UDC 711

Bin Cong, Wei You, Wowo Ding
School of Architecture and Urban Planning, Nanjing University,
Hankou Road 22, Nanjing, Jiangsu, China, 210093
e-mail: nandacongbin@gmail.com

ASSESSING STREET SPATIAL CHARACTER: COMBINING FRACTAL ANALYSIS OF STREET EDGES AND SKYLINE

Abstract: *The character of urban space is a hot research point in urban morphological studies. James J. Gibson's research proved that the physical morphology is better to be measured by the visibility of geometry rather than geometry itself (Batty 2001). There have been many approaches such as sky view factors (SVF), which developed a 3D viewsphere model to measure the spatial openness, and fractal analysis. The fractal analysis of street edges proposed by Jon Cooper is one of the most helpful indexes describing spatial character because it directly reflects the space shape cognized. However, the height of a street wall and the width of a street, two of the most important dimensions related to the space, have not been involved yet. Following Cooper's research, this paper tries to introduce the height of a street wall into the fractal analysis of street edges. Firstly, we chose several streets in the center of Nanjing city with various widths and building heights along the street. Through setting viewpoints within the street, the geometric relations between all edges and points have been built, so had the skyline. Furthermore, combining SVF techniques, we have developed the 3D viewsphere model as a tool to get continuous visual perception data of the street and the heights of the street walls related. According to the visibility theory, the street spatial character could be described and generated, vice versa.*
Finally, this paper tried to use the spatial configuration codes based on the fractal analysis and data-graph of perception to generate a new street with the similar spatial characteristics. It proves the value of the research as a tool for urban design.
Keywords: *spatial typology, viewsphere, data-graph, fractal analysis.*

Introduction

The urban space is an important research object in urban morphology studies. One of the most important research issues is how to decode street space, that is, how to summarize quantitatively the characteristics of different spaces and use these indicators to help control and design the street space. There are several research paths in previous research.

The first one starts from the formation of the street space that is the classical morphological research method - block dimensions, plot measurement and recording of façade details. The street space is defined by these three parameters.

The second one is studying a 2D isovist by setting viewpoints in the plan to study the geometric properties of visible space. Benedikt (1979) describes an isovist as "the set of all points visible from a given vantage point in space". Isovists can be defined for every vantage point constituting an environment, and the spatial union of any particular geometrical property defines a particular isovist field. His definition takes an isovist as the foundation of the urban and architectual visual studies. Batty (2000) began to describe the isovist quantitatively by the computer and developed several indicators including an average distance, a maximum distance, an area, a perimeter, a compactness ratio, and a cluster ratio. Batty's research proved the feasibility and importance of studying an isovist by means of computer. Moreover, Turner (2001) mapped the relations of the distance from one viewpoint to all the others. Instead of studing the properties of one single point, he summarizes the whole characteristics of the space with the visual graph of mutual visibility between locations. The computer research of a 2D isovist is greatly developed, but it still lacks the three-dimensional information.

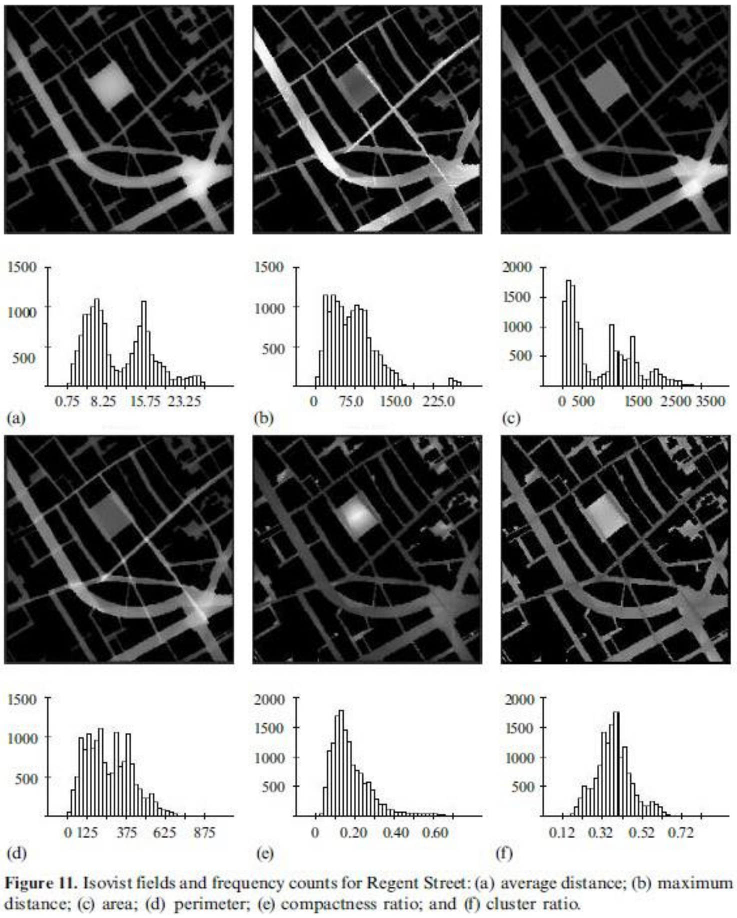


Figure 1. The six isovist analysis of Regent Street (Batty M, 2001)

The third one is studying a 3D isovist. Although the isovist is a three-dimensional concept in the initial stage of the isovist research, it is limited by technical means and many studies have only completed the two-dimensional calculations. However, this situation has changed in recent years. With the extensive use of computer technology in the field of research, more complex 3D isovists can be calculated, which promotes the development of urban spatial visual research. Based on previous studies and definitions, researchers such as Fisher-Gewirtzman (2003) used a SOI (a spatial openness index) to study the urban space between buildings. The SOI is defined as the sum of the visible space volumes from which the line of a sight is not obstructed by the Body mass as seen from the given point to the surrounding three-dimensional space. Perry Pei-Ju Yang (2007) combined the previous research results and developed a 3D urban spatial isovist model called Viewsphere. The development of the Viewsphere analysis is mainly based on the research contributions of an isovist and viewshed. It also includes other sphere research models including a sky view factor, the spatial openness index (SOI), and sky opening. Perry Pei-Ju Yang and others explored ways to measure the spatial vision of 3D cities based on GIS. However, due to the immature GIS technology in 3D analysis, they could not achieve a complete three-dimensional visual analysis. In Liu Yang’s (2011) research at Nanjing University, a complete 3D visibility research platform was set up on the Rhino's Grasshopper to distinguish different street spaces through the data Viewsphere visualization, but it still did not summarize the features quantitatively and did not describe the street space as a whole.

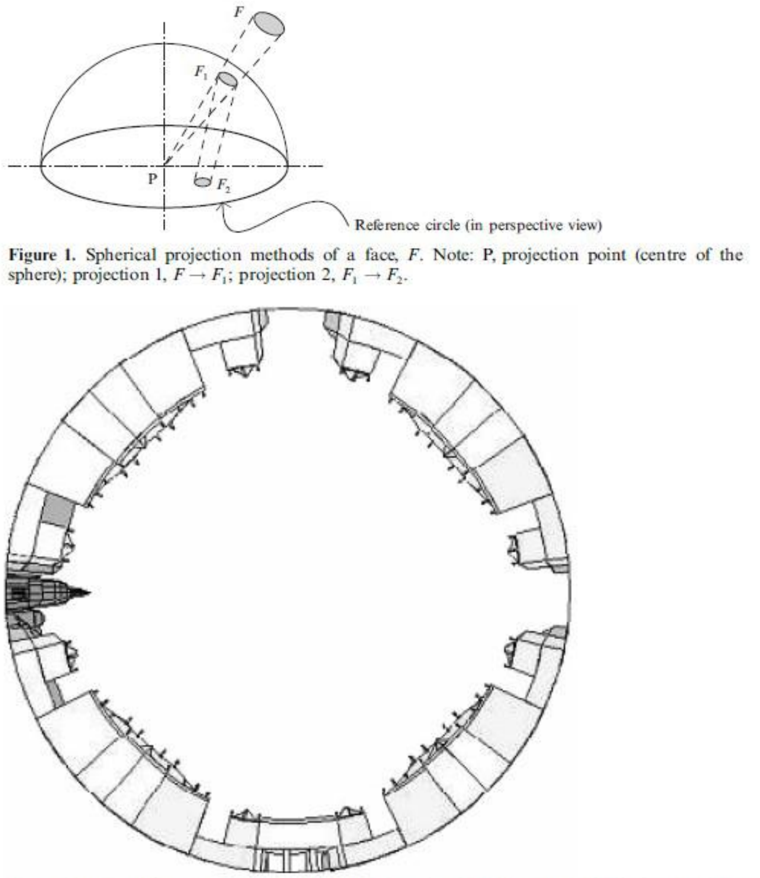


Figure 1. Spherical projection methods of a face, F. Note: P, projection point (centre of the sphere); projection 1, $F \rightarrow F_1$; projection 2, $F_1 \rightarrow F_2$.

Figure 2. Example of a stereographical projection: Amalienborg Plads, Copenhagen.

Figure 2. Spherical projection and stereographical projection (Teller, 2003)

The forth one is studying with the use of fractal analysis. The continuous spaces in the city are mostly complex, while the classic Euclidean geometry is difficult to describe their characteristics. The fractal analysis is often used to describe the natural form, therefore, can describe and characterize complex urban spaces. Cooper (2000) used fractal analysis to characterize the complexity of urban and natural skylines. Mizuno and Kakei (1990) and Rodin and Rodina (2000) examined the curves of urban streets networks with a fractal dimension. Batty and Longley's (1994) used the fractal dimension to characterize the irregularity of certain urban boundaries. Cooper (2005) examined the fractal dimension of street edges to obtain the synthetic complexity of physical features. However, the calculation of the fractal dimension requires a continuous curve, while most of the street facades (especially in China) are non-continuous. The determination of the boundary affects the calculation of the fractal dimension. Meanwhile, the street edge is still a 2D form, which does not include the height and the width of the street. Moreover, the fractal dimension is the overall description without any spatial details, so it is hard to do further research. Cooper (2007) examined the use of the fractal dimension to measure the complexity of street scenes. However, there are too many spatial factors constituting the street space including trees, pedestrians, vehicles, etc., so it is still hard to help control and design the street space.

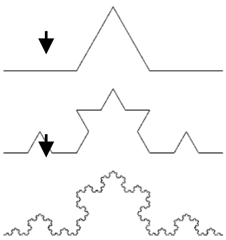
Based on the several methods mentioned above, this paper tries to explore a better way to decode the street space quantitatively. Firstly, following Cooper's research of the street edges fractal dimension, this paper tries to discover the relationship between the fractal dimension and the street vision and find the limitations of the fractal analysis. Secondly, following the research of a 3D isovist, this paper further develops the Viewsphere to measure the synthetic characteristics like the fractal dimension and reflect the details of the street space.

The fractal dimension (Dr)

The Euclidean geometry classifies objects into one, two, or three dimensions. Lines have one dimension: the length, the plane has two dimensions: length and width, and the cube has three dimensions: length, width, and height. These applies to the description of perfectly regular objects or shapes, but Mandelbrot (1977) argues that many natural objects, including man-made urban forms and spaces, cannot be adequately described by the concept of Euclidean geometry. The concept of the fractal geometry introduces the possibility of fractal dimensions between the N-dimensional in the world of mathematics. The concept of the fractal dimension can calculate the irregularity of a shape or an object and represent it as a number. This number (D) is between Euclidean dimensions 1, 2 and 3 that can be expressed as a non-integer number. For example, the fractal dimension of an irregular line (such as a coastline) is between 1 and 2: it is neither a simple straight line nor a two-dimensional plane. Actually, the fractal dimension is a measure of how much a particular object fills the space it is drawing. For example, using the concept of theoretical fractals, one can imagine infinitely long lines drawn in a limited space. This line is infinitely folded and irregularly scaled down. Its length can be infinitely increased because it increases the density of lines in a fixed space through the increase of irregularities.

There are several methods to calculate the fractal dimension of irregular or rough lines, including the “box dimension” method and the “ruler” method. By comparison, the “ruler” method is more accurate. The fundamental of “ruler” method is that the irregular line length increases with the measurement of smaller and smaller rulers. In its simplest form, the “ruler” method uses a set of scales of different length (s) to measure and then we record the subsequent total length (N). After that, we take the logarithm of these two numbers and put them on Cartesian coordinates. These log/log graphs are called Richardson (1961) graphs. When the points on the log/log graph fall on a straight line, there is a power law relationship between the two sets of data. Therefore, the slope of this line (d) can be obtained through regression analysis. Then the fractal dimension is D which is equal to 1 + d. In the ideal mathematical model, the rulers do not affect the fractal dimension of the curve. However, as the irregular lines in reality are not ideal fractal curves, the rulers do affect the measurement result of the fractal dimension. It is important to select the rulers’ range. In the street model chosen in this article, it is the width, height, receding distance, and volume shape of the building that affect the fractal dimension which does not include the details of the windows and doors on the façade. The smallest ruler is selected as about 1.5 meters, while the maximum ruler is about 50m. Because the N/s is a power function relationship, the ruler's size increases by a power. For the sake of accuracy, 15 rulers with the increase of 1.5 times have been selected.

This paper uses Grasshopper in Rhino as a platform to calculate the fractal dimension. Rhino is an accurate modeling tool, so it is better than some other software calculating Dr like Fractalise which uses pictures of curves. First, we make an experiment with the classic Koch curve. Mathematically, the Dr of the Koch curve is 1.2619. Using the “ruler” method, the program comes up with the Dr of 1.2573. This proves the accuracy of the program.



ruler(m)	number	ln(ruler)	ln(number)
1300	1536.226	7.170	7.337
1690	1024.531	7.432	6.932
2197	1024.048	7.695	6.932
2856	554.772	7.957	6.319
3713	512.084	8.220	6.238
4827	320.189	8.482	5.769
6275	256.106	8.744	5.546
8157	170.581	9.007	5.139
10604	128.151	9.269	4.853
13786	80.414	9.531	4.387
17922	64.207	9.794	4.162
23298	40.689	10.056	3.706
30288	32.241	10.318	3.473
39374	21.709	10.581	3.078
51186	16.321	10.843	2.792

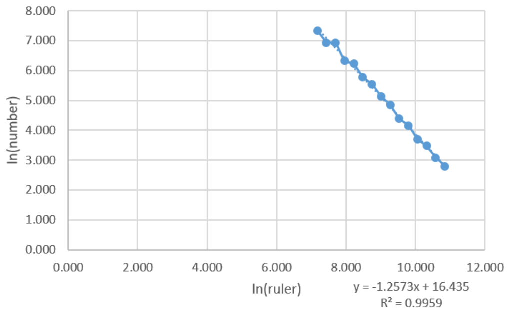


Figure 3. The Koch curve and the Dr

The Dr of street edges and skyline

In the context of the urban morphology in China, the urban texture can be divided into four kinds: Commercial area, Residential area, Historical area and Scenic area. The scenic area is not taken into account in this paper as its elements are mostly not buildings. We choose three streets in Nanjing as samples in this paper: a historical street; a street between residential buildings; a commercial street. The first street consists of two parts: a totally historical street and a street with some residential buildings.

Figure 4. Four street samples, No.1 and 2 in old town, No.3 in residential area, No.4 in commercial area

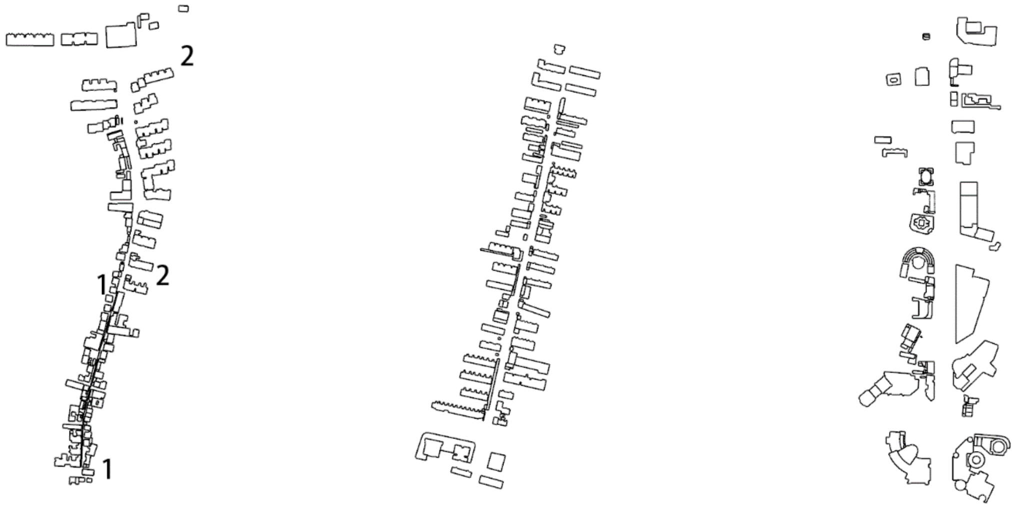


Figure 5. The model of the streets in Rhino

First, we extract the street edges of them. Unlike the streets in Cooper's research, the streets in Chinese cities usually do not have a clear edge as the façades are not continuous. In this paper, the historical street has a continuous edge, the residential street has a fence as the edge, while the commercial street's edge can be connected between two adjacent buildings.

No.1 Street	Dr	No.2 Street	Dr	No.3 Street	Dr	No.4 Street	Dr
	1.1334 R^2=0.999		1.1310 R^2=0.999		1.1020 R^2=0.999		1.0882 R^2=0.999
	1.1048 R^2=0.999		1.088 R^2=0.999		1.1019 R^2=0.999		1.0552 R^2=0.999

Figure 6. The street edges and their Dr

As we can see, the Dr of these streets are different, the historical street has the biggest Dr while the commercial street has the smallest one. The street edge is perceived by a human through eye perspective, so we further choose two vistas of each street and measure the Dr of the skyline.

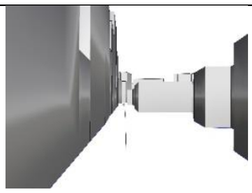
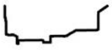
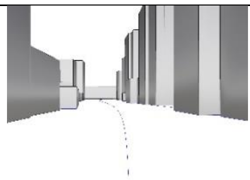
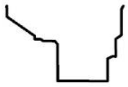
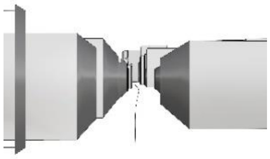
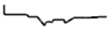
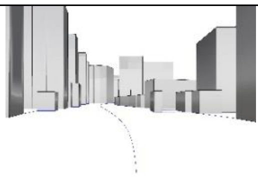
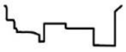
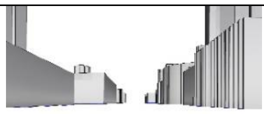
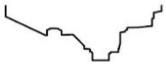
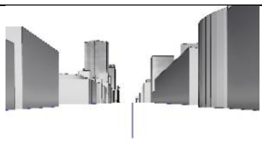
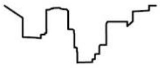
No.1 Street Skyline		Dr	No.2 Street Skyline		Dr
		1.047			1.028
		1.046			1.062
No.3 Street Skyline		Dr	No.4 Street Skyline		Dr
		1.091			1.051
		1.074			1.054

Figure 7. The street skyline and their Dr

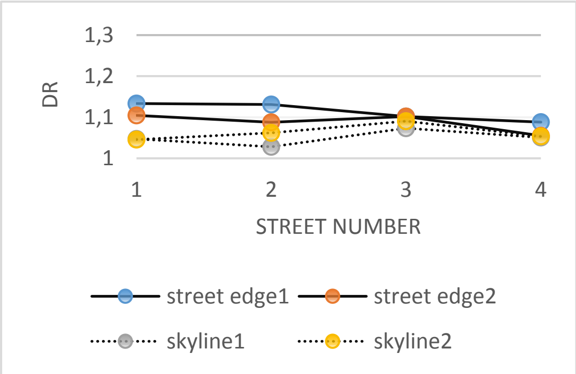


Figure 8. The relation between Dr of street edge and skyline

We can find that the Dr of the skyline does not fully correspond to the Dr of the street edge. The Dr of the skyline cannot distinguish the four totally different street views. We need a more accurate tool to present the details of each street view.

Actually, the street edge is similar to the function graph of the distance between the viewer and the buildings along the street. Clearly, this street edge does not include the information of the height and the width, which is important visually. According to the previous research, the best way to turn 3D into 2D isovist is to project the volume into the viewsphere and then project to the

2D plane. So we draw the function graph of the cosine value of the height angle relative to the viewpoint height along the street. This has two advantages: first, we do not have to consider how to draw the street edge; second, this function graph considers the vision of the street wall height and the street width. In this case, we select the radius of 50m. Then, we measure the Dr of these function graphs.

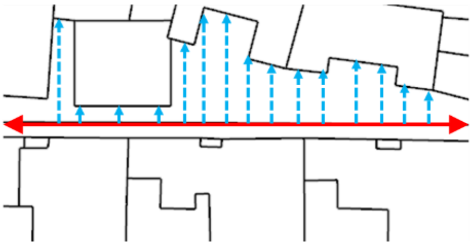


Figure 9. The distance between viewpoint and street edge

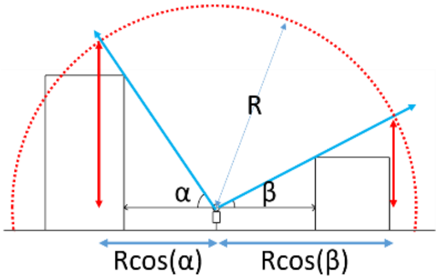


Figure 10. The projection of skyline to the 2D plane

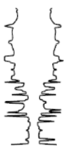
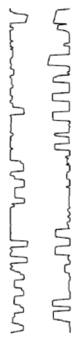
No.1 Street	Dr	No.2 Street	Dr	No.3 Street	Dr	No.4 Street	Dr
	1.2646 R^2=0.995		1.1964 R^2=0.997		1.1689 R^2=0.996		1.0603 R^2=0.999
	1.3097 R^2=0.995		1.2119 R^2=0.993		1.1840 R^2=0.995		1.0343 R^2=0.999

Figure 11. The Dr of the projected skyline

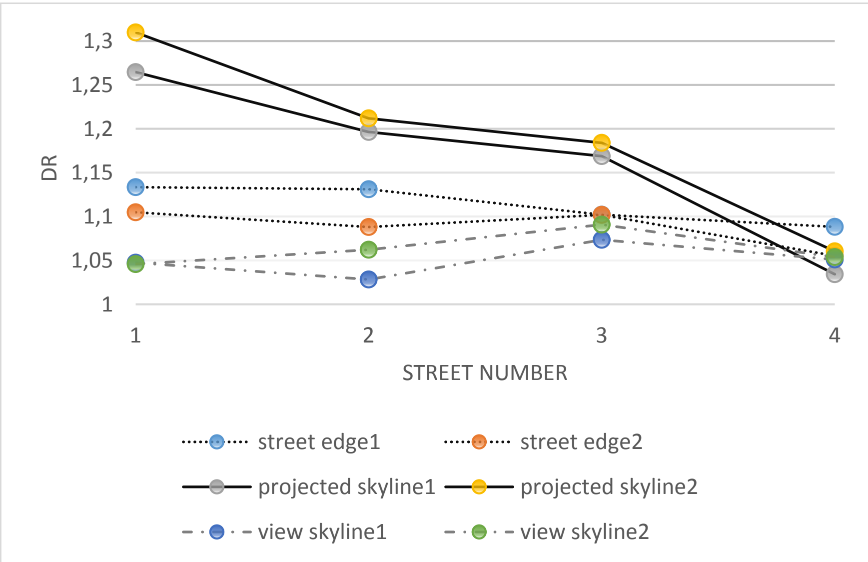


Figure 12. The Dr of the projected skyline

Relatively, the projected skyline is better than the street edge to distinguish the different types of street. However, it cannot correspond to the street view. Mathematically, there are many possibilities resulting in the variety of the street edge and the skyline, but the fractal dimension does not give these possibilities as it is only a number between 1 and 2.

In order to find the relationship between the Dr and the street form, we use the viewsphere tool to find the way both showing the synthetic variety and the details.

Viewsphere and SVF

We also use the Grasshopper in Rhino as the platform to measure the 3D isovist. Batty (2003) has found some geometric characteristics of the 2D isovist like an average distance, a maximum distance, an area, a perimeter, a compactness ratio, and a cluster ratio. His research inspired us to go further to find the geometric charateristics of the 3D isovist. We use the viewsphere with the radius of 200 meters to project the volumes and the sky to the sphere then project the curve to the plane-just like the fisheye photo.

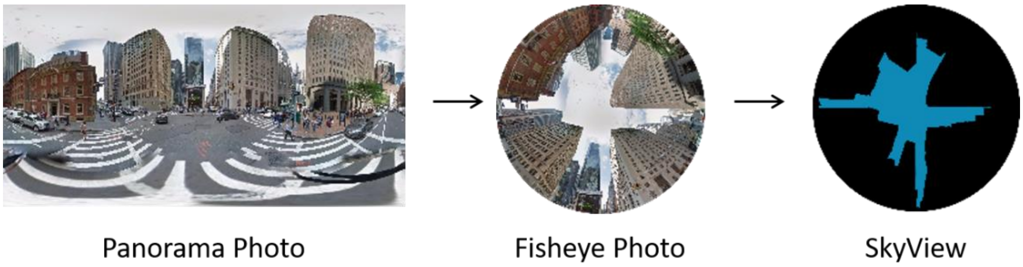


Figure 13. the conversion of panorama and fisheye photo

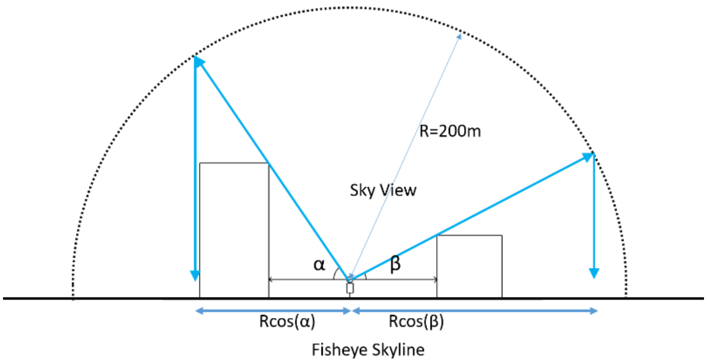


Figure 14. The viewsphere and the projection of volumes

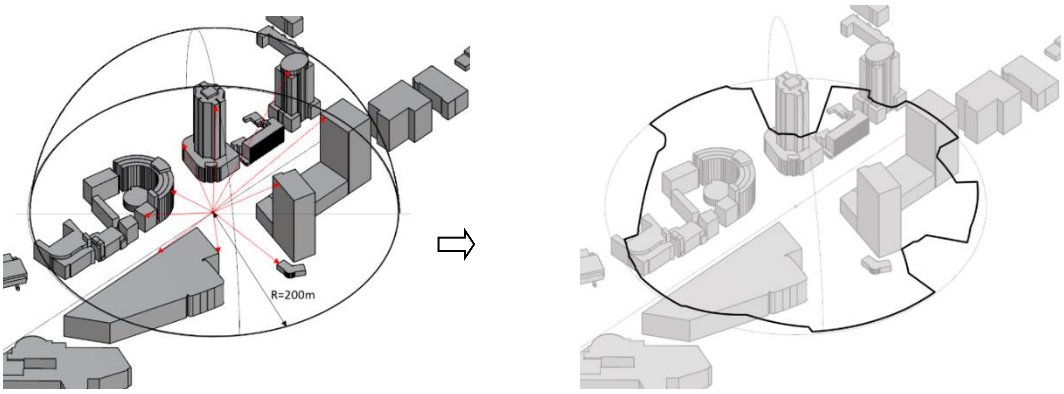


Figure 15. The conversion from the model to the sky view curve

This proved that we can get the sky view curve either by the panorama in Google Map or by the programing a computer model. In this paper, we choose the second way to correspond to the previous fractal analysis.

Although we can get the data by setting continuous viewpoints in the streets, we need to know the biggest distance between each point so that we can set least points to get full information. Through setting viewpoints every 20 meters, we calculate the biggest number of continuous viewpoints (N) a building can be seen from. If we do not want to lose the information of one building, then the distance should be at most 20*N meters. In this paper, the radius of viewsphere is 200 meters.

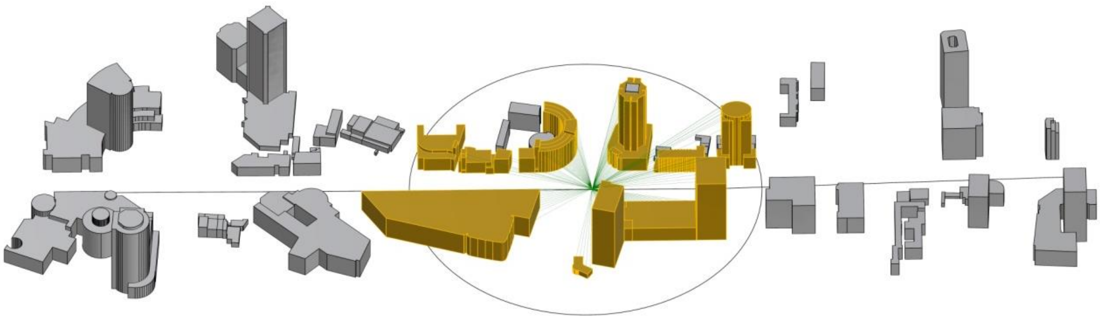


Figure 16. The buildings seen from the viewpoint

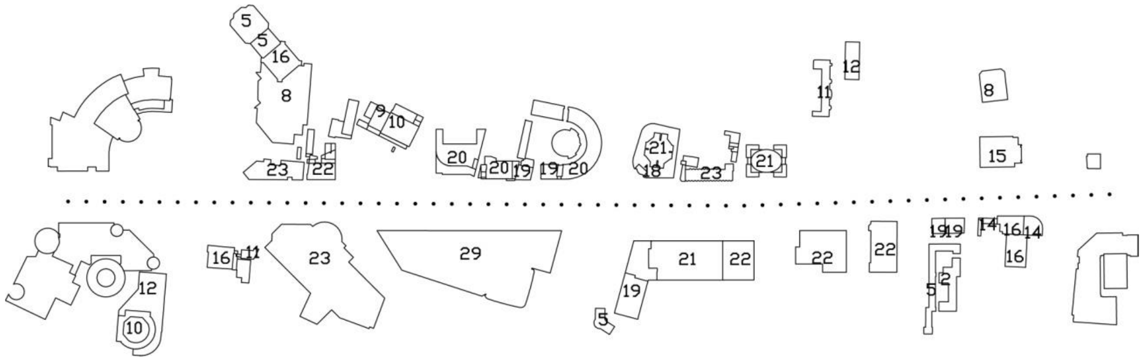


Figure 17. The viewpoints every 20 meters and the biggest number of continuous viewpoints (N) a building can be seen from

From the experiment we can see that the N is effected by the size and height of the building, the distance to the street and the relations with the other buildings. Based on this, the distance of viewpoints depends on how many buildings we want to include. In this case, if we only need to include the buildings close to the street, the distance between each viewpoint should be at most 18*20=360 meters. However, if we want to include every building in Figure 16, the distance should be at most 5*20=100 meters.

This paper finds a way to calculate the viewing time of each building along the street, which means the visual importance of each building. The distance of viewpoints can also be estimated by this way. Due to the limited time, we have not compared different streets and do further research.

The sky view curve is a closed curve just like the isovist curve, so it clearly has many geometric indices which represent the spatial characteristics. Taking the sky view curve above as an example, we set a view point at the eye height of 1.65m, and set N=360 sight lines from the point. After being projected to the viewsphere with radius of 200 meters, the sky view curve is constructed by 360 projected sight lines with the length of r=Rcos(α). Then we can measure the following geometric indices.

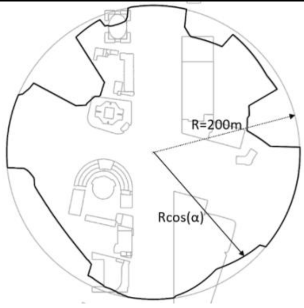
The Sky View Curve	Sign	Formula	Meaning	Value
	S	S(sky view area)/Π $*R^2$	The relative area to the standard circle	0.8202
	P	P(sky view perimeter)/2*Π*R	The relative perimeter to the standard circle	1.1808
	C	P^2/S	The degree of the curve similar to the round	1.6999
	L	$\frac{1}{R*N}*\sum_1^N r$	The average relative radius of the sky view curve	0.8972

Figure 18. The four basic indices of the sky view curve

In order to detect the mutation of the curve that means the border in the sky view, we measure the difference of the 360 projected sight lines and map them on the plane:

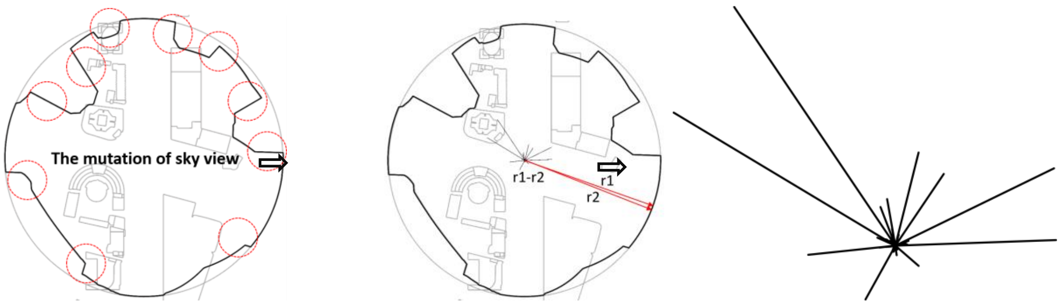


Figure 19. Measuring the difference between each two neighboring lines

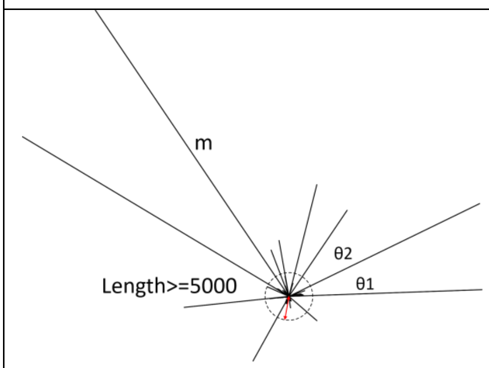
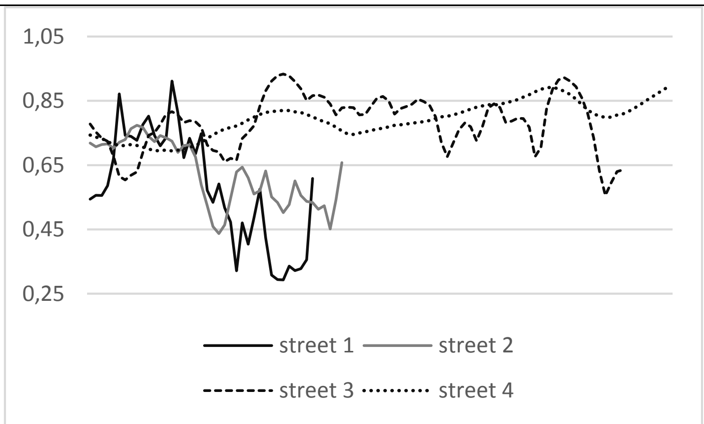
The difference between each two neighboring lines	Sign	Formula	Meaning	Value
	Nm	Number of lines>=5000	Number of the mutations	11
	Sd	$\frac{1}{R}*\sum_1^N m$	The sum of the degree of every difference	2.6773
	Dm	$\sqrt{\sum_{i=1}^{Nm}(\theta_i-\bar{\theta})^2}$	The dispersion of the mutations	18.859

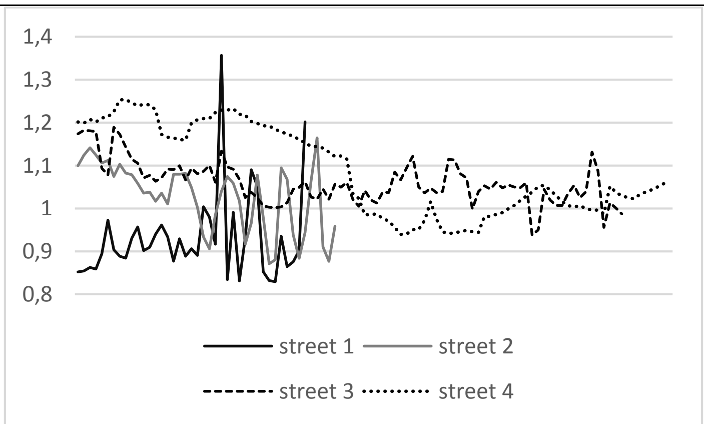
Figure 20. The three indices describing the mutations

Here we have 7 indices describing the sky view curve, then we apply them to the four different streets above. One cannot feel the street by only one viewpoint, so we need continuous viewpoints along the route. We set viewpoints at every 6 meters. The continuous indices are presented in 7 function graphs.

<table>
<tr><th>Street</th><th>The function of S</th><th>Average</th><th>R^2</th></tr>
<tr><td>1</td><td rowspan="4">


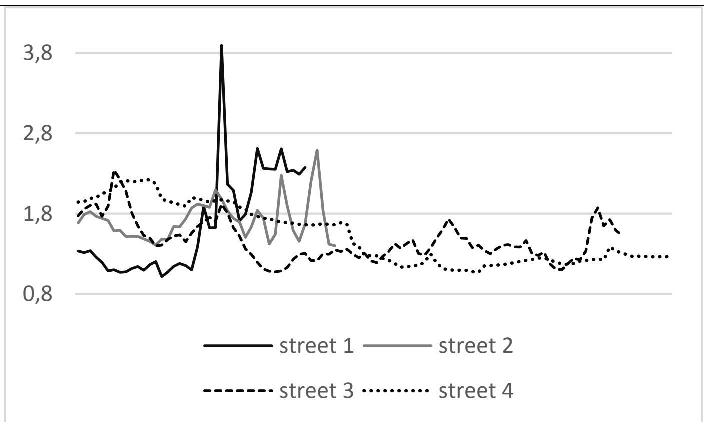
</td><td>0.577932</td><td>0.030786</td></tr>
<tr><td>2</td><td>0.624134</td><td>0.009885</td></tr>
<tr><td>3</td><td>0.782625</td><td>0.007581</td></tr>
<tr><td>4</td><td>0.79148</td><td>0.003017</td></tr>
</table>

Figure 21. The relative area to the standard circle along the street

<table>
<tr><th>Street</th><th>The function of P</th><th>Average</th><th>R^2</th></tr>
<tr><td>1</td><td rowspan="4">


</td><td>0.930198</td><td>0.010253</td></tr>
<tr><td>2</td><td>1.02591</td><td>0.00621</td></tr>
<tr><td>3</td><td>1.059689</td><td>0.002507</td></tr>
<tr><td>4</td><td>1.088304</td><td>0.010729</td></tr>
</table>

Figure 22. The relative perimeter to the standard circle along the street

<table>
<tr><th>Street</th><th>The function of C</th><th>Average</th><th>R^2</th></tr>
<tr><td>1</td><td rowspan="4">


</td><td>1.665827</td><td>0.410185</td></tr>
<tr><td>2</td><td>1.714711</td><td>0.061016</td></tr>
<tr><td>3</td><td>1.46204</td><td>0.066291</td></tr>
<tr><td>4</td><td>1.529363</td><td>0.136257</td></tr>
</table>

Figure 23. The degree of the curve similar to the round along the street

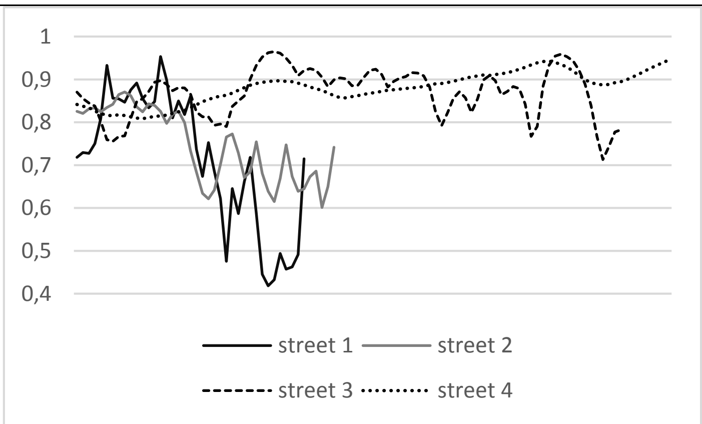
Street	The function of L	Average	R^2
1		0.712377	0.02444
2		0.747115	0.00704
3		0.868864	0.003308
4		0.879409	0.001376

Figure 24. The average relative radius of the sky view curve along the street

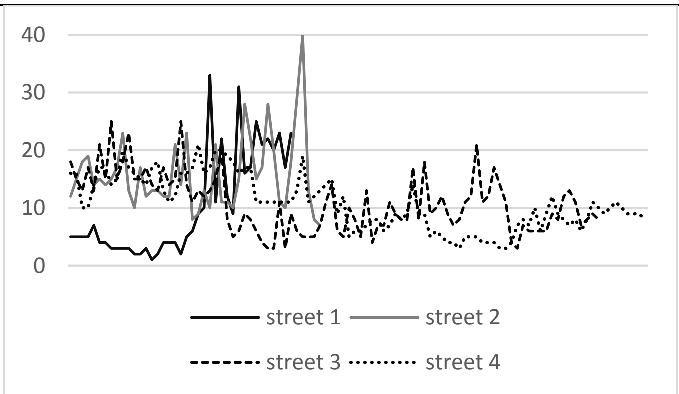
Street	The function of Nm	Average	R^2
1		10.333333	79.247863
2		15.818182	42.14876
3		10.815217	25.715855
4		10.83	21.9211

Figure 25. Number of the mutations along the street

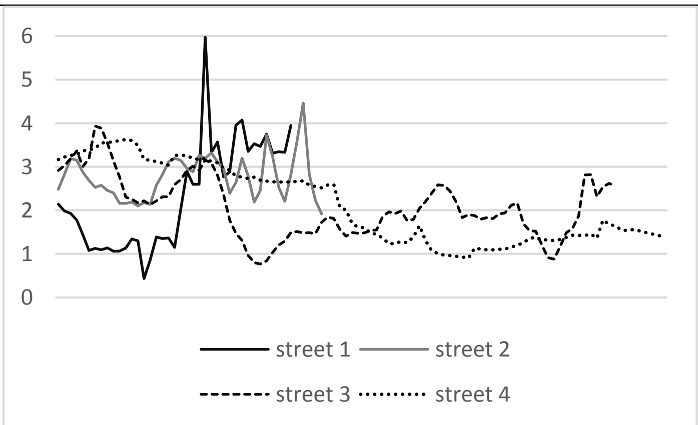
Street	The function of Sd	Average	R^2
1		2.329611	1.486007
2		2.769627	0.256768
3		2.071824	0.50073
4		2.134576	0.800291

Figure 26. The sum of the degree of every difference along the street

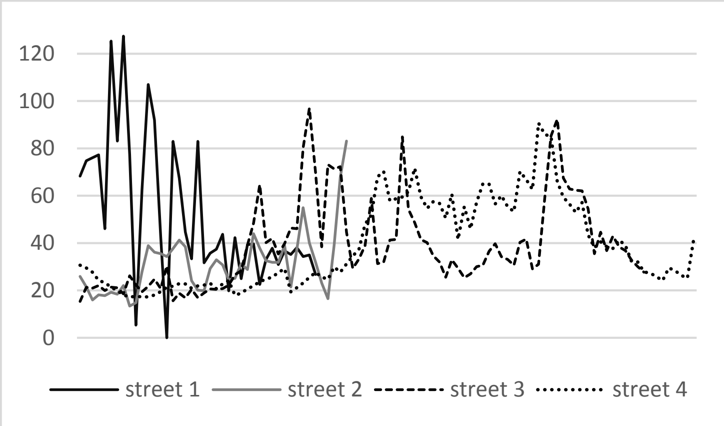
Street	The function of Dm	Average	R^2
1		51.829339	870.333282
2		31.276208	177.899885
3		38.606308	344.806094
4		38.775633	345.261446

Figure 27. The dispersion of the mutations along the street

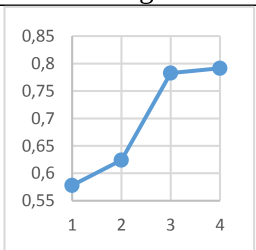
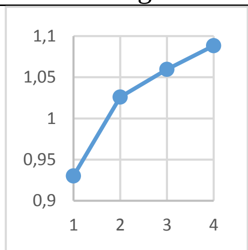
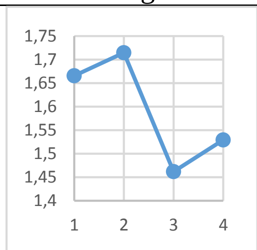
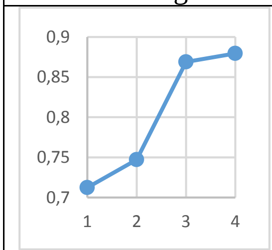
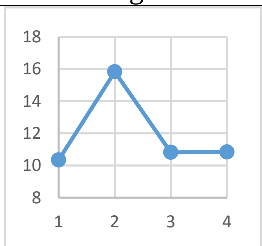
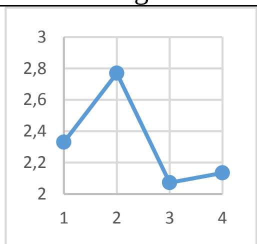
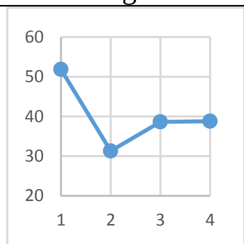
	Average S	Average P	Average C
			
Average L	Average Nm	Average Sd	Average Dm
			

Figure 28. The comparison of the average index value

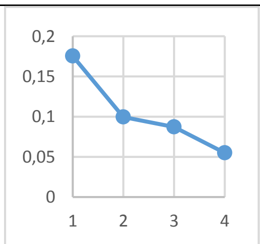
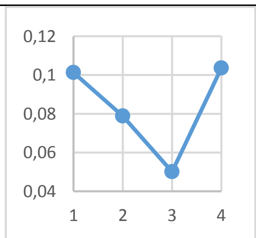
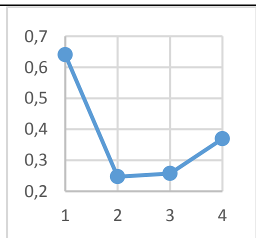
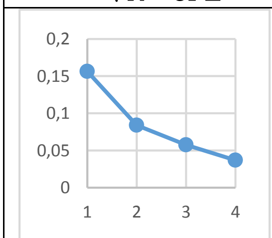
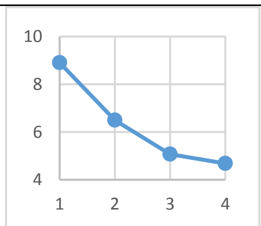
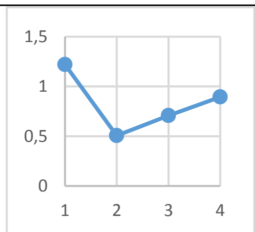
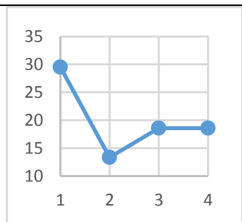
	$\sqrt{R^2}$ of S	$\sqrt{R^2}$ of P	$\sqrt{R^2}$ of C
			
$\sqrt{R^2}$ of L	$\sqrt{R^2}$ of Nm	$\sqrt{R^2}$ of Sd	$\sqrt{R^2}$ of Dm
			

Figure 29. The comparison of the standard deviation of each index value

There are geometric meanings behind these indices. The standard deviation shows the jitter degree of the index along the street. The area of the sky view means the space openness, so it gradually increases from the historical street to the commercial street. The deviation of the area (S) is consistent with the fractal dimension of the projected skyline within these four streets, which means the fractal dimension can be shown from the sky view analysis.

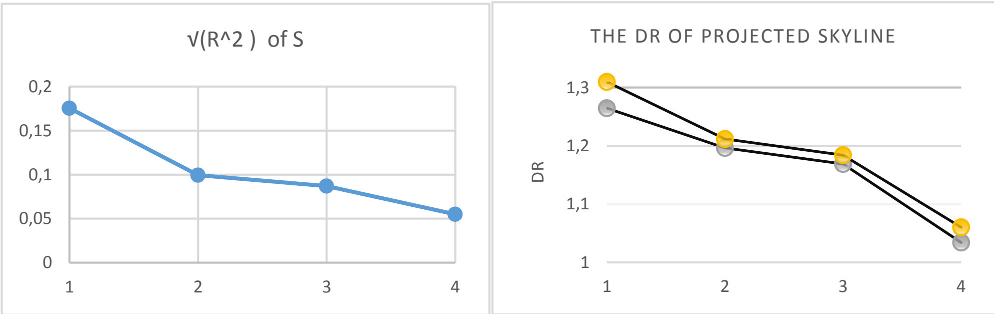


Figure 30. The comparison of the standard deviation of each index value

As it is presented above, the fractal dimension is just one of many characteristics of the sky view curve. Surely, there are more correlation of these indices with the street space and the block texture. For example, the second street is mixed with old buildings and residential buildings, so its average Nm (number of the sky view mutations) and the average Sd (The sum of the degree of every sky view sight line difference) are bigger than any other streets. This suggests that the second street has more visual stimuli because of the texture mixture. Meanwhile, we find that the $\sqrt{R^2}$ of P (a standard deviation of the relative sky view perimeter) corresponds to the regularity of the block texture, as the third street has more regular texture comparing to the residential buildings. However, we need more samples and experiments to prove the correlation.

Conclusion

Following Cooper's research, this paper further develops the fractal analysis and finds the limitation of the fractal dimension to represent the spatial characteristics. With the samples of four typical streets in Nanjing, we introduce the fractal skyline analysis to avoid the discontinuous edge and to include the height of the street walls and the street width. It can distinguish these different streets, but it cannot go deeper to be directly related to the street space.

To find the geometric reason of the fractal dimension, we use the Viewsphere to generate the projected Skyview and try to discover the correlation between the indices of the sky view curve and the street's characteristics. The experiment proves the feasibility of sky view analysis to characterize the space. The fractal dimension is just one of many features inside the continuous sky view along the street.

This paper also finds a way to calculate the viewing time of each building along the street and estimate the largest distance between each viewpoint selected.

Acknowledgement

This study was financially supported by National Science Foundation of China (No.51538005).

References

1. Benedict, M. L. *To take hold of space: isovists and isovist fields*[J]. Environment and Planning B: Planning and Design, 1979, 6: 47-65
2. Batty, M, *Exploring Isovist Fields: Space And Shape In Architectural And Urban Morphology*[J], Environment and Planning B: Planning and Design 28, 2001

3. Turner, A., Ratti, C., Richens, P., *From Isovists To Visibility Graphs[J]*, Environment and Planning B: Planning and Design 28, pages 103 ^ 121 ; 2001
4. Teller. J., A *Spherical Metric For The Field-Oriented Analysis Of Complex Urban Open Spaces[J]*, Environment and Planning B: Planning and Design 2003, volume 30, pages 339- 356
5. Fisher – Gewirtzman, D. etc., *A 3-D visual method for comparative evaluation of dense built-up environments[J],* Environment and Planning B: Planning and Design-575-587, 2003
6. Fisher – Gewirtzman, D. , etc., *View-oriented three-dimensional visual analysis models[*J], Urban Design international10,23-37, 2005
7. Yang, P. P., Putra, S. Y., Chaerani, M. *Computing the sense of time in urban physical environment* [J]. Urban Design International, 2007(12): 115-129.
8. Yang, P. P., Putra, S. Y., Wenjing, L.. *Viewsphere a GIS-based 3D visibility analysis for urban design evaluation 10.1.1.88.3190[J*]. Environment and Planning B: Planning and Design, 2007, 34: 971-994.
9. Yang, P. P., Putra, S. Y., Chaerani, M. *Computing the sense of time in urban physical environment* [J]. Urban Design International, 2007(12): 115-129.
10. Mandelbrot, B. (1977) *The fractal geometry of nature* (Freeman, New York).
11. Cooper, J.C. (2003) '*Fractal assessment of streetlevel skylines – a possible means of assessing and comparing character*', Urban Morphology 7, 73-82.
12. Cooper, J.C., Oskrochi, R. *Fractal analysis of street vistas:a potential tool for assessing levels of visual variety in everyday street scenes[J]*. Environment and Planning B: Planning and Design, 2008, 35: 349-363.
13. Cooper, J. *Assessing urban character: the use of fractal analysis of street edges[J*]. Urban Morphology, 2008, 9(2): 95-107