

Research Article

Landscape Genes and Spatial Configuration in a Traditional Village: An Angular Space Syntax Analysis of San-Qing Village, China

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Abstract

Traditional villages preserve cultural identity and spatial memory through long-term interactions among environmental conditions, social organization, and settlement evolution. However, existing landscape gene studies have primarily focused on the identification and preservation of physical cultural elements, while the configurational mechanisms underlying their organization remain insufficiently explored. This study integrates landscape gene theory with angular space syntax to investigate the relationship between landscape genes and spatial configuration in San-Qing Village, Hainan, China. Based on field surveys, spatial mapping, and segment-based analysis in Depthmap, angular connectivity, integration, choice, and synergy analyses were employed to examine accessibility, movement patterns, and spatial hierarchy within the village circulation system. The results reveal a hierarchical and partially centralized circulation structure in which highly integrated and high-choice routes function as the principal movement corridors. Synergy analysis indicates a moderate relationship between local and global accessibility ($R^2 = 0.255394$), while representative landscape gene elements, including ritual and communal spaces, are concentrated along highly accessible and structurally significant routes. These findings demonstrate that angular space syntax provides an effective framework for interpreting the configurational characteristics of traditional village landscape genes and offers practical implications for heritage conservation and sustainable village revitalization.

Keywords: traditional village, landscape genes, angular space syntax, spatial configuration, cultural landscape.

1. Introduction

1.1 Landscape genes in traditional settlement conservation and research

The concept of landscape gene originates from biological genetics and theories of cultural transmission. Cultural information can be inherited and transmitted through socially shared units known as “memes,” providing a theoretical basis for understanding cultural continuity in human settlements (Dawkins, 1989). Building on this perspective, landscape gene theory explains how cultural characteristics are encoded and expressed through settlement morphology, architectural forms, and environmental adaptation (Liu et al., 2010). Moreover, this perspective is closely related to cultural landscape studies that interpret landscapes as reflections of social and cultural processes (Rowntree & Conkey, 1980).

Recent research has extended landscape gene studies beyond morphological identification toward the visualization and interpretation of cultural information embedded in traditional settlements (Hu et al., 2021). Furthermore, digital technologies have facilitated the documentation and conservation of landscape genes through information systems and heritage databases (Sa et al., 2024). Landscape gene mapping has also been applied to reveal regional spatial characteristics and cultural continuity within traditional village systems (Cao et al., 2024).

However, existing studies mainly focus on identifying and preserving physical landscape elements, while the spatial mechanisms underlying their organization remain insufficiently explored. Therefore, this study employs angular space syntax analysis to examine the relationship between landscape genes and spatial configuration in San-Qing Village.

1.2 Research gap and significance

As illustrated in Figure 1, previous studies have mainly focused on the identification and preservation of traditional settlement landscape genes, emphasizing their cultural and morphological characteristics (Chen et al., 2020). Heritage conservation research has also highlighted the interaction between cultural landscapes and environmental systems in traditional settlements (Dastgerdi et al., 2020). However, the configurational mechanisms underlying the organization and expression of landscape genes remain insufficiently explored. In particular, issues related to spatial organization, movement structure, local–global spatial relationships, and socio-spatial interaction have received limited attention. Although landscape gene mapping has improved the documentation of cultural elements, its relationship with spatial configuration remains poorly understood (Cao et al., 2024).

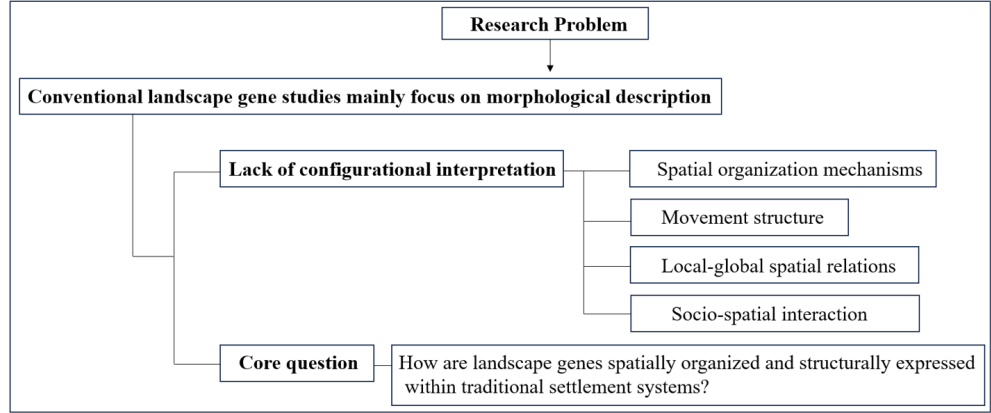


Figure 1. The framework of research problem (made by the author)

Therefore, this study addresses the research gap identified in Figure 1 by integrating landscape gene theory with angular space syntax analysis to examine how representative landscape genes are spatially organized and structurally expressed within San-Qing Village. By applying Angular Connectivity, Angular Integration, Angular Choice, and Synergy analyses, the study establishes a quantitative framework for investigating the relationship between landscape genes and spatial configuration.



Figure 2. The location of San-Qing Village (Drawn by the author)

2. Study area

2.1 The location of San-Qing Village

San-Qing Village is located in northern Hainan Province within a volcanic landscape that has shaped its settlement form and building traditions. As shown in Figure 2, the village preserves a dense fabric of Ming- and Qing-period basalt dwellings formed through long-term adaptation to volcanic conditions and clan-based social organization. Volcanic stone construction, courtyard-centered layouts, and hierarchical circulation patterns embed lineage relationships into the built environment, reflecting the interaction between environmental constraints and socio-cultural systems. The long-term habitation and national recognition of San-Qing Village as a traditional village make it a valuable case for investigating how environmental adaptation and cultural heritage are reflected in settlement morphology. Similar studies have highlighted the importance of vernacular settlement morphology in preserving regional identity and cultural continuity within traditional settlements (Qiao & Shih, 2020).

2.2 The spatial morphology of San-Qing Village

Figure 3 presents a ring-like settlement layout centered on ancestral houses and shared public spaces, with primary circulation loops forming the social core and secondary alleys linking residential clusters to surrounding agricultural land. Similar spatial characteristics have been observed in traditional village groups in China, where circulation structure plays an important role in organizing settlement morphology and inter-village relationships (Pei et al., 2020).

3. Methodology

3.1 Introduction of methodology

As illustrated in Figure 4, the methodological framework integrates angular space syntax analysis with field investigation and spatial reconstruction to examine the configurational characteristics of San-Qing Village. The workflow includes field survey, AutoCAD reconstruction, segment map generation, and Depthmap analysis. Space syntax provides a quantitative framework for evaluating accessibility, movement patterns, and spatial relationships within settlement systems (Hillier & Iida, 2005).

Based on angular segment analysis, the study examines global accessibility through Angular Integration R_n , local accessibility through angular integration R_5 , movement potential through angular choice analysis, and local-global spatial relationships through synergy analysis. Together, these indicators reveal circulation structure, spatial hierarchy, and movement organization. Through this multi-scale framework, the study investigates how representative landscape genes are associated with accessibility and configurational characteristics within the settlement system. The effectiveness of space syntax in evaluating heritage environments and public spaces has been demonstrated in previous studies (Gümüş et al., 2022).

3.2 AutoCAD-based Road Centerline Mapping

Based on field investigation, the circulation network of San-Qing Village was reconstructed in AutoCAD as a road centerline map (Figure 5). The network was simplified into a topological system representing movement paths and spatial connections, providing the basis for subsequent Depthmap analysis of connectivity, integration, choice, and local-global spatial relationships. To facilitate angular segment analysis, the reconstructed centerline network was subsequently imported into Depthmap and converted

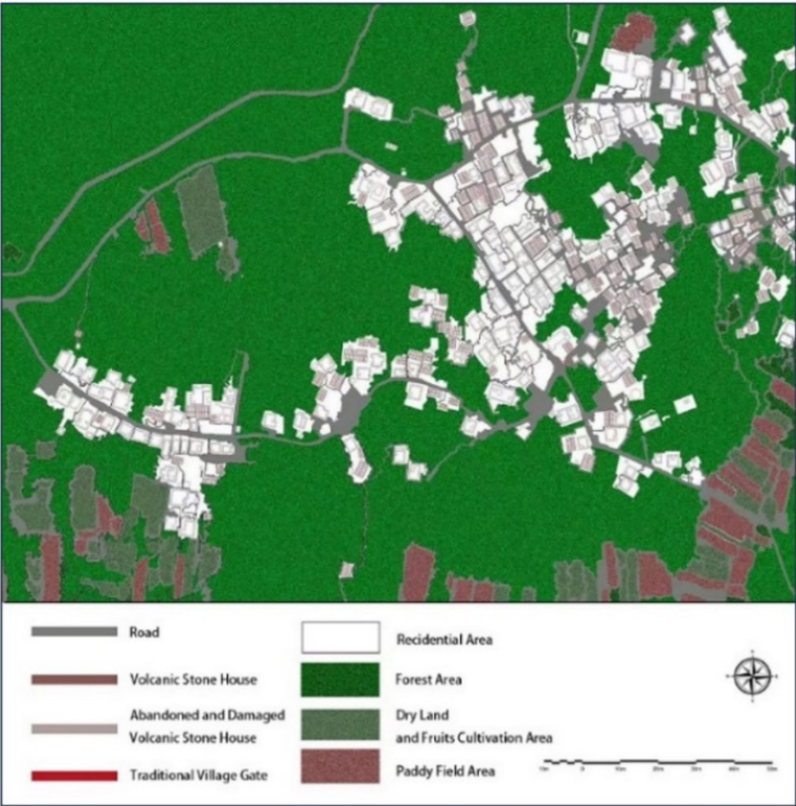


Figure 3. The layout of San-Qing Village (Drawn by the author)

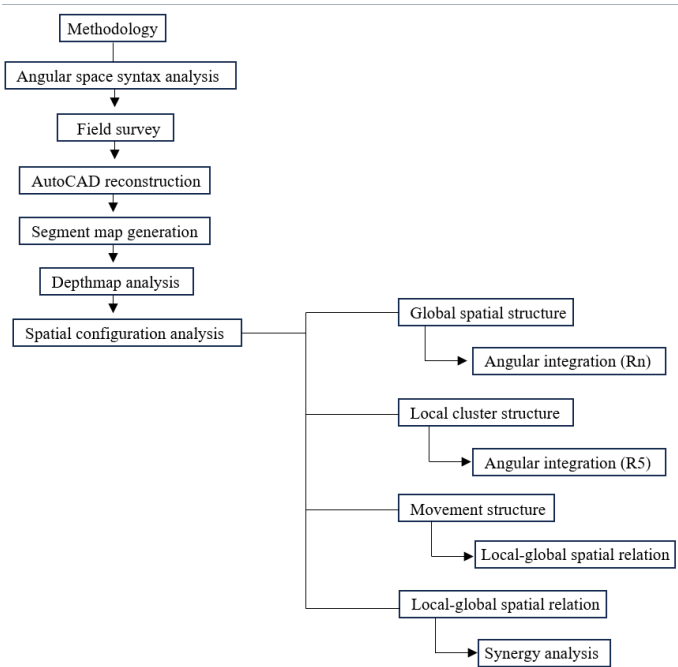


Figure 4. Research methodology framework (made by the author)

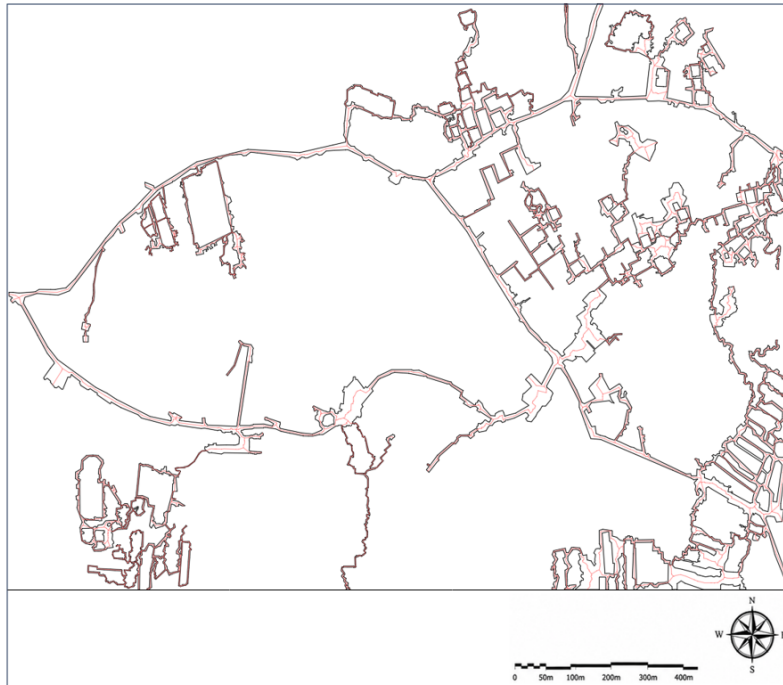


Figure 5. The AutoCAD-based road centerline (red line) (made by the author)

into a segment map, enabling the circulation system to be analyzed as a network of interconnected spatial segments.

3.3 Segment map generation

Following the reconstruction of the road centerline network, the spatial data were imported into Depthmap and converted into a segment map for angular space syntax analysis (Figure 6). The conversion process divides the circulation network into individual segments based on intersections and directional changes, enabling topological analysis of the village. Compared with the original centerline map, the segment map better captures movement behavior and route selection within the irregular street network. This transformation provides the basis for subsequent analyses of integration, choice, and local-global spatial relationships, revealing the settlement's configurational characteristics.

3.4 Spatial syntax indicators and angular segment analysis

Five angular space syntax indicators were applied to examine the relationship between landscape genes and spatial configuration. The selected indicators are described below:

- Angular Connectivity measures the degree of direct linkage between street segments within the circulation network. Higher connectivity values indicate stronger local spatial connections and greater potential for immediate movement between adjacent spaces (depthmapX Development Team, n.d.).
- Angular Integration R5 evaluates local-scale accessibility within a radius of five steps. Segments with higher integration R5 values are more easily accessible from surrounding spaces and generally function as important neighborhood circulation routes (depthmapX Development Team, n.d.).

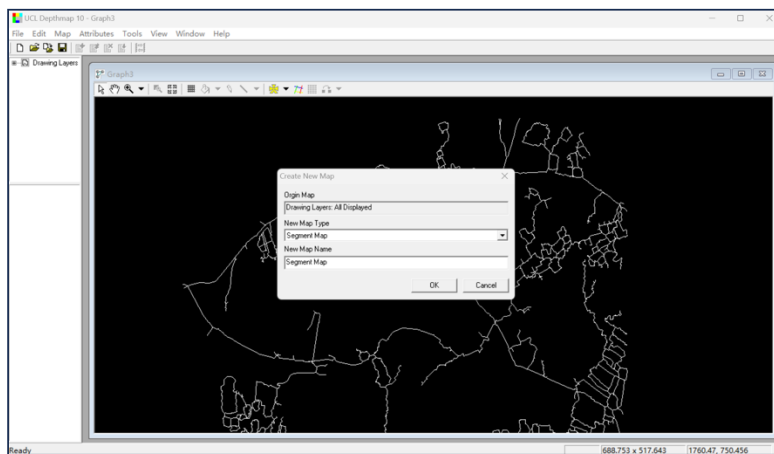


Figure 6. Conversion of the imported map into a segment map (made by the author)

- Angular integration Rn measures global accessibility across the entire settlement network. High integration Rn values indicate spatial segments that are more centrally located within the overall circulation structure and therefore possess stronger configurational centrality (depthmapX Development Team, n.d.).
- Angular choice R5 reflects local movement potential and route-selection characteristics within a neighborhood-scale radius. Segments with higher choice R5 values are more likely to serve as important connectors between adjacent residential clusters (depthmapX Development Team, n.d.).
- Angular choice Rn evaluates global through-movement potential across the entire settlement. High choice Rn values indicate routes that are more frequently traversed as part of shortest movement paths and therefore function as major circulation corridors within the village network (depthmapX Development Team, n.d.).

Together, these five indicators provide a multi-scale framework for examining local linkage, spatial accessibility, movement hierarchy, circulation structure, and the spatial distribution of landscape genes within San-Qing Village.

4. Results and discussion

4.1 Refined segment map analysis after removing low-accessibility alleys and vacant areas

As shown in Figure 7 and Figure 8, field investigations revealed a clear spatial differentiation between active cultural landscape areas and underutilized spaces within San-Qing Village. Major cultural landscape elements, including ritual spaces, ancestral halls, commercial facilities, and public resting areas, are concentrated along Lane 1, which functions as the principal social and spatial core of the settlement. In contrast, abandoned alleys, undeveloped land, vacant spaces, and construction zones are mainly distributed along peripheral streets and southern alleys connected to

San-Qing Road. Due to their limited role in daily circulation, these spaces were removed from the reconstructed AutoCAD-based map. These segments are currently inaccessible, abandoned, or rarely used in everyday village activities and therefore contribute little to actual movement patterns within the settlement. Due to their limited role in daily circulation, these spaces were removed from the reconstructed AutoCAD-based map. These segments are currently inaccessible, abandoned, or rarely used in everyday village activities and therefore contribute little to actual movement patterns within the settlement. The refined segment network was subsequently re-imported into Depthmap for spatial syntax analysis, improving the reliability of the results and providing a more accurate representation of the village circulation structure.

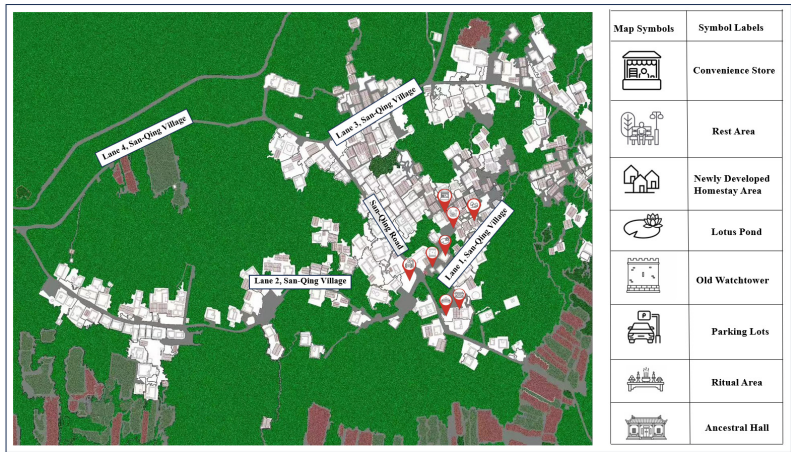


Figure 7. Distribution of spatial functional nodes and cultural landscape elements in San-Qing Village (made by the author)

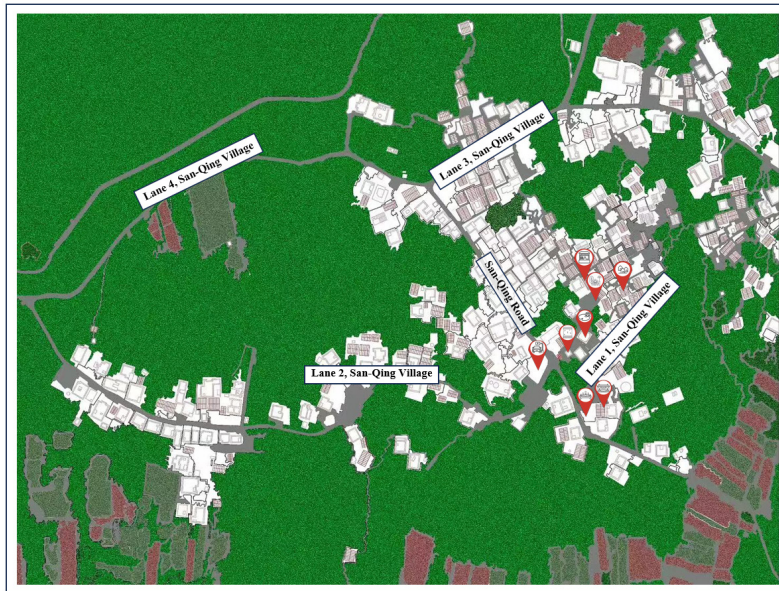


Figure 8. Distribution of abandoned and underdeveloped spaces in San-Qing Village (made by the author)



Figure 9. Optimized segment map for refined Depthmap analysis (made by the author)

To improve analytical accuracy, underutilized and non-traffic-related segments identified through field investigation were removed from the original network (Figure 9). The refined segment map was re-imported into Depthmap, providing a more accurate representation of the circulation structure of San-Qing Village. Based on this optimized network, Angular connectivity and Angular integration analyses were subsequently conducted to examine patterns of spatial linkage, accessibility, and configurational hierarchy.

4.2 Connectivity and integration analysis

Figure 10 presents the angular connectivity and angular integration analyses of the optimized segment network in San-Qing Village, revealing the overall accessibility pattern and spatial hierarchy of the settlement.

Figure 10(a) shows the Angular connectivity distribution map, in which higher connectivity values are concentrated along the central corridor and its adjacent intersections, indicating stronger direct spatial connections and greater local accessibility. Figure 10(b) presents the angular integration (R5) distribution map, where highly integrated segments are primarily distributed within the central area of the settlement, reflecting their importance in neighborhood-scale movement and local accessibility. Figure 10(c) illustrates the angular integration (Rn) distribution map, which exhibits a similar pattern to the R5 results, with the highest values concentrated along the same central corridor. This correspondence suggests that the spatial core identified at the local scale also functions as the principal globally accessible route within the village network.

In contrast, peripheral alleys and marginal routes consistently display lower values across all three analyses, indicating weaker connectivity and lower levels of spatial integration. While these results reveal the accessibility structure and configurational hierarchy of the settlement, they do not fully capture the distribution of movement flow and route-selection behavior within the circulation network. To further investigate the movement potential of different street segments and identify the principal through-movement corridors, angular choice analysis was subsequently conducted.

4.3 Choice analysis

As shown in Figure 11(a), the choice analysis R5 distribution reflects localized through-movement potential within the village. High-choice segments are concentrated around the central circulation network and interconnected neighborhood streets, indicating their importance as local movement corridors supporting daily activities and neighborhood interactions. In contrast, peripheral alleys exhibit relatively low choice values, suggesting limited movement potential and weaker spatial interaction. Figure 11(b) illustrates the global choice analysis Rn reveals a more concentrated movement structure across the entire settlement. The highest choice values are clustered along the principal longitudinal circulation axis and central intersections, identifying these routes as the dominant through-movement corridors. Compared with the R5 results, the Rn analysis demonstrates a clearer hierarchy of movement flow, highlighting the critical role of the main circulation spine in organizing village accessibility, route selection, and inter-cluster connectivity. The observed differences and correspondences between local and global movement structures further suggest the need to examine the relationship between neighborhood-scale accessibility and the overall spatial configuration of the settlement, which is explored through the subsequent synergy analysis.

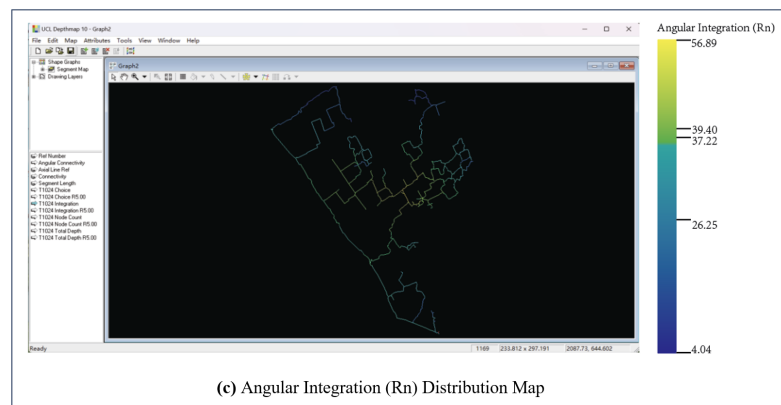
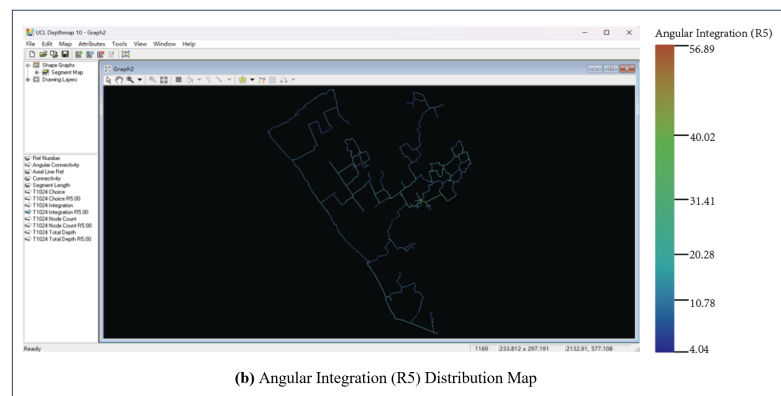
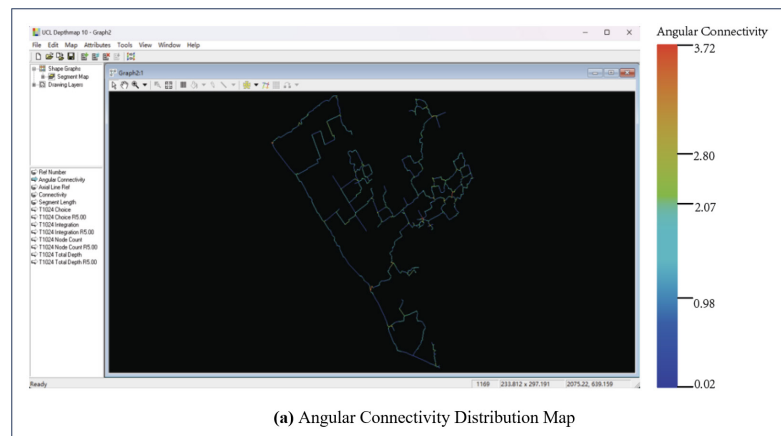


Figure 10. Optimized spatial syntax analysis results of San-Qing Village (made by the author)

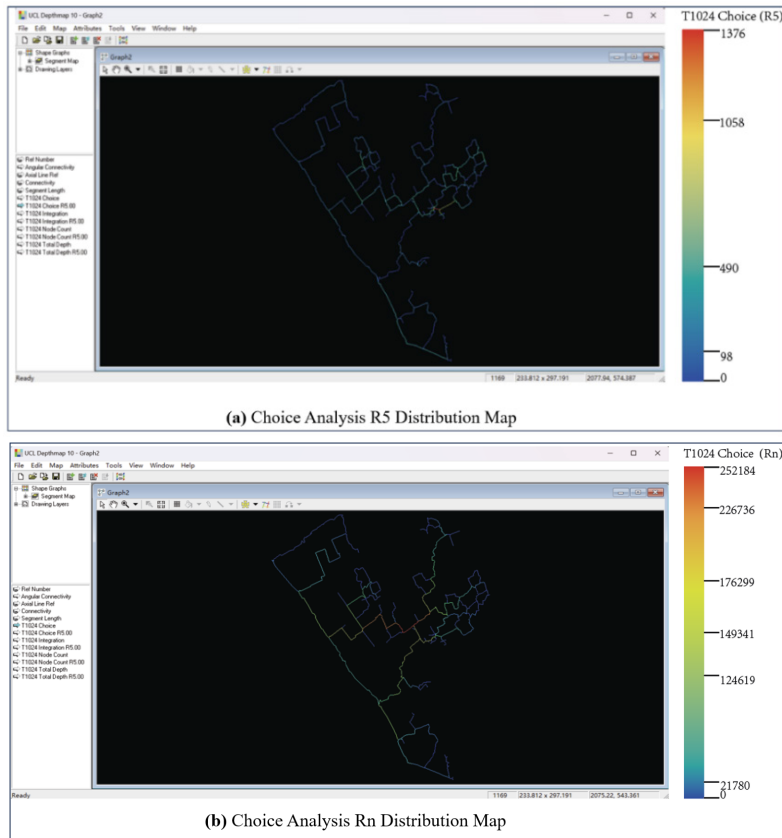


Figure 11. Optimized multi-scale spatial choice analysis (made by the author)

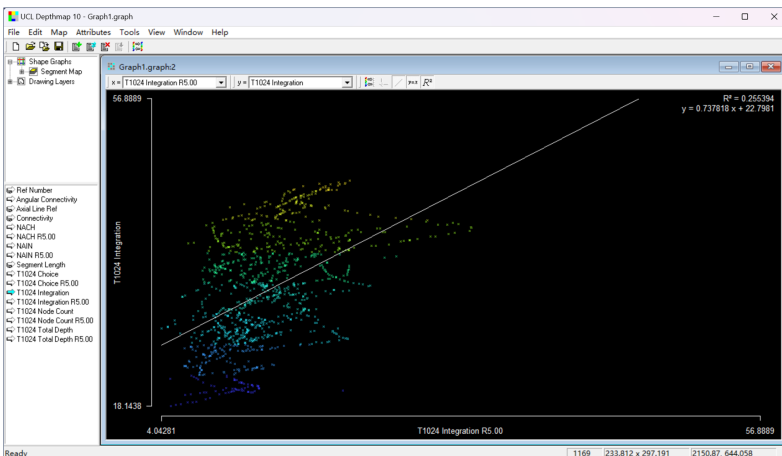


Figure 12. Optimized scattergram of R5 and Rn integration values (made by the author)

4.4 Synergy analysis

Figure 12 presents the synergy relationship between local integration (R5) and global integration (Rn) within the refined segment network of San-Qing Village. The scatter plot exhibits a weak-to-moderate positive correlation ($R^2 = 0.255394$), indicating that spaces with higher local accessibility generally tend to possess higher global accessibility. The distribution of data points reveals a discernible linear trend, suggesting a degree of consistency between neighborhood-scale spatial organization and the overall settlement structure. Segments with relatively high integration values are concentrated along the principal circulation spine and central streets, whereas peripheral alleys remain within the lower integration range. This pattern reflects a hierarchical circulation system in which a limited number of core routes organize accessibility across the village. The observed local–global relationship indicates that spatial accessibility is unevenly distributed and concentrated within structurally significant areas, providing an important basis for examining how representative landscape genes are associated with the spatial configuration of the settlement.

Table 1. Spatial syntax characteristics of representative landscape gene elements (made by the author)

Functional Space	Estimated Integration (Rn)	Estimated Choice (Rn)	Spatial Interpretation
Convenience Store Area	45.28–45.93	129022–129414	Located along the principal circulation corridor with strong accessibility and concentrated movement flow.
Rest Area	43.66–44.70	126362–126752	Functions as a semi-public transitional space connected to the main circulation network.
Newly Developed Homestay Area	38.87–39.76	85210–85830	Benefits from proximity to tourism circulation routes and village accessibility.
Lotus Pond	35.56–36.68	127138–127898	Serves as an important landscape and public gathering space with relatively strong accessibility.
Old Watchtower	35.68–35.90	126362–126752	Primarily functions as a scenic destination space rather than a major movement corridor.
Ritual Area	28.87–29.61	61915–63612	Possesses cultural and symbolic significance with relatively limited through-movement.
Ancestral Hall	30.48–31.71	65305–66994	Functions as an important communal and cultural node within the village structure.

4.5 Relationship between landscape genes and spatial configuration

According to landscape gene theory, ancestral halls, ritual spaces, village gateways, and traditional public spaces represent key carriers of cultural information and collective memory within traditional settlements (Liu et al., 2010). The results presented in Table 1 reveal a clear relationship between representative landscape gene elements, functional spaces, and the spatial hierarchy of San-Qing Village. Integration and choice values were extracted from the street segments on which each representative landscape gene element is located in the optimized angular integration (Rn) and angular choice (Rn) maps. Tourism-related facilities and village entrance spaces generally exhibit relatively high integration and choice values, indicating strong accessibility and movement concentration. The convenience store area and rest area, located along the principal circulation spine, function as

important service and transitional spaces within the village network. The lotus pond and newly developed homestay area occupy intermediate positions within the spatial hierarchy, benefiting from proximity to the main circulation structure while maintaining localized tourism and recreational functions.

In contrast, ritual spaces, ancestral halls, and the old watchtower exhibit moderate accessibility but relatively low movement concentration, reflecting their roles as cultural and destination-oriented spaces. Taken together, the distribution of representative landscape gene elements corresponds closely with the spatial hierarchy identified through spatial syntax analysis. The concentration of representative landscape genes along highly integrated routes suggests that cultural information is embedded not only in physical forms but also in the configurational structure of the settlement. These findings indicate that landscape genes are not randomly distributed within

the village but are closely associated with patterns of accessibility and movement. Similar relationships between cultural landscape elements and spatial organization have been reported in cultural landscape studies (Rowntree & Conkey, 1980). Therefore, the spatial configuration of San-Qing Village plays an important role in shaping the location, accessibility, and functional significance of cultural landscape elements within the settlement.

5. Conclusion

This study applied segment-based angular space syntax analysis to examine the spatial morphology and circulation structure of San-Qing Village. The optimized segment model produced results that correspond closely with field investigation findings.

Overall, the analyses revealed a hierarchical and partially centralized circulation system, with central streets functioning as the primary spatial framework of the village. Furthermore, highly integrated and high-choice routes were concentrated along the principal circulation spine, highlighting their importance in accessibility, movement organization, and spatial connectivity. Moreover, synergy analysis indicated a moderate relationship between local and global spatial structures, suggesting a degree of coherence within the settlement configuration.

Consequently, the results demonstrate that representative landscape genes are closely associated with spatially accessible and structurally significant areas. Therefore, spatial configuration plays an important role in shaping the distribution and functional significance of cultural landscape elements. This study highlights the value of angular space syntax as an effective approach for interpreting landscape genes and supporting the conservation and sustainable development of traditional villages. Furthermore, the study extends conventional landscape gene research from morphological identification toward configurational interpretation, providing a quantitative perspective for understanding the spatial expression of cultural landscape elements.

Nevertheless, the study is limited to a single case village and relies primarily on configurational analysis rather than observed movement data. Future research may incorporate multiple traditional settlements and behavioral observations to further validate the relationship between landscape genes and spatial configuration.

6. Declaration of generative AI and AI-assisted technologies in the writing process

The authors used generative AI tools solely to improve language and readability during manuscript preparation. All AI-assisted content was subsequently reviewed and verified by the authors, who accept full responsibility for the accuracy and integrity of the manuscript.

CRediT Authorship Contribution Statement

Yuhan Zhou: Conceptualization; Methodology; Validation; Formal analysis; Investigation; Resources; Data curation; Writing – original draft; Writing – review and editing; Visualization; Project administration.

Shimizu Ikuro: Conceptualization; Methodology; Validation; Resources; Writing – review and editing; Supervision; Project administration; Funding acquisition.

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