

# Digital Analysis of Natural Territorial Public Space Morphology Based on Spatial Syntax

Liwen Zhang\*, Yiyang Cao, Riya Chen, Lujuan Jia, Chengfang Zhang

*School of Civil Engineering of Wuhan Huaxia Institute of Technology, Wuhan, Hubei, China*

*\*Corresponding Author.*

**Abstract:** Spatial syntax, as a quantifiable analytical tool, utilizes spatial scale division and segmentation to visually represent the morphology of natural territorial public spaces in a quantified graphic language, aiming to explore the relationship between public spaces and human behavioral activities. In order to enhance the quality of natural territorial public spaces and promote rural revitalization, this paper takes the example of Heshan Village in Xiaochang County. Utilizing the axial analysis method based on spatial syntax theory, the paper quantitatively analyzes the point, line, and area-based public space morphologies of Heshan Village using ArcGIS and Depthmap. It dissects the characteristics and intrinsic causes of its public space morphology, and proposes development strategies for planning and construction. In future planning and design, Heshan Village should particularly focus on creating emblematic spaces of points, optimizing the structures of spaces of lines, restructuring the system of spaces of lines, and refining the spaces of planes.

**Keywords:** Digital Analysis; Natural Territorial; Spatial Syntax; Public Space Morphology; Depthmap

## 1. Introduction

The evolution of computer technology and advancements in data processing methodologies have facilitated the accurate quantification of complex spaces under real conditions through spatial syntax[1,2]. Foreign scholars such as Bill Hillier, Jiang Bin, and Batty have extensively researched the fundamental theory and methods of spatial syntax, offering in-depth analyses, improvements, and innovations from various perspectives. As a result, spatial syntax has

reached a level of maturity that allows for practical application. Furthermore, this methodology has been introduced into the study of rural public spaces, particularly within rural settlements as typical natural territorial settings. In these environments, public spaces have undergone varying degrees of transformation in response to human activities, impacting internal architecture, streets, alleys, and public space morphology. In this paper, drawing upon spatial syntax theory, and taking Heshan Village as a case study, its natural territorial public spaces are categorized into three types: points, lines, and areas. By employing quantified metrics such as choice, integration, depth, connectivity, and intelligibility, an axial model analysis is conducted, creating a visual language to explore the relationship between the structure of public space morphology and human behavioral activities. This endeavor aims to provide optimized strategies for the preservation and development of rural areas.

## 2. Theoretical Framework Overview

### 2.1 Overview of Spatial Syntax Theory

The concepts related to spatial syntax were first introduced by Professor Bill Hillier of the University of London in the 1970s. This framework is utilized to investigate social logic within spatial structures and the spatial rules governing them, treating space as an independent element that can be quantitatively described and evaluated[3]. It aims to visually depict “inexpressible spatial relationships” and “complex spatial structures” through graphical representations[4]. The fundamental principle lies in exploring the relationship between human activities and spatial morphology through quantitative spatial relationships[5], thereby elucidating how changes in spatial morphology impact human activities.

When employing the spatial syntax theoretical model to study the morphology of public spaces, three primary methods are commonly used: convex space analysis, axial line analysis, and visibility analysis[6]. In this paper, we have chosen to employ the axial line analysis

method, particularly utilizing metrics such as choice, integration, depth, connectivity, and intelligibility (Table 1) to analyze the public spaces in Heshan Village.

**Table 1. Overview of Spatial Syntax Related Metrics**

| Parameters of Syntax | Characteristics      | Meaning                                                                                                                                                                                                                                 | Expression  |
|----------------------|----------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|
| Choice               | Permeability         | The frequency with which a particular element in a spatial system serves as the shortest topological distance between two nodes.                                                                                                        | Axis models |
| Integration          | Degree of connection | The degree of clustering or dispersion between an element and other elements within a spatial system.                                                                                                                                   |             |
| Connectivity         | Mutual permeation    | The extent to which spaces affect one another, where the number of connections to adjacent nodes at a certain stage represents the connectivity of the space.                                                                           |             |
| Depth                | Convenience level    | The minimum number of connections required for a space to reach other spaces.                                                                                                                                                           |             |
| Intelligibility      | Comprehensibility    | The level of discernibility between global and local spaces. When $R^2 < 0.5$ , the correlation is weak, and the intelligibility is low. When $R^2 \geq 0.5$ , the correlation is high, and the degree of intelligibility is also high. |             |

## 2.2 Overview of Public Space Theory

**Table 2. Types of Public Space Morphology**

| Spatial Parameters | Characteristics | Meaning                                                                                                                                                       |
|--------------------|-----------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Space of points    | Nodal Space     | Generally referring to a nodal spatial structure with distinct functional significance and a central point from which the spatial structure radiates outward. |
| Space of lines     | Strip Space     | Developed from enclosed ends on both sides, representing a narrow and directional spatial type.                                                               |
| Space of planes    | Planar Space    | Possessing essential information exchange and connectivity functions, and open plaza spaces in the form of public plane space.                                |

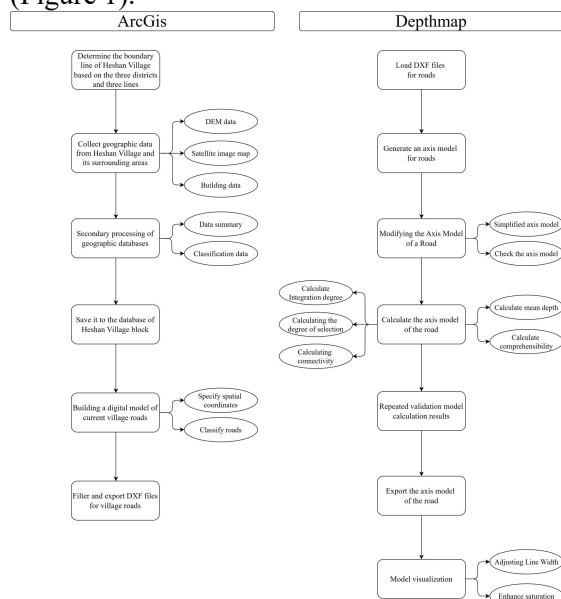
Public space is a geographical realm defined by various characteristics of community culture, referring to both outdoor and indoor

spaces used by the public for daily and social activities[7,8]. At a deeper level, it encompasses the individuals entering the space and the extensive participation, exchanges, and interactions that take place within. In his work *The Structural Transformation of the Public Sphere*, the contemporary German philosopher Jürgen Habermas categorizes rural public spaces into three spatial forms: space of points, lines, and planes (Table 2).

## 2.3 Digital Analytical Methods

Utilizing ArcGIS, the satellite imagery of the Heshan Village is employed as a reference to chart an actual road network, facilitating the creation of a closed line segment model. Adhering to the principle of drawing the longest and the least number of axes, the intricate spatial layout of streets and alleys is converted into an axis map. The aim is to ensure that the length and positioning of the axes accurately portray the genuine spatial relationships. Subsequently, this data is input into the Depthmap software, where spatial topological relationships are established. The systematic and scientific exploration of the quantitative features and internal organizational patterns of the street and alley spaces is conducted using the Depthmap software[9]. Before commencing with computations, pertinent analytical parameters

are configured to conduct a vectorized analysis of the spatial structure. This process automates the identification of connection relationships between axes, resulting in the construction of a comprehensive spatial network model. The computed results are represented by the color spectrum of the line segments, with warmer colors indicating larger values and cooler colors representing smaller ones. Furthermore, by integrating metrics such as connectivity, integration, choice, understandability, and depth values, a visually comprehensive account of the issues within the public spaces of the Heshan Villages is presented[10] (Figure 1).



**Figure 1. Technical Workflow Diagram**

### 3. The Present State of Public Spaces in Heshan Village

Located in the southwestern part of Xiaohetown, Heshan Village was formed in 2017 through the amalgamation of the former Honghe Village and Dashan Village, encompassing a total of 9 bays with a combined area of 479.86 hectares (approximately 7197.9 mu). The village boasts abundant agricultural resources with well-connected and concentrated farmland, and relatively centralized land resources. The presence of the thousand-mu agricultural photovoltaic complementary project bolsters the village's eco-friendly development.

Heshan Village features various types of spaces of points, such as the Ancestral Temple of the Zhou Family, Nangang Land Temple, and Hongshizui Land Temple. ArcGIS

delineates the boundaries of Heshan Village through the Three Zones and Three Lines approach, collecting geographical data of the village and its surrounding areas (including DEM data, impact data, and building data). This information undergoes secondary geographical data processing (data consolidation and classification), subsequently inputting into the village's district database. From there, a digitized model of the current village road system is established (involving spatial coordinate designation and road hierarchy), followed by the filtration and exportation of the village road DXF files.

Depthmap then imports these road DXF files to generate a road axis model, which is further processed (simplified and scrutinized for any omitted axes). The model is subject to calculations (integration, choice, and connectivity), leading to repeated examinations of the computed results, ultimately resulting in the exportation of the axis model. This model is visualized, with adjustments made to line width and saturation.

These public spaces of points possess a sense of place, identity, and specific historical significance. Sun-drying areas, street corners, and squares serve as punctuate public spaces, providing recreational functions for the community. Meanwhile, ancient wells, millstones, and ancient trees not only present beautiful scenic spots, but also serve as public gathering spaces for emotional exchange among the villagers. Despite the evolving lifestyles of the villagers, whereby the utility of some spaces of points has gradually diminished, they still stand as significant witnesses to the historical rural life.

The spaces of lines in Heshan Village primarily comprise the interconnected roads that traverse the village. The street and alley spaces link residential areas with crucial public nodes, serving as not only integral components of the overall spatial form, but also indispensable linear structures and frameworks within the village, effectively providing both connective and divisive functions. The village's street and alley system can be roughly categorized into two levels—main roads, side roads, and lanes—working together to form a complex and comprehensive road network system, crisscrossing and enriching the spatial fabric of Heshan Village.

Meanwhile, the spaces of planes mainly

encompass open spaces around the land temples, stages, and cultural squares. These public spaces play a critical role within the village, primarily hosting the day-to-day gatherings of the villagers, providing them with a venue for communication, interaction, and leisure. These spaces of planes not only serve as physical spaces, but also embody social, cultural, and ecological values. For instance, the cultural square at the entrance to the village committee in Heshan Village (Figure 2) is situated at a conveniently accessible intersection, where multiple roads converge. It serves as a transportation hub for villagers, while also serving as an important resting place and activity node within the village.

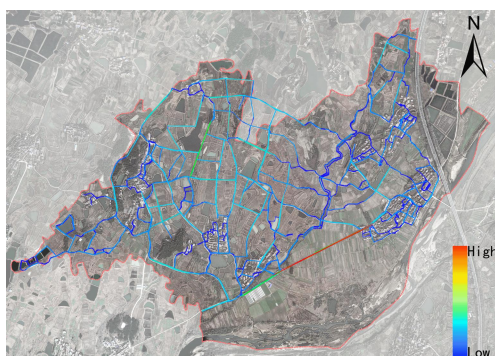


**Figure 2. Status Quo Research Diagram**

#### 4. Analysis of Public Space Form in Heshan Village

##### 4.1 Generation of Axis Line Model

Following the vectorization process in Depthmap software, the topological analysis chart of village road axis lines is generated, visually distinguishing digitized axis lines of varying degrees with distinct colors (Figure 3). The significance of these colors varies under different parameter variables.



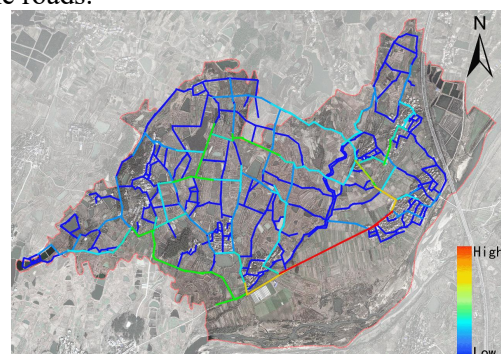
**Figure 3. Topological Axis Line Diagram**

The colors of the choice degree axis lines change according to the quantified numerical

values of the roads. As the numerical value increases, the hue tends towards warmth, appearing more red; conversely, lower values tend towards coolness, manifesting in shades of blue. Higher numerical values indicate a higher likelihood of selection and frequency of use, and vice versa. Spaces with higher integration exhibit greater accessibility and centrality, promoting easier congregation of human traffic and activities. Greater depth values signify increased difficulty in reaching one space from another and are predominantly situated within the peripheral regions of the village. Higher connectivity values indicate a closer relationship with surrounding spaces, exerting a stronger influence on neighboring areas and possessing heightened mutual permeability. Furthermore, spaces with higher intelligibility represent enhanced traffic accessibility and perceptibility.

##### 4.2 Degree of Choice Analysis

The degree of choice analysis map for the village (Figure 4) suggests that internal road connections within the village are rather limited, resulting in an overall low level of permeation. The predominant color of the axis lines is blue, with a sparse presence of orange and yellow lines, and only a single red line, indicating an overall tendency toward lower degrees of road selection. This phenomenon is attributed to the fact that the red roads, along with their connecting orange roads, constitute the main thoroughfares of Heshan Village. As such, these roads serve as the primary routes for both internal and external village activities, hence exhibiting the deepest coloration. The prevalence of blue and green lines reflects the overall road system of Heshan Village, characterized by low permeation, simplicity in structure, and fewer interconnections among the roads.



**Figure 4. Degree of Choice Analysis**

### 4.3 Integration Analysis

Integration reflects the level of closeness among spaces, signifying the aggregation or dispersion of one space relative to others within the system, with the calculation method as follows:

$n$ —total number of axes or nodes in the village space;

$D_v$ —average depth;

$d_i$ —the minimum number of connections from a specific axis line to any other axis line in the network;

$N_d$ —the number of connecting axis lines.

From the integration analysis diagram (Figure 5), it can be inferred that the central area of Heshan Village is dominated by yellow, orange, and red axis lines, with a smattering of blue and green lines. When combined with the current village status analysis, it is apparent that the concentrated and contiguous farmland of the village is mostly centralized around the middle area of the village. Human activities are relatively intense in this region; the index of human activity reaches its peak during the autumn harvest and spring planting seasons, manifesting as the public space with the highest integration in the overall spatial form.

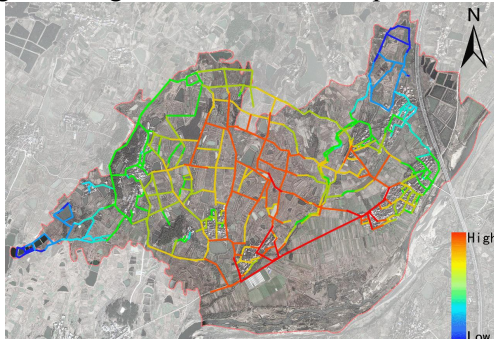


Figure 5. Integration Analysis

### 4.4 Depth Value Analysis

A scrutiny of the depth value analysis diagram (Figure 6) reveals that the predominant colors of the overall village axis lines lean towards blue and green, with deeper shades present in the eastern and western segments. The two regions with the highest depth values are situated in the northeast and southwest corners of the village, representing the most remote and naturally restricted areas with relatively narrow spatial forms. The organization of transportation in these areas is not convenient, and their connectivity with other spatial areas is relatively weak. Access to these regions is rather limited, resulting in comparably sparse

human activities.

$$I = \frac{2(D_v - 1)}{n - 2} \quad (1)$$

$$D_v = \frac{1}{n - 1} \sum_{i=1}^n d_i N_d \quad (2)$$

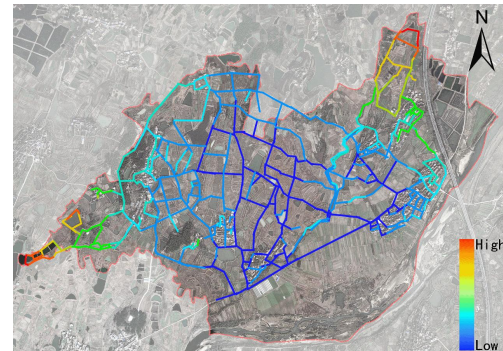


Figure 6. Depth Value Analysis

### 4.5 Connectivity Analysis

According to the analysis diagram (Figure 7), the overall axis lines of the village appear predominantly in shades of blue-green, with one line appearing in red, signifying a high level of connectivity with surrounding spaces. This indicates a strong influence on neighboring spaces and a favorable permeation between spaces. The red axis line represents the primary entrance thoroughfare of the village, serving as the sole link between the village interior and the external environment. All access to and from the bays relies entirely on this main thoroughfare, hence its red coloration and highest connectivity value. The overall connectivity values within the village are moderate, with the axis lines mainly shaded in blue-green. When combined with the analysis of degree of choice and integration, the overall road axis lines appear rather disordered, with weaker spatial permeation, thus posing the risk of congestion due to the tendency for human activities to accumulate at certain points.

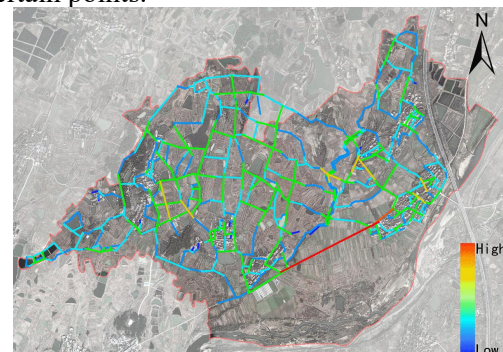


Figure 7. Connectivity Analysis

#### 4.6 Intelligibility Analysis

In the intelligibility coordinate system, the X-axis represents global integration (topological radius  $R=n$ ), while the Y-axis represents local integration (topological radius  $R=3$ ). By analyzing the linear regression equation fit, the ease with which the local space's spatial form can be comprehended within the overall space can be determined. When intelligibility is high, it indicates a clearer spatial form, making it relatively easy for individuals to comprehend the overall space while living in the local space. That is, when  $R^2 > 0.5$ , the intelligibility of space is high; when  $R^2 < 0.5$ , the intelligibility of space is low, making it difficult for people to perceive the overall spatial form through the local space. Based on the regression analysis scatter plot for Heshan Village, the linear regression equation is  $y=1.33077x+0.742038$ , with a fit of  $R^2=0.13457$ , less than 0.5 (Figure 8). This indicates that the overall spatial form of Heshan Village is relatively chaotic, with a complex network of streets and alleys. It is difficult for people, whether residents or visitors, to comprehend the overall spatial form of Heshan Village through the local space. One of the main reasons for this difficulty is that Heshan Village is the result of the merger of Honghe Village and Dashan Village. As a result, the increase in global integration far exceeds the increase in local integration. At this point, the y value is relatively reduced

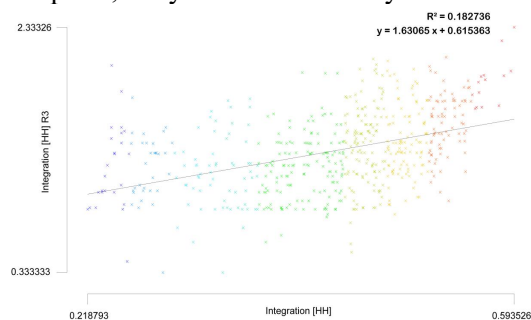


Figure 8. Scatter Plot of Intelligibility

#### 5. Conclusions

The present study focuses on Heshan Village in Xiaohe Town, Xiaochang County. Building upon the current status analysis, this research introduces the spatial syntax theory and its quantitative spatial analysis methods to examine the spatial form of the village from a combined qualitative and quantitative perspective. The aim is to explore the intrinsic

connections between the spatial morphology of the village, its different land use functions, and human behavioral activities. Based on the results of computer analysis reflecting the current state of the public spatial form in Heshan Village, optimization strategies are proposed in response to the identified issues.

Through the spatial syntax analysis, it is observed that the existing spaces of points in Heshan Village lack spaces capable of accommodating the behavioral activities and interactions among villagers. Concerning the spaces of lines, taking into account the quantitative analysis from multiple angles including integration, choice, depth value, connectivity, and intelligibility, it is found that the road network system is rather disorderly, lacking main and secondary arteries. Additionally, the quantitative indicators of road axis lines in the central area of the village show minimal differentiation, resulting in a lack of proper classification of road hierarchy. Moreover, there is a relatively low level of permeability between the spatial areas of the different village bays. Further integration with current information gathered through research reveals that the foundational infrastructure of Heshan Village's spaces of planes is inadequate. The environmental hygiene facilities are not well planned, there is a lack of fitness and elderly care equipment, the landscape greenery is relatively uniform, resulting in a poor overall experience for the populace and low usage rates of activity squares.

Based on the summarized analysis of existing issues, the following recommendations are proposed:

1. Develop iconic public space nodes within each village bay to create a sense of regional identity, such as the ancient well, millstone, and ancient trees in Heshan Village. Once these unique public spaces are developed and planned, they can function as spaces of points for activities, thereby enhancing emotional exchanges among the residents.
2. Rationalize the village road network in accordance with the natural terrain. Optimize the road network structure, increase internal road connections between different village bays in Heshan Village, widen the roads linking the village bays, improve road quality, and enhance the choice and connectivity values of village roads.

3. Provide basic activity facilities to meet the daily leisure, walking, and fitness needs of the villagers. Consider constructing small parks or pavilions to serve as public spaces for daily activities, enriching the hierarchical structure of spaces of planes, enhancing interactions between the villagers and public spaces, and promoting social activities among them.

In addition, the economic development of Heshan Village is closely tied to agricultural development. It is essential to prioritize the optimization of primary industry, leverage secondary industry, and drive the development of tertiary industry to realize the integrated development of the three industries, thus achieving economic growth, boosting the enthusiasm of farmers, and ensuring that the expansion of agricultural land contributes significantly to the green revitalization and development of the village.

Spatial syntax, through its digitized analysis of spatial forms, provides data support and theoretical basis for research, emphasizing the characteristics of spatial forms. Nevertheless, its analysis results have certain limitations as they lack a comprehensive consideration of various factors such as historical development in natural terrains, environmental changes, and human activities at different times. Future research should integrate the social and economic conditions of rural natural terrains, strengthen the credibility of data, refine strategic content, and empower rural revitalization from both qualitative and quantitative perspectives.

## References

- [1] TIAN Haonan, LI Minzhi, WEI Cheng, et al. Study of the Sociospatial Relevance of Traditional Family-Type Settlements: A Case Study based on Tangwei Village in Dongguan. *South Architecture*,2024(3): 88-98.
- [2] ZHANG Wei-qing, HU Jiang-ling. Syntactic Analysis of Historical and Cultural Neighbourhoods in Yining City—Taking Six Star Street as an Example. *Journal of Xinjiang Normal University(Natural Sciences Edition)*,2024,43(02):43-51.
- [3] Liang Buqing, Tu Xiaolan, Huang Ziyue. Research on Spatial Form and Activation Strategy of Traditional Villages in Fuhe River Basin based on Spatial Syntax:A Case of Chenghu Village in Jinxi County, Fuzhou City. *Architecture & Culture*,2023,(07):86-88.
- [4] Zhou Zhiyi, Xie Yuchen,Zhou Binqian, Research on Spatial Morphology of Tourist Villages based on Spatial Syntax:Taking Shukou Village and Heyuan Village in Fuzhou as Examples. *Architecture & Culture*, 2023,(04):137-139.
- [5] Wu Yufei, Lin Qing. Study on the Enhancement of Historic Districts and Lanes Based on Spatial Syntax: A Case of Beijing Guozijian Historic District. *Urbanism and Architecture*,2024,21(05):20-25+74.
- [6] ZHANG Chen-xi. Analysis of the Spatial Structure of Streets and Alleys in Qianwei Qingxi Ancient Town from the Perspective of Space Syntax. *Intelligent Building& Smart city*,2024,(04):57-59.
- [7] Liang Qianqian, Hei Qingmin, San Shuqin. Study of Public Space in Old Blocks based on Spatial Syntax:A Case Study of Wangping Block in Chengdu. *Urbanism and Architecture*, 2024,(02):177-179.
- [8] Chen Jianhua, Song Yingyu. Spatial Form Cognition of Traditional Villages in the Guangfu Area Based on Space Syntax: Taking Shenjing Ancient Village of Guangzhou as an Example. *Huazhong Architecture*,2024,42(03):102-108.
- [9] Liu Ying. Spatial characteristics and renewal strategies of historical and cultural blocks based on space synta:Taking Xiwenmiaoping Historical and Cultural Block of Changsha City as an example. *Future urban design and operation*,2023,(06):60-63.
- [10] Xie Xiangcong. Research on vitality of traditional village public space based on space syntax and analysis of influencing factors .*Water Resources Planning and Dsign*,2023,(01):108-110+127.