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Study on the Spatial Organization Mechanism and Simulated Evolution of Tibetan Buddhist Monastic Settlements on the Western Sichuan Platea

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Abstract: The western plateau of Sichuan Province is dotted with many Tibetan Buddhist monastic settlements, present extremely unique spatial characteristics of settlement and are an important part and unique type of human settlement system. Taking the Lharong Wuming Buddhist Institute in Seda County, Ganzi Prefecture, Sichuan Province as an object, we reveal the organizational evolution mechanism of monastic settlement space from the perspective of microscopic subjects, and accordingly establish the Tibetan Buddhist monastic settlement cellularular automata (TBTS-CA) model to simulate and predict the development trend of monastic settlement space form.

1. Introduction

The western Sichuan Plateau is part of the southeastern edge of the Qinghai-Tibet Plateau and the Hengduan Mountains. There are many Tibetan Buddhist monastic settlements on the plateau, which, present extremely unique settlement and habitat characteristics, and are an important part of the human settlement system and a unique type, a living human cultural landscape heritage. The spatial pattern of monastic settlements on the western Sichuan plateau contains the original spatial genes, organizational order and derivative logic[1]. It is of great theoretical significance to explore the dynamics and mechanisms of spatial development of settlements in the context of the complex topography and fragile ecological environment of the western Sichuan Plateau [2], in order to optimally guide the orderly development of settlement space and to inherit and protect the culture of regional settlements.

Tibetan Buddhism, as the faith upheld by all Tibetans, is the core of the spiritual life of the Tibetan people and the place where Buddhism conducts its religious activities[3] Many Tibetan Buddhist monasteries also have a systematic teaching function[3] They tend to be more integrated in terms of spatial structure and function, general pattern and form, transportation and infrastructure, This study defines this type of habitat system in terms of a Tibetan Buddhist monastery settlement[4]. This particular type of monastic settlement is numerous, especially in the entire area of Ganzi and Aba Tibetan Autonomous Prefecture.

2. Study object and data layer

The Larong Wumin Buddhist Institute is located in a valley (Larong Gully) surrounded by a mound of hills in the north-eastern direction of the town of Luo Ruo in the southern part of Seda County, Ganzi Prefecture, Sichuan Province. The terrain rises gradually from south-west to north-east, with the eastern end being a basin enclosed by high slopes on three mountain ranges, 1300m wide from west to east, creating an inwardly coalescing space. The difference in height between the ridges on either side of the gully and the bottom of the gully is large, but the slopes of the hills around the gully are not steep, allowing sunlight to reach the entire gully, making it an ideal place for gathering and inhabiting in a highland environment. The Lharong Five Minds Buddhist Institute retains many of the aesthetic features and rituals of the Nyingma religious culture of Tibetan Buddhism and is a purely religious settlement. The Wuming Buddhist Institute, which has been gradually built up in the Lharong Valley, is a unique Tibetan Buddhist practice, study and exchange colony of its own scale and form, and is known as the 'Nalanda of the Snow Region'[5].

In the 1980s, the Nyingmapa monk Jigme Phuntsok expanded the Lharong Five Minds Buddhist Institute and it gradually evolved into the monastic settlement it is today. In the green grass of the highland hills, the red wooden houses that cover the hillside are a powerful decoration of the entire Lharong Valley[6] (Fig. 1). The main reason for the Lharong Wuming Buddhist College as an experimental research object is based on its natural growth and the characteristics of a general monastic settlement built on a hill, which is basically in a natural development process and conducive to the research experiment of the CA model.

Figure 1: Research scope of Wuming Buddhist College. (Source: Self-drawing).

2.1. Study scope

The settlement area selected for this study is mainly the new settlement close to the town and the gathering area formed by the original site of the Lharong Ngamin Buddhist Institute. For the sake of authenticity and researchability we focused on the original settlement area, which covers an area of 460.32 hectares.

2.2. Land use layer

Land use data for 2002, 2014, 2017 and 2021 were selected, mainly including monastic residence land, road and street land, Sutra and Buddha Hall land, other land and vacant land. According to the operation principle of the cellularular automaton, the cellularular division of the built and unbuilt areas is done in a cellularular way to facilitate the subsequent simulation experiments.

2.3. Road traffic layer

Road traffic is a very important factor in the development of settlements, especially in the case of monastery settlements that are generally located in mountain passes, where communication with the outside world needs to be accomplished by main roads. Road traffic has a guiding role in the development of monastery settlements, and is influenced to a different extent at different distances. Of course, road traffic in monastic settlements is dynamic and needs to be updated and iterated during the data analysis and utilisation.

2.4. Slope layer

The slope suitable for building is re-graded according to the slope factor in the site suitability rating: Class I 0-15 °(suitable for building), Class II 15-25 °(suitable for building) and Class III 25 ° or more (unsuitable for building), and different weighting values are given to the different grades.

2.5. Exclusion layer

Due to policy factors, no-build areas have been designated on the periphery of the settlement and these areas need to be excluded from construction, which requires matching local policy. The Larong Wumin Buddhist Institute underwent partial demolition work in 2016-2017 due to policy reasons and was designated as a no-build area.

3. Construction of a ca model for monastic settlements

3.1. Definition of the monastic settlement cellular

The spatial evolution of monastic settlements is much slower and more subtle than that of cities, so the cellular size of 50*50 m or 30*30 m used in general cities cannot accurately simulate the spatial evolution of settlements. Based on the analysis of the size and evolution of monastery settlements in general, a base cell scale of 10*10 m is determined, and the land is divided into two categories: construction cells and natural cells, according to whether there are houses built on the divided land.

3.2. Construction idea of TBTS-CA model

The Tibetan Buddhist temples Settlement cellular automaton (TBTS-CA model), draws on some of the experiences and methods of the SLEUTH model [7] and extends the traditional CA model (Figure 2).

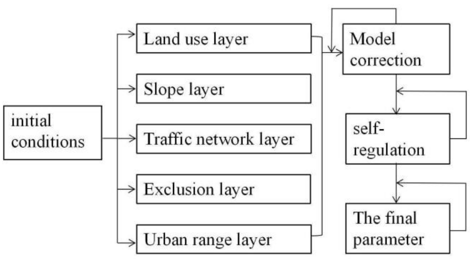

Figure 2: Schematic diagram of model construction ideas. (Source: Self-drawing).

TBTS-CA starts from a set of starting conditions and is controlled by three rules: natural growth, edge growth, and growth along the traffic network, which are in turn influenced by the intersection of dispersion parameters, reproduction parameters, propagation parameters, road traffic parameters, and slope coefficients. These growth rules act continuously and the state of the entire spatial cellular is updated [9]. In order to plan and regulate the spatial morphological changes of the monastic settlement, a planning constraint coefficient is set in the TBTS-CA model for each of the five parameters to regulate the growth of the cellular in real time.

3.3. Parameters and growth rules of the TBTS-CA model

● Topographical and traffic parameters

Most of the monastery settlements in the western Sichuan plateau are located in the mountain depressions, and the settlements are built on the mountains. So the CA model takes the slope of the terrain as an important limiting parameter for analysis. Most of the monastery settlements in the western Sichuan plateau are located in areas with poor access and high dependency on road traffic conditions, and most settlements are built close to major traffic routes and develop along traffic axes. Roads have a guiding role, so the road attractiveness parameter and reproduction parameter are taken as important parameters for consideration.

● Dispersal parameters and reproduction parameters

A spontaneous growth of the settlement cell has a certain chance to become a new expansion center in the process of development, and this situation should also be included in the consideration when setting the rules. This type is mainly affected by the dispersal parameters and propagation parameters.To describe the growth of the boundary, that is, any one cell around an expansion center produces another settlement cell in its neighborhood, which is mainly affected by the combination of dispersal parameters and propagation parameters.

● Definition of growth rules

We classify the growth rules of the TBTS-CA model into three types: Spontaneous Growth, Edge Growth, and Road lnfluenced Growth rules (Table 1).

1Table 1: Growth Rule Definition Table (Source: Self-drawn).

	Natural growth	Edge growth	Growth along the transportation network
definition	This refers to the gradual transformation of open spaces, grasslands, etc. into settlement sites within settlements, the gradual fleshing out of looser settlements.	New building cellular units are formed by expanding outwards from the edge of the settlement, with the newly growing cellular attaching to the edge of the existing settlement.	New cellular units are created by extending along traffic arteries, and the growth of such construction cellulars is mostly linear.
characteristic	randomness	Edge expansion	Different distances are also more highly attracted to them
application condition	The settlement boundaries are not yet built up, but are vacant land that could be used as a building site for houses, with building cellulars randomly populated.	If there are at least two construction cellulars and one natural cellular adjacent to each other, the natural cellular will be transformable into a construction cellular.	The number of cells within a 20 m radius of the road, the building cell adjacent to the road,if there were more than two neighbouring clusters.
restrictive condition	Number of adjacent building cells ≤ 2; Number of adjacent natural cells ≤ 1 or the site is a non-buildable area or the site is regulated by policy or the slope of the site is ≥ 25°		

The TBTS-CA model provides a deductive simulation of the growth process of monastic settlements through the five parameter types and three growth rules mentioned above. These rules and parameters interact and complement each other to relatively well represent the expansion process of monastic settlements from nothing to something, from missing to complete, and ultimately to form the full form of the settlement model. In addition to the common influencing factors, the socio-economic development of the general environment may also have different degrees of facilitating or inhibiting effects on the growth of the settlement, thus leading to a different focus on the development of the settlement. In order to improve the accuracy and feasibility of this prediction model, this external element should be taken into account during the simulation operation, and the growth rate and outward expansion direction of different periods should be appropriately adjusted at the right time to enhance the accuracy of the operation results as far as possible [8].

4. Application of the tbts-ca model

4.1. Model parameter tuning

The TBTS-CA model first selects the areas according to the definitions of the three rules selected above (natural type growth rule, edge type growth rule and growth rule along the traffic network) and measures the initial values of propagation parameters, propagation parameters, slope parameters, dispersion parameters and road growth factors using the ring growth rate method. The measured initial parameters and the required graphical data such as traffic network layers are then input into the model for calibration (Table 2).

2Table 2: Parameter Settings and Parameter debugging Table. (Source: Self-drawing).

Parameter test Parameter	Communication parameters	Breeding parameters	Slope parameters	Spread the parameters	Road traffic parameters	Results	cause
Initially parameters	0.03	0.3	0.2	0.00004	0.2	inconformity	Too many walking parameters
Experiment a	4.55	1.241	0.2	0.00004	1.8	inconformity	Slope parameters are too small, spread parameters are small, and road attraction is small
Experiment 2	4.55	1.241	0.15	0.03	1.9	inconformity	The spread parameters are too large
Experiment 3	4.55	1.241	0.15	0.00001	1.9	inconformity	The processing and distribution parameters are small
Experiment 4	4.55	1.241	0.15	0.00002	1.9	Conformity	

The specific operation is as follows: firstly, the current status quo data layer of the Lharong Wuming Buddhist Institute site in 2002 is used as the original data input to the model, and the model is run according to the initial parameters (each run of the model is one year) and the simulation results for 2014, 2018 and 2021 are obtained in turn. The simulation results obtained from the first run were compared with the actual status quo raster map, and the degree of deviation of the parameters was initially judged according to the definition of the three growth rules, and then some coarse corrections were made to the parameters with deviations in the initial measurement, and the simulation was run again to obtain a new set of simulation results. The new set of simulation results are then compared with the current situation again, the parameters are again judged and corrected, and the simulation is run repeatedly until a suitable set of results is simulated, and the combination of parameters is used as the optimal combination of parameters for the model simulation.

4.2. Model accuracy check

The evolution of monastic settlements is influenced by multiple uncertainties, and this process is uncontrollable and irreversible. The construction of a TBTS-CA model to simulate its growth process can only restore it to the greatest extent possible, but it cannot control all the influencing factors with complete accuracy. Even so, the TBTS-CA model still needs to be adapted to the actual results and checked for accuracy. In such simulation experiments, no uniform evaluation method has been established, and the more frequently used method is the point-by-point comparison method [9]. This is an approach where the results of the run are compared with the actual situation in an overlay, and accuracy corrections are made unit by unit. The best parameters of the settlement are input into the TBTS-CA model for calculation, resulting in morphological maps for different periods in different years of the Lharong Ng Ming Buddhist Institute, which are compared point by point with the historical satellite images of 2014, 2018 and 2021.

We simulated the growth process of the settlement morphology of Lharong Wuming Buddhist College through the model of TBTS-CA, and the point-to-point comparison accuracy of the TBTS-CA model simulating the simulation results in 2014, 2018 and 2021 was 75%, 64% and 61% respectively after adjusting the parameters. Excluding the influence of artificial infinitesimals, the fit of the model arithmetic results correlates well with the real situation, proving that the rule deduction of the TBTS-CA model is feasible, thanks to the fact that influencing factors derived from the settlement, including traffic, natural development rate and contemporary policies, are included in the consideration of model building and parameter adjustment when constructing the CA model of the monastery settlement, and the intervening effects of these factors are process, resulting in a high level of simulation accuracy.

4.3. Simulation results and evaluation

Through continuous debugging to find the best simulation parameters, the parameters were imported into the previously defined TBTS-CA model to produce the selected spatial morphology simulation map of Lharong Wuming Buddhist College for each representative year (Figure 3). The accuracy of the simulation map in 2014 is relatively high compared with the current situation map, because before 2014, the growth of the settlement form was still in the self-growth stage, and the overall growth type was more inclined to the natural growth type, without large artificial factors, so the growth trend of the simulation map and the current situation map are more or less the same. In 2018 and 2021, the accuracy of the mock-ups is relatively low compared to the current situation, and there are some areas of growth that do not exist in the current situation: firstly, in the southwest of the Lharong Wuming Buddhist Institute, the growth and development is controlled by the obvious no-build boundary; another part of the non-existent growth area is in the northwest of the boundary of the Buddhist Institute, and the analysis of the reasons can be concluded that the religious altar in the north and the slope factor restrict the growth of buildings and spaces; in the north of the Lharong Wuming Buddhist Institute, the growth of buildings and spaces is restricted by the slope factor. The small area of non-existent growth located to the south and east of the Lharong Ngamin Buddhist Institute is analysed as a result of the roads on the boundary of the Lharong Ngamin Buddhist Institute regulating the growth of its buildings and spaces, making the growth and development of the whole Lharong Ngamin Buddhist Institute more regulated and making the overall form more integral.

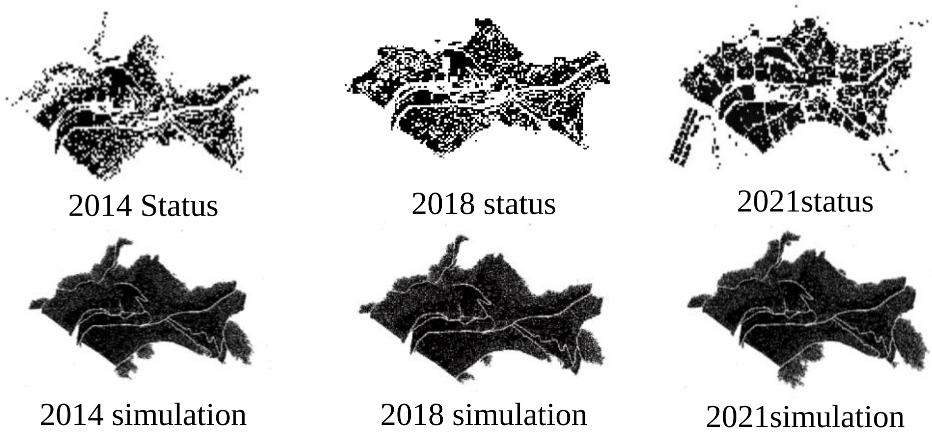

Figure 3: Results of spatial evolution simulation experiment. (source: self-drawing).

Through the simulation (Figure 4), it is clear that, according to the current development trend, the Lhasa Lhasa Rong Ng Ming Buddhist Institute is expanding to the southeast and local areas to the south, and that the entire Lhasa Rong Ng Ming Buddhist Institute will reduce or stop growing to the northwest due to the topography and government control. In 2030, the settlement will expand further, with more of its form breaking out beyond the road boundary than in 2021, and in 2035 it will slowly form small groups attached to the basic settlement, creating a new settlement form. In summary, the development of the Lharong Wuming Buddhist Institute will avoid the sloping areas and will slowly break away from the road and ridgelines to the south and east, gradually forming new settlement patterns.

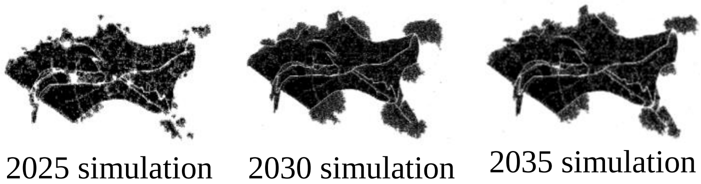

Figure 4: simulation prediction of spatial evolution. (source: self-drawing).

5. Conclusion

In this study, a model TBTS-CA is constructed to simulate the growth of monastery settlement under the CA theory system, and the simulation results are good in simulating the evolution of monastery settlement space. The results of the simulations can be used as a reference and guide for the future development of monastic settlements. As the model is defined with a 10*10 cell division, it does not correspond to the actual spatial scale, just for the convenience of model building, which to a certain extent affects the accuracy of the model simulation and needs attention in subsequent studies.

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