Journal of Applied Sciences

ISSN 1812-5654

science alert

ANSInet
an open access publisher
http://ansinet.com

Journal of Applied Sciences 13 (7): 1155-1159, 2013
ISSN 1812-5654 / DOI: 10.3923/jas.2013.1155.1159

Study on Fractal Characteristics of Hilly City

[1]Li Zexin, [1]Liu Bo, [2]Wang Rong and [1]Li Zhi
[1]Institute of Architecture and Urban Planning, Chongqing University, Chongqing, 400045, China
[2]Institute of Resource and Environment, Yunnan Agriculture University, Kunming 650201, China

Abstract: At this stage, descriptions about urban spatial form are mainly qualitative not quantitative from the perspective of urban planning, this study will use fractal theory to give a quantitative analysis on urban spatial form and propose some optimization suggestions. The inherent law of urban spatial structure of hilly city's in irregular terrain can be catch through fractal theory's quantitative analysis. Compared with the existing urban form fractal dimension value of experience, this paper puts forward the development tendency of hilly urban morphological fractal dimension values. Combined with mountain ecology principle, this paper proposed optimization suggestions from the perspective of fractal space: compact urban spatial structure and efficient and intensive land use.

Key words: Hilly city, fractal characteristics, morphological fractal dimension value

INTRODUCTION

With the complexity of the spatial shape, lack of land for construction and sensitive ecological environment, the development of hilly city is subject to the constraints of the natural environment. Currently, the pursuit of plain areas layout by large-scale filling and digging, or over-dispersed layout, are two outstanding problems exist in the planning and construction of hilly city: Some large and medium-sized hilly cities blindly apply the planning and construction mode in plain areas and does not respect the topography, resulting in uncoordinated city spatial shape and the natural environment; Some small hilly cities and towns apply the layout pattern of large and medium-sized cities, in the form of linear layout, multi-center group layout and so on, resulting in increased infrastructure investment and running costs, they will be overwhelmed if things continue. The common types of hilly city spatial shape are linear type, grouped type and so on. Hilly cities of different scales and in different stages of development, should have the spatial shape in according with its own law of development and environmental features. The scientificalness and rationality of its shape need not only qualitative research, but also quantitative analysis. The planning methods of "organic decentralization and partial concentration" have been accepted by more and more people, but what is organic decentralization and what is concentration? What kind of city structure and standard of Intensive use of land should be adopted at different stages of urban development? How to judge the "degree" with scientific methods? This is the problem that government and academia have been hoping to solve for years. Currently, studies of city spatial shape are mostly qualitative text description and are lack of quantifiable criteria.

The fractal theory is created by in the 1970s. The fractal theory refers to some kind of broken, irregular shape, it means there are some similarities between the global and local and it can be understood as a constant in the change, in brief, it means some kind of characteristics of shape exist similarities in different scales. The coastline on the map is a good example of naturally existing fractals. Figures of the coastline depicted at different scales, are all shown as similar zigzag line, then to enlarge these zigzag line of the coastline, it will be a smaller coastal zigzag line and so on, it will be endless. Like the Koch curve of snowflakes, there exist fractal structures in the nature, such as cloud, coastline and some of the fractal structures are relatively regular, but some of them are irregular. Since the fractal theory was created, it has brought in new research ideas and methods for many disciplines and it has been promoted and applied in management, economics and engineering technology and was soon introduced to urban planning as a theory of natural science, introduced to the study of urban spatial structure, the fractal theory made up for the lack of quantitative research in urban planning: In the regional system, the central place theory, introduced the concept of infinite fractal and quantified fractal dimension of the original hexagonal structure, in the practical process, depending on different research objective, one can construct different fractal dimension model to calculate the fractal dimension value, in order to examine its fractal characteristics. Generally, speaking, in the spatial

Corresponding Author: Li Zexin, Institute of Architecture and Urban Planning, Chongqing University, Chongqing, 400045, China

fractal characteristics, the lower the fractal dimension value, the lower its spatial degree of fragmentation, the more compact the city. Zhu and Ji (2010) discussed the fractal dimension of city plane shape, such as gathering and the population density and explored the scaling behavior of the city gathering in different scales. Peng and Qi (2011) compared many cities in case study and summarized the fractal characteristics of the evolution of the settlement pattern in the process of urbanization. The above research involved city boundaries, urban networks (transport network, bus, suburban railway and sewage facilities), urban land use, urban shape and urban growth and so on.

SPATIAL FRACTAL CHARACTERISTICS OF HILLY CITY

The hilly cities belongs to the mountain cities. According to the division of China's three steps, the first step include the hilly cities on the plateau, mainly distributed at an altitude of 2000-4000 m, such as Dali, Lijiang on the Yunnan-Guizhou Plateau. The second step include the hilly cities on basin regions, located at an altitude below 2000 m, such as Fuling, Jiangjin, Yongchuan, Wanzhou in Chongqing and Mianyang, Yibin, Luzhou and Zigong, Ya'an, Leshan in Sichuan, etc. The third step include coastal hilly cities in the middle and lower reaches of the Yangtze River and Yellow River, such as Qingdao, Yantai, Penglai in Shandong, Dalian in Liaoning, Hong Kong, Macau, Zhuhai, Guangzhou, Nanjing, Kaohsiung in Taiwan and so on (Huang, 2006). The hilly city is different from plain city and is also different from the mountain city, it is somewhere between these two types of urban space, with more varied landscape than plain city and more delicate and pleasant city space than mountain city.

Fractal characteristics of hilly topography: The topography is the objective condition for the development of urban spatial structure. Hilly areas have diverse topographic relief, with mountains and rivers surrounded. Hills have the following characteristics: Firstly, with characteristics of topographic relief, hills are combination of slopes made up of all kinds of rocks. The slopes are generally moderate and desultorily cut, without certain direction. Secondly, the altitude is less than 500 m and the relative height is no more than 200 m. According to space type, hills can be divided into two categories, one is punctiform hills space, with fragmental space and no directionality. The other is linear hilly space, mainly consists of intervals, the space has obviously directionality and intervals is usually accompanied by a river. In practical situations, both of them are mostly exist simultaneously.

Hilly topography has the characteristic of complexity and self-similarity as well. It is found that, in fact real topography had not only strict fractal part, but also non-fractal part of linear trend and scale-related. These scale-related parts are easily observed in the actual topography. By comparing pictures captured from Google Earth at different view heights, one can draw a conclusion of the hilly topography characteristics at different scales that the image at view height of 1 km is highly similar to that of 2 km and the image at view height of 5 km is highly similar to that of 10 km. As with the Koch curve, hilly topography also has self-similarity in the sensory.

Fractal characteristics of hilly city spatial structure: In the discussion of city spatial structure, city geometry relation is an important feature of spatial structure and the point, line and plane in space is an important factor of structure.

The fractal characteristics of the spatial structure of urban system: In the hierarchical structure of urban system, there are also obvious spatial fractal characteristics. Compounded two factors of hilly topography and urban system which has the fractal structure, hilly urban system structure also has fractal characteristics. This fractal phenomena like the Sierpinski carpet spread on the hills. Elements of carpet flow to intervals in self-organized way, forming a more homogeneous structure.

The city spatial structure also has fractal structure characteristics; it is reflected in various aspects of city space, such as boundary system, traffic system, functional structure etc. The self-similarity of city topography at different scales and that of natural topography and plane shape of mountain city at different scales, can be summarized as the self-nested structure of non-linear fractal structure (Long and Meie, 2007). Yue and Ran-Ran (2010) draw the fractal characteristics of the city space shape. In the fractal figure, the structural units exist in the form of groups, each group has a closed boundary and the function is relatively independent. It described the space structure changes of community in the city scale. For example, there are residential districts, commercial districts, city main roads in the entire city and similarly, there are residential areas, commercial shops, city secondary main roads system in residential districts. Hilly city boundaries at different scales, from city boundary to group boundary, till the boundary of every land, have similar characteristics

of irregularity; the characteristics of freestyle traffic system also penetrate from the main road system to bypass system.

From the fractal characteristics of each element, it is not difficult to find that it requires three conditions for the existence of fractal structure of city: The hierarchical structure, the basic unit and self-similarity. Hilly city exist double fractal structures, one is the fractal structure of natural topography, the other is the fractal structure of city space and they form the balance of organic and mutual adaptation under the condition of spatial self-organization.

Fractal dimension value of hilly city shape: The hilly urban space fractal characteristics, one need to use a mathematical model for the quantitative description of the extent of the fractal and different fractal dimension measurement method represent different connotations. At present, the measurement methods of fractal dimension of city space include boundary fractal dimension, grid dimension and the radius dimension. When use the boundary fractal dimension, one can calculate the fractal dimension of the whole city land and can also calculate he fractal dimension of different kinds of land. Its value means the fragmental degree of land boundary, or the land area of different space. The grid dimension means to divide different city land is into grids and then calculate the boundary fractal dimension of grids, in order to reveal the evolution of city shape and land use structure. The radius dimension method reflects the centripetal aggregation degree and spatial distribution pattern of city land and can be used as the quantitative basis for judging the efficiency of city center.

For the calculation of the fractal dimension of urban shape, it involves mainly plain cities at present and there are less mountain cities and hilly cities involved. From existing research, though the statistics and comparison of fractal dimension values of cities at home and abroad, one draw a conclusion that the suitable fractal dimension value city space is about 1.7 (Yong, 2006). The connotation of the fractal dimension of urban shape can be explained though a simple graphical reasoning. Contrast the urban space structure on the figure at right, one can see that A stand for integral city space and B for gapped city space. There is a difference at the ratios of boundaries and area sizes between the two types of urban space and the fractal dimension value of A-type city shape is obviously smaller than that of B-type. In real life, the A-type cities have fully populated urban space and are also cities with plane shape of the most efficient urban land utilization and they are similar to cities on plains. However, there are kinds of non-construction land located in the B-type cities, such as urban ecological protected areas, geological disaster area, rivers, etc. and they are similar to cities on heterogeneous topography, generally the mountain cities such as grouped cities and linear cities. Higher fractal dimension value of boundary, indicating that the city layout is more scattered. The boundary fractal dimension value of the typical linear cities of Fengjie and Yunyang in Three Gorges reservoir area is as high as 2.0 which is decided by the special geographic environment and cultural background of immigrant cities. The method of organic decentralization is often advocated in mountain city layout, but it lack of basis when judging it. Though boundary fractal dimension values, one can judge whether it is compact and reasonable and make quantitative study of the layout of urban space. In the analysis of urban shape, there are two methods that to compare fractal dimension values of individual city in different time periods, or to compare fractal dimension values of the different cities in the same period. Taking into account that the research object is hilly urban shape, the article will study the spatial shape of one hilly city in different periods and analyze the changes of urban spatial shape fractal dimension values, to sum up the evolution features of hilly city shape.

APPLICATION OF HILLY CITY SHAPE FRACTAL DIMENSION VALUE-TAKE THE CITY OF MIANYANG IN SICHUAN PROVINCE AS AN EXAMPLE

The city of Mianyang is located in the hilly area in the northwestern of Sichuan Basin, Fujiang and its tributary of Ann Changhe cross the city. The city is made up of the Fucheng District and Youxian District. There are hills, such as Dong-shan, Fuleshan, Laolongshan, Xishan, Wujialing in Mianyang. In 2010, the area of urban built-up district is 120 km^2, with a permanent population of 108 million and the total population is about 1.5 million with floating population counted. According to the urban plan, the size of the permanent population in 2015 is 120 million people, 150 million in 2020. Urban spatial structure will rely on the natural landscape situation in Mianyang that Surrounded by four mountains and crossed by three rivers, to form multi-grouped spatial layout structure with landscape intervals and inter-digital growth. According to the elements of the natural landscape and road etc. The central city is divided into 11 groups that the central area, Gardening area, High-tech Zone, Tangxun, Youxian, Science City, Songya, Qingyi, Xiaojian, circular economy park, Mojia.

Boundary fractal dimension values in different periods of development in Mianyang city: Take the built-up area of Mianyang City at different six periods from 1980 to 2009 as objects, to measure the perimeter (P) and area (A) of relatively independent land and then using the modified model for the measurement of urban form complex nonlinear characteristics based on the conventional model:

$$D = 2\lg(P/4)/\lg(A)$$

where, P is the perimeter of the construction land, A is the area of land for construction and D is the fractal dimension.

Comparison of Mianyang fractal dimension value: Compared with 1.7, the experiential fractal dimension value of existing city shape, the fractal dimension value of Mianyang is around 1.6, it is small. This shows that under the conditions of limited land resources, the degree of land intensive utilization is higher in integral land; on the other hand means greater space eccentricity and it is typical spatial layout mode of organic decentralized and partial concentration. Compare fractal dimension value of Mianyang city shape, you will find that it decreasing year by year. This shows that even the space of one city extend organically, its form will become more and more integral and the utilization efficiency of city space will be improved. This is the performance of city compact development. From 1996 to 2009, the area of urban construction land increased by about 35 km^2 every five years, City fractal dimension values fluctuated from 1996 to 2005, the fractal dimension values decreased by 0.2 which shows that the city space at this stage spread and the utilization efficiency of city space also increases rapidly. From 2005, the urban construction land grow at the same rate, but the fractal dimension values kept stable. This shows that the utilization of urban space has changed, being more intensive, there are less gap sites in the city and become more integral.

Suggestions of Mianyang city space development: Through the analysis people can conclude that, in the early development of Mianyang, hilly topography is an important factor restricting the development of city and it is natural selection to the flat land. When the city droved by urbanization, economic, traffic and other driving forces, city native body is in the checks and balances of the topographical constraints and economic development and then the hilly topography had not been the resistance of development for long, it is inevitable to transform the hilly topography into city construction land at this stage. Even the part of topography is hard to transform, the hilly land transformed from the original non-constructive ecological green land into city public green land, thus one step closer to the integration of city shape, making the city space tends to be continuous.

Concentrated and compact urban structure: Mianyang city is located on the alluvial plain of Fujiang, Ann Changhe between hills of Dongshan and Xishan etc. From the analysis of natural environmental factors, the urban construction costs to develop eastward or westward in short and medium term are two high and the ecological environment will be affected. Therefore, the city should be forced to develop along the upstream and downstream of Fujiang River and the upstream of Anchanghe, to form the compact layout of one city area and three groups. The long-term direction of city development can be, either new space outward across Dongshan and Xishan and Wujialing, forming a multi-center group layout; or to develop some of the hills, making the built-up areas of city contiguous. From the analysis of city fractal dimension values, cities with multi-center group layout have higher fractal dimension values, higher infrastructure costs and worse operating economical efficiency, but the reservation of mountains are good for the environment. The latter is just the opposite, with concentrated compact and contiguous development, their fractal dimension value is low, but the natural environment of mountains will be damaged. Though comprehensive analysis of environmental capacity and location conditions of Mianyang, conclusions can be get that when the city scale is small, it should be concentrated and compact and when it has a population of more than 100 million, the city should adopt the layout that combine concentration and decentralization, but groups should not be too much, group size should not be too small. At present, Mianyang is divided into 11 groups. When the city reaches a certain size, some groups will naturally become contiguous and Mianyang spatial structure will eventually evolve into 5~6 larger groups (or areas), urban planning should guide this trend. In 1980s in Chongqing, there are farmlands and mountains between Dayangshi group (Daping, Yangjiaping Shiqiaopu region) and Shapingba group to separate the two groups, but now basically contiguous. This is a trend of urban development.

Efficient and intensive land use: Mianyang is one of the biggest cities in Sichuan province, so it is an inevitable choice for the intensive utilization of central city. The per capita index of construction land in some hilly cities is high; resulting in fragmentation of urban layout and it is not conducive to the city centralized and compact

development. In terms of Mianyang, as it located on the hilly area in the basin, it is different from cities which is situated at the edge of the basin like Kangding, Hanyuan, Wushan, Fengjie, Kangding, YunYang, limited by the condition of mountainous topography, the latter generally take multi-center group layout or linear layout while Mianyang, as a hilly city, should be relatively concentrated. This requires that, on one hand, to appropriately raise land plot ratio in city center or group centre, as bigger and stronger center could drive the surrounding area; on the other hand, to strengthen the reconstruction and renovation of the old city and to integrate scattered land, to improve land use efficiency; at the same time, to discover the available land for construction around built-up area, in the case that ensured the natural ecological environment and geological safety, the construction area could extend onto the hills to appropriate extent, to expand the space of city development.

CONCLUSION

Since the emergence of the fractal theory in 1980s, the domestic urban planning academia had made a series of researches and applications, using these basic principles and methods. Such as those made by Chen Yanguang, Chen Bingzhao, etc., from the field of regional and city planning and they are of great theoretical value. In recent 30 years, with the rapid urbanization in China, the city size grows exponentially. However, some cities present a state of disorder, so they urgently need the theoretical support of quantitative analysis technology and technical guidance. Currently, in the macro background of the intensive use of land, the hilly topography features are gradually eliminated and tend to space intensive. However, the integral urban space destroyed the original ecological environment in hills. So, how to scientifically define the rational use of urban land in the hilly regions requires a lot of research to support. From the perspective of topography, spatial structure, hilly city has typical fractal characteristics. The fractal dimension value of city shape can quantitatively judge the use efficiency of urban space and the reasonable degree of city shape. It can be further applied to many aspects of urban planning, to make up the lack of quantitative analysis techniques.

REFERENCES

Huang, G.Y., 2006. Theory of Mountain Urbanology. China Architecture and Building Press, Beijing, pp: 53-54, (In Chinese).

Long, M.Y. and O. Meie, 2007. On characteristics of fractal aesthetics in mountainous cities. J. Mountain Sci., 3: 148-152.

Peng, L.Q. and Z.X. Qi, 2011. Progress and prospect of the research on fractal cities in China since 2000. Cent. China Norm. Univ. J. Postgrads, 18: 153-158.

Yong, H., 2006. City spatial morphology Fractal Research-Taking Wuwei city as an example. M.Sc. Thesis, Lanzhou University, Lanzhou.

Yue, W. and W. Ran-Ran, 2010. Fractal and city planning. Modern Urban Res., 4: 53-57.

Zhu, H. and C.C. Ji, 2010. Fractal Theory and its Applications. Science Press, China, pp: 102-105.