

# Comparative Analysis of Spatial Morphology of Tulou Settlements Based on Spatial Syntax

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## ABSTRACT

Research on Tulou settlements at home and abroad mostly focuses on qualitative research on humanistic culture and spatial morphology of Tulou settlements, but lacks quantitative research on road network, ancestral hall distribution and cultivated land space of Tulou settlements. Based on the spatial syntax method, the typical river distribution “bifurcation type” Hekeng Tulou cluster and “meandering” type Hongkeng Tulou cluster are compared and analyzed from a qualitative and quantitative point of view. According to the results, both of them show commonality and difference in the data of accessibility, integrated high center area, ancestral hall and cultivated land space, etc. Accordingly, we explore the potential law of Tulou settlement, in order to provide reference for the related research at home and abroad.

**Keywords:** Fujian Tulou, Spatial syntax, Accessibility, Comparative analysis, Spatial relationship.

## 1. INTRODUCTION

The spatial forms of traditional villages are the result of a harmonious coexistence between human culture and nature, embodying the integrated development of regional history and culture. These villages hold high historical and cultural value, along with potential for tourism development and aesthetic appeal[1-2]. Tulou structures, with their unique cultural background, architectural techniques, and distinctive residential environment, are among China’s most iconic vernacular buildings and are recognized as a UNESCO World Heritage site, attracting global attention. Unlike previous studies that mainly focus on qualitative aspects such as historical evolution, spatial forms, and residential transformations, this paper uses space syntax to analyze the spatial accessibility, intelligibility, and ancestral hall spaces of Tulou settlements, integrating both qualitative and quantitative perspectives.

Space syntax is a research method developed in the late 1970s by Professor Bill Hillier and his colleagues at University College London[3]. It provides a robust analytical tool for exploring the relationship between spatial configurations and human behaviors, making it one of the most critical theories and methods in urban morphology. By

employing topological mathematical models to quantify spatial structures, space syntax can reveal the accessibility of specific spatial areas or the network as a whole. In this study, we select two representative Tulou clusters in Fujian, China: the “branching” river-patterned Hekeng Tulou cluster and the “meandering” river-patterned Hongkeng Tulou cluster. Both clusters share similarities in the historical development and scale of their Tulou settlements, but they exhibit differences in Tulou distribution and agricultural spaces. This study explores how factors such as river distribution and natural geographic environments affect spatial accessibility, central settlement areas, and variations in agricultural spaces, aiming to offer new perspectives for analyzing the spatial form of Fujian Tulou settlements.

## 2. RESEARCH METHODOLOGY

The fundamental principle of space syntax is to analyze spatial configurations by dividing space into scales and segments. This involves breaking down large-scale urban spaces into smaller-scale spaces to capture the core characteristics of the urban morphology. By establishing a connectivity graph of these small-scale spatial configurations and analyzing the connections between them using graph theory and visibility measures, space syntax

enables the calculation of various morphological variables. This approach facilitates a comprehensive understanding of the structural form within large-scale systems, particularly in relation to pedestrian flow patterns shaped by settlement road networks[4-5].

### 3. RESEARCH SUBJECTS

The Tulou has a long developmental history and is a valuable cultural heritage. At the 32nd World Heritage Committee meeting held in Quebec City, Canada, 46 Fujian Tulou structures, also known as the "6 Clusters and 4 Buildings," were included in the World Heritage List. These 46 Tulou structures are primarily located in the southwestern region of Fujian Province, with many of the clusters in Yongding District, Longyan City, and Nanjing County, Zhangzhou City, forming settlement-like arrangements. This study conducts a comparative analysis of two representative clusters: the Hekeng Tulou Cluster, representing the Nanjing Tulou and the "branching river" layout; and the Hongkeng Tulou Cluster, representing the Yongding Tulou and the "meandering river" layout.

#### 3.1 Hekeng Tulou Cluster

The Hekeng Tulou Cluster, located in Qujiangwei, Shuyang Town, Nanjing County, is a prominent example of the Nanjing Tulou. It consists of 13 World Heritage-designated Tulou

buildings—Chaoshuilou, Yangzhaolou, Yongshenglou, Shengqinglou, Yongronglou, Yongguilou, Yuchanglou, Chunguigulou, Dongshenglou, Xiaochunlou, Yongqinglou, Yuxinglou, and Nanxunlou—with a total of 14 Tulou buildings dispersed around the confluence of the Qujiang Creek and its tributaries. Spatially, the 14 Tulou structures in the Hekeng Cluster form a "double Big Dipper" layout. Initially, the Hekeng Tulou Cluster was established by multiple family clans and later developed into a Hakka settlement primarily inhabited by the Zhang clan. The cluster includes ancestral halls, temples, and shrines, such as the Shiyingtang and Qingfengtang, serving as sites for worship and ancestor veneration. Shiyingtang is particularly unique, as it was established as an ancestral hall by esteemed overseas clan members returning to pay homage.

The Hekeng Tulou Cluster is a quintessential example of the "branching river" Tulou cluster type among the "6 Clusters and 4 Buildings" of Fujian Tulou ("Figure 1"). This type of settlement is characterized by its layout around multiple streams, with a relatively flat surrounding terrain conducive to spatial development. The streams provide essential resources for residents and support agricultural productivity by supplying fertile soil and abundant water. Due to the "four rivers and three confluences" hydrological pattern, the Hekeng Tulou Cluster holds a unique advantage in agricultural production over other Tulou clusters.

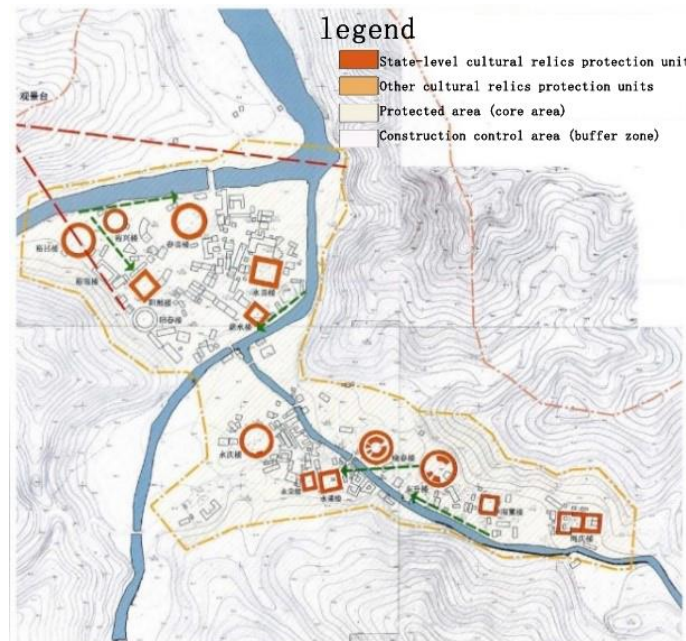


Figure 1 Plan of Hekeng earth building cluster.

### 3.2 Hongkeng Tulou Cluster

The Hongkeng Tulou Cluster, located in Hukeng Town, Yongding District, Longyan City, Fujian Province, is a representative example of the Yongding Tulou. Centered around the Hongchuan Creek, this cluster comprises seven World Heritage-listed Tulou buildings—Guangyulou, Fuxinglou, Kuijulou, Fuyulou, Rushenglou, Zhenchenglou, and Qingchenglou—with a total of 38 Tulou buildings forming the settlement. The Hongkeng Tulou Cluster is a typical Hakka single-surname village. In the 13th century, the Lin clan ancestors settled here, reclaimed land, and built Tulou structures, which led to the formation of the Hongkeng cluster to accommodate the community's residential needs. This settlement structure helped foster a unique clan culture, where the Lin family placed significant emphasis on family rules, discipline, and values since their

migration from Central China. In 1483, the ancestral hall "Lin Family Ancestral Temple" was constructed, dedicated to the Lin clan's founding ancestor. Outside the hall, stone dragon pillars were erected in honor of the ancestors of the Lin family in Hongkeng.

The Hongkeng Tulou Cluster is a prime example of the "meandering river" type among the "6 Clusters and 4 Buildings" of Fujian Tulou ("Figure 2"). This type of settlement is characterized by its distribution around a single river that traverses the cluster. The spatial layout and scale of the settlement are also influenced by the surrounding mountainous terrain. Compared to the "branching river" Tulou clusters ("Figure 1" and "Figure 2"), the "meandering river" clusters exhibit a more compact network of roads, denser distribution of Tulou structures, and concentrated agricultural spaces.



Figure 2 Plan of Hongkeng earth building cluster.

## 4. ANALYSIS OF SPATIAL FORMS IN TULOU SETTLEMENTS

### 4.1 Comparative Analysis of Integration Degree

Integration, also referred to as the integration degree, is a measure of how connected a specific space is with other spaces; higher integration values indicate spaces more likely to attract people to linger[6]. The road networks of the Hekeng and Hongkeng Tulou Clusters form an essential part of residents' daily lives. By converting the primary

road networks into axial maps and using Depthmap software for calculations, we can better understand the basic spatial relationships within these villages. This study analyzes the global and local integration degrees and accessibility of the Hekeng and Hongkeng Tulou Clusters by setting the topological parameters of the main road networks, respectively. ("Figure 3") Accessibility here mainly reflects the ease of movement between any two points in the space, and in the context of settlements, it describes the connectivity between local spaces. Higher accessibility indicates stronger connectivity, and vice versa.



Figure 3 Hekeng Tulou cluster road network territorial integration degree.

#### 4.1.1 Comparative Analysis of Global Integration Degree

When the topological parameter is set to  $n$ , differences in accessibility and spatial clustering are observed between the two clusters. The global average integration degree of the Hekeng Tulou Cluster is 0.282 (Figure 3), with the highest spatial centrality found around Tiandingfen and the central areas of Xiaochunlou, Dongshenglou, and Yongshenglou, where the average integration degree is 0.386. This reflects strong spatial centrality, marking it as the central area of the

Hekeng Tulou Cluster. In contrast, the global average integration degree of the Hongkeng Tulou Cluster is 0.377 (“Figure 4”), with its highest spatial centrality in the Jiangxinzhou region—an area formed by Hongchuan Creek’s alluvial plain—where the average integration degree reaches 0.562. This region represents a highly integrated central area of the Hongkeng Tulou Cluster. Data comparisons reveal that the overall spatial accessibility is relatively low for both clusters, though Hongkeng shows better accessibility than Hekeng.

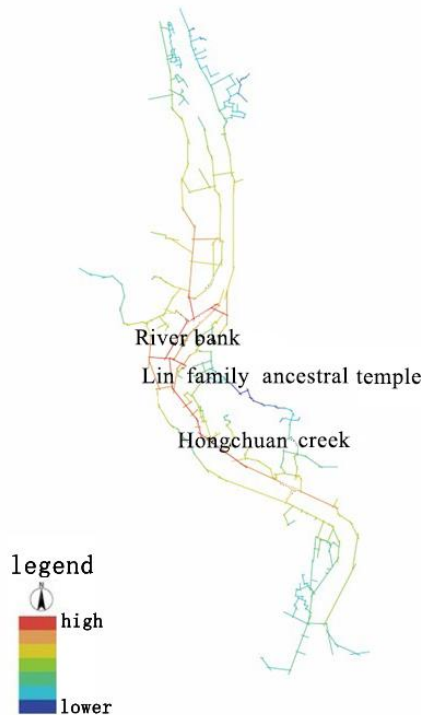


Figure 4 Territory-wide integration of road network in Hongkeng Tulou cluster.

From a hydrological perspective, Hekeng's highly integrated central area, Tiandingfen, is located at the confluence of secondary and tertiary streams within the "four rivers and three confluences" structure. Spatially, Hekeng's central area lies at the midpoint of the cluster's "double Big Dipper" layout, comprising 14 rectangular and circular Tulou buildings, marking it as the settlement's most integrated area. Conversely, in the Hongkeng Tulou Cluster, Jiangxinzhou represents the central area of the sole Hongchuan Creek, which serves as the village's core location. Spatially, Jiangxinzhou is situated below the Lin Family Ancestral Temple, acting as a vital corridor connecting both sides of the village and forming the most central region of the Hongkeng Cluster. Comparatively, the Hongkeng Tulou Cluster demonstrates a more compact spatial layout and better accessibility.

#### 4.1.2 Comparative Analysis of Local Integration Degree

When the topological parameter is set to 3 ("Figure 5"), the local average integration degree of the Hekeng Tulou Cluster is 1.043, with the higher integration areas centering around Tiandingfen. The local integration areas, however, are distributed

around the 14 Tulou buildings in Hekeng and Shiyingtang, with specific values such as 1.475 for Shiyingtang, 1.750 for Chaoshuilou, and 1.800 for Yangzhaolou. In the Hongkeng Tulou Cluster, with the parameter set to 3 ("Figure 6"), the local average integration degree is 1.072, with certain areas exhibiting values far exceeding the local average, such as 2.210 for Zhenchenglou, 2.178 for Guangyulou and Fuyulou, and 1.834 for Jiangxinzhou. These areas represent central regions of local activity and are key centers within the village.

In both the Hekeng and Hongkeng Tulou Clusters, some regions have a local integration degree notably higher than the village average, indicating areas where activity is concentrated and marking them as partial centers within the settlements. From the perspective of spatial relationships, this demonstrates that even within the same settlement, Tulou buildings can exhibit strong spatial independence, with individual structures showing notable spatial autonomy. Commonalities exist between Tulou settlements, where single buildings maintain spatial independence, exhibiting a high degree of individuality in varying spatial layouts.



Figure 5 Local integration of road network of Hekeng Tulou cluster.

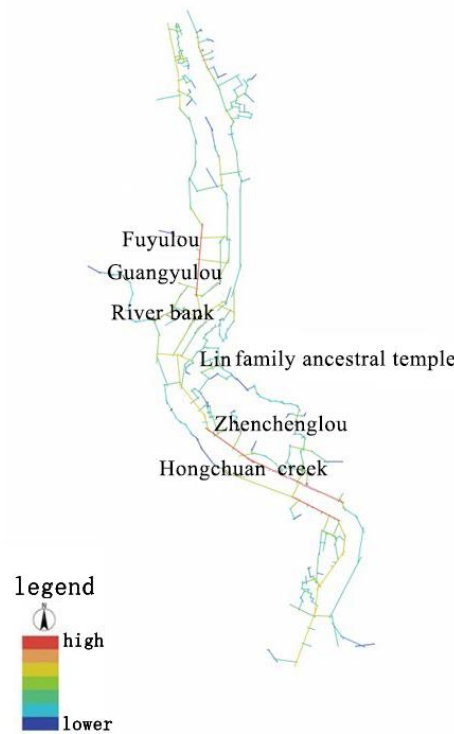


Figure 6 Hongkeng Tulou cluster road network local integration degree.

#### 4.2 Comparative Analysis of Spatial Legibility

Legibility refers to the ability to understand the larger spatial structure through the perception of smaller spaces[6]. Higher legibility indicates greater recognizability of a space. According to  $R^2$  values, the legibility of the Hekeng Tulou Cluster is  $R^2 = 0.199$  (“Figure 7”), while that of the Hongkeng Tulou Cluster is  $R^2 = 0.214$  (“Figure 8”),

indicating that the overall legibility in both clusters is low, with limited spatial distinctiveness and high independence of local spaces. This aligns with the characteristic functions of tulou settlements, which were originally designed to avoid conflicts and resist invasions, thus emphasizing the independence of each tulou. Hongkeng’s slightly higher legibility compared to Hekeng can be attributed to its more compact, linear layout between mountains, as constrained by rivers and terrain.

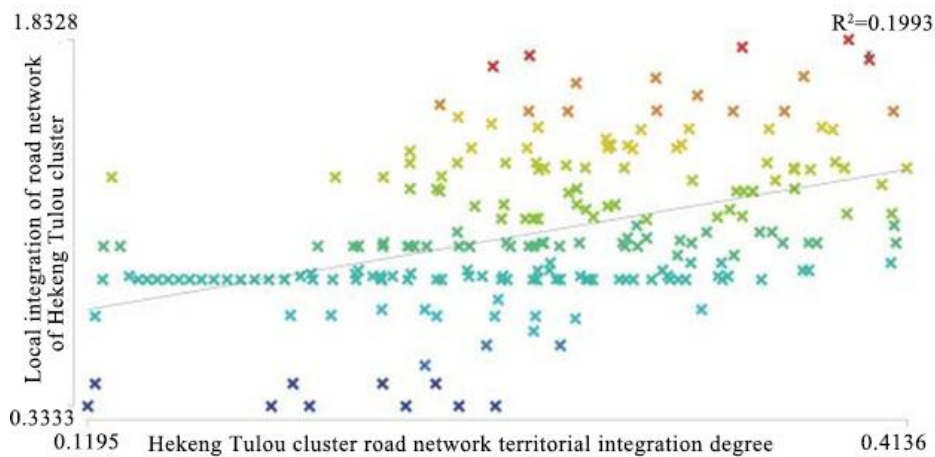


Figure 7 Road network comprehensibility analysis diagram of Hekeng Tulou cluster.

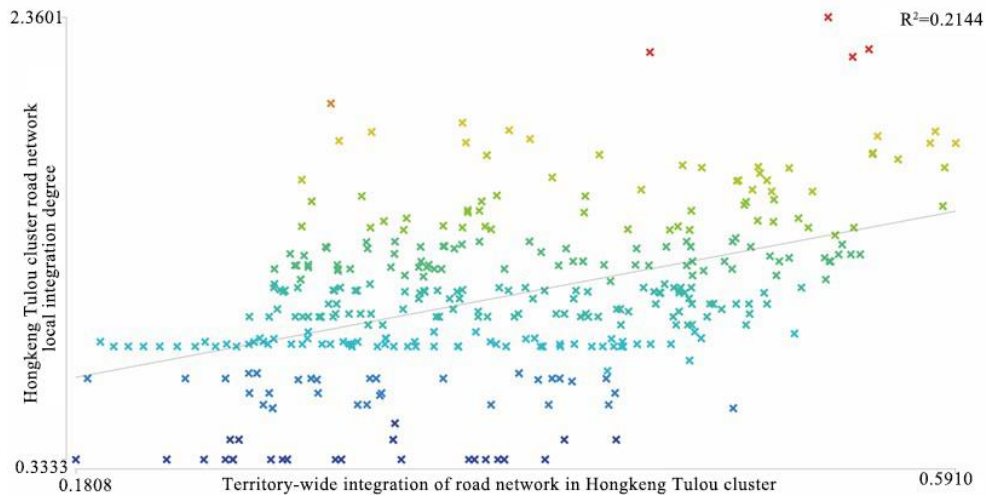


Figure 8 Road network comprehensibility analysis of Hongkeng Tulou cluster.

### 4.3 Comparative Analysis of Ancestral Hall Spatial Distribution

Ancestral halls serve as the communal buildings representing clans, where various clan activities are conducted, historically fulfilling a vital role in social instruction and contributing to a rich ancestral hall culture[7]. Within the Hekeng village, numerous temples and ancestral halls, such as Qingfengtang, Shiyingtang, and the land temple, are located in and around the settlement, providing spaces for religious worship and ancestral veneration. This study selects Shiyingtang for comparison; in Hekeng, Shiyingtang is located on the outskirts of the settlement, primarily surrounded by agricultural and production spaces. Constructed during the Wanli period of the Ming Dynasty, Shiyingtang symbolizes the establishment of the Zhang clan in Hekeng. In contrast, the Hongkeng Tulou Cluster is a typical Hakka single-surname village, with its ancestral hall, the Lin Family Temple, positioned at the village center, serving as the primary communal building. The Lin Family Temple holds unique significance for all residents, and its spatial layout contrasts with that of Shiyingtang.

#### 4.3.1 Comparative Analysis of Global Integration of Ancestral Halls

When the topological parameter is set to  $n$ , Shiyingtang's global integration degree is 0.276 ("Figure 3"), below the village average of 0.282, indicating that Shiyingtang is not a primary gathering space for residents in daily life. The Lin Family Temple's global integration degree, on the

other hand, is 0.465 ("Figure 4"), higher than the village's average of 0.377, showing that the Lin Family Temple has better accessibility and is more likely to attract people than Shiyingtang.

#### 4.3.2 Comparative Analysis of Local Integration of Ancestral Halls

With a topological parameter of 3, Shiyingtang's local integration degree is 1.475 ("Figure 5"), surpassing that of spaces used in daily life, such as Chaoshuilou and Yangzhaolou. Meanwhile, the Lin Family Temple has a local integration degree of 0.941 ("Figure 6"), below the local average of 1.072, and lower than spaces such as Guangyulou and Fuyulou. In terms of local integration, Shiyingtang surpasses the Lin Family Temple, indicating better accessibility in surrounding spaces. Shiyingtang is not the center of daily resident activity but becomes a focal point during special ceremonial occasions. In contrast, although the Lin Family Temple does not typically gather crowds outside of specific rituals or cultural events, the higher local integration in the surrounding areas supports crowd gathering for events. The Lin Family Temple is relatively secluded in everyday life, with features of exclusivity, making it harder for visitors to locate, aligning with the traditional function of ancestral halls.

#### 4.3.3 Reasons for Differences

The differences in local integration between the Lin Family Temple and Shiyingtang stem primarily from the contrasting spatial layouts of the two settlements. Although both ancestral halls

demonstrate low activity levels in daily life and heightened activity during specific events, Shiyingtang's peripheral location in Hekeng shows lower global integration and higher local integration. In contrast, the Lin Family Temple, located at the center of Hongkeng, exhibits high global integration and lower local integration, reinforcing its role as the settlement's central structure.

## 5. COMPARATIVE ANALYSIS OF AGRICULTURAL SPACE DISTRIBUTION CHARACTERISTICS

### 5.1 Comparison of Agricultural Space Integration

Agricultural spaces in Depthmap calculations aids in understanding the spatial form and layout of Tulou settlements, offer insights into current agricultural production within these areas. When the topological parameter is set to  $n$ , the global average integration degree of agricultural spaces in the Hekeng Tulou Cluster is 0.348 ("Figure 9"). The central area around the main roads shows integration values above the average, with buildings such as Chaoshuilou (0.487), Xiaochunlou (0.558),

and Dongshenglou (0.526) exemplifying this. In the Hongkeng Tulou Cluster, the global average integration degree is 0.349 ("Figure 10"), with high integration in the Shuiwei agricultural area due to its simple road network. The highly integrated central areas remain unchanged, concentrated around Jiangxinzhou, Fuyulou, and Guangyulou. The global integration degree of both clusters shows similarity, reflecting the importance of agriculture in their early formation.

With a topological parameter of 3, the Hekeng Tulou Cluster's local average integration degree reaches 1.126 ("Figure 11"), with higher integration along main roads and near tulou structures, including Yongqinglou (2.033), Yuchanglou (1.850), and Xiaochunlou (1.963). The local average integration degree of the Hongkeng Tulou Cluster is 1.046 ("Figure 12"), with high values for Zhenchenglou (2.363), Qingchenglou (1.875), Zhenxinglou (2.188), and Fuyulou (2.422). Both clusters exhibit similar local integration, with close connections between tulou buildings and agricultural spaces. Hekeng's spatial layout shows high integration around the agricultural center, Tiandingfen, demonstrating a close link between each tulou and surrounding agricultural spaces ("Figure 1").



Figure 9 Heceng Tulou cluster territorial integration degree.



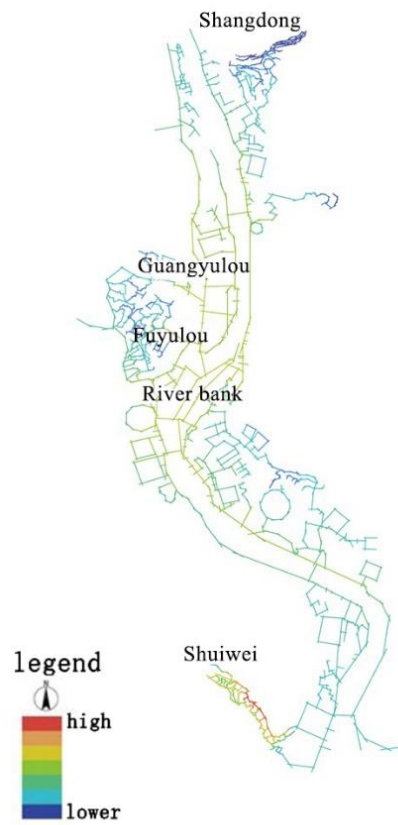


Figure 10 Hongkeng Tulou cluster domain-wide integration degree.

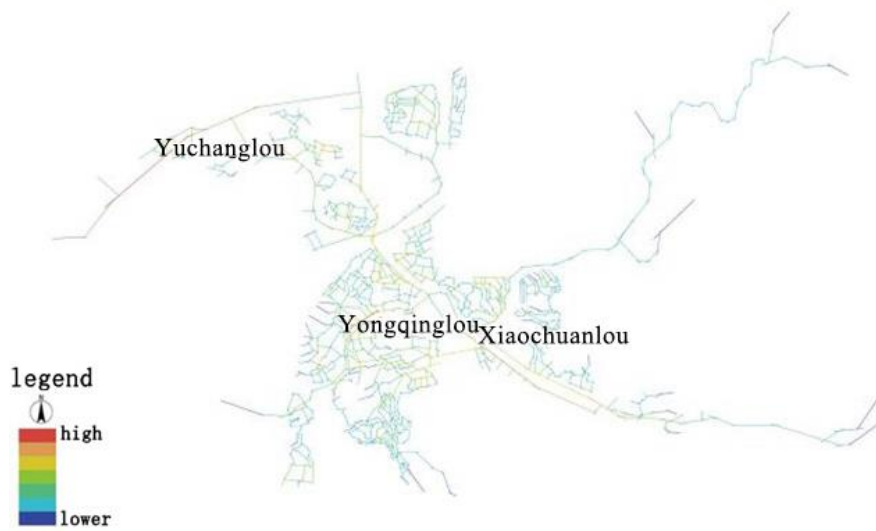


Figure 11 Local integration of Hekeng Tulou cluster.

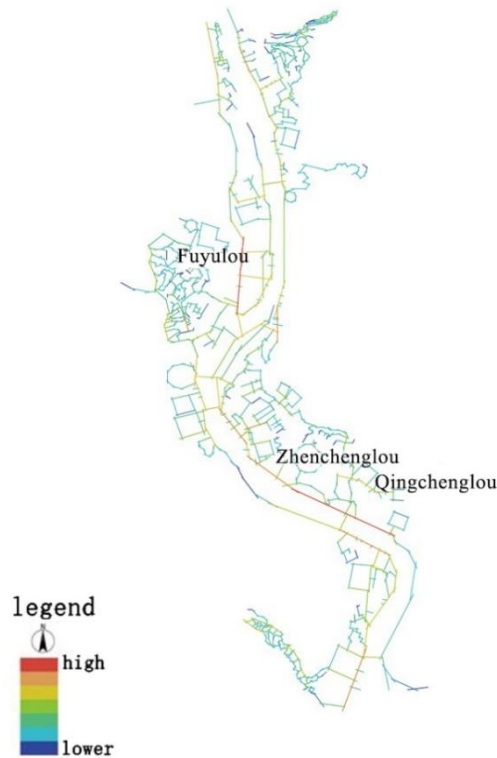


Figure 12 Hongkeng Tulou cluster local integration degree.

### 5.2 Comparative Analysis of Legibility

Legibility describes the correlation between local and global variables, assessing whether the local view within a space aids in understanding the overall spatial structure. With agricultural spaces included in the analysis, the legibility of the Hekeng Tulou Cluster is  $R^2 = 0.108$  (“Figure 13”), and that of the Hongkeng Tulou Cluster is  $R^2 =$

0.141 (“Figure 14”). Compared to the previous legibility of the road networks, overall legibility decreases, and spatial distinctiveness is reduced, indicating stronger independence of local spaces. This further demonstrates the high degree of spatial isolation characteristic of tulou buildings, affirming their strong individual independence within the settlement.

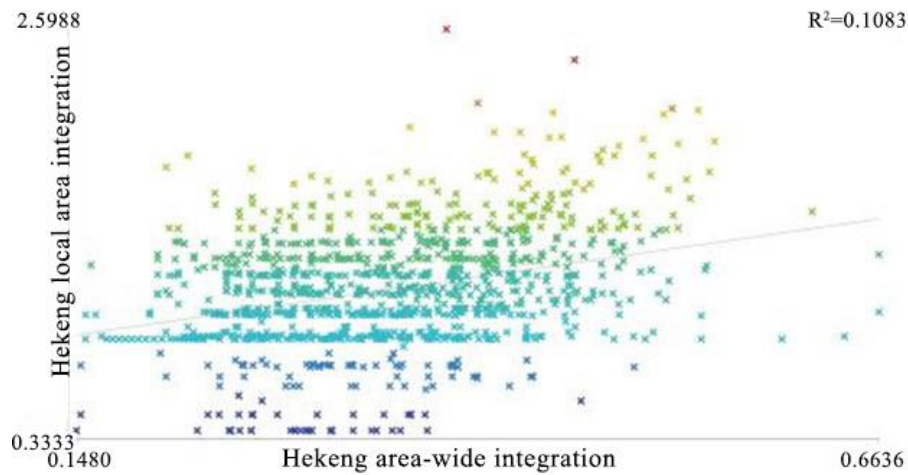


Figure 13 Comprehensibility analysis of Hekeng Tulou cluster.

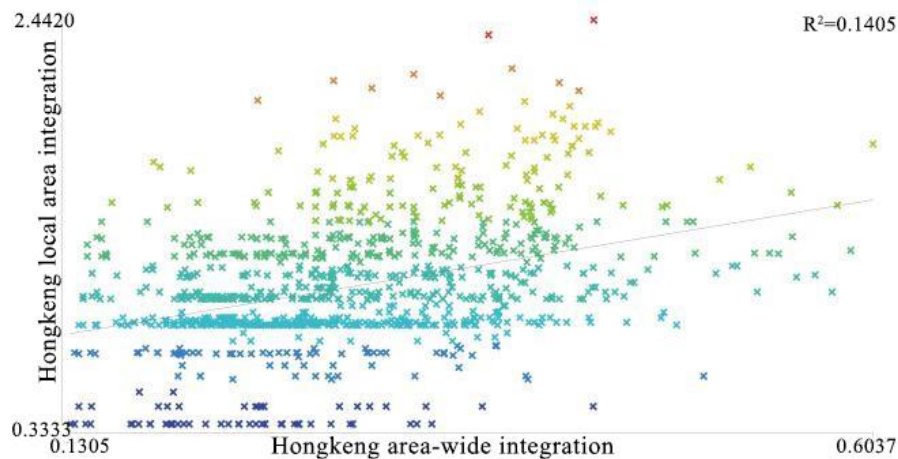


Figure 14 Comprehensibility analysis of Hongkeng Tulou cluster.

## 6. CONCLUSION

This study explores the characteristics of tulou settlements, including road network accessibility, central integrated areas, ancestral hall spaces, and agricultural spaces, from a qualitative perspective combined with a quantitative spatial syntax approach. This initial examination of these features in Fujian tulou aims to support related research on tulou culture, architecture, and settlement patterns domestically and internationally.

- **Comparison of Hekeng and Hongkeng Tulou Clusters:** The comparative study reveals common features of tulou in different settlements, with both having central roads that enhance accessibility. However, the spatial layout and road network distribution in the Hongkeng Tulou Cluster is more concentrated than in the Hekeng Tulou Cluster.
- **Legibility Analysis:** Tulou buildings exhibit a high degree of independence as standalone structures, consistent with their historical development and the Hakka people's intent to escape warfare and resist external threats.
- **Central Integrated Areas:** Both clusters show a commonality in having highly integrated central areas, organized around the main road of the overall spatial layout.
- **Differences in Accessibility, Spatial Cohesion, and Ancestral Hall Distribution:** The Hekeng Tulou Cluster benefits from the "four rivers and three confluences" layout, which provides fertile soil and ample irrigation resources, enhancing its agricultural development potential. Conversely, the Hongkeng Tulou Cluster,

limited by mountainous terrain, displays a more compact spatial layout and has a more concentrated distribution of tourism resources, making it well-suited for tourism development.

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## REFERENCES

- [1] Li B, Liu P, Dou Y, et al. Research progress on transformation development of traditional villages' human settlement in China [J]. *Geographical Research*, 2017, 36(10): 1886-1900. DOI: <https://doi.org/10.3321/j.issn:1002-1329.2009.08.017>
- [2] Li B H, Luo Q, Liu P L, et al. Knowledge maps analysis of traditional villages research in China based on the Citespace method [J]. *Econ. Geogr*, 2017, 37: 207-214. DOI: <http://doi.org/10.15957/j.cnki.jjdl.2017.09.026>
- [3] Qi L H, Chen Y Y, Ma Y P, et al. Research on the Construction of Community Public Art Space Based on Space Syntax: Taking Zhusigang Community in Guangzhou as an Example [J]. *Art & Design*, 2023, (05): 127-129. DOI:

<https://doi.org/10.16272/j.cnki.cn11-1392/j.2023.05.001>

- [4] Dawson P C. Space syntax analysis of Central Inuit snow houses [J]. *Journal of Anthropological Archaeology*, 2002, 21(4): 464-480. DOI: [https://doi.org/10.1016/S0278-4165\(02\)00009-0](https://doi.org/10.1016/S0278-4165(02)00009-0)
- [5] Chen Z, Xu J, Jiang H. Multi-scale spatial analysis of historic district based on syntax: Taking three lanes and seven alleys in Fuzhou as an example [J]. *City planning review*, 2009, 33(8): 92-96. DOI: <https://doi.org/10.3321/j.issn:1002-1329.2009.08.017>
- [6] Min Z R, Fang C Y. Spatial Cognition of Guild Building Based on Space Syntax: Taking Yanshan Hekou Ancient Town as an Example [J]. *Art & Design*, 2022, (01): 139-141. DOI: <https://doi.org/10.16272/j.cnki.cn11-1392/j.2022.01.029>
- [7] Li B, Song Y, Yu K. Evaluation method for measurement of accessibility in urban public green space planning [J]. *Acta Scientiarum Naturalium Universitatis Pekinensis*, 2008, 44(4): 618-624. DOI: <https://doi.org/10.13209/j.0479-8023.2008.096>
- [8] Wu Z K, Wang H S. The Ancestral Culture: Its Social Educational Function and Social Governance Logic [J]. *Jilin University Journal Social Sciences Edition*, 2014, 54(04): 155-162+176. DOI: <https://doi.org/10.15939/j.jujsse.2014.04.001>