concentrated in lobbies (L), staircases (S), and specific floor hallways (e.g., 13thTGF, LR[RA]). This indicates that privacy control is now enacted through vertically segmented thresholds, delimiting private residential strata from lower-level commercial or rented spaces.

This functional substitution is quantitatively mapped in Figure 8, which demonstrates the migration of peak CVs across different spatial categories. The data visually confirms the sequential transfer of the gatekeeping role: originating in the traditional courtyard, intensifying in

Table 4. Migration of the "gatekeeper" across contexts

Context	Primary gatekeeper nodes (max control value)	Mechanism of boundary regulation
Traditional	C	Outdoor distributor/primary interface
Rural	C/LR	Outdoor-to-indoor transitional interface
Town	SC/C/B	Intensified semi-outdoor buffer
Urban	L/floor hallways/staircase	Vertical stratification/infrastructural threshold

Abbreviations: B: Balcony; C: Courtyard; L: Lobby; LR: Living room; SC: Semi-covered area

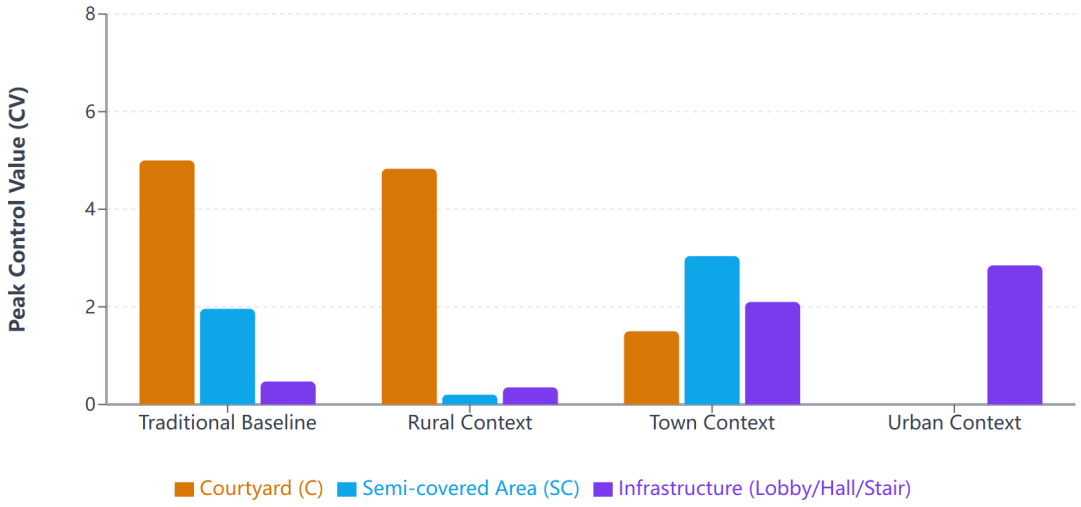


Figure 8. Migration of the gatekeeper: Distribution of peak control values across primary transitional interfaces

the semi-covered area within townhouses, and ultimately being absorbed by shared architectural infrastructure in urban high-rises.

4.4. Global configurational differentiation

To assess whether the overall "social logic" of the Thai Lue dwelling remains consistent despite local adaptations, the H* was calculated for all 26 configurations in Table 5. H* functions as a size-normalized measure of overall configurational differentiation, where values closer to 0 indicate strong hierarchical structure, and values closer to 1 indicate homogenization.

The Pure Prototype (H* = 0.729) and the Transitional Prototype (H* = 0.768) establish a baseline of moderate differentiation inherent to traditional Thai Lue spatial logic. Analysis of the 24 contemporary cases reveals a stable global structure. The pooled mean for the contemporary dataset is 0.723. By context, the mean H* values are 0.736 for rural, 0.733 for town, and 0.697 for urban.

The quantitative results indicate no pronounced differences in H* values across the rural, town, and urban contexts compared to the traditional baseline. The slight decrease in the Urban mean reflects the centralized nature of elevator and staircase cores in high-rises, which, structurally, increases the efficiency of mathematical integration. However, the overall variance remains limited. This stability demonstrates that while the architectural phenotype, including materials, room layouts, and verticality, has transformed, the spatial configurations have not shifted toward homogenization. Instead, contemporary dwellings maintain a baseline degree of "structured inequality" consistent with the traditional genotype, providing the overarching configurational foundation required to sustain the specific cultural boundaries and hierarchical sequences identified in the local metric analysis.

5. Discussion

To bridge the quantitative findings with the sociocultural dimensions of Thai Lue life, this section establishes the interpretive logic guiding the discussion. The Space Syntax metrics employed, MD, step depth, integration, CV, and the H*, quantify specific configurational capacities. These capacities comprise topological segregation, global accessibility, local regulation, and overall structural

Table 5. Summary statistics of the relative difference factor (H*)

Context	*N* (Cases)	Mean H*	Min–Max range of H*
Rural	8	0.736	0.671–0.789
Town	8	0.733	0.656–0.801
Urban	8	0.697	0.651–0.744
Traditional	2	0.748 (Mean)	0.729 (Pure)–0.768 (Transitional)

differentiation. These mathematical indices do not directly measure cultural meanings. Therefore, cultural imperatives, including ritual propriety, intergenerational hierarchy, family solidarity, and the insider/outsider distinction, are inferred from the identification of recurrent relational roles within the configuration. By treating syntactic patterns as structural correlates of social requirements and synthesizing them with field observations and established literature, this section decodes how the spatial genotype persists through structural invariance and adapts through specific configurational strategies across changing architectural forms.

5.1. Decoding the persistence of the spatial genotype: Structural invariance

The cross-contextual analysis demonstrates that the core organizational principles of Thai Lue domestic culture remain highly legible in contemporary reinforced-concrete dwellings. This persistence challenges the prevalent narrative that modernization and material substitution inevitably lead to the homogenization of vernacular architecture (L. Chen, 2014; Zhu, 2020). The findings prove that cultural continuity is maintained through structural invariance.

5.1.1. The topological nature of sacred hierarchy

A fundamental tenet of Thai Lue society is the strict stratification between the secular public realm and the sacred ancestral domain (Fan, 2008). Table 1 shows that the Family Shrine does not represent the absolute maximum MD in every case. Syntactically, utility spaces such as the storeroom or bathroom function as single-access terminal nodes, accumulating high topological depth. Field interviews in Manxiu explain the specific placement of the bathroom. Traditional Thai Lue practices associate sanitation with impurity, requiring these activities to occur outside the settlement. The pure traditional prototype lacks an indoor bathroom. When introduced in the Transitional Prototype, the bathroom was placed on a distant balcony to separate it from the living areas. Contemporary cases inherit this spatial logic, positioning the bathroom at the topological periphery. Excluding these specific utility nodes, the Family Shrine consistently occupies the deepest topological tier among all primary domestic and cultural spaces.

By maintaining the shrine at the terminal end of the spatial sequence, contemporary dwellings reproduce the traditional outer-to-inner progression. This aligns with Hillier and Hanson's (1984) assertion that spatial depth is a primary mechanism of social segregation. The findings confirm that sacredness in the Thai Lue context is operationalized as a structural condition of inaccessibility. Even as the architectural form shifts from horizontal timber compounds to vertical concrete high-rises, the configurational ordering ensures that ritual authority remains systematically buffered from the public interface. This structural persistence of sacred domains is not isolated to the Thai Lue; a recent study on Tibetan vernacular dwellings similarly found that chanting halls consistently maintain low integration and isolated topological positions across historical periods to preserve spiritual privacy (Lei & Li, 2025). This suggests a broader cross-cultural mechanism where religious sanctity is universally encoded through topological depth.

5.1.2. The resilience of the insider/outsider cognitive schema

Privacy in Thai Lue culture is conceptualized as the active regulation of permeability to manage the distinction between insiders and clan members versus outside guests (Ai, 2016; Guo & Zhang, 2024). The syntactic analysis of CVs substantiates that this graded permeability persists as a core structural property.

While the traditional prototype relies on the courtyard as the primary spatial valve, contemporary configurations demonstrate that the regulatory function persists even after the physical loss of the courtyard. The concentration of local control systematically migrates to alternative transitional nodes, specifically semi-covered areas in townhouses or infrastructural lobbies in urban high-rises. This migration indicates that the Thai Lue spatial genotype inherently demands a filtered interface to mediate host-guest relations. The resilience of this valving mechanism supports Madanipour's (2003) theory that boundaries are culturally mediated and highly adaptable, proving that the social logic of access control remains intact despite morphological transformations.

5.1.3. Resistance to configurational homogenization

To assess the overarching stability of the spatial logic, the H^* serves as a macro-level indicator of structured inequality (Ostwald, 2011). The traditional baseline indicates that the Thai Lue genotype naturally exhibits a specific degree of spatial differentiation, as reflected in a baseline H^* range of 0.729 to 0.768.

The contemporary cases yield an average H^* of 0.723, showing no significant deviation from this traditional range across the rural-town-urban gradient. In the context of spatial syntax, this absence of a pronounced difference is a critical structural finding. It provides quantitative evidence against the prevalent assumption that modernization and material substitution inevitably lead to spatial homogenization.

If the traditional social order had collapsed under urban constraints, modern layouts would have trended toward H^* values closer to 1, indicating a generic, mathematically undifferentiated grid in which all rooms share similar accessibility. Instead, the stable H^* values confirm that contemporary self-built housing actively resists this homogenization. These dwellings maintain the baseline level of configurational inequality required to enforce traditional family dynamics, such as the separation of the sacred and the secular and the distinction between insiders and outsiders. The spatial genotype has successfully migrated into new material shells, preserving its overarching structural order without being flattened by modern architectural standardization.

5.2. Mechanisms of spatial adaptation: Re-encoding cultural relations

While the genotype persists, it does not do so passively. The transition from rural expanses to urban density introduces severe structural and spatial constraints. The findings reveal that Thai Lue residents act as active agents, employing sophisticated configurational strategies to negotiate the transition between cultural imperatives and modern limitations.

5.2.1. Topological compression: Reconstructing depth under spatial scarcity

As rural compounds transition into compact urban plots, the physical metric distance available to separate the secular entrance from the sacred inner sanctum is drastically reduced. According to traditional spatial logic, this compression threatens to collapse the necessary buffer zone and potentially violate ritual propriety.

To counteract this, residents employ a strategy of topological compression. By manipulating internal partitions, introducing short corridors, and utilizing segmented stair turns, the configuration artificially inflates the topological distance within a compressed physical footprint. This strategy demonstrates profound vernacular intelligence. When physical distance is no longer available to express reverence, topological complexity is deployed as a structural substitute. It allows the dwelling to satisfy the cultural requirement for a deep sacred sequence without requiring the expansive footprint of a traditional stilt house.

5.2.2. Functional substitution: Preserving boundary control

The observed migration of the primary gatekeeping nodes illustrates a strategy of functional substitution. Transitional interfaces are culturally indispensable for filtering outsiders. When urbanization eliminates the traditional courtyard, the spatial system faces a potential breakdown in privacy regulation.

Instead of abandoning the boundary logic, the configurational role is reassigned to the next available transitional space. In townhouses, the semi-covered area absorbs this function and intensifies its role as a buffer. In urban high-rises where private outdoor space is entirely absent, infrastructural nodes are co-opted to serve as the new gatekeepers. This substitution process proves that while the architectural element performing the function is highly adaptable (Xian et al., 2024), the cultural requirement for boundary control is non-negotiable.

5.2.3. Vertical displacement: Decoupling the syntactic core from social hubs

An adaptation occurs in the urban high-rise context to address the structural divergence between mathematical efficiency and functional spatial requirements. Preliminary studies on spatial shifts in Xishuangbanna housing indicate that verticalization forces a reorganization of domestic gravity. In traditional and rural contexts, the mathematical syntactic core coincides with the communal living room to foster family solidarity. However, the integration data in Table 3 confirms that in urban cases, the necessity of vertical movement causes the syntactic core to be occupied by infrastructural elements such as elevators and staircases.

This structural shift imposes spatial limitations on domestic activities. Family gathering spaces require the traditional kitchen as a functional anchor. The operation of a traditional kitchen depends on the support of open or semi-open spaces, such as a courtyard, balcony, or semi-covered area. The infrastructural nodes occupying the urban syntactic core lack the physical capacity and environmental conditions to support these open-space functions.

Consequently, the data indicate a strategy of vertical displacement to resolve this spatial conflict. Residents decouple the mathematical center from the social center. While vertical connectors record the highest Integration values to handle multi-floor movement, the actual communal gathering spaces and large kitchens are relocated to higher topological depths. As demonstrated by the step depth sequences, nodes representing family gathering and large kitchens are positioned at the terminal ends of the vertical sequence on top floors or rooftops in the Mandou cases.

These elevated, deeper nodes provide the necessary open space to accommodate the traditional kitchen and support family gathering. This topological separation ensures that the family nucleus remains protected from the transient flow of the circulation spine. This decoupling

strategy allows the urban dwelling to function as a vertical structure while securing the required spatial conditions for the family nucleus. It is a testament to the dynamic nature of the spatial genotype, proving that residents manipulate spatial usage to ensure cultural survival within modernized frameworks.

6. Conclusion

This study transcends a primarily morphological reading of Thai Lue dwellings by arguing that, through urbanization, the persistence of traditional architecture lies in an underlying topological logic, representing a spatial genotype distinct from a particular material shell or stylistic motif. By decoding configurations across rural, town, and urban contexts, the results indicate that the transition from timber stilt houses to reinforced concrete units can be understood as a migration of cultural meaning into new building typologies, where the deep structure of social relations is re-expressed. Specifically, sanctity remains configurationally protected through persistent sacred depth, and privacy continues to be organized by regulated interfaces that assume essential gatekeeping roles, even as the architectural carriers of these relations change.

For Xishuangbanna, this provides theoretical grounding for an evolving urban vernacular, reframing contemporary self-built concrete housing as a site of cultural persistence and challenging its perception as merely a form of heritage degradation. The identification of three distinct adaptation mechanisms, specifically topological compression, functional substitution, and vertical displacement, further highlights residents as active agents who re-encode traditional rules under constraints such as compact footprints and vertical living. This suggests that authenticity is sustained through lived spatial practice, extending beyond the static preservation of symbols. In the broader vernacular architecture discourse, the study challenges a strict opposition between tradition and modernity by treating tradition as a dynamic configurational process capable of inhabiting new typologies. Accordingly, a practical implication is that design guidance and heritage policy in rapidly urbanizing ethnic regions should prioritize configurational affordances for ritual hierarchy, graded access, and social interaction over imitation at the façade level.

Although this study demonstrates the structural persistence of the Thai Lue spatial genotype, certain methodological boundaries present opportunities for future research. The J-graph method serves to extract abstract topological logic from physical forms. However, as a configurational tool, it inherently quantifies spatial affordances and structural potentials but does not capture real-time behavioral frequencies. Therefore, while the syntactic metrics indicate that the traditional spatial framework remains intact, future studies would benefit from integrating qualitative approaches such as ethnographic interviews and behavioral mapping. Combining these quantitative topological findings with qualitative narratives will provide a broader understanding of how residents perceive, negotiate, and assign cultural meaning to these spatial adaptations in their everyday lives.

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Conflict of interest

The authors declare they have no competing interests.

Author contributions

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

Ethics approval and consent to participate

The ethical approval was obtained for the field interviews. The study was approved by the Chiang Mai University Research Ethics Committee (Approval ID: CMUREC 67/321). Informed consent to participate was obtained from the interviewees.

Consent for publication

Informed consent for publication was obtained.

Availability of data

Raw data from on-site measurements, recordings, and field research are available from the corresponding author.

Further disclosure

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