

Settlements Generating System (SGS)

Research on Self-adapting Method of Rural Settlement Planning

Xin Li, Beijing University of Civil Engineering and Architecture, China

Abstract

We present here an automated Settlements Generation System (SGS). Our self-adapting computer planning and design simulation system can characterize the environmental adaption, cultural customs, community structures, and spatial features of traditional rural settlements & villages. It is significant for protecting traditions and landscapes in rural-urbanization.

Keywords

SGS, rural settlement, simulation, Dong nationality, self- adapting

1. Introduction

In the face of large-scale construction of new rural settlements & villages in China (Guo, J. Z et al. 2006), it is very urgent to provide highly efficient and intelligent computer aided methods of planning and designing settlements & villages in rural areas in order to effectively protect the rural cultures and landscapes.

Our research includes two sections: learning and simulation.

In the learning section, the topological structure model and traditional "culture genes" which control the growth of the settlements are extracted from settlements under study.

We have used the Dong nationality in Tongdao, Hunan, as the research basis. Tongdao is located in the southwest of Hunan province, China, bordering Guangxi and Guizhou provinces, and is one of the major settlements of the Dong people. Located in the mountains and physically isolated from major centers of population, Dong towns & villages are less influenced by Han culture and customs. As a result, the traditional culture and ethnic characteristics of the Dong people are well preserved through the distinctive architectural character and design of their settlements (Liu, S. 2008).

In the simulation section, the SGS system is used to simulate the emergence and expansion of settlements & villages, utilizing the extracted "culture genes" of the learning section.

The use of computer simulations in relation to human settlements has become more common in recent years. For example, Parish and Müller proposed a user guided city-generation based on an L-system (2001). Weber et al. developed an interactive geometric simulation of 4D cities (2009). Vanegas et al. presented an interactive dynamic system for the design of urban spaces using geometrical and behavioral modeling (2009). Emilien discussed village growth simulations on arbitrary terrains (2012). Beneš et al. demonstrated procedural modelling of urban road networks (2012). Batty simulated the urban form of a randomly established tree structure (2009). Leach established the concept of "group intelligence" to generate swarm cities (2009). Panahikazemi and Rossi applied computational strategies for intervention in informal settlements (2014).

In our SGS presented here, we show how to extract the “genes” of the traditional Dong settlements by studying the traditional cultures, spatial patterns and geographical environment information of Dong towns & villages, and how to perform simulation in a way that meets the traditional context and captures the specific local geographical, ethnic characteristics, and cultural customs.

2. Learning section

2.1. Field survey and data collection

The author conducted a field survey of 13 Dong towns & villages in Tongdao (Figure 1, Table 1). Among them, there are 4 mountain-type towns and 9 riverside-type towns.

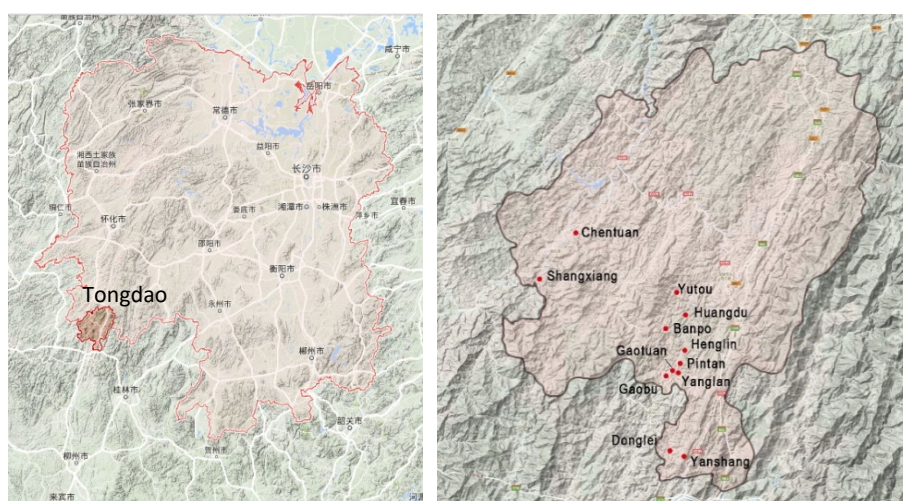


Figure 1. Location of Tongdao in Hunan province (left), distribution of the surveyed towns in Tongdao (right). Image Source: Google map (redrawn).

Table 1. Surveyed villages sorted by type.

Mountain-type				Riverside-type				
Yutou	Yanshan	Banpo	Gaobu	Huangdu	Pintan	Gaotuan	Shangxiang	Donglei
				Hengling	Yanglan	Zhongbu	Chentuan	

A comprehensive statistical analysis of the Dong towns in Table 1 is conducted through related paper reading, field investigation, aerial photography, three-dimensional model reconstruction and CAD drawing.

We converted the 3D terrain model into a smoother surface with elevation accuracy of 4 meters, reduced the height of trees and houses to the ground to eliminate their impact on the terrain (Figure 2), From the orthophoto map we mapped out all the 3D information of houses, river and roads for further use (Figure 3).

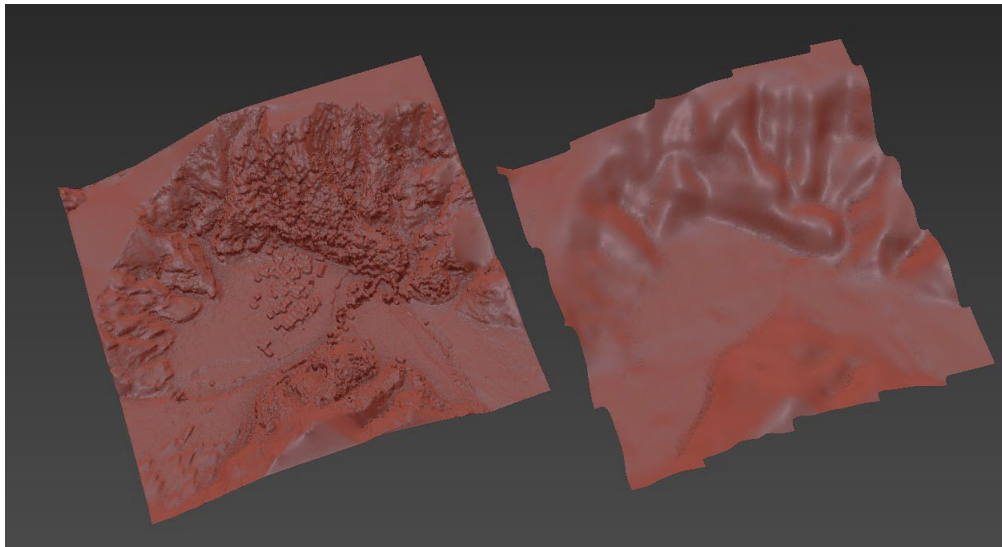


Figure 2. The raw model (left) and smoothed model (right).

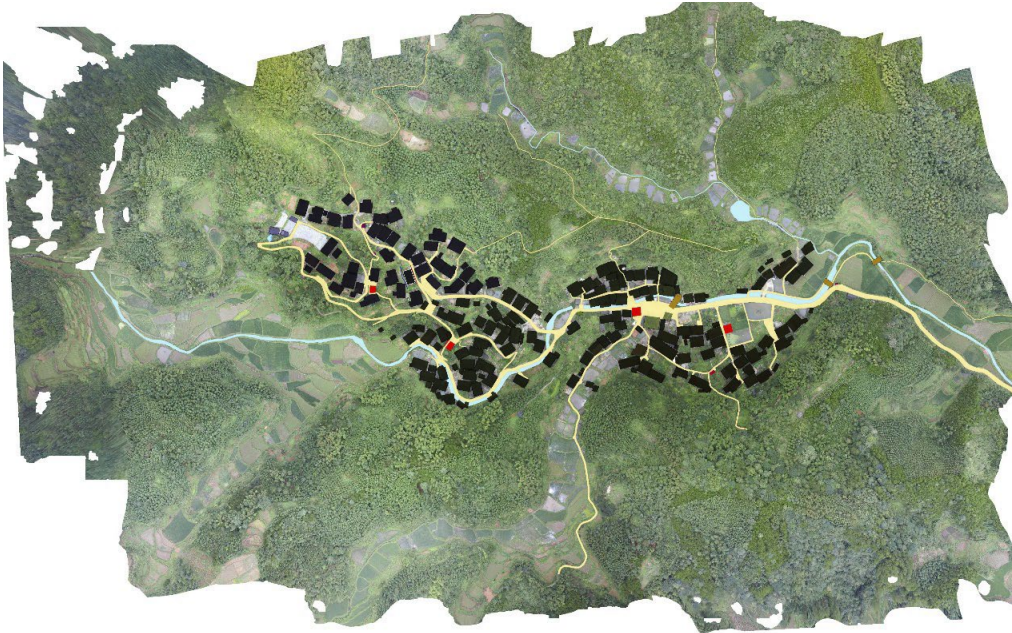


Figure 3. The orthophoto map with information of houses, river and roads.

2.2. Gene selection and extraction

The word “gene” comes from the Greek word, meaning "birth". It refers to the DNA sequence that contains the genetic information of organisms and is the basic unit of heredity that controls the growth of organisms. In our research, it refers to the specific, visible, and quantifiable social, cultural, and natural environment influencing factors related to the spatial layout of traditional settlements (Li, X. 2020).

The gene in our research include four natural environmental factors: slope, elevation, and hydrophilicity, geographic dominance as well as five social and cultural factors: social, clans, worship, accessibility, and feng shui.

We will discuss the characteristics of some of these genes and their extraction methods.

1) Hydrophilicity

Hydrophilicity is a major Influence factor of traditional settlement layout. The main livelihood of Dong people is farming and forestry. The basic principle of residential site selection is to rely on mountains and water (Song, J. J. et al. 2016).

Dong Settlements can be divided into two groups according to the different terrain types, the mountain-type and the riverside-type (Cai, L. 2013). Unlike the flood control layout in which riverside-type settlements often keep a certain distance from the river, the water sources in mountain-type settlements mostly come from small streams. Therefore, mountain-type settlements have a closer relationship with water sources.

The hydrophilicity analysis adopts the distance method. The closest distance from the center of the building to the river is used as the hydrophilicity index. The smaller the distance, the higher the hydrophilicity level (Figure 4).

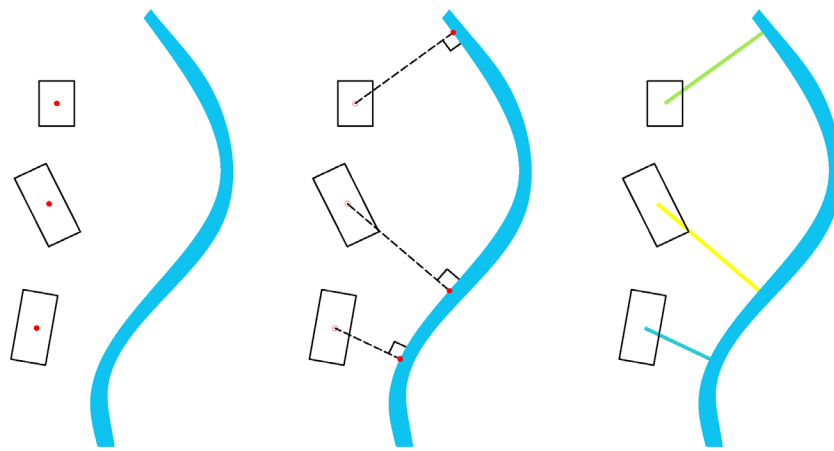


Figure 4. Measurements of the closest distance to the river for different buildings.

We will discuss the hydrophilicity of the two types of settlements separately, comparing the similarities and differences of the hydrophilicity of mountain-type and riverside-type settlements. (Figure 5 and Figure 6).

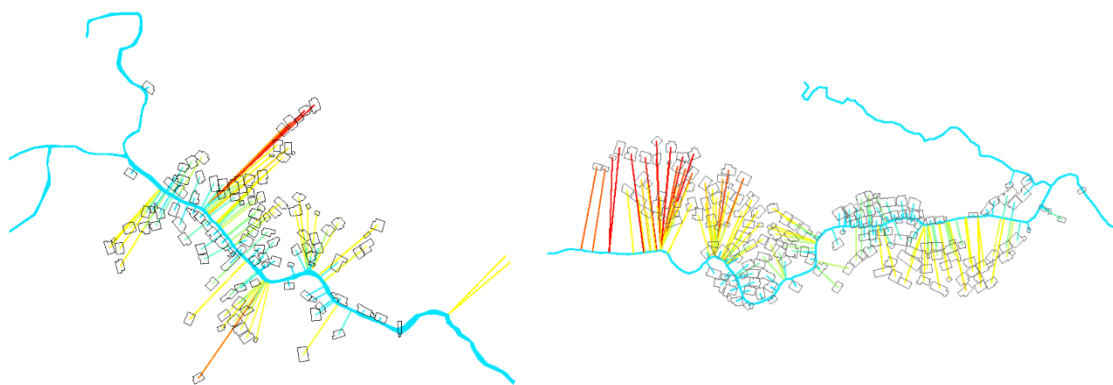


Figure 5. The hydrophilicity analysis of mountain-type settlements.

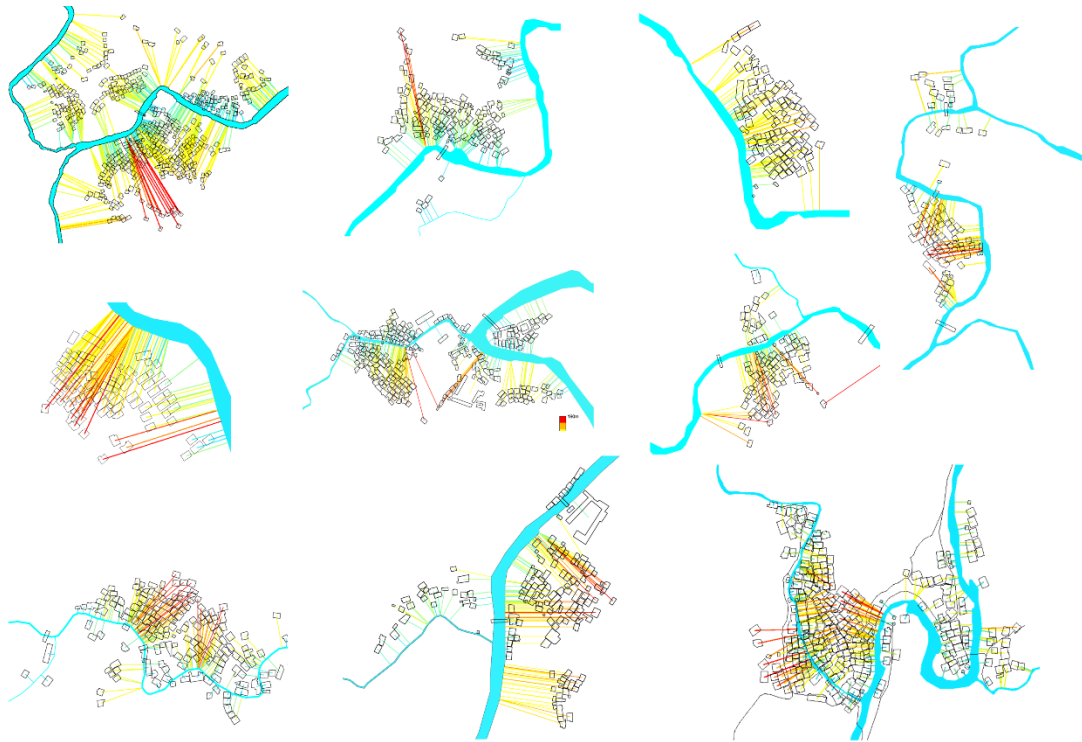


Figure 6. The hydrophilicity analysis of riverside-type settlements.

Taking the hydrophilicity diagram of typical mountain-type settlement Yutou as an example (Figure 7), the hydrophilicity of mountain-type settlements is generally high (colored with blue-green), and the number of house distribution according to hydrophilicity distance changes regularly and evenly (Figure 7. right). The closer the distance to the river, the more the houses, and vice versa.

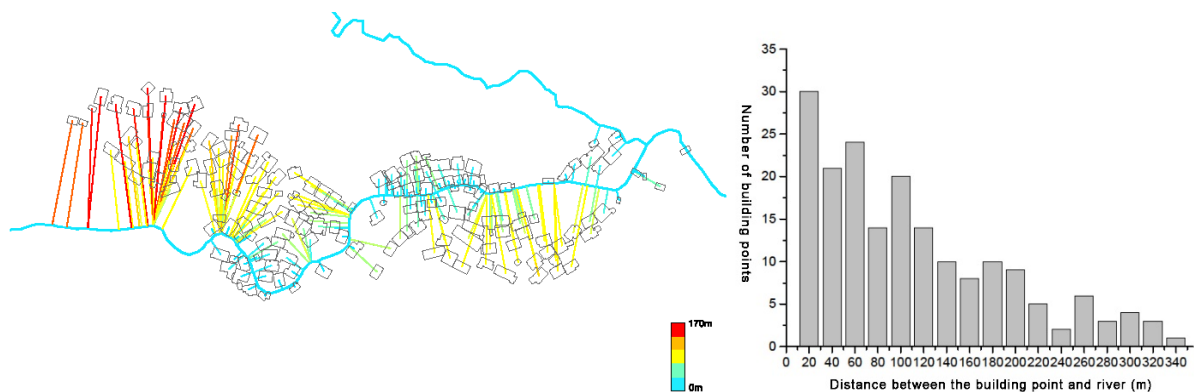


Figure 7. The hydrophilicity analysis of Yutou.

The distribution curve and curve function of the hydrophilicity of the house can be calculated using the method of nonlinear fitting. The hydrophilic gene of mountain-type settlements is extracted with Gaussian nonlinear fitting (Table 2-Table 3), and the curve function is as follows:

$$y=y_0 + (A/(w*\sqrt{PI/2}))*\exp(-2*((x-xc)/w)^2)$$

Thus, this curve can represent the settlement's gene of hydrophilicity. The fitting results of Banpo and Yutou villages show the gene map of hydrophilicity of the mountain-type settlements: a concave curve. The largest number of buildings in the curve is within 5 meters. Then the building number decreases rapidly along the curve, and it falls to the lowland in the curve about 200-300 meters. This result vividly reflects the architectural distribution law of the mountain-type settlements according to hydrophilic distance. That is, the buildings are located as close to the water as possible.

Table 2. Fitting Curve of Hydrophilicity of Banpo.

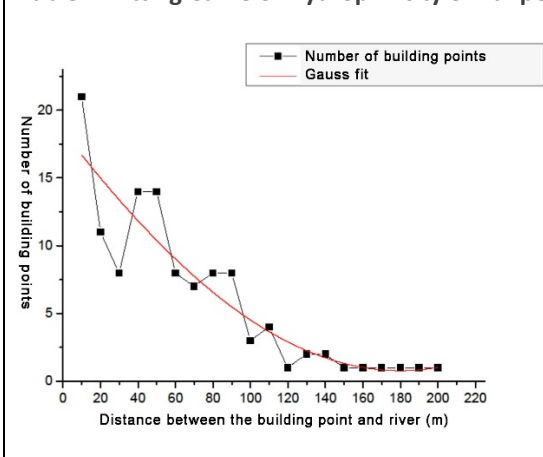
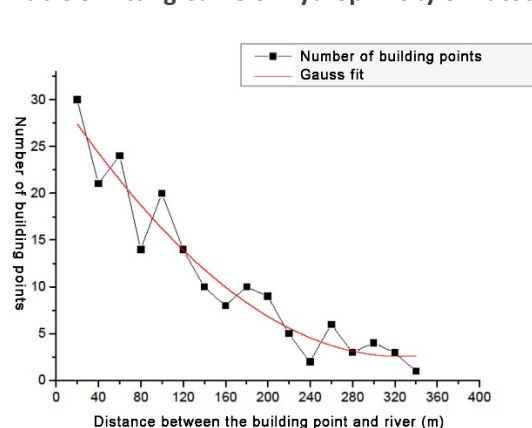


Table 3. Fitting Curve of Hydrophilicity of Yutou.



The hydrophilicity gene map of riverside-type settlements (Table 4-Table 5) was significantly different from mountain-type settlements. Take typical riverside-type settlement Gaobu as an example (Table 4): a peak appears in the curve around 80 meters. On the left of the peak, the closer the distance to the river, the fewer the houses, and the number of houses within 80-90 meters from the river is the largest. Over 90 meters, the number of buildings decreases sharply, and the water distance between the farthest building and the river is 200 meters. This curve shows a typical flood control layout pattern. That is, the building must keep a certain distance from the river to prevent flooding.

Table 4. Fitting Curve of Hydrophilicity of Gaobu.

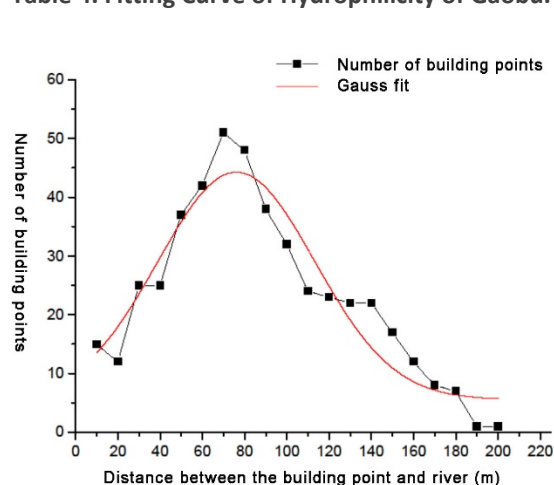
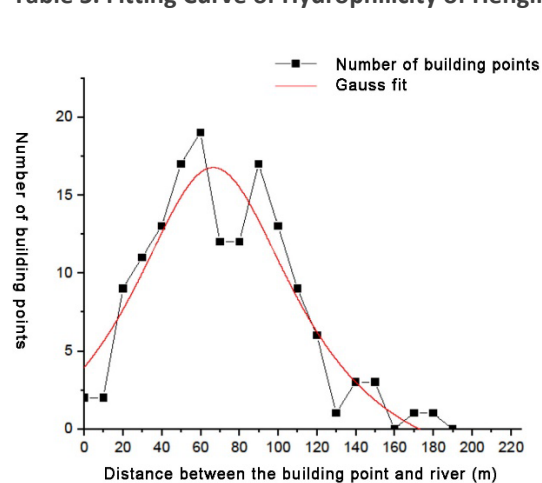


Table 5. Fitting Curve of Hydrophilicity of Hengling.



2) Social interaction

Social interaction refers to the communication between people in settlements. During the formation of a settlement, the social relationship between people largely defines the physical relationship of the architectural layout.

Geographers usually divide settlements into two types, scattered and collective settlements (Liu, S. J. 2013). The Dong settlements are typical collective villages. Blood-related clan members live together, due to the common religion, farming, and defense needs, resulting in a dense architectural layout (Figure 8).



Figure 8. The architectural "social" relationship in Dongzhai.

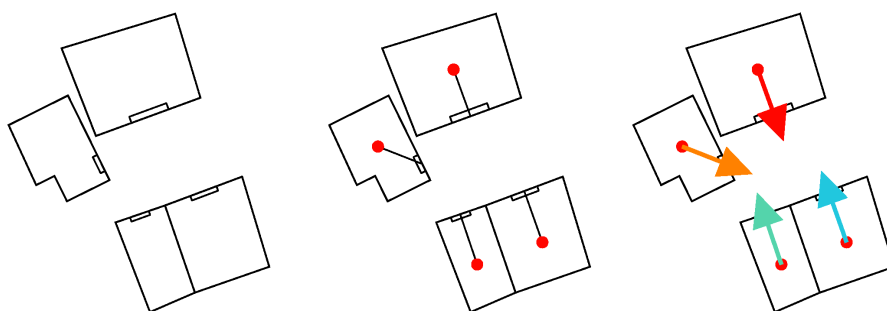


Figure 9. Architectural orientation analysis.



Figure 10. The architectural orientation analysis of Donglei settlement.

Orientation and distance methods are used to extract social interaction gene.

The orientation of the building can reflect the relationship between people, which is an important factor in social gene. We have visually analyzed the door opening direction of houses: first draw the center points of all houses, and then connect the center point of the building to the direction of the door opening. Assign the corresponding color according to the vector angle of each line segment (Figure 9). From this diagram, we can intuitively observe the orientation relationship between the houses, drum tower and the river (Figure 10).

The distance between houses is an important factor to describe their social relations. We have applied center distance method to analyse the social gene of Dong settlements. The shortest line segment that connecting the building center points is filtered out to get a diagram of social distance (Figure 11). From this diagram, we can intuitively observe the strength of sociality among the houses in the settlement.

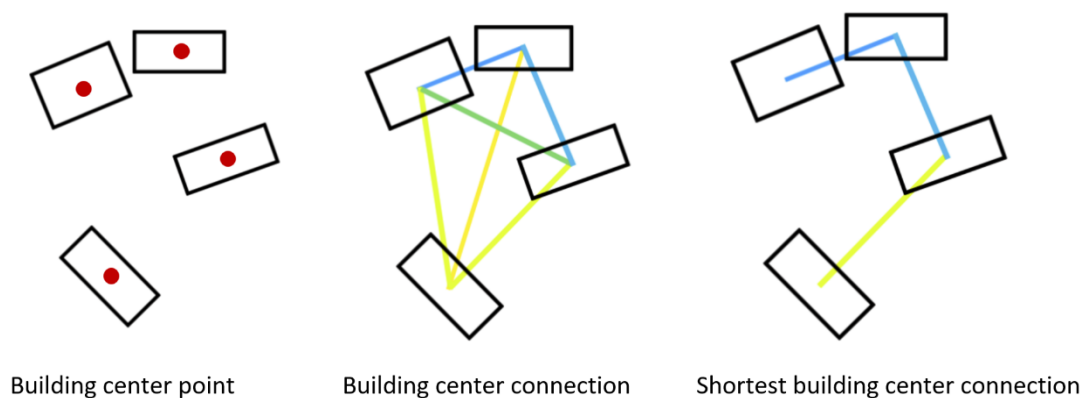


Figure 11. Building social distance analysis.

Settlement's terrain type has significant impact on the social relationship between houses. Therefore, we will discuss the results of social distance analysis of mountain-type settlements and the riverside-type settlements separately. (Figure 12-Figure 13).

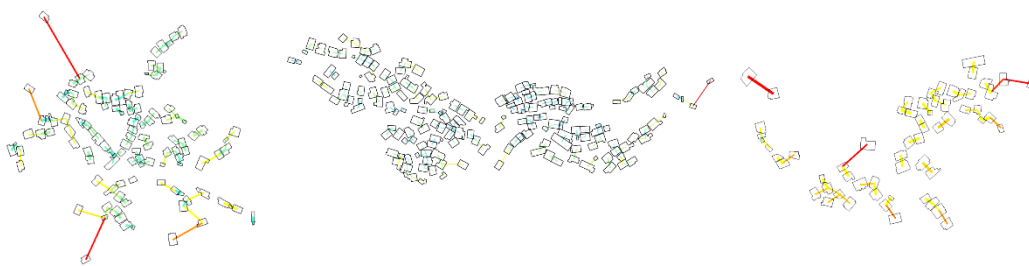


Figure 12. Social analysis of mountain-type settlements.

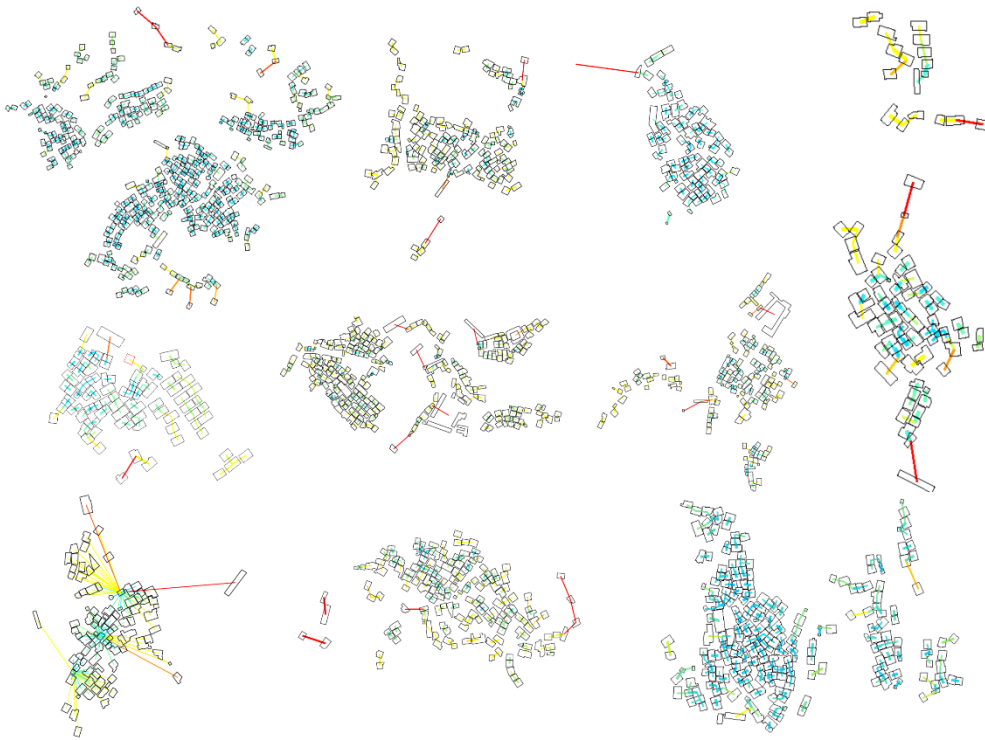


Figure 13. Social analysis of riverside-type settlements.

Typical mountain-type settlement Banpo shows a very close social distance according to the histogram map (Figure 14), reflect the Dong people's culture custom of "living together in clans". Social distance from 15 to 25 meters has the most house numbers (75%). As the distance increases or decreases, the number of buildings shows a sharp decline, and rarely exceeds 30 meters.

However, the social distance of typical riverside-type settlement Donglei (Figure 15) is slightly shorter than mountain-type settlements. The peak value is between 10-20 meters.

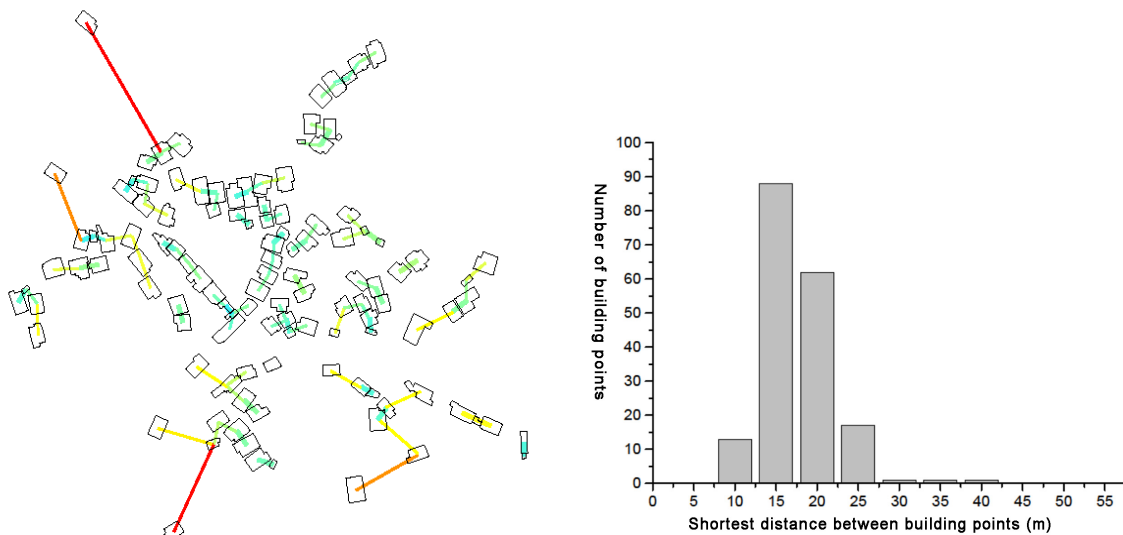


Figure 14. The social analysis of Banpo settlements.

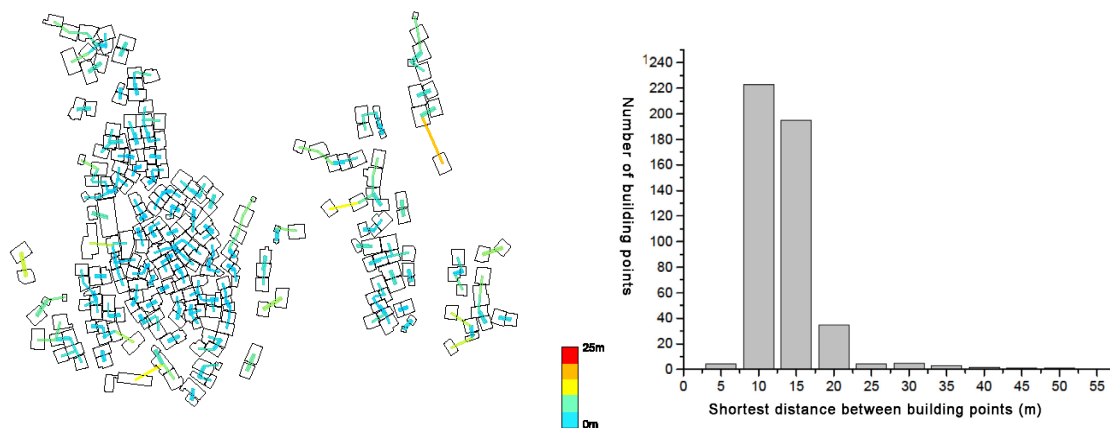


Figure 15. Social analysis of Donglei settlements.

We use the method of nonlinear Gaussian curve fitting to find the distribution curve of social distance based on the scatter plot of the relationship between the number of houses and social distance. The social distance gene of both mountain-type and riverside-type settlements can be expressed by the following curves in Table 6 and Table 7, respectively. Their curve function is as follow:

$$y=y_0 + (A/(w*\sqrt{\pi/2}))*\exp(-2*((x-x_c)/w)^2)$$

The fitting results show the commonality of the social distance of Dong settlements: the curves present an "inverted bell" shape with a high middle and a low end, with a peak around 10-25 meters. There are rarely houses with a social distance smaller than 10 meters, considering the width and depth of the house, the center distance of houses couldn't be smaller. From this curve of social gene, it can be seen that the social distance of the Dong settlements are very close.

Table 6. Social Fitting Curve of Banpo settlement.

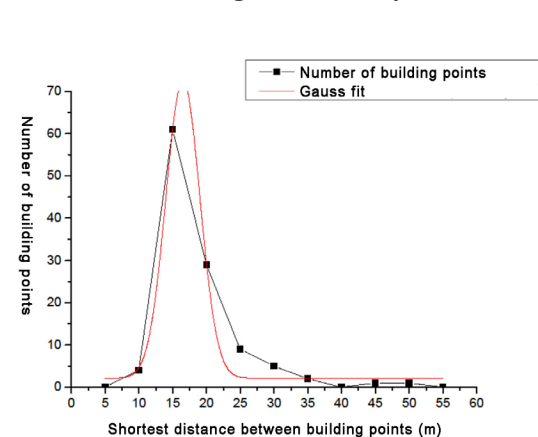
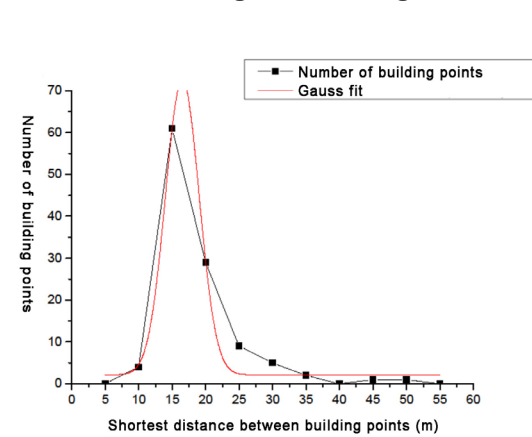


Table 7. Social Fitting Curve of Donglei settlement.



3. Simulation section

3.1. System structure

Our SGS is built with unity engine, and scripted in C#. Simulations are based on a grid system of 4*4 meters. Outside point of the village is predefined for the generation of main roads (Figure 16). There are 5 major parts of the system: site selection, house location, road generation, building plot generation and model generation.

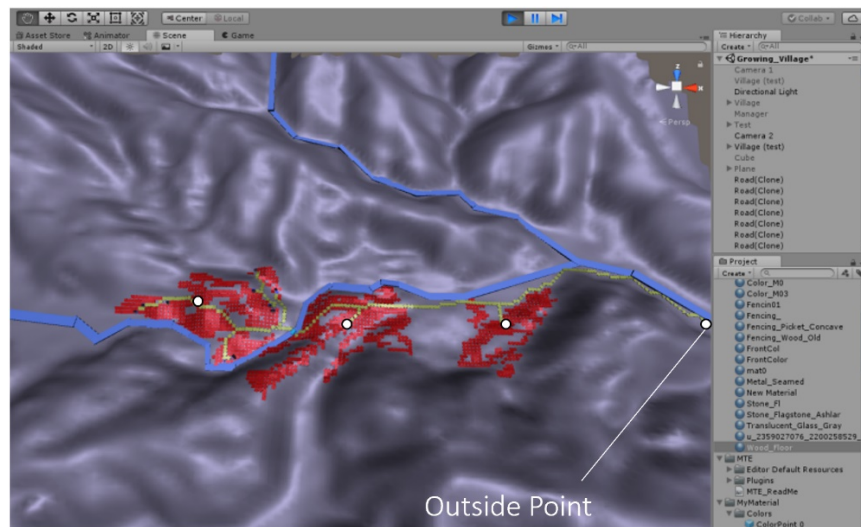


Figure 16. The system interface and outside point settings.

3.2. Site selection

The Dong people live on rice farming and plantation forestry (Cai 2013). Therefore, the basic principle of site selection is being close to a mountain or river. From the cultural point of view, the Dong people inherited the remains of the ancient Baiyue culture, namely the tradition of "being in the valley, among bamboos," and "mountain and water". This is because rice cultivation requires a source of water, and the mountain can provide wood for the construction of houses, while providing space for plantation forests and terraced fields (Cai 2013).

Mountain and water are the most important influence factors for site selection of Dong towns & villages. System simulates the influence of mountains and water resources on the site by controlling the gene of hydrophilicity, elevation, slope, and geographic dominance of the given terrain (Figure 17).

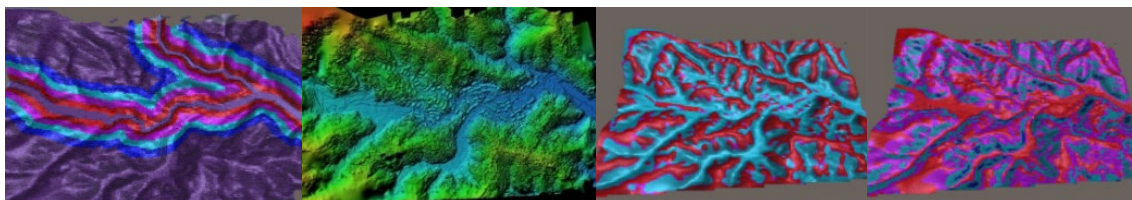


Figure 17. Yutou town's hydrophilicity, elevation, geographic dominance and slope analysis.

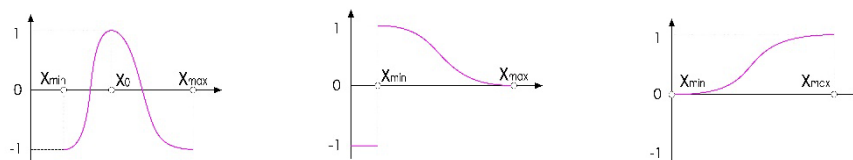


Figure 18. From left to right, scoring function of slope & elevation, hydrophilicity, geographic dominance.

The control of genes is reflected in a scoring function at each point ("P") of the terrain model. Each point has a score range of -1 to 1. Negative numbers indicate sites undesirable for selection, and positive numbers indicate sites ideal to be selected. There are different functions for different genes to obtain their corresponding scores (Figure 18). x_{\min} , x_0 , and x_{\max} are parameters set according to different function. x_{\min} , x_{\max} represent the maximum and minimum values of a gene factor. The x_0 value represents the ideal value. Finally, the system combines various criteria scores with different weight factors. From the combined results, we can choose the area ("G₀") that is the ideal site for the settlement (Figure 19-Figure 22).

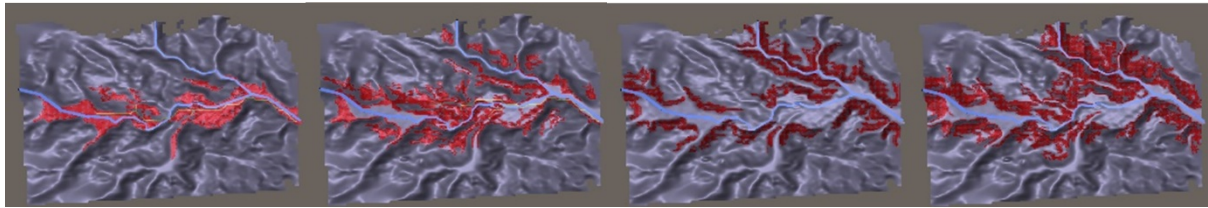


Figure 19. Influence of slope on site selection. x_0 value: 0, 15, 30, 45 degrees (from left to right).

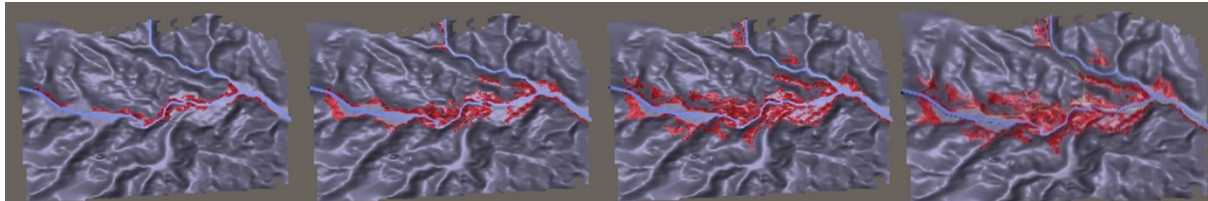


Figure 20. Influence of hydrophilicity on site selection. x_{\min} value: 40, 100, 160, 200 meters (from left to right).

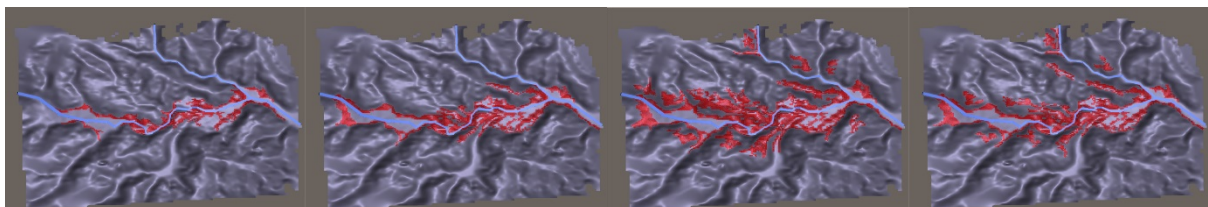


Figure 21. Influence of elevation in site selection. x_0 value: 280, 400, 520, 760 meters (from left to right).

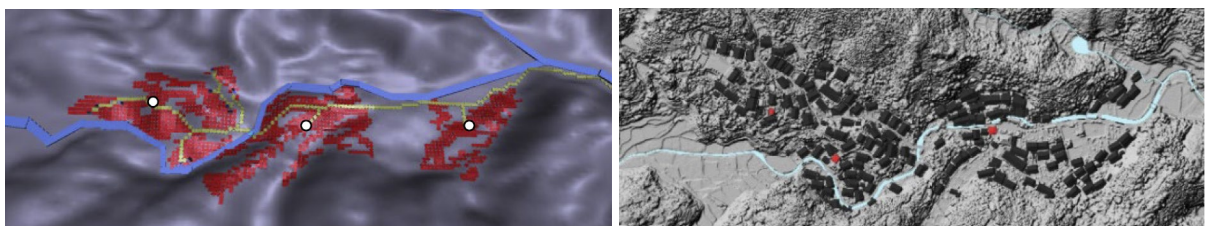


Figure 22. Combined site selection result G_0 (left) and actual layout of Yutou settlement (right).

3.3. Building locating

The Building location is represented by the center point of the building. Building $B = (T, p)$, where T represents the building type (such as drum tower, bridge, temple or residence), p represents the location of the building.

3.3.1. Evaluation

The building locating process requires a comprehensive assessment of the relationship between the environment and the surrounding buildings. The assessment content includes natural environmental genes such as slope, elevation, and hydrophilic and cultural genes include: clan, worship, social, and accessibility. The system evaluates the scores of all the points in the site area using the same scoring function of site selection (disused in 3.2) to reflect the infection of various genes,

We will explain the evaluation process by social gene. From the learning section, we can get the fitting curve of social gene representing building distribution pattern according to social distance (Figure 23, left). So, the evaluation function of social gene can be set as follow (Figure 23, right). x_0 represents the ideal social distance. As the social distance increases or decreases, the social evaluation score decreases accordingly. x_{\min} and x_{\max} values of -1 represent unlikely social distance.

The building location points are selected in an order from high to low, according to the scoring function. In this manner, the system gradually generates a points cloud from scratch, which represents the settlement's architectural layout.

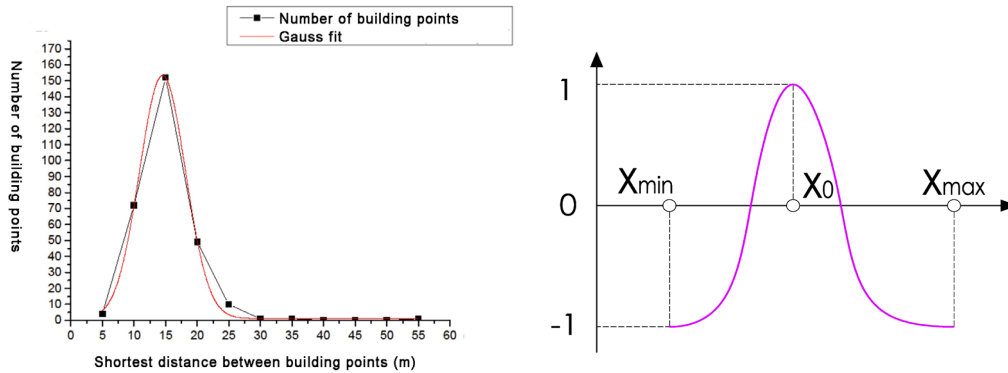


Figure 23. Fitting curve (left) and scoring function curve (right) of social gene.

To show the influence of the social gene to the settlement's architectural layout, we conduct the following simulation tests (Figure 24), the x_{min} and x_0 values of the scoring function $f_i(a)$ are set according to the x value corresponding to the trough and peak of Figure 23 (left). By adjusting the x_{max} value, we can get various settlements layout (Figure 24).

When the social distance x_{max} value is low, the settlement presents a high-density layout. With the increase of social x_{max} value, the settlement layout gradually stretches. When x_{max} reaches 40, it is closest to the actual situation, which is consistent with the result from the learning section (Figure 23. left).

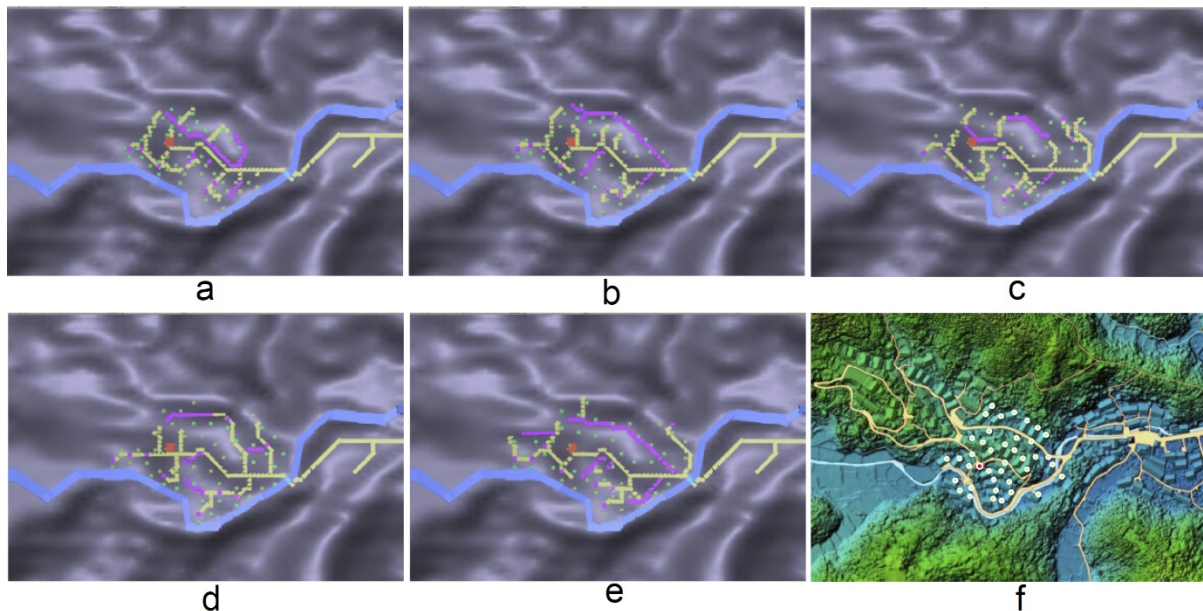


Figure 24. The social layout simulation (x_{max} values A-E are 20, 25, 30, 35 and 40 respectively) compared with the actual layout (f).

3.3.2. Sequence of site selection

In order to reflect the Dong settlement culture and customs, different types of buildings are generated in different order. Studies have shown that the drum tower and the stage is usually the first building constructed in the Dong settlements (Liu, S. J. 2013). In SGS, the core buildings such as drum tower, main square and the stage are first generated. The subsequent generations are general buildings such as houses, temples, altars, pavilions and so on.

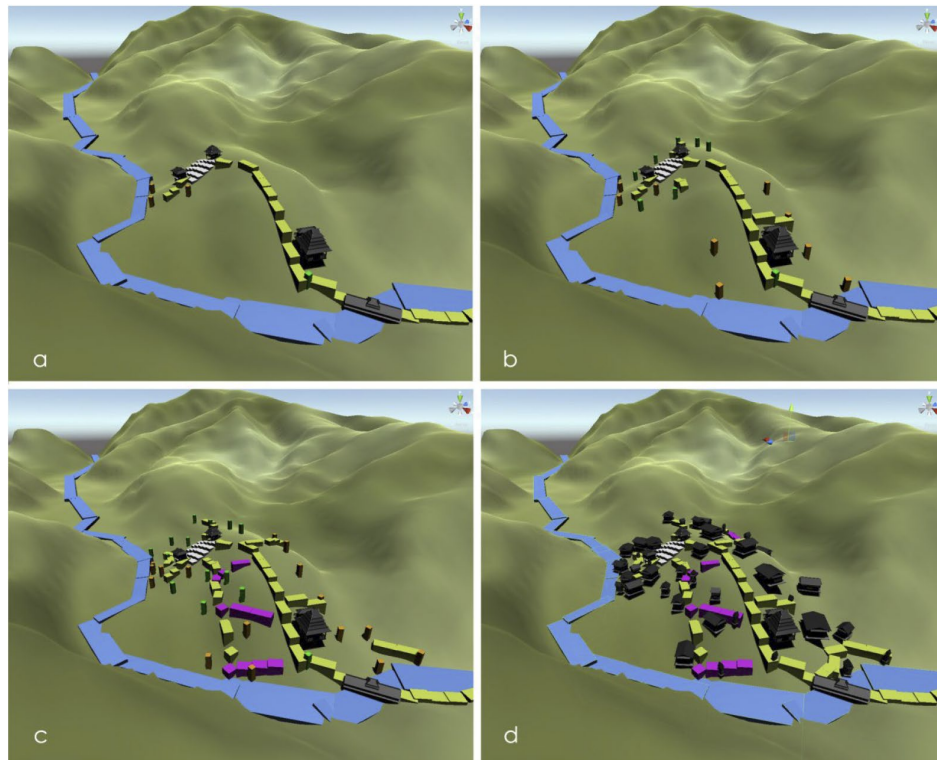


Figure 25. The process of real-time update.

3.3.3. Real-time update

In order to reflect the self-adaptability and organic nature of traditional settlements, the newly added construction points will affect the overall score of the evaluation system, and the evaluation results will be updated in real time. In this way, the post-generated building must consider its relationship with the existing buildings, and finds its location that conforms to the social and cultural logic. In this way, the system dynamically and progressively generates the entire settlement (Figure 25).

3.4. Road generation

The generation of road is based on A* algorithm and extended. Road R consists of a series of points $\{P_R\}$, which control the shape of the road curve. Road generation depends on several cost functions $C(R)$. Road R is the minimum cost path between two points. Cost factors such as slope, bridge, hydrophilicity, curvature and collision are considered to simulate the Dong settlement's road generation. Thus, road R is the result of the addition of different road cost functions g according to the relevant weight W , expressed as: $C(R) = \sum wg(R)$.

Taking the slope cost as an example. Costs of slope can be expressed as: $CP = |h(x) - h(p)|$, point p represents the sampling point, and $h(p)$ represents the altitude of point p . The greater the slope from the sampling point to the road point x , the higher the cost.

Through the simulation test (Figure 26), it is not difficult to find that when the weight of slope is small, the road tends to generate the path with the shortest horizontal distance. With the increase of the weight of slope, the road tends to be arranged parallel to the contour line. For steep slopes, the road presents a Z-shaped layout, which is closer to the real situation when the weight is 10.

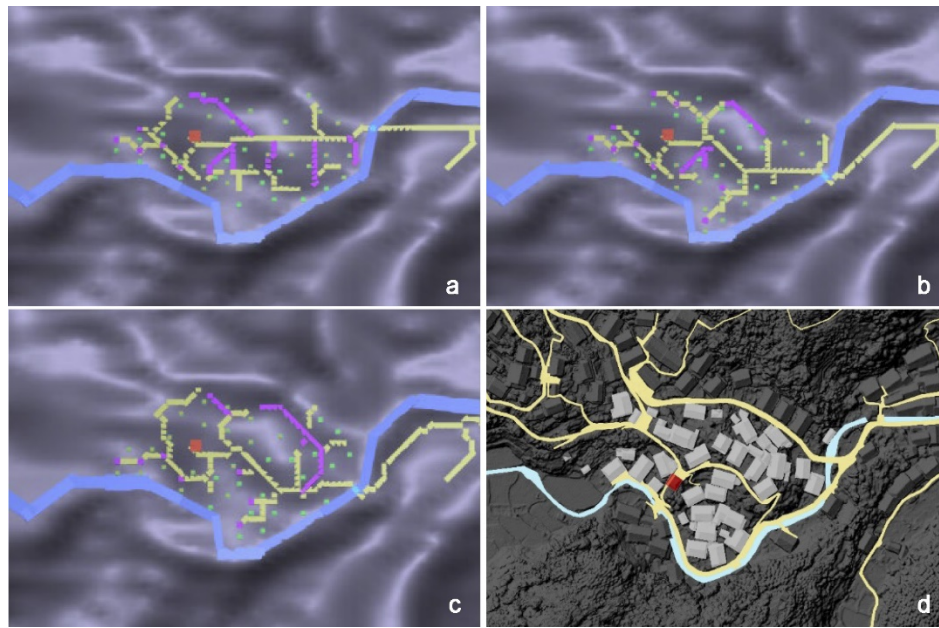


Figure 26. The road slope cost simulation (weight values a-c are 1, 5, 10 respectively) compared with the actual layout (d).

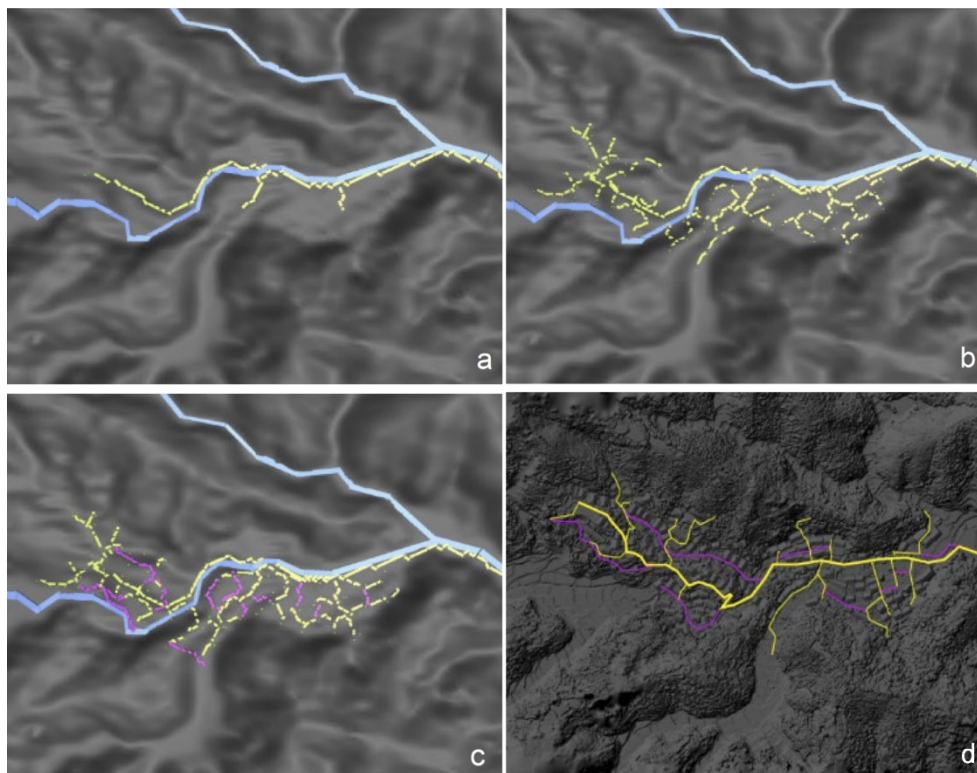


Figure 27. From a-c are trunk roads, branch roads, loop roads (purple) respectively compared with the actual road layout (d).

According to the characteristics of Dong nation, the road network is divided into three road systems: trunk road, branch road and loop road. Each time a new building point is generated, the system will generate a minimum cost path R between the building point and point Q outside the settlement. According to the generation sequence of building points above, the earliest generated road, trunk road, is the path between point Q and the drum tower (and the main square in front of the drum tower). With the generation of residential buildings and other types of building points, corresponding branch roads are also generated. The generation of branch roads adds the function of reusing existing roads (with no cost), resulting in a

tree-like road network composed from trunk roads and branch roads. On this basis, starting from the end of the branch roads, system will find the nearest road point in a certain range to generate the loop roads to avoid too many unreal dead ends (Figure 27).

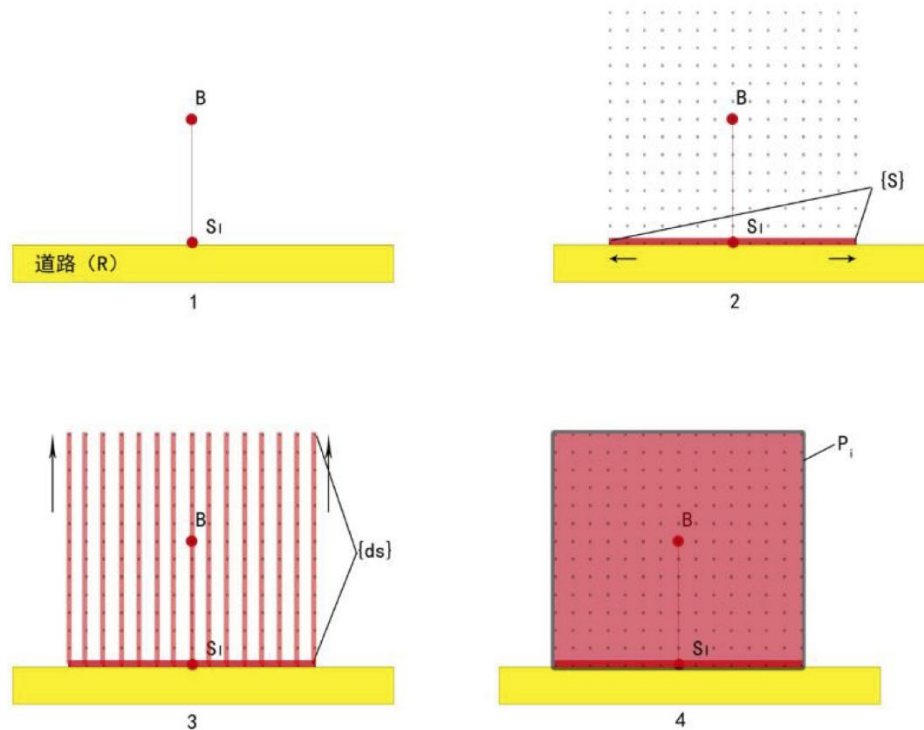


Figure 28. Building plot generation diagram.

3.5. Building plot generation

Every building in the system has its own building plot (P_i). Our system first finds the nearest point S in the road according to the relationship between the building point and the road network, and then expands from two directions parallel to the road $\{S\}$ and perpendicular to the road $\{D\}$ (depth), resulting a squared shape, which forms a building plot (P_i) (Figure 28). The length of the building plot ($\{S\}$ and $\{D\}$) is set based on the survey and statistical results, and relevant cost factors such as distance, slope and collision are calculated to avoid unrealistic building plot's size and shape.

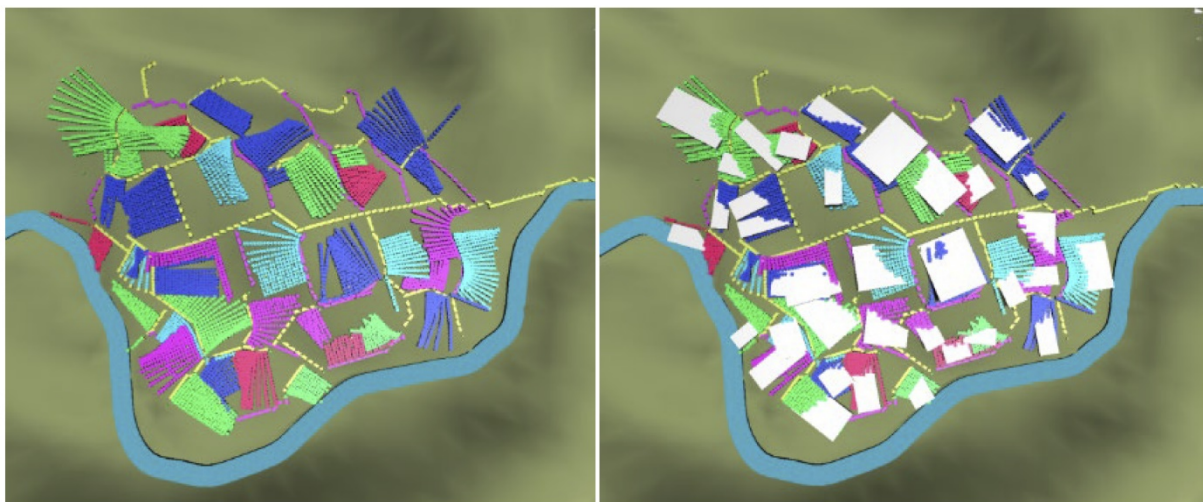


Figure 29. System generated building plot (left) and building outline (right).

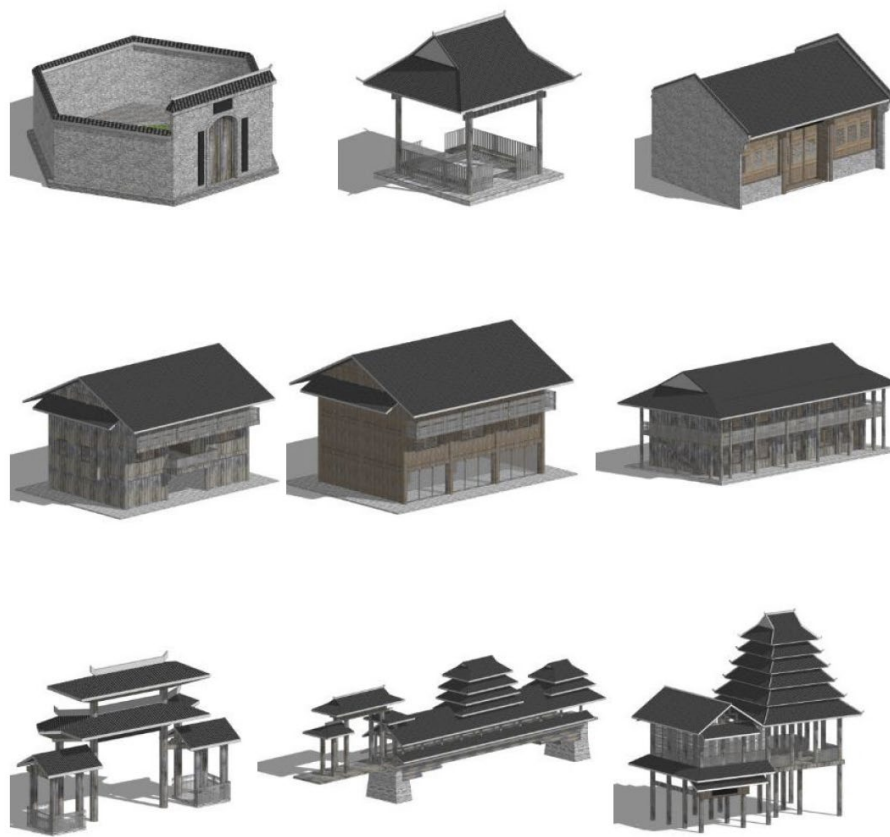


Figure 30. Examples of building model library.

Within the building plot (Pi), a quadrilateral representing the building outline is generated parallel to the road (Figure 29). The size of quadrilateral is set based on the survey and statistics results and needs to meet the corresponding floor area ratio limit as well.

3.6. Model generation

The last step is to generate building models, which are stored in the preset model library (Figure 30). Different building type information (T) are contained in different building points. When system generates a new building model, the model with corresponding building type are selected from the model library and will be placed within the range of the building outline (Figure 31).



Figure 31 Model generation.

4. Self-adapting Settlement Planning

Villagers-led self-adapting rural planning is the research hotspots of rural planning in recent years. Respecting the needs of villagers, planners participate in rural construction as helpers rather than leaders, and advocating bottom-up autonomous planning is the consensus of many scholars and rural planners (Li Y. 2008, Dai, S. et al. 2010). However, the villagers' educational level is relatively low, their cognition and participation will in rural planning are weak, which makes the self- adapting model difficult to implement.

We put forward a new idea of self-adapting rural planning route (Figure 32): taking villagers as the main body and using SGS system to generate rural planning results in line with local cultural and environmental logic. With the assistance of government and planners, villagers put forward modification suggestions according to the simulation results. Through simple gene manipulation, planners can quickly generate design results in line with the needs of villagers. After the villagers are familiar with the artificial intelligence system, they can also directly input the desired parameters and adjust the results to achieve their needs. After the simulation results are recognized by the villagers and the government, the planners will deepen the simulation results and finally guide the rural construction.

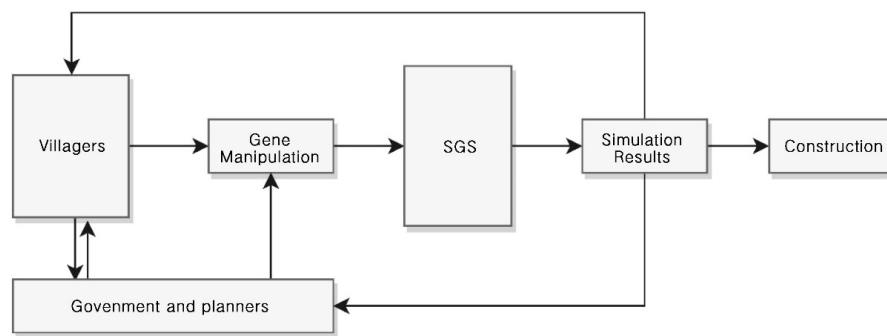


Figure 32. SGS assisted self-adapting rural planning route.

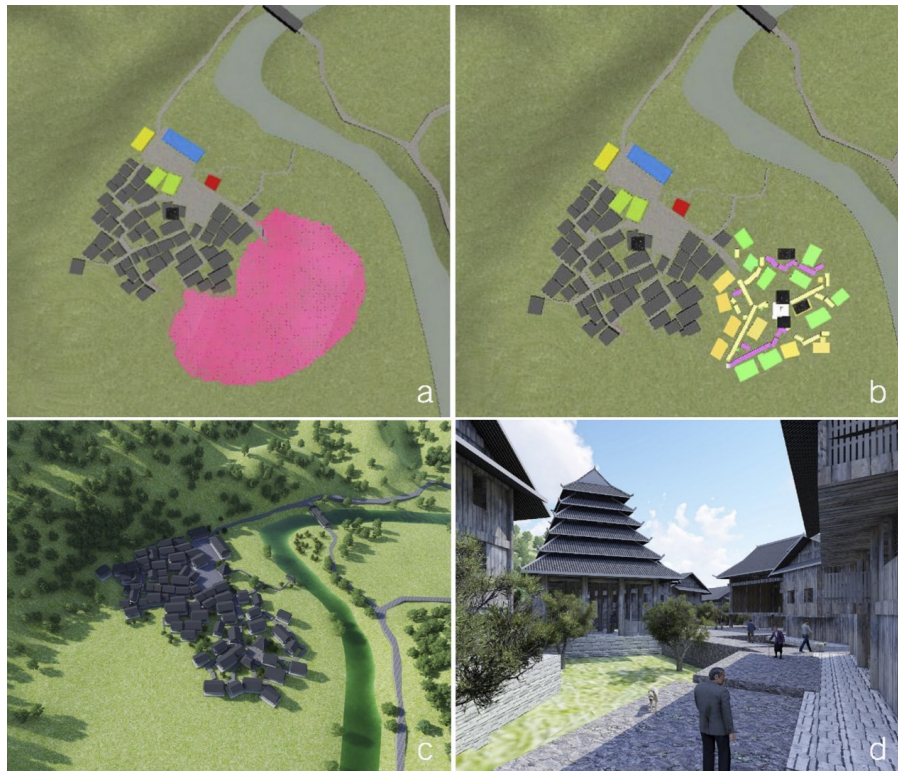


Figure 33. From a-d are, expansion site selection, building outline and roads generation, building model generation, perspective rendering respectively.

Base on the SGS system, we designed the expansion of Shangxiang Settlement. The system successfully simulated the site selection of the expansion area, the architectural layout, the road network and the establishment of building models (Figure 33). The simulation results can well reflect the Dong culture and characteristic layout.

5. Conclusions

This paper has detailed a novel planning & design system SGS that can be used to simulate the establishment and growth of rural settlements, through automated “site selection”, “building locating”, “road generation”, “building plot and model generation”. The system can also adapt to various terrain types.

With appropriate learning of existing traditional settlements, our system could successfully reproduce the growth patterns, layout and expansion sequence of existing Dong towns & villages. More importantly, this system can be used to help villagers, planners and governments to adopt the self-adapting rural planning method, to construct the new rural settlements in China, in a way that captures and preserves local environment, culture and history.

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