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Quantitative research on the degree of disorder of traditional settlements: a case study of Liangjia Village, Jingxing, Hebei Province

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Abstract

Traditional settlements are vital carriers of Chinese history and culture, reflecting the direct and original needs of generations. However, the modernization of settlements will inevitably disrupt the spontaneous growth patterns inherent in traditional settlements. The degree of disorder of the settlement is not only the embodiment of its form, but also the concrete manifestation of its construction intention. We use the degree of disorder in settlements to assess the construction intentions of the settlements, the results allow us to assess whether new planning aligns with the original construction logic, thereby assessing the extent of interference by modernization in traditional villages. This can provide guidance and assistance for settlement conservation and future planning. By using the Delaunay triangulation network, street polar histogram and direction entropy, and comprehensibility of settlements, this paper quantitatively analyzes the degree of disorder in the three levels of architecture, street and local environment of the settlement. Liangjia Village, the example in this research, is divided into three areas—two new and one old. degree of disorders in architecture, streets, and local environment are calculated and compared with the overall settlement. The study finds that the construction logic for buildings and streets remains stable throughout development. However, notable differences exist in environmental construction principles between new and old sections. The analysis suggests that traditional settlements, guided by inherent principles, maintain stability under external influences, serving as a benchmark for future planning and modernization decisions.

Keywords Construction intention, Degree of disorder, Future settlement planning, Growth pattern, Quantitative analysis, Settlement conservation, Settlements modernization, Traditional settlements

Introduction

A settlement consists of a collection of building blocks and streets. The building blocks and streets are organized and constructed as the local environment of the settlement through their form and direction, and some local environments are organized and constructed through topological transformation.

The final form of the settlement is the result of the gathering of buildings, streets and environments, and the way of gathering is based on "order". The overall "order" of the settlement reflects the deeper intention of the ancient people in creating their homes. This research aims to explore the inherent principles of settlement growth by investigating the degree of disorder of settlements, thereby providing a basis for determining whether the expansion of settlements conforms to these principles.

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Settlement order is an external manifestation of the spatial organization within a settlement. It is based on the ordered spatial entities present within the settlement. Addressing the order issues in the existing plan form of settlements involves primarily theoretical and methodological research.

In terms of theoretical research, Western countries have experienced urbanization earlier, resulting in a more systematic development of corresponding theories. These theories integrate with relevant disciplines, contributing to a wealth of academic research. The main theoretical aspects include Figure-Ground Theory, Texture Theory, Spatial Syntax Theory, and Spatial Perceptual Theory [1].

The Figure-Ground Theory is an important urban design theory proposed by Roger Trancik [2]. In the field of architectural planning, Figure-Ground Theory typically manifests in planning layouts, architectural spaces, landscape environments, building facades, and other aspects. This allows for the analysis of designers' design approaches and compositional relationships. Kevin Lynch uses the term "texture" to describe the morphological characteristics of settlements [3]. In his monograph, he extensively elaborates on the concept of settlement texture, considering it as the spatial combination of various elements formed during the development of settlements. He believes that urban texture is the spatial composition of different elements that have evolved over many years in a city, providing a way to grasp the characteristics of the city. Colin Rowe analyzed the process and generative principles of urban tissue morphology changes [4]. The Space Syntax Theory is a settlement spatial analysis method proposed by the British scholar Bill Hillier, originally applied in the analysis of urban spaces. Space syntax, at the level of topological models, employs an objective and precise descriptive method to link social variables with architecture and streets. Through simulation experiments using relevant software, the experimental results serve as a tool for spatial analysis or evaluating designs [5]. The space-perceptual theory is a theoretical framework that explores the process of human recognition of surrounding objects and their relative positions. J Piaget's theory of cognitive development further elucidates the nature of spatial perception [6].

The analysis of settlement order is primarily divided into two research methods: qualitative analysis and quantitative analysis.

Qualitative analysis is based on subjective human cognition, summarizing settlement order characteristics through verbal or graphical language. It relies on subjective experiences, employing methods such as internal element exploration and external element exploration. Internal element exploration focuses on aspects like streets and buildings, while external element exploration examines geometric features.Quantitative analysis employs computer-aided design software like Rhino, ArcGIS, and AUTOCAD, along with mathematical models or statistical methods, for a more precise study of settlement site plans.Just as fractal theory explains spatial organizational efficiency, it elucidates issues related to orderliness associated with spatial efficiency [7]. Geoff Boeing developed a novel directional order metric that quantifies how urban street networks adhere to the geometric ordering logic of a single grid. Through cluster analysis, he explored the similarities and differences of these study locations across multiple dimensions. Utilizing entropy as a measure of dispersion, it can be employed to study the impact of the landscape on the evolution of two cities and the related patterns of streets [8]. Spatial syntax models can analyze the morphological structure of streets and building spaces in traditional settlements, providing more objective theoretical guidance for the sustainable development of settlement spatial structures [9].

Currently, quantitative research is the mainstream. However, existing studies mainly focus on the methodological aspects of settlement order, with limited application of these research methods. As rural modernization progresses, it becomes necessary to find a suitable method to examine the outcomes of settlement modernization. This paper, through the analysis of order and the inference of construction concepts, aims to determine whether new and old areas share similar principles. This helps assess the intervention in the spontaneous growth of settlements during the process of modernization.

This study selects Liangjia Village in Jingxing, Hebei, as the research subject. Dividing the existing settlement into three parts and employing quantitative methods to measure settlement order, we assess the disorder levels in the architecture, streets, and local environments of these three areas. Our aims include exploring: (1) How disordered is the existing settlement? (2) What construction principles does the current disorder in the settlement reflect? (3) How do the disorder levels in new and old areas differ, and why? This research intends to provide a basis for the orderly planning of traditional settlements and establish a theoretical foundation for the topological study of traditional settlements.

The article introduces a method for calculating settlement disorder levels and applies it to both the overall Liangjia Village and specific parts for disorder quantification. The significance of calculating disorder levels lies in using this data to assess whether the construction patterns of the new and old settlements are based on similar construction logic. This can also provide guidance and assistance for settlement conservation and future planning.

Case study and settlement area division

Case study

The process of settlement formation is the process of ordering the aggregated elements. In this paper, the "disorder" is used to evaluate the degree of "order" in the settlement. We take Liangjia Village as an example (Fig. 1), search for the mathematical and theoretical relationships of "quantity" in the relevant geometric sense in the settlement configuration map to describe the "disorder" [10]; we also search for the internal logic of the spatial composition of the settlement, and interpret and analyze these quantified relationships. The quantitative study of the disorder of traditional settlements can help us to understand the building instincts and intentions of the ancient people, and the relevant data will certainly become an important basis and fundamental for the analysis of settlements and even future planning [11].

Our traditional farming civilization has had a profound influence on the Chinese. During the late Yuan and early Ming dynasties, Liang's ancestors migrated here from Niangziguan, Shanxi, in search of more fertile and extensive farming land.

The settlement is located in the hinterland of the Taihang Mountains at the junction of Shanxi and Hebei, surrounded by deep ditches and hills, with a vast mountain field. After hundreds of years of development, the village is full of old trees, and the streets and buildings are built according to the terrain and the mountains, and they are lined up in a row, with extraordinary appearance.

The selection of a flat location in the mountainous area for building a village and the strict patriarchal concept for internal order management are the characteristics of many traditional settlements in China that have been developed to this day [12]. Although terrain, rivers and sunlight have various impacts on the location of traditional settlements, these occur indirectly via their influences on agricultural resources [13].

With its back of mountains and face to the water, Liangjia Village has been a typical traditional farming type settlement under the premise of clan gathering since its establishment. Due to the influence of clan rituals, the Liangjia Village settlement group was centered on the Liang clan ancestral hall and spread out in all directions with it as the center, and the settlement was divided into areas and organized into living spaces according to the clan and its subordinate clans. After the founding of the country, the population expanded and the original buildings of the old village could not meet the needs of people's production and life. At the same time, the east–west direction of the mountain field of Liangjia Village is long, and its basin is also in the shape of a belt, so the villagers extend to the east and west on the basis of the original old village, and there is no big expansion in the north–south direction, so that the existing settlement form is distributed in the shape of a belt according to the township road, as shown in Fig. 2. This township road is generally running east–west, and the courtyard according to the township road can also meet the demand of residential houses facing south since ancient times, plus the undulation of the terrain, the settlement is high in the north and low in the south, and the light is not affected. Therefore, the existing village are in east–west long strip, houses are also built according to the

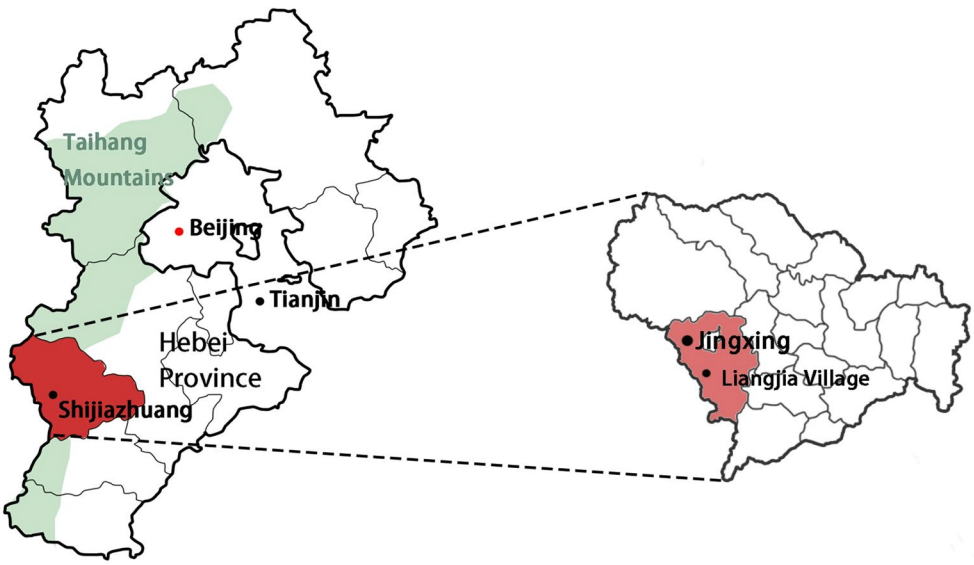


Fig. 1 Location of Liangjia Village in Hebei Province

Fig. 2 Belt basin extruded by mountain fields

trend, high in the north and low in the south. Villages have become established social units [14, 15].

In 2012, Liangjia Village was announced by the Ministry of Housing and Urban–Rural Development, the Ministry of Culture and the Ministry of Finance as one of the first traditional settlements in China.

The characteristics of rural areas are small size, wide distribution, and significant impact of topography [16–18]. However,the process of tourism development and large-scale construction, turned the rural living environment into a"miniature bonsai"and deprived it of its profound cultural ambiance [19–21].

Settlement area division

In order to assess whether the growth of the settlement during its development aligns with the construction principles inherent in the original old village, we divide the settlement into three zones, encompassing new and old areas (Fig. 3).

From the macroscopic point of view, the plan layout of the settlement seems to grow spontaneously and presents a large degree of randomness. But there is order in disorder and vice versa. Both "orderly" and "disorderly" here have multiple meanings. For example, in the spontaneous growth of the general plan, the building units generally face south, which is "order in disorder", and in the self-similarity between the local and the whole, the combination after multiple topological transformations is "disorder in order". The "orderly" originates from the law of construction, and the "disorderly" originates from self-reliance construction and external defense needs.

Method

The formation of settlement space is the presentation form of a regularized setting between each unit, and this regularity is reflected in the spatial form, which is the orderly outward manifestation between the elements of the settlement. "All things that are manifested are things that are ordered. In this world there is almost only order. All the settlements and buildings have been ordered" [22].

The 3D model was generated by computer software with the aid of UAV in the preliminary research. First, the highest point of Liangjia Village was selected, and

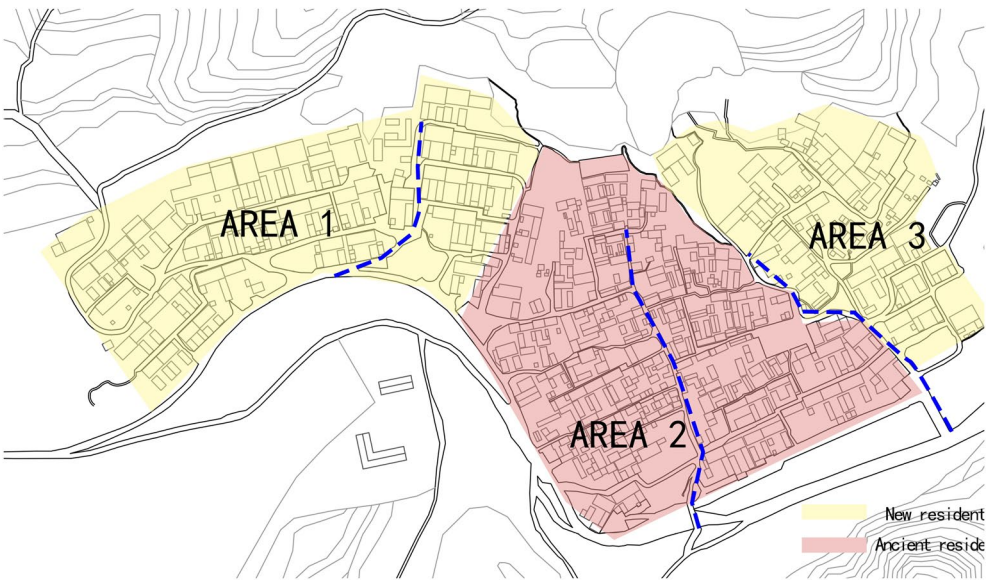


Fig. 3 Three residential areas in Liangjia Village

the UAV flew at a constant height of 25 m to take pictures. The reason for selecting 25 m was that it was difficult to maintain accuracy if the height was too high, and the perspective angle of the photo was too large if it was too low, which was not conducive to the post-synthesis of the mode [23]. After drawing the overall plan based on the 3D model, the current situation of the settlement was analyzed from the plan form.

On the architectural level, the buildings in the settlement are presented in the state of points. If a single building unit is hidden from its architectural form, the collection of building units can be abstracted as a collection of points, and the order state of the points is the order state of the buildings. The study uses Matlab software to calculate and explore the "building disorder" in the sense of "points".

From the street level, if the effect of street width is not considered (the difference of street width within the settlement is limited), the order state of the line is the order state of the street in the settlement. The study calculates the "street disorder" in the sense of "line" with the help of Python software.

On the environmental level, the local area of the settlement can be abstracted as a surface. How is the similarity between the local area and the whole settlement? The order status of the "face" is the prediction of the overall shape of the settlement by the local area of the settlement. The study uses depth map software to calculate the "environmental disorder" in the sense of "face".

The disorder of "point, line and surface" elements reflects the disorder of the settlement at their respective levels. The process of settlement formation, i.e., the continuous order of "point, line, and surface" elements are continuously ordered.

Methods of building degree of disorder based on Delaunay triangular network algorithm

Principle of building degree of disorder

The original meaning of settlement is a place where human beings live and gather, and various groups of buildings build the settlement. In the traditional settlement, the dwellings are built according to their respective "rules" and "order", either in accordance with the topography, orientation, patriarchal law, or the pursuit of "Feng Shui", forming a variety of "order ". The arrangement is subjective and conscious. From the architectural point of view, each settlement has a unique architectural composition of the bottom of the relationship, forming a specific settlement texture. The overall order of the settlement is controlled by the architectural order. The organization of the buildings defines the spatial form of the settlement. It is meaningful to explore space diversity and its driving factors from within the settlements [24]. Before each building is built, it will be directly influenced by the surrounding "neighboring" buildings, and after it is built, it will also influence the "neighboring" buildings. The orientation, height and structure of the building will have a direct impact on the neighboring buildings. If any two buildings were to be calculated and compared, the data would be too large and not entirely informative. Therefore, counting the angles and distances between each building and the planform centers of neighboring buildings one by one, and calculating the standard deviation and mean value are important indicators to explore the disorder of buildings within a settlement.

Ideally, if the angle between any two building centers in a cluster is 90° or 0°, i.e., if any two buildings are perpendicular or parallel, the building angle disorder is the lowest and the degree of order is the highest; if the angle between any two building centers in a cluster is 45°, the disorder is the highest and the degree of order is the lowest. Therefore, it is necessary to count the angles between all neighboring buildings that have influence on each other and calculate the average of the magnitude of the deviation of the angle α from 45° between all neighboring buildings to each other, i.e. $A = \alpha - 45$. The larger the value of A, the larger the average of the difference between the angles of the buildings and the absolute disorder angle of 45°, that is, the lower the disorder of the building angles in the cluster and the higher the order.

In addition, the average value of the distance between the building form centers expresses the average value of the distance between the buildings in the settlement. However, unlike the relationship between building angles, 45°in the angle is an absolute disorder value, and the disorder of this data can be obtained by making a difference between any data and 45°. However, there is no "absolute disorder" value in distance, so the distance standard deviation is used to express the distance fluctuation between the buildings in the settlement to express the distance disorder.

The Delaunay triangle is an algorithm proposed by the Soviet mathematician Delaunay in 1934. The Delaunay triangle is used to calculate the building disorder because of its excellent properties: Firstly, closeness. Because the triangle is formed by the nearest three points. In a traditional settlement, the construction of each building is directly influenced by the neighboring buildings, while the non-neighboring buildings are less affected. Secondly, the regionality, when adding, deleting or moving a vertex, it only affects the adjacent triangles, similar to the concept of "neighbors" in the architectural sense required for the study. Finally, the uniqueness of the triangle network system, no matter where to start building from the region, the final result will be consistent. In the operation, we use Matlab to construct the triangular network

for each building in the settlement, and the algorithm function is as follows.

DT = delaunay(x, y);

triplot(DT,x, y);

After generating the triangular mesh the angular deviation and length of each side length is calculated one by one and then generalised to find the angular mean and distance variance.

Steps to generate Delaunay triangular network using matlab

Step 1, draw the outline of all the buildings in the settlement, and draw the building outline shape centers.

Step 2, the coordinates of all the building contours' form centers are derived.

Step 3, use the Delaunay algorithm in matlab to draw the Delaunay triangular network about the coordinates of the building form center points.

Step 4, the distance and angle parameters of each edge are organized and calculated.

Methods of street degree of disorder based on street direction entropy

Principle of street degree of disorder

"Entropy" is a thermodynamic concept used to measure the degree of disorder in a computational system, which shows the relationship between the magnitude of the quantity and its uncertainty. In this paper, we use the concept of "information entropy" to measure the disorder of street direction. The "information entropy" can solve the problem of quantitative measurement of information. The greater the uncertainty of a variable, the greater the entropy value, and the greater the amount of information needed to sort it out. Therefore, the higher the entropy value, the more chaotic the system is, and the less likely it is to be correctly valued. If the system is ordered, the information entropy value decreases. Information entropy is a function of the percentage of each part of the system and can be used to measure the degree of system disorder. In order to study the directional disorder of the settlement streets, we use the concept of information entropy to construct a "directional entropy" function to quantify the directional order of the streets, whose formula is

$$H(X) = -\sum_{x}^{n} P(x)\log_2[P(x)]$$

where H(X) is the directional entropy value of the settlement streets and P(x) refers to the frequency value of the occurrence of streets in the x-direction. To facilitate the calculation and study in conjunction with the CAD plan, a 360° week on the plane is divided into 36 equal groups (i.e., each group contains 10°). Let the due east direction be 0°, and number them counterclockwise from 356° as the starting point. To avoid extreme edge effects around common values (e.g., 0° and 90°), each group is shifted counterclockwise by 5° to be at the center of the group, not at the edge [25]. That is, the direction of the first group of data is 356°–5°, the direction of the second group of data is 6°–15° …… and so on, counting the number of occurrences of each group of directional data paths and performing frequency calculation, the directional entropy value can be found. The more orderly, the lower the entropy value [26]. The software was then used to generate polar histograms of streets for visual comparison and study.

Steps of calculating directional entropy and generating polar histogram of streets using Python

Step 1, according to the street trend, the street is abstracted into line segments based on the street centerline, and the settlement street centerline map is drawn.

Step 2, the street centerline data is exported.

Step 3, transform the tabular data into a visual polar histogram with the help of Python.

Step 4, organize the street centerline line data, group the data together, count the frequency of each group of data, and calculate the directional entropy value based on the data.

Methods of environmental disorder based on spatial syntax

Spatial syntax comprehensibility interpretation

Bill Hillier points out that it is difficult to experience both urban and architectural space immediately in its original place. One must observe it in motion through the system in order to gradually build up a picture of the whole spatial system, part by part [27]. People can learn more about their own living space using spatial syntax [28, 29]. When one perceives and observes the space in the local area, whether one can try to understand the whole space through the local area, this introduces the concept of comprehensibility. Comprehensibility data is often used to identify correlations between tourism situations and street networks, which helps decision-makers to optimize the spatial layout of tourism facilities in historic district planning [30].

Comprehensibility is the value that measures the similarity between the local environment and the overall environment and is calculated as follows.

$$R^2 = \frac{\left[\sum (Ci - \overline{C})(Ii - \overline{I})\right]^2}{\sum (Ci - \overline{C})^2 \sum (Ii - \overline{I})^2}$$

It can be seen that the comprehensibility R^2 is a function about the degree of connection and integration

between the local and the whole [31]. When $R^2 < 0.5$, the spatial comprehensibility is poor, the similarity of the overall space is low, the spatial structure is more confusing, and people cannot perceive and know the overall space effectively through the local space when they experience the local space. When $0.5 \leq R^2 < 0.7$, the degree of spatial comprehensibility is moderate, and when $R^2 \geq 0.7$, it is considered that there is a significant correlation between the horizontal and vertical axes, that is, the degree of spatial comprehensibility is higher, the overall spatial similarity is higher, the sense of spatial order is stronger, and people's awareness of local space is a better guide to understand the overall space.

Steps of using depth map to generate comprehensible degree map

Step 1, draw the street axes in CAD and import the CAD to depth map software in dxf format.

Step 2, check the correctness of the axis map by Node Count command in depth map (if there are isolated axes or axes not intersecting or out of the head, you need to redraw them).

Step 3, use the software to calculate. Open Scatter Plot and change the x-axis to the value of infinite topological radius integration degree and the y-axis to the value of three-step topological path to get the comprehensibility degree of the overall settlement at R = 3. Similarly, we can get the value of cluster comprehensibility at R = 5,7,9.

Quantitative analysis of the disorder level in Liangjia village settlement

Results

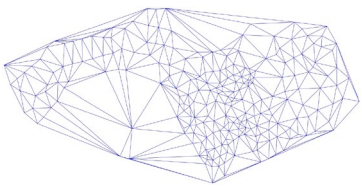
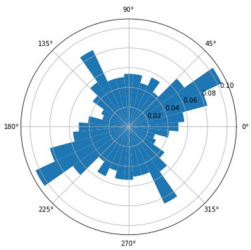
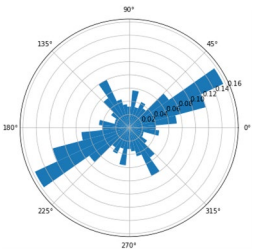
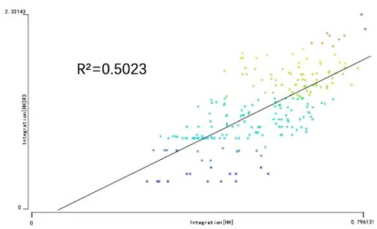
The results show that conclusion of degree of disorder in Liangjia Village is in the intermediate state (Table 1).

Building

Diversity is nature to big cities [32, 33]. The construction of any building in an urban residential area is subject to multiple levels of approval by higher-level planning units. The appearance, material and height of the building are clearly defined before construction begins. Therefore, the formation of urban architecture has been planned from the top-down. However, unlike urban architecture, the generation of traditional settlement architecture is bottom-up, which contains great subjective initiative of the builders, creating both order and disorder in traditional settlement architecture.

In the planning and renewal of traditional settlements, we must fully consider the lives of the people and ensure the stability of people's lives [34, 35]. Liangjia Village is located in a basin area with many mountains, and due to the influence of the terrain, the basin sandwiched by

Table 1 Conclusion of degree of disorder in Liangjia Village

Levels	Step1	Step2	Conclusion	Evaluate
Point			22.56	Medium-value
Line			2.74	Little higher than medium
Surface			0.5023	Little lower than medium

the mountains on the north and south sides is relatively gentle, so the villagers of Liangjia Village have been building their homes spontaneously in this basin for generations, and this spontaneity is the main reason for the architectural disorder. The building form of Liangjia Village is the common courtyard dwelling in North China, with the main house in the north, and the compartments with smaller floor areas in the east and west, which are used for living or subsidiaries. Some of the courtyards also have some shorter buildings used as grocery rooms. Due to the large number of east and west rooms, any of the rooms take the north room as the main reference for angle and distance, and the area of the east and west rooms and the miscellaneous room is small, which can be regarded as the auxiliary room of the living space in the overall courtyard. Therefore, the study does not consider the order of the compartments and miscellaneous rooms in each compound separately. The settlement buildings are considered as residential subunits with courtyard as the basic unit for calculation.

To calculate the angles and distances of adjacent buildings in Liang's village, it is first necessary to fade away the building boundaries and transform the buildings into prime points. The study uses the shape center of the plane contour of the building compound to represent the building. For a rectangular courtyard, it is the intersection of its long and short axes. CAD mapping software is used to extract the coordinates of the shaped center of the compound, and the point coordinates are imported into Matlab to generate the Delaunay triangular network of the point coordinates of the building in Liangjia Village, as shown in Fig. 4.

The data of each line segment is extracted, organized and calculated.

If the absolute value is subtracted from the most disordered state of 45° first and then the average value is calculated, when the result is 0°, the buildings are all at an angle of 45° with each other and are in an absolute disordered state. When the result is 45°, the angle between buildings is 90° or 0°, that is, all buildings are perpendicular or parallel to each other, and the whole settlement is in the state of absolute order. The data of Liangjia Village were extracted and calculated, and the result was 22.56°. From the results, it can be seen that the average value of building angles in Liangjia Village is in the middle position between 0° and 45°, i.e. the middle state between absolute disorder and absolute order.

In order to infer whether there are similar architectural construction principles during the process of settlement formation through disorder analysis, we divided the settlement as shown in Fig. 3 and conducted calculations using the same procedure. The conclusions drawn are as follows (Table 2):

The disorder levels for the three zones are between 22.38–24.51, with an overall settlement disorder level of 22.56. After integrating the slightly more orderly parts

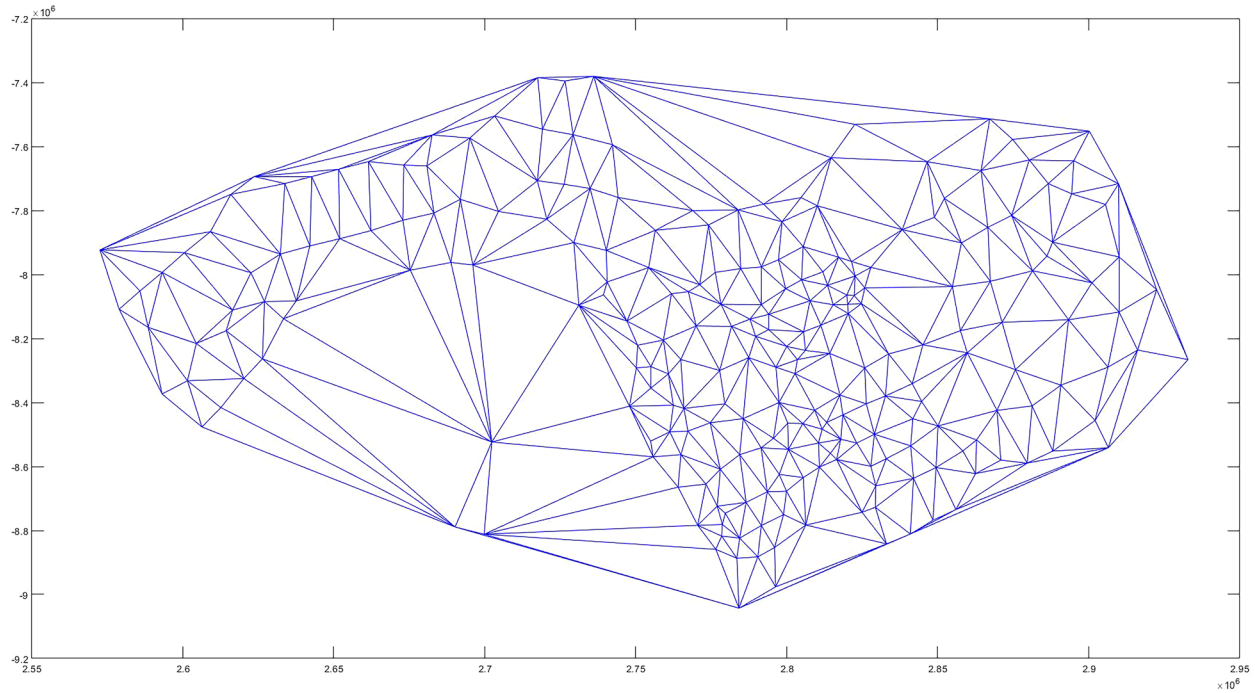
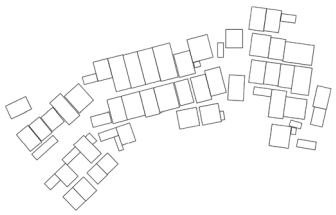
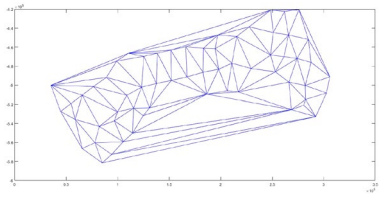
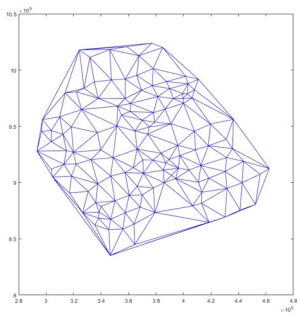
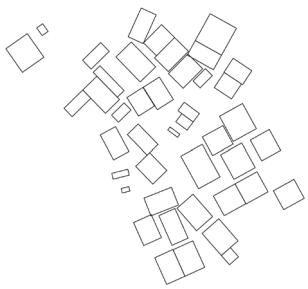
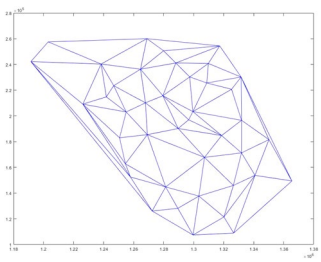
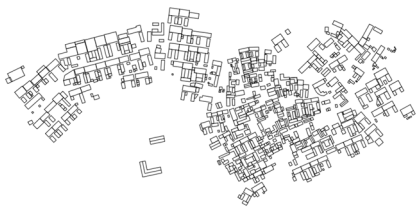
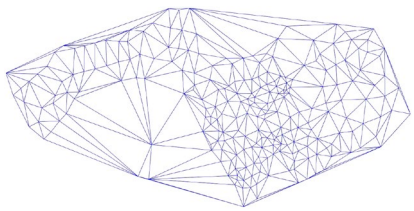


Fig. 4 Delaunay triangle network diagram of Liangjia Village Architecture

Table 2 Building degree of disorder of the three residential areas

Area	Step1	Step2	Conclusion
Area1			24.51
Area2			22.38
Area3			23.56
Overall			22.56

with the slightly less orderly parts into a whole, the overall settlement disorder level becomes the intermediate value. This indicates that during the process of settlement development, there is a similarity in the logic of architectural construction, resulting in a moderately disordered final architectural form.

Street

As shown in Fig. 5, there is an S-shaped township road in the south of the village, which is the main street connecting the village to the outside world. Several major roads in the village are connected to it and lead out from it. The main road in the north–south direction generates secondary streets to connect the main road, which together form the internal transportation skeleton of the settlement (Fig. 6).

The street is zigzag, but the road axis we use for directional entropy calculation is a straight segment, so the street centerline is converted into several straight segments instead of a zigzag street. In the drawing process, the street centerline should be as long as possible but not beyond the street boundary. Therefore, Fig. 6 is obtained and used to perform the directional entropy calculation.

After exporting the length and angle data of the street centerline shown in the figure, the data is organized. The 360° of a week on the plane is divided into 36 groups equally, and the angular offset range of each group of data is 10°, and the number of axes of each group of data

Fig. 5 Liangjia Village settlement structure map

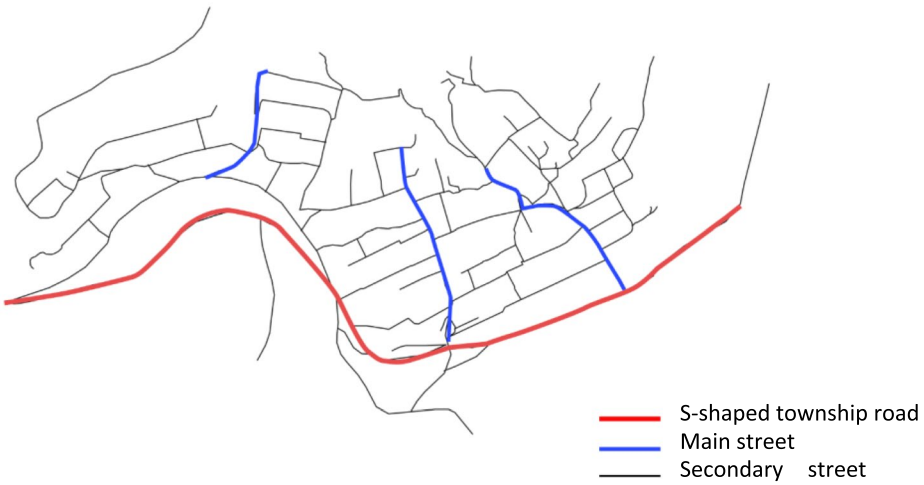


Fig. 6 Street skeleton of Liangjia Village

is calculated. Then divide the frequency of each group by the total number of all axes. The data of the axis of Liangjia village is 227 axes, and the frequency P (i) is calculated in turn. The meaning of P (i) is the frequency value of the data of the ith group, that is, the frequency of the data appearing in the angular segment of the data of the ith group. Finally, the direction entropy function is used to calculate, and the calculated direction entropy of Liangjia Village street axes is 2.84. If the total length of each group of streets is considered to be different, the direction entropy is calculated after the length weighting of each group of street frequencies, and the weighted direction entropy value is 2.74.

The data were imported into the programming software for visual representation. The histogram of polar coordinates of streets in Liangjia Village was calculated and shown in Fig. 7; then the length of each street was integrated and the histogram of weighted streets in Liangjia Village was obtained after the weighting of street lengths, as shown in Fig. 8.

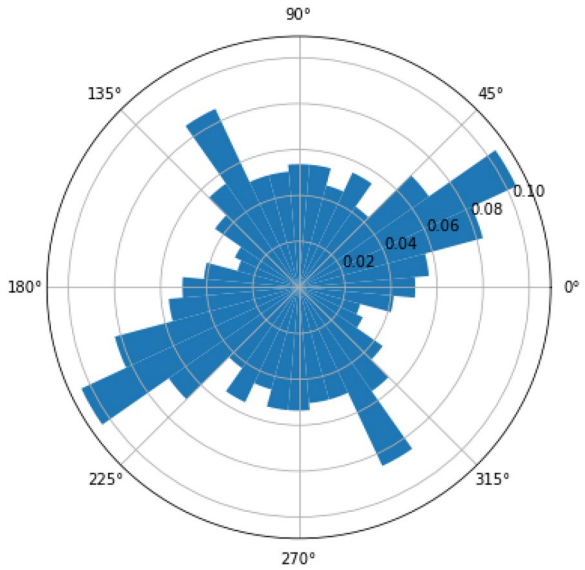


Fig. 7 Unweighted street polar histogram

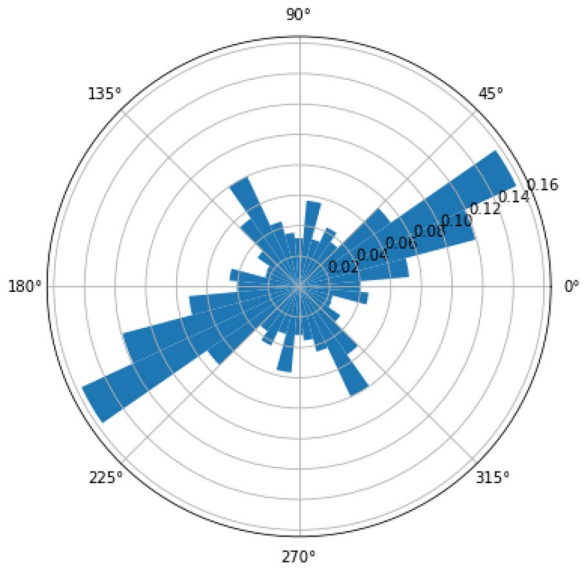


Fig. 8 Histogram of length-weighted street polar coordinates

Similarly, in order to infer whether there are similar street construction principles during the process of settlement formation through disorder analysis, we divided the settlement as shown in Fig. 3 and conducted calculations using the same procedure. The conclusions drawn are as follows (Table 3):

The disorder levels for the three zones are between 2.70859–2.84577, with an overall settlement disorder level of 2.74. After integrating the slightly more orderly parts with the slightly less orderly parts into a whole, the overall settlement disorder level becomes the intermediate value. This indicates that during the process of settlement development, there is a similarity in the logic of street construction, resulting in a little higher than medium disordered final architectural form.

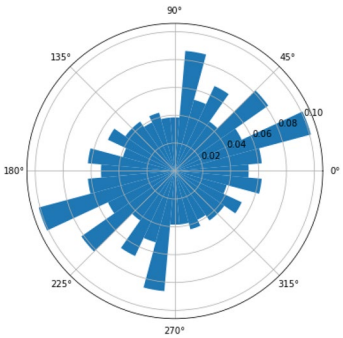
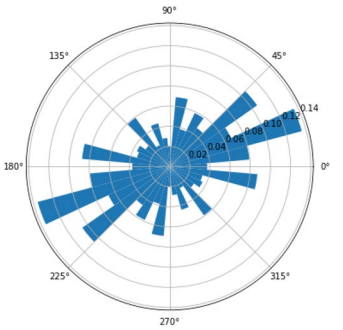
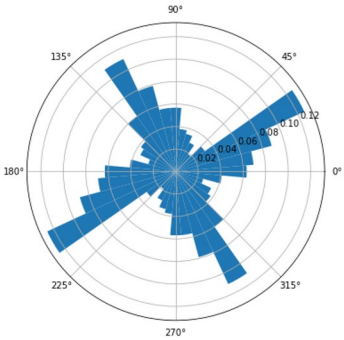
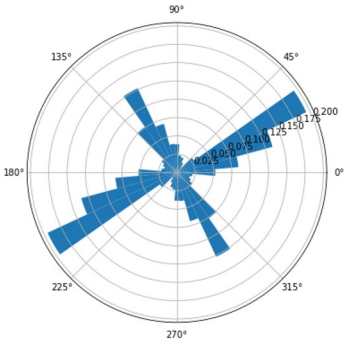
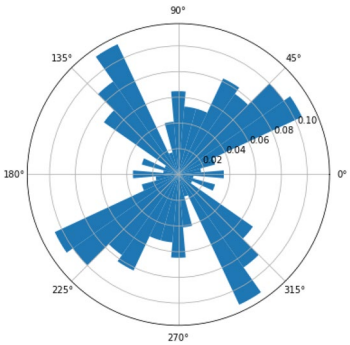
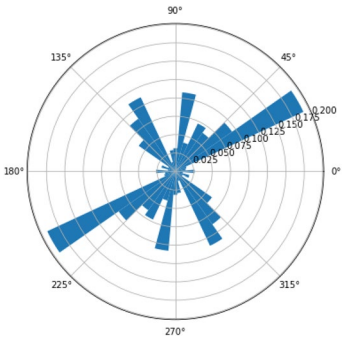
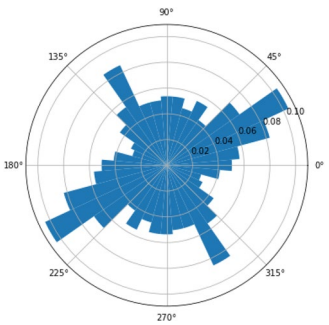
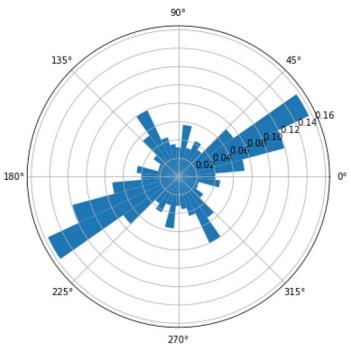
Environment

Intelligibility is a concept in spatial syntax that reflects the degree of difficulty in passing through the environment, i.e., how easy it is for a pedestrian to reach a target location from any one position throughout the street space [36]. The regression coefficient R^2 explains the degree of variability of Rn. The smaller R^2 is, the greater the variability of Rn, the lower the order and the higher the disorder of the region [37]. The computational mechanism of comprehensibility lies in whether the overall structure can be effectively predicted from the local order and used as a guide to build a picture of the whole spatial structure. If the spatial structure of the local and the whole is more similar, people will easily and correctly integrate the piecewise and ephemeral small-scale spatial cognition into the holistic and co-temporal large-scale spatial cognition. However, if the similarity between local and overall spatial structure is low, the small-scale spatial cognition does not correctly reflect the overall spatial structure, and the overall structure cannot be reflected by the local, then the spatial order is weaker and the disorder is higher. In other words, the lower the comprehensibility, the weaker the similarity between the local and the whole, the lower the correlation between the local environment, and the higher the environmental disorder.

According to the spatial syntax, the axes tangent to the turning point of the street and extending to the edge of the street, and the "longest and least" axes were used to summarize the street, and the relevant calculation was performed with this axes map. After drawing the axis map of Liangjia Village, it was imported into Depth Map software for calculation, and the integration degree Rn-R3 scatter plot was obtained, as shown in Fig. 9. Theoretically, the regression coefficient $R^2=0.5$ is taken as the cut-off point, and a value of R^2 greater than 0.5 is considered a better fit, and vice versa is worse. The regression coefficient R^2 of Liangjia Village is 0.502, which is very close to 0.5, and can be considered to be in the middle state of comprehensibility, i.e., mediocre comprehensibility.

Comprehensibility is an important indicator of whether one can effectively perceive the global spatial structure, and a higher comprehensibility can better predict the use of space in the environment. Therefore, a high spatial comprehensibility of the settlement makes the whole predicted by localization more effective. At the macro level, the spatial structure of that settlement becomes clearer, the possibility of knowing the whole through the local

Table 3 Street degree of disorder of the three residential areas

Area	Unweighted street polar histogram	Length-weighted street polar histogram	H
Area1			2.84277
Area2			2.76330
Area3			2.708599
Overall			2.74

is higher, the similarity between local environments is stronger, and the settlement environment is more orderly. For a traditional settlement, the higher the degree of comprehensibility, the closer to the single-core space, the simpler the space. Rural settlements have complex and diverse spatial characteristics.The lower the comprehensibility, the easier it is to get lost [38]. It is under the care of both external defensiveness and internal orderliness

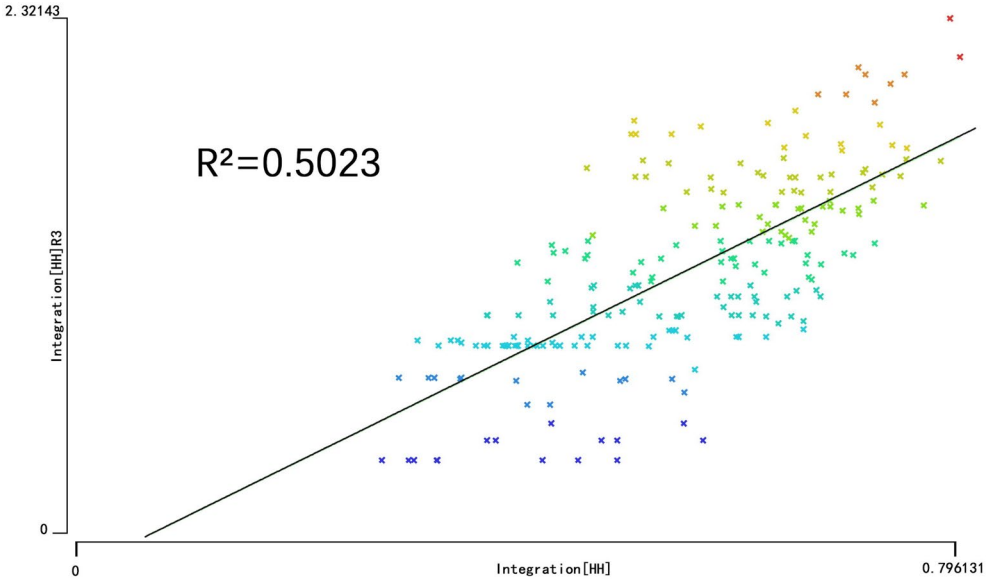


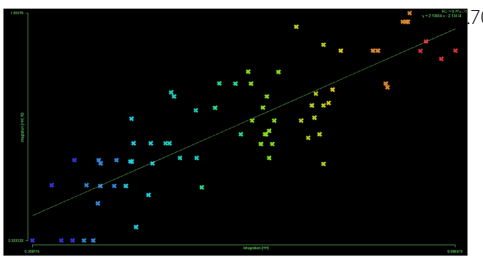
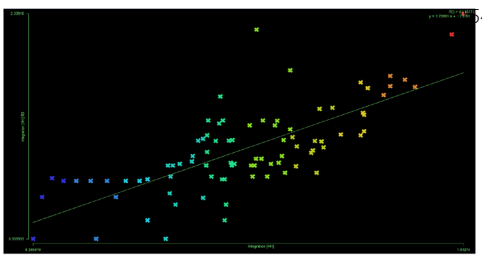
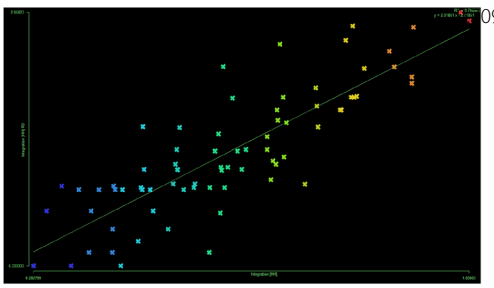
Fig. 9 Integration Rn-R3 scatter plot of Liangjia village

that the comprehensibility of the settlement is placed in the middle of "refusal to predict" and "effective cognition", so the R^2 value of Liangjia Village is 0.502, which is a good illustration of the planning design that takes both into account.

In order to infer whether there are similar environment construction principles during the process of settlement formation through disorder analysis, we divided the settlement as shown in Fig. 3 and conducted calculations using the same procedure. The conclusions drawn are as follows (Table 4):

Unlike the residential communities in the cities which are planned and approved at different levels, the bottom-up spontaneous construction in the traditional settlements often includes the strong initiative of the residents, so the local environmental disorder of the traditional settlements is relatively higher than that of the urban residential areas. Even though there is a certain order in the small environment of the settlement, with the population expansion and the development of social production, the original settlement environment is no longer suitable for the existing social development needs, and the "new village area" is born. The differences in topography, housing layout and building density between the old and new village areas will aggravate the environmental disorder and lead to the reduction of overall comprehensibility. The new village and the old village are two parts of Liangjia Village, and their structures and paths are very different. The old village has a complex environment and winding streets, while the new village has a clear structure and straight streets. The R^2 value of the old village section of

Table 4 Environment degree of disorder of the three residential areas

Area	Figure	Conclusion
Area1		1708
Area2		5461
Area3		09

Liangjia Village is 0.546, but the values of the new village section at the east and west ends are both around 0.71 (Table 2). It seems that the new village R^2 value is higher and the overall R^2 will be boosted when calculating jointly with the old area. However, the actual situation is that the structural logic of the east and west new villages is completely different from that of the old village, which basically belongs to an independent system, and the overall R^2 value is pulled down after the integrated calculation, which to a certain extent expresses the departure between the present late planning and the original design intention at the beginning of the village.

Conclusion on degree of disorder of Liangjia village

For Liangjia Village settlement disturbed degree, the above three methods were analyzed at three levels: point, line and surface, and their main meaning is to express the degree of disorder in quantitative data. The result (Table 1) indicates that in the process of building Liangjia Village, the power of spontaneous construction and external planning is nearly equal, which is very consistent with the traditional academic view of combining subjective construction and objective planning. The study of the degree of disorder not only provides a direct sense of the disorder of the settlement, but also reveals the process of confrontation between the inner self-generated development and construction and the external planning power in the process of settlement growth.

The innovation lies in the reverse deduction of disorder level conclusions to construction principles and the analysis of whether the construction logic of the new zone aligns with the original zone, aiming to provide guidance for future planning.

Disorder level serves as a direct expression of construction principles. In conclusion, the construction principles of buildings and streets in Liangjia Village are relatively consistent between the new and old villages. However, there are significant differences in the environmental construction principles between the new village and the old village.

The geopolitical condition of Liangjia Village determines that there is enough space for "spontaneous growth" of the buildings in the settlement, which gives a slight advantage to the self-built construction in the struggle with the later planning, and the subjective initiative of the ancestors' construction can be expressed to a greater extent.

What sets China apart from other countries in the world is Chinese attach great importance to clan ideology and blood relations. The geopolitical edge determines the relaxed living environment of the settlement and the outward appearance of the building instinct, while the blood relationship is related to the cohesiveness of the settlement, as the maintenance and bond of future generations, in the process of generating the streets of the settlement implicitly affects the construction. Since the ancestors of the Liang moved in, they established the Liang ancestral hall at the core of the original base of the settlement, and the settlement has been developing for generations, with the ancestral hall as the center of balanced development. The central street next to the ancestral hall is the main street network within the settlement, and the development of the street skeleton in the following generations has been seeking more or less the connection with the central street.

Since the development of Liangjia Village, geography and blood relations are the material and spiritual conditions on which the settlement has developed. The current situation of the settlement is the result of the balance and harmony between nature and the inner being at the same time. The development of the buildings, streets and environment of Liangjia Village is logical and sensible under the influence of the relationship between geography and blood. After more than six hundred years, the three levels of disorder have finally become the current form. If we look at the traditional settlement planning by the standard of modern settlement groups,it has shortcomings. We should look for "order" in the construction and explore the reasons of "order" or "disorder".

Discussion

We seek to infer the causes behind the existing disorder quantification results in three zones, specifically, what intentions drove the ancestors of Liang to construct the current settlement. Why do the buildings and streets in the new zone align with the established construction intention of the original settlement, while the environmental construction at the local level differs significantly from the original settlement? Based on this data, strategic analysis can be carried out for the renewal or maintenance of the traditional settlement.

Regarding the buildings, after quantification, the conclusion shows that the building disorder is in the middle state between absolute disorder and absolute order. Regarding the street, after quantification, the conclusion shows that the street disorder is at the orderly end of absolute disorder and absolute order. Regarding the local environment, after the quantification process, the conclusion shows that the local environmental disorder is basically in the middle value between absolute disorder and absolute order.

The creation of settlements is based on human initiative, and the differences in perceptions inevitably lead to different results. For the traditional settlements, which were not created "overnight", the ideologies of different periods and creators have contributed to the current state

of affairs. There is a certain order in the disorder, and this order has remained relatively stable over the millennia. This "order", which is the architectural intention handed down from generation to generation, is not unchanging, but it is different from the modern natural science based on data, and it is a rational and sensual comprehensive construction concept that affects today.

Architectural construction intention

After the village was established, villagers reclaimed the mountainous land for farming and built houses in the flatter basin area surrounded by mountains, and the terrain limited the area of housing within the village. After the village was built, the area of the village enclosed by the surrounding cultivated land changed constantly due to war, disease, and social changes, but the area of the basin for houses almost unchanged. The rich basin area has given more space for the residents to build houses spontaneously, and the spontaneous construction has led to a variety of architectural forms. The topography and economic conditions also have a considerable influence. Although the basin area was chosen to build a home, it is difficult to completely avoid the undulations of the terrain. Conforming to the topography, reducing the amount of earthwork and workload, and generating the compound according to local conditions when economic conditions allowed, were also important reasons for the differences in orientation and scale among the compounds. After the founding of the country, with the gradual increase of industrialization in China, materials such as cement and concrete were applied in large quantities, and many new buildings in the village were built with mixed materials instead of the all-stone structure of the Ming and Qing dynasties; the courtyards increased substantially, and although each was built by the terrain and by the mountain, there were more repetitive elements in the plane, and the courtyards were more modularly presented.

The settlement has been built and planned by several generations since it was first established. In addition to the internal process of spontaneous construction, the present state is also influenced by external overall planning, topographical conditions, economic patterns, and patriarchal order. While spontaneous construction can cause disorder, planning under the influence of the economy and patriarchy can create order. The form of any traditional settlement is the result of a mutual counterbalance between the two. The topography of the village and the large size of the basin have allowed the construction of the village to be carried out under relaxed external conditions since its foundation. The planning under the influence of the patriarchal concept was also well organized and orderly. The relaxed site created space for both spontaneous construction and external planning. There is a certain twist between the three patches as a whole, but the buildings within the patches are still relatively orderly. The angular order result of Liangjia Village is 22.56°, which is roughly in the middle state between absolute disorder and absolute order.

In ancient times, the country was founded on agriculture, and this social relationship prompted our ancestors to seek a self-sufficient "small social environment". Based on the defense function, its construction and site selection are pursuing a certain inward-looking. At the same time, the ancients attached great importance to ancestor worship and blood ties, and the concept of ancestral rituals influence a lot. As a traditional farming settlement, the base of Liangjia Village is an inward-looking basin, and the house pattern is also an inward-looking compound. Although there are changes in building materials and shapes, as well as differences in size and orientation, the compound pattern of the basic living unit has not changed. With the expansion of the overall house base, the settlement is still developed evenly in the east–west direction with center of the ancestral. Although not yet written, this is the potential normative culture in the minds of villagers over the generations. Under the influence of this normative culture and the good geopolitical conditions (the surrounding hills have low slopes and fertile land, suitable for cultivation), the central hills enclose a large area suitable as a house base. Therefore, for a hundred years, Liangjia Village did not have the situation of the cultivated area and the residential area were squeezed and encroached upon each other. This phenomenon allowed the village houses to follow the villagers' self-will and grow in a natural and orderly manner under more relaxed conditions. Even after the sharp population decline caused by the war in the Republic of China and the steep increase in population due to the production needs in the early years of the founding of the People's Republic of China, the residential area of Liangjia Village changed slightly, but the residential groups still changed evenly in a balanced and symmetrical pattern under the patriarchal concept based on the first-born system, and the inner order of the buildings remained stable. Although the buildings follow the ups and downs of the terrain and have their own twists and turns in accordance with the orientation and "Feng Shui" of their respective house bases, they are all inwardly oriented courtyards as the basic unit, high in the north and low in the south, lined up in a row, and the overall order is particularly obvious and clear at a glance.

Street construction intention

In order to measure the street direction entropy value of Liangjia Village, two comparison cases are cited in this

Fig. 10 Satellite view of Century Garden District

Fig. 11 Satellite view of the Humble Administrator's Garden

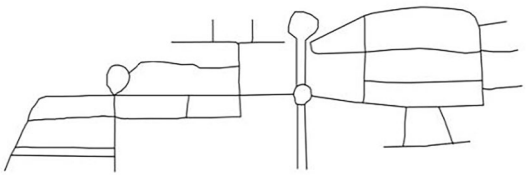


Fig. 12 Path map of Century Garden District

paper, and their direction entropy is calculated separately to compare with the entropy data of Liangjia Village. The comparison cases take the settlement with street density similar to that of the traditional settlement as the alternative condition. As shown in Figs. 10, 11, 12, 13, the satellite and path maps of the Century Garden residential community in Shijiazhuang and the private garden The Humble Administrator's Garden in Suzhou are shown respectively. The entropy values of Century Garden and The Humble Administrator's Garden are calculated to be 1.86 and 2.51, respectively, and the value of Liangjia Village street direction entropy is 2.74, which is slightly higher than that of The Humble Administrator's Garden. The values are very close. It should be noted that the Liangjia Village street network covers a total area of about 15 hectares, the Century Garden neighborhood street network covers about 12 hectares, and The Humble Administrator's Garden road network covers only 3 hectares. Therefore, if we compare Liangjia Village with

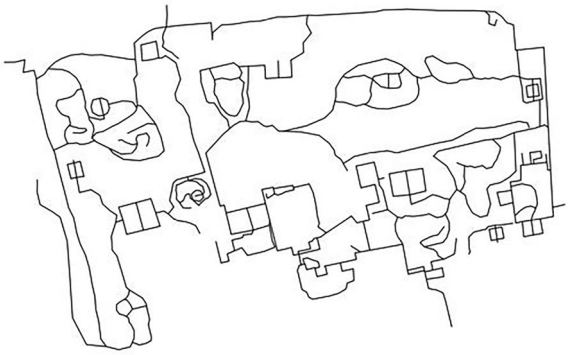


Fig. 13 Path map of the Humble Administrator's Garden

The Humble Administrator's Garden, the area of Liangjia Village is much larger than that of The Humble Administrator's Garden in the case of similar street density, i.e., the sample size is much higher than that of The Humble Administrator's Garden, but the directional entropy values of the two are comparable, indicating that the street disorder of Liangjia Village is much smaller than that of The Humble Administrator's Garden. Compared with the modern residential community Century Garden, Liangjia Village has a higher degree of disorder. Although the streets of Liangjia Village are not as open and clear as those of the modern residential communities, the street network grows in an orderly manner under the constraints of various factors such as clan rituals and laws. Compared with the intentionally winding and haunting private gardens of Jiangnan, the street network of Liangjia Village can be described as hierarchical and orderly. On the whole, the disorder of Liangjia Village streets is in the middle of the orderly side.

The results can be directly derived from the data and the polar histogram: under the premise of grouping in groups of 10°, counting counterclockwise from due east, the 3rd and 4th groups have the most samples in the data. It means that the street angle of Liangjia Village is the most shifted by 16°–35°. From the street skeleton of Liangjia Village in Fig. 6, it can be seen that the streets at this angle are roughly the branch roads of the old village part. The old village part has many and dense buildings, and needs more street connections to reach every household. The branch road is approximately parallel to the S-shaped township road on the south side, and the main road is longer and the street condition is better, so the street in this direction is extremely prominent in the weighted map. In addition, the branch roads in the new village part on the west side follow the topography and are also basically offset in the 16°-35° range. In summary, the direction of the streets which the number are more prominent in the inner part of the settlement converges

with the direction of S-shaped township road in the south of the settlement.

Since the process of settlement formation is a spontaneous, bottom-up process, the growth of streets within traditional settlements in accordance with the topography accounts for a relatively large proportion of the cases. In addition to the influence of relatively objective geopolitical conditions, the order of the street skeleton within Liangjia Village was also influenced by blood relations. Since the founding of the village, the concept of clan has been deeply rooted, and the clan ritual system has been an important factor in sustaining the development of the settlement for centuries. As shown in Fig. 14, the settlement is centered around the ancestral hall, and the central street neighboring the ancestral hall is the main body of the street skeleton. The central street is oriented north–south, and several east–west branch roads are extended from it. During the Republican period, the number of residential groups increased, the residential base was expanded, and the streets in the east–west direction were gradually extended. After the founding of the country, new villages were opened in both the east and west of the old village, and then each developed a main street in the north–south direction in the east and west, with the rest of the branch roads connected to it". From the development of the street skeleton evolution process, the entire street skeleton evolution process is the core of the central street, to the east and west of the uniform spread growth of the three main roads in the settlement are nearly vertical with the township road, the branch road will be three and they connected to the main road in turn" [39]. In addition, the topography creates a relative reversal between the old and new settlement groups of the settlement, but within each settlement group, the street network follows the topography and grows relatively loosely and naturally. The disorder of the street direction in Liangjia Village also comes from the overall twist of the three clusters, as shown in Fig. 15.

The traffic function of the street is reflected in the connectivity and accessibility of the street. The buildings are generally distributed in rows, and the streets are connected to allow access to all households. Even though the streets are graded, the streets of the same level are generally in parallel relationship. The streets of Liangjia Village follow the topography and change in direction, and the degree of disorder is low, so the process of street formation is reasonable and the street skeleton is clear.

The directional entropy value of the streets indicates that the street network system of Liangjia Village is "orderly" and "disorderly" together, with a general preference for "orderly", but not absolutely in the middle state. Like the buildings, the streets of the settlement were not created overnight, but were built along with the buildings. Street formation itself is also closely related to the location and scale of the houses.

Environmental construction intention

Settlements consist of buildings and streets together. The stronger the order of the buildings and streets, the greater the intelligibility of the local environment. The comprehensibility of Liangjia Village is very close to 0.5, and the comprehensibility of space can be considered to be in the middle state. This "disorder" is also due to the planning gap between the new and old villages. In both the old and new villages, the main streets follow the topography, which ensures a flat land in a certain area and facilitates construction, which is a relatively reasonable way of planning. However, the topography of the

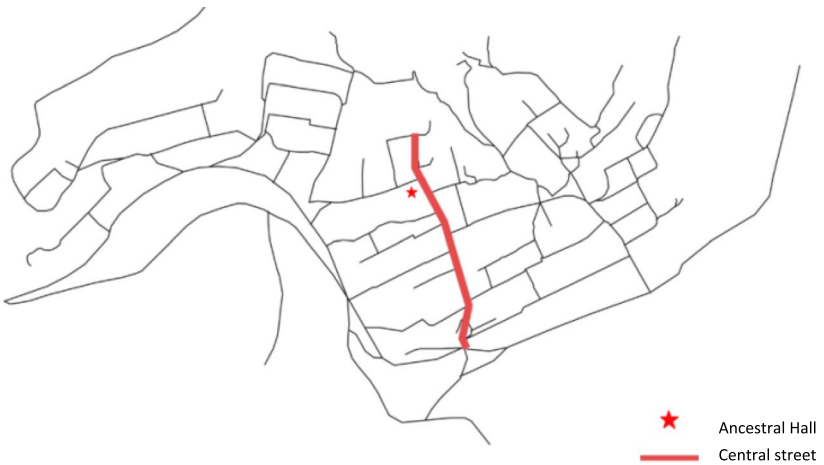


Fig. 14 Liang Family Village Ancestral Hall and Central Street

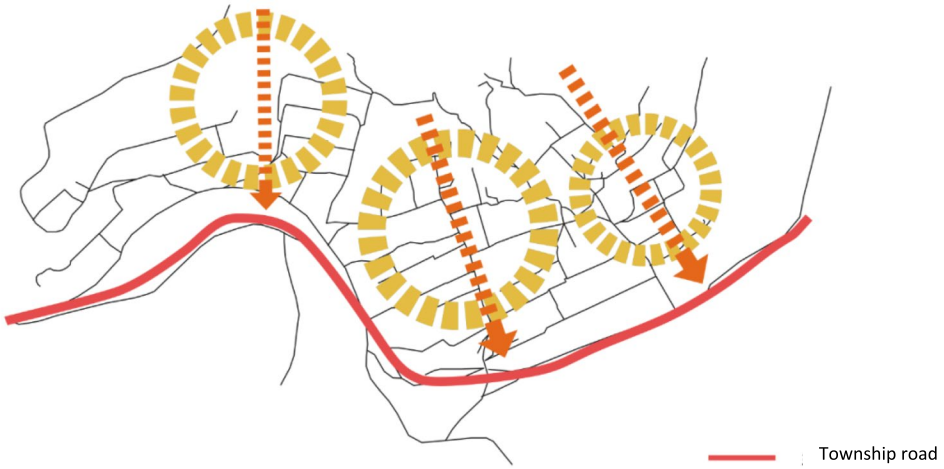


Fig. 15 Reversal of Liangjia Village Group

new and old villages is different, and the construction methods differ greatly from one era to the next, resulting in a relatively disordered overall environment. After all, the villagers' demands are different at different times, and this disorder is not the same as a planning mistake. The designers should consider whether to continue the original disorder and maintain a natural and intact historical appearance, or to create a new-era village with a clear contrast between the old and the new in the planning of the settlement.

The building, street and environmental degree of disorder influence each other and complement each other. Since there is no clear sequential and causal relationship between streets and buildings,an increase in the disorder of any one element will cause the disorder of the other two elements to increase. Liangjia Village has been built for hundreds of years, and its construction pattern and materials are naturally different, so its disorder must be higher compared with modern villages. However, thanks to the relaxed natural and historical conditions, the relatively stable inner construction concept has ensured the "orderliness" of the settlement to a certain extent, which is the deep reaction of the settlement construction intention.

Future application of topological order

When a street needs to create a "T" or "Y" shaped fork in the road due to height difference or destination, the "fork" will be avoided to face the entrance of the building. When a temple, theater, well, mill or old tree is encountered, the street will expand partially to form a "site", similar to a square in a modern city. From this perspective, the street is an important skeleton that connects the public activity sites in the settlement. Therefore, streets and buildings influence each other and are "ordered" by the "order" of the buildings. The properties of the two are different: the houses are purely private, but the streets have a more public character. This nature facilitates the overall planning of the street network, and therefore its orderliness is stronger. The macroscopic order of the street network is also reflected in the fact that the main side streets run east–west, which is due to the north–south orientation of the building. Although the east–west secondary street is long and forms the main skeleton of the street network, its form is not the straight and "consistent to the end" similar to the modern road network, but a longer folding form, which is the same reason as the role of the indoor screen, to prevent the line of sight "at the end". At the same time, the bending line and the "end of the road" and other forms can play a better defense function. Unlike cities, settlements do not have walls and other defensive systems, so their street networks naturally have to take on the important role of external defense. Second, from the geometric point of view, the settlement street network also shows a certain "topological" pattern. As shown in Fig. 16, the "⊥" shape and the "□" shape constitute the basic unit of the topological transformation of the street network.There are a number of "⊥" shape and "□" shape. After a certain degree of topological deformation and re-lap, thousands of "similar" and "strange" forms can appear. After these forms are reorganized to form a street network, not only can they have a "regular" effect on people in the village, but also make outsiders feel lost and confused. So this inner "topology" not

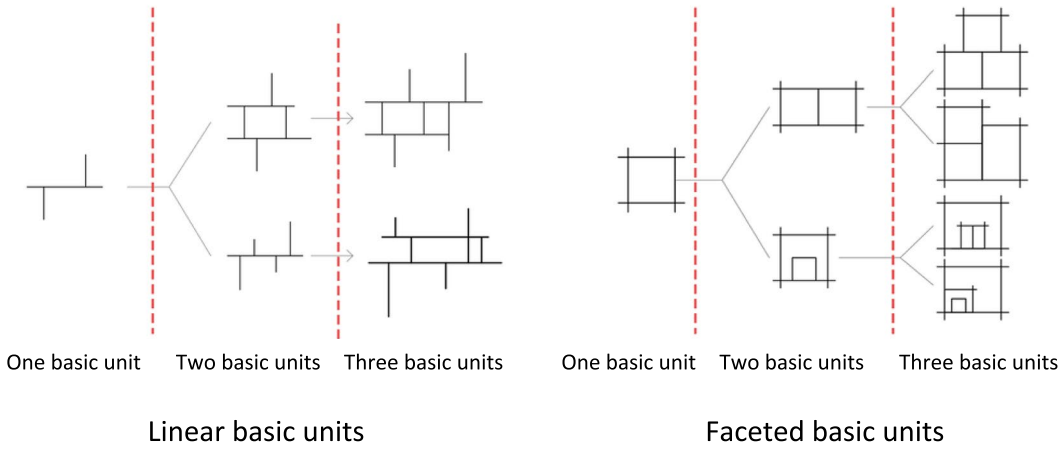


Fig. 16 Schematic of the combination of topological transformations with increasing basic units

only makes the insiders easily familiar with the order, but also produces a better defense of outsiders, which is also "Disorder accompanies order, and order is contained in disorder".

For example, traditional settlements exhibit self-similarity, meaning that local and global (where "global" refers to a larger scope of "local") features are similar. Based on this characteristic, we employ fractal iterative techniques derived from fractal theory. By conditionally iterating on the "source structure" of settlements, the generated fractal patterns exhibit topological similarity to the original settlement plane height. Building on this, traditional subjective empirical design is applied, and the final solution undergoes verification at three levels of disorder—points, lines, and surfaces—to select the solution that is closest in disorder to the original settlement. This solution inherits a high level of intrinsic coherence with the original settlement. The application of this technique introduces innovative elements into settlement planning by incorporating structures that are more suitable for settlements themselves while adhering to the laws of nature and human social development. The iterative technique based on fractal theory is, in essence, a scientific prediction of settlement development. By simulating the morphogenesis process in the natural world, it accurately depicts the evolution of the internal structure of settlements. Therefore, this technique is not only a planning tool but also a means of foreseeing the future direction of settlement development.

Additionally, with regard to the development and expansion of settlements, we can use degree of disorder as an evaluation criterion to assess the recent or long-term planning of settlements. By delving into the disorder of settlements, we can gain a more comprehensive insight into their development and expansion. The introduction of disorder not only aids in evaluating the effectiveness of planning but also provides decision-makers with more specific and actionable information, thereby helping to optimize the layout and allocation of resources in settlements.

The evaluation of degree of disorder, as an additional dimension of assessment, provides important evidence for validating the application of fractal iteration in settlements. By quantifying the degree of order in the internal structure of settlements, we can more accurately judge whether fractal iteration technology can effectively integrate into settlement planning. This multidimensional evaluation method not only enhances the scientific nature of decision-making but also provides planners with more actionable recommendations, making settlement planning more targeted and sustainable.

Conclusion

Studying disorder levels in traditional settlements helps deduce construction intent, aiding in evaluating the compatibility of new plans with the original logic. This provides a scientific basis for the protection and future development of settlements. The paper introduces disorder calculation principles, applying them to Liangjia Village. Preliminary conclusions are as follows: (1) The degree of disorder of the buildings, streets and environment in the settlement is all moderate. (2) The overall disorder levels of buildings and streets in Liangjia Village are moderate within each zone, but the overall environmental disorder level surpasses that of any individual local area. (3) The construction logic of buildings

and streets in Liangjia Village remains stable throughout development, while significant differences exist in environmental construction principles between the new and old sections.

But what we need to clarify is disorder means confusion and clutter, and a higher degree of disorder only means a more disorderly state in terms of plan or spatial perspective. In fact, for the residents or visitors who actually use the space, it is the experience that is the main standard for judging the merits of the settlement space. The diversity of spatial types was the most direct criterion for evaluating space diversity [40]. A higher degree of disorder may not help visitors to grasp the overall context, but it reflects the diversity and interest of the space. The exploration of degree of disorder reveals the order in which the settlement is generated, serving as an indicator to assess whether the development of a settlement conforms to its original logic. Therefore, disorder is not the only indicator for evaluating the merits of a settlement plan, and the level of disorder does not absolutely correspond to the quality of the space.

Disorder is an objective quantitative index used to measure the order of the settlement. Through the correspondence between local and overall aspects, it can be determined whether the new planning conforms to the original construction logic. Through the analysis of the quantified data, we can investigate the causes and consequences of disorder, explore the intention of the settlement and guide future planning, which is very important for the in-depth understanding of the settlement.

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Availability of data and materials
Data will be made available on request.

Declarations

Competing interests
The authors declare that they have no conflict of interest.

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