UDC 711

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A QUANTITATIVE APPROACH MEASURING STREETSCAPE

Abstract: *Since 1960s, Kevin Lynch had raised the importance of people's perception of urban space, as the part of it, the role of street spaces became very important, so did the streetscape in the research and design aspects. Usually photo pictures or street perspective drawings are used to indicate the streetscape for studying, which means that three-dimensional street space has to turn into a two-dimensional object. For this reason many researches have tried to study photo pictures or street perspective drawings for developing a spatial measuring tool, our work belongs to this field. The previous study has shown that street widths and heights of side buildings could be evaluated based upon a streetscape image or a perspective drawing, however, there are questions needed to answer. If a street photo reflects streetscape of human's view experience, how perspective drawings can refer to the relevant street photo? What are the regularities between a street width, a building height, its position and lines of a drawing? And how we should judge if the height of an object in perspective refers to the real height of the building in the city. All those questions are worthwhile to be studied for urban design. This research has tried to develop a method or a tool for measuring urban street spaces based upon the street perspective drawings. Various street experimental digital models have been built according to the urban regulations and 2D measurement scales have been established simultaneously for measuring and a statistical analysis. Through the statistical analysis we have found the answer, and then a measuring tool has been made. Finally, we have validated the tool by testing a real street view, the results will be discussed. This experiment successfully shows the possibility of street space measurement by using 2D perspective drawing, which is a useful tool for architects and urban designers.*
Keywords: *Streetscape, street space, quantitative approach, urban design.*

1. Introduction

Streets are an important part in urban morphology (Conzen,1969), they are also the main aspect of people's perception of the city, streets space are the most widely distributed urban public space, carrying most of people's daily activities. In the 1960s, Kevin Lynch proposed the important role of street space in people's perception of the city, on the macro level, streets space give people a clear urban structure, and on the micro level, a subtle part of the street will leave a deep impression on people (Kevin Lynch,1960). Jacobs believed that rich street life was the root of urban vitality, small-scale blocks and various small shops along the street increase people's chances of communication, and at the same time the small shops as the Street Eyes ensure the security of the street space (Jacobs,1961). Yoshinobu Ashihara proposed the creation of the street visual order should be the starting point for designing a building's plane and classification, components, proportions and a scale of streets will have great influence on people's feelings, for example, when the ratio of the street width to the building height is more than one it will make people feel far away, but when the ratio is less than one it will make people feel close, when the ratio is equal to one, the street will give people a well-balanced feeling. (Yoshinobu,1979).

Although people's perception of the city is based on the human scale, planners and architects tend to design with overlooked perspectives. The lack of consideration of people's street perception results in the scale when the street space does not conform to the human scale and the street is not attractive to people. Therefore, it is necessary to study the regularities of streetscape and quantify the streetscape making it connect to the plane scale, and then it will help designers and architects to design streetscapes accurately and quickly while designing the plane and creative a livable street.

2. A review of quantitative approaches of studying streetscape

Since 1960s, Kevin Lynch has put forward an approach that can be descriptive to people's perception of urban space, after that many researchers have made many attempts to the quantitative study of people's perception of urban space, as the part of it, the role of the street spaces became very important, so did the streetscape in the research and design aspects.

Sergio Porta and John Luciano Renne (2005) studied sustainable development indicators by streetscape. They established eight street evaluation indicators, a sky exposure, facad continuity, softness, a social width, visual complexity, number of buildings, sedibility and detractors to evaluate the livability of a street space. Through field research and observation they got photos of urban streets. They dealt with those photos with AutoCAD to get the levels of streets evaluation indicators. Finally, they graphically showed the evaluation results on the plane. Cooper and Oskrochi (2008) sought to develop the use of fractal-analysis techniques in evaluating visual variety in everyday street vistas and identified a positive correlation between levels of fractal dimension and levels of visual variety as judged by urban-design experts. Cooper and Watkinson (2010) continued the work begun by Cooper and Oskrochi to address the issues of preference or evaluations of overall quality. Reid Ewing and Otto Clemente attempted to measure subjective properties of the urban streets perceptual qualities comprehensively and objectively, they put forward 51 indicators of perceptual qualities, eight of those were selected for the measurement: imageability, enclosure, human scale, transparency, complexity, legibility, linkage and coherence. They collected data by video clips of commercial streets, the video clips needed had the same experience of people's walking. Then they made operational definitions of urban design qualities based on ratings by experts' panel of these video clips. (Ewing and Handy2009; Ewing and Cervero 2010; Ewing and Clemente 2013). Wowo Ding (2011) studied the influence of speed on people's perception of street space by moving imaging. By decomposing a moving image, each frame image was extracted, from which she could get the width and height of the street by frame section. A series of width and height were draw into the 't-x' coordinates for mapping urban streets spatial patterns at different speeds. Tao Liu (2011) continued the work begun by Ding, he studied the visual range of people on streetscape and defined the middle position of the best view is the frame section. Also he attempted to vector the image and extract the width and height from the image by processing. Zhouyan Wu (2014) studied the effect of variety of heights of the buildings and widths of the streets on the streetscape images to develop a graphic tool like a ruler relating a perspective drawing to plan.

When we tried to apply those approaches to urban design, we found that the approaches given by Sergio Porta and John Luciano Renne and Reid Ewing Otto Clemente all answer the question what contributes to livable streetscape, rather than made the physical connection between street configuration and pattern. Cooper and Oskrochi's fractal analysis method can only evaluate the overall variety of streetscape, but it can't guide a specific design. Although Ding and Liu combined the perception of street space with specific street location, the visibility of the streetscape and the frame section are still needed to be discussed. Wu's study talked about the rules between perspective drawings and street widths and buildings heights, but the rules need to be further explored, and the graphic ruler she developed is difficult to use. Based on the work begun by Ding and Liu and Wu, this paper is doing further research of the rules in streetscape images, so those rules could really guide urban design.

3. Method

Since the Renaissance, artists and architects have begun to use the perspective method to study three-dimensional objects and spaces. They projected three-dimensional space onto a two-dimensional plane to express the three-dimensional space. The two-dimensional perspective is the visual presentation of three-dimensional space and contains the same spatial information. Hence the street perspective drawings and photos are usually used to indicate the streetscape for studying.

In the human scale, street spaces are defined by the size and arrangement of large objects such as buildings (Harvey and Aultman Hall, 2016), people's perception on streetscapes is most sensitive to the moving objects and the vertical objects (Yang et al. 2007), so we can develop digital models in computer to simulate the overall characteristics of the streetscape, based on perspective drawings derived by these digital models, we attempted to develop a method or a tool for measuring urban street spaces.

Figure 1. Dürer's Perspective Machine (Source from Albert Perez-Gomez. Architecture Representation and the Perspective Hinge [M]. Boston: The MIT Press. 2000)

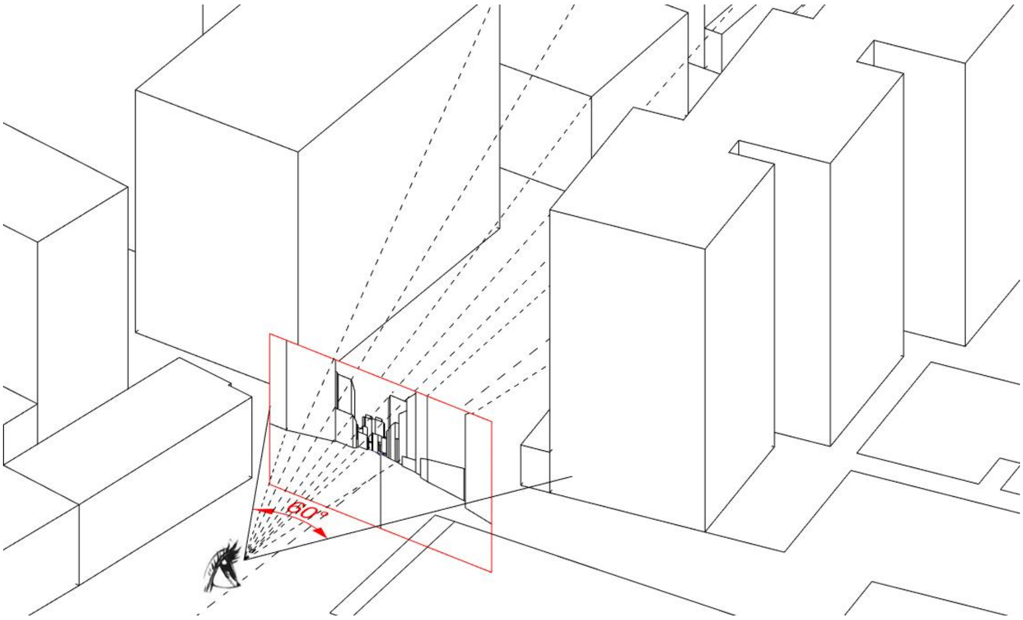


Figure 2. Two-dimensional perspective drawings are used to express three-dimensional space

In order to make the frame of the perspective drawings derived by these digital models match that of the streetscape perceived by people, we need to make it clear that the perceived viewing range of people and then set the frame of the perspective drawings. Usually, the streetscape photos are used to indicate the street view seen by a human eye, the eye height is 1.6m and the normal viewing angle for left and right eyes is 60° (Hu, 2009; Liu, 2011; Wu, 2014). The viewing angle of a photo is affected by the camera's focal length and camera's frame. When the focal length of the camera is

35mm and the frame is FX format, the viewing angle of the photo is similar to visual field of people. The camera model we used in this experiment is NIKON D5100, which is a DX format camera and zoom camera, we need to cut out the frame matching the visual field of people of 60°. The aspect ratio of the frame is consistent with that of the photo which is 3:2.

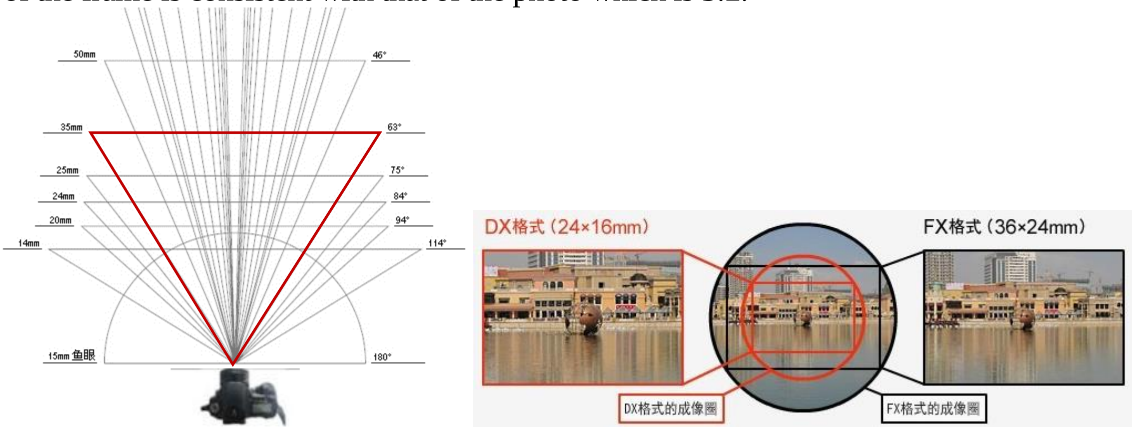


Figure 3. Viewing angle of photo is affected by the camera's focal length and camera’s frame. ((a)source from https://zhidao.baidu.com/question/1821986652365632108.html, (b) source from blog.163.com/xiayu_0629)

The relationship between the camera's focal length and viewing angle. (b) the camera’s frame usually has two specifications and the aspect ratios are all 3:2.

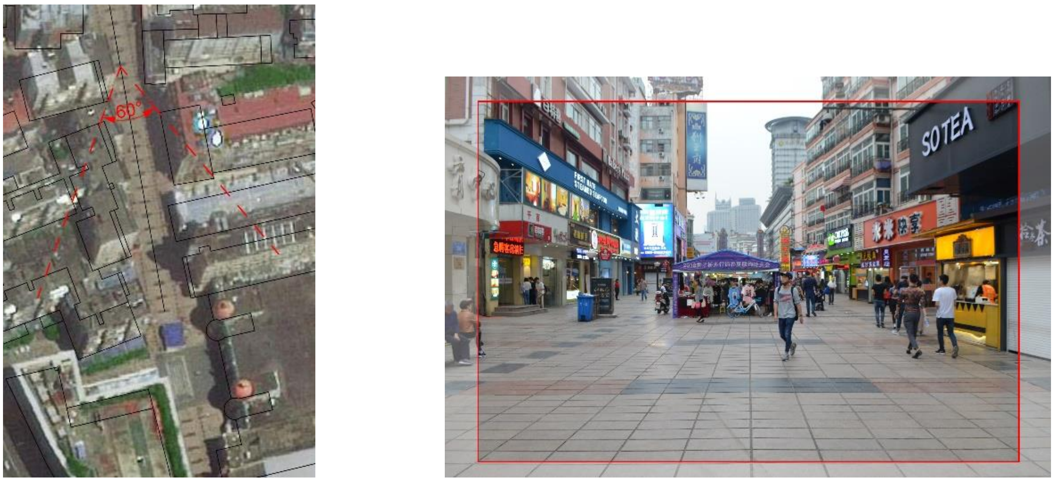


Figure 4. the viewing angle and frame of the photo and people (the satellite imagery in (a) is from www.baidu.map.com). The range of people’s vision (b) the red line represents the boundary that people can normally see

In order to make the perspective drawings match the photos, the height of the camera in a digital model should be 1.6m and the visual angle of the camera should be 60°, the frame should be the same as that of the photo, the aspect ratio is 2/3. As the frame of the perspective drawings derived by digital models is limited by the screen size of the computer, we had to set the focal length to 25mm to expand the frame and then cut out the full-frame of 35mm focal length (the viewing angle is 60°) from it.

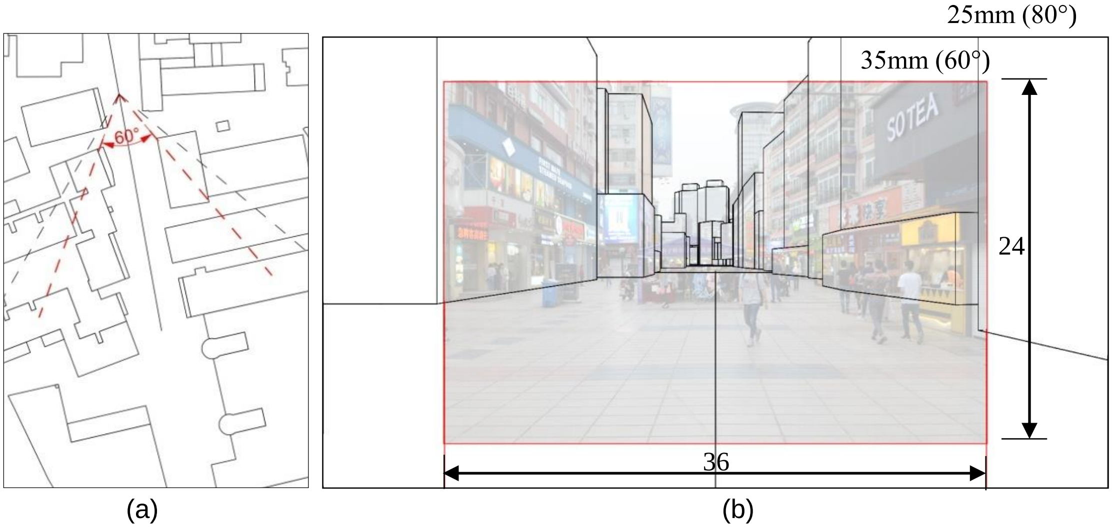


Figure 5. (a) The range of people's vision and the camera of 25mm focal length;
(b) cut out the full-frame of 60° viewing angle from the frame of 25mm focal length

According to the visibility of the architectural skyline in the Streetscape images, the height of the building can be further divided into the visual height and the real height (Wowo Ding, 2011), which will mainly affect the overall characteristics of the streetscape in the human scale.

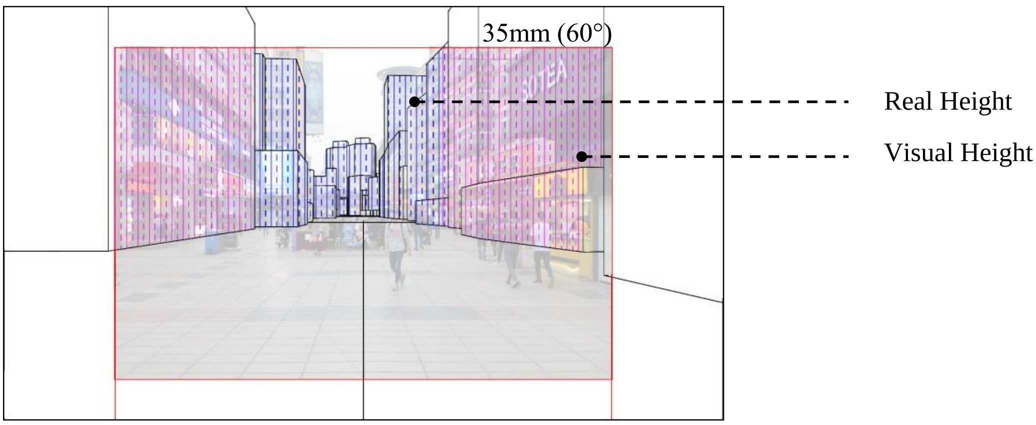


Figure 6. The real height and visual height of the perspective drawing

In the following experiment, we will study the relationship between the characteristic of the real height of each image and the width of the street (2W) and the height of the building (H) and the depth of the building (R), in addition, the distance required from the viewpoint to the visual area for the building to enter the perspectives (N) will be studied.

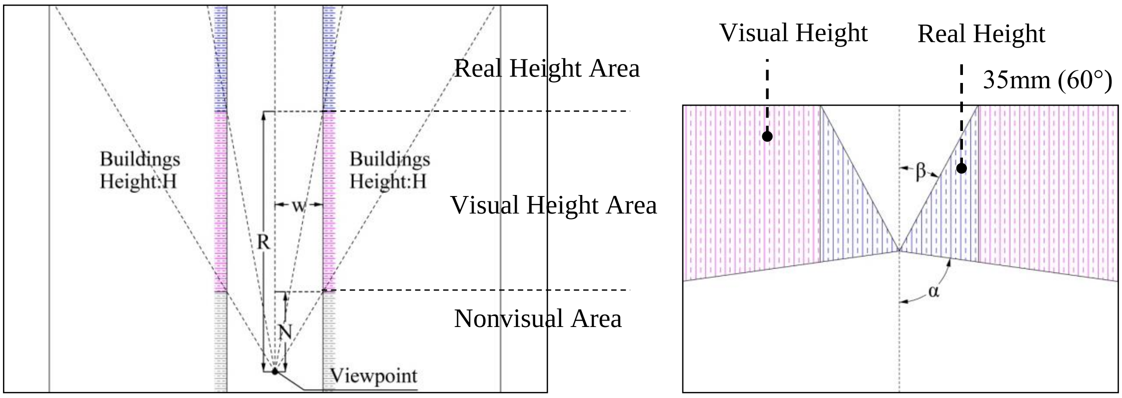


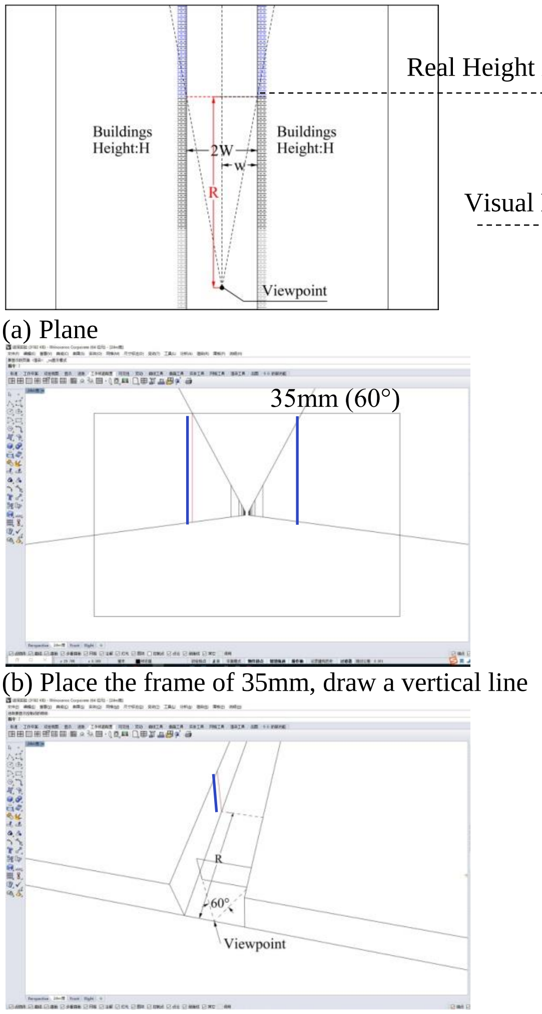
Figure 7. The name of the configurations of street space.

4. Experiment

In order to study what are the regularities between lines of perspective drawings and variety of street widths, building heights, positions and judge the height of an object in the perspective refers to the real height of the building in the city, a series of an ideal street models have been developed in Rhino.

4.1. H-N, W-N; H-R, W-R experiment

In this experiment, we have developed a few groups of models with the same street width but different building height. The first group of models has been set up with the street width of 4m, the building height of 3m, 6m, 9m, …, 99m respectively; the second group of models have been set up with the street width of 8m, the building height of 3m, 6m, 9m, …, 99m respectively, the third group of models have been set up with the street width of12m, the building height of 3m, 6m, 9m, …, 99m respectively, following this rule until the street width increases up to 100m. And then we have measured the R and N values in each model. To measure the R value we have needed to place the full frame of 35mm in each model (Fig.8(b)), then to draw a vertical line at the intersection of the skyline and the frame (Fig.8(b)), and then to measure the distance from the observation to the vertical line in the model (Fig.8(c)), measuring N has been the same as measuring R. At last, we have used Excel to record the values of H and W and R and N of each model.



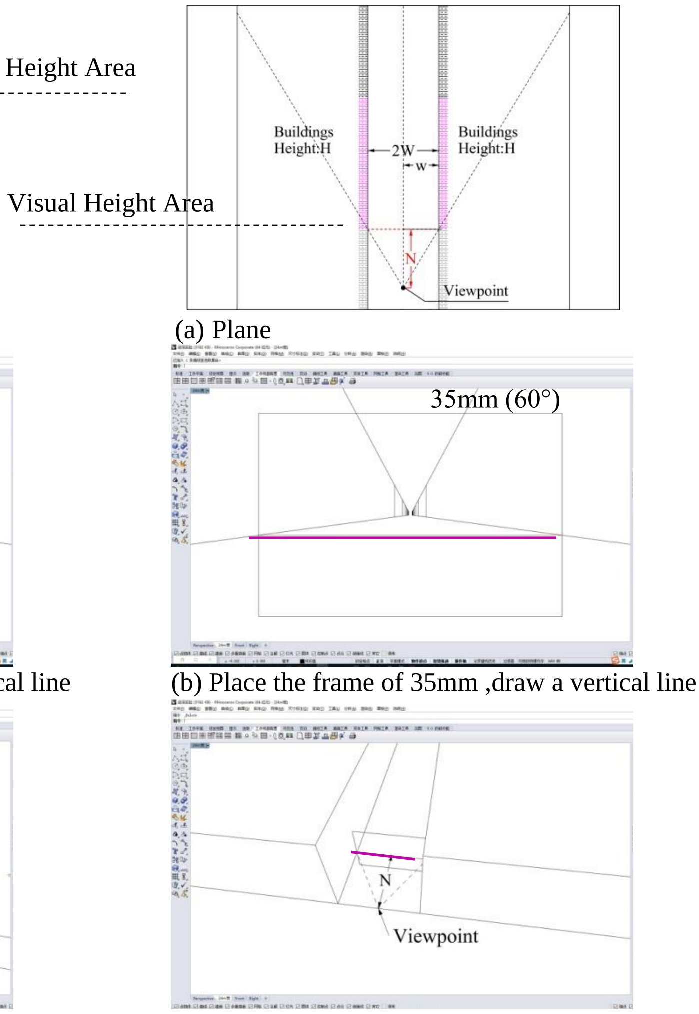


Figure 8. The method of measuring R

Figure 9. The method of measuring N

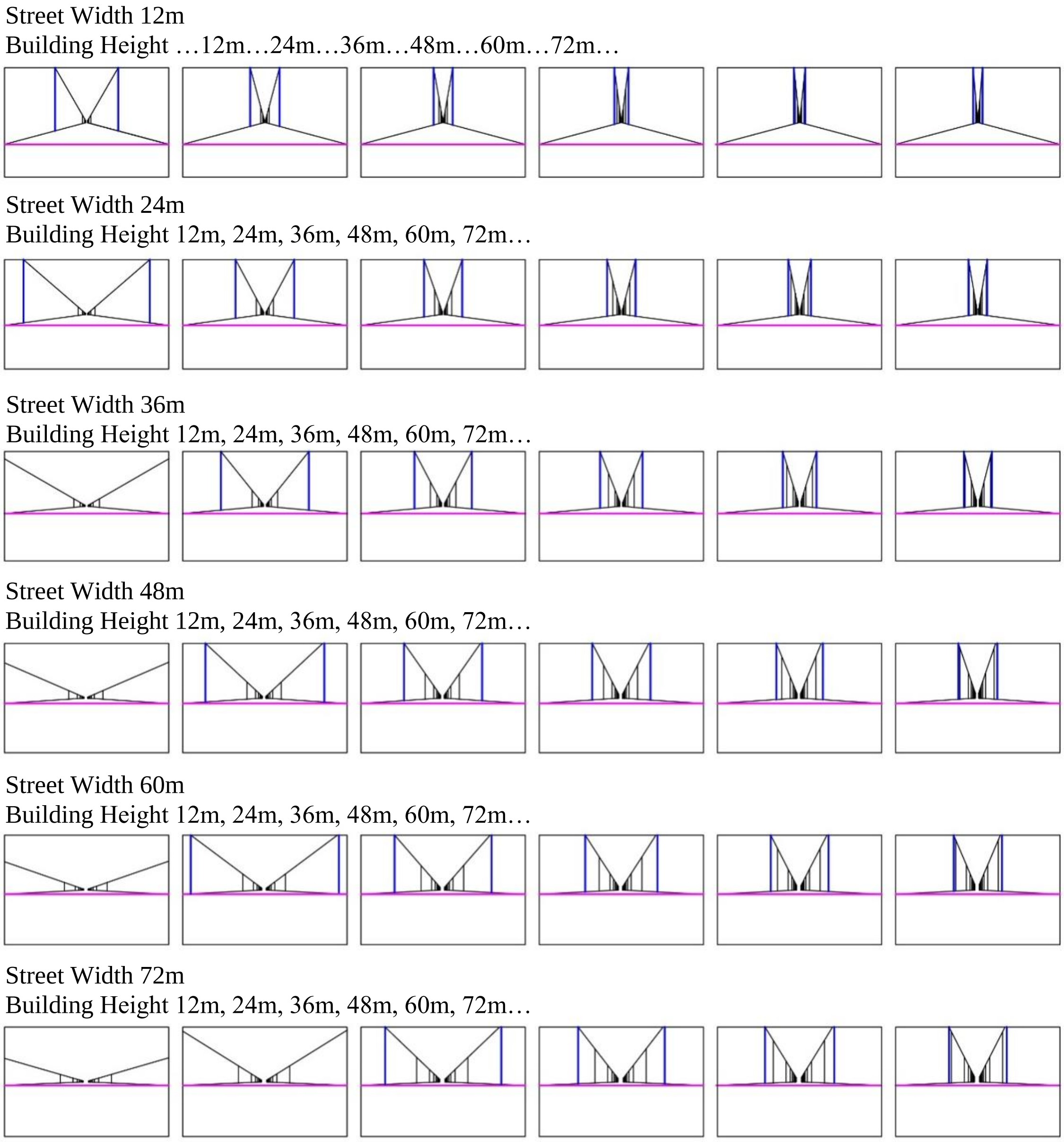


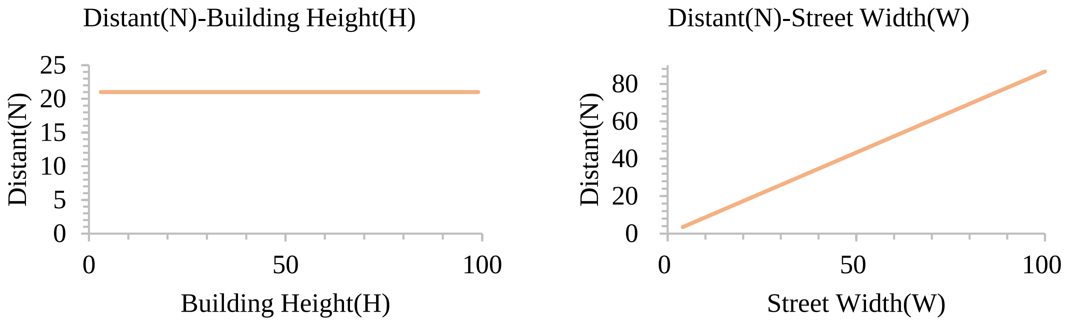
Figure 10. The perspective drawings with different street width and building height

4.2. Analysis of H-N, W-N; H-R, W-R

We have analyzed the regularities between H and W and N and displayed the results in Figure 9. We have found that the distance from the view point to a visual area (N) has not been effected by the building height but it increases gradually with the street width (W). So we have got the formula between N and W according to the result.

$$\mathbf{N=\sqrt{3}W} \qquad (1)$$

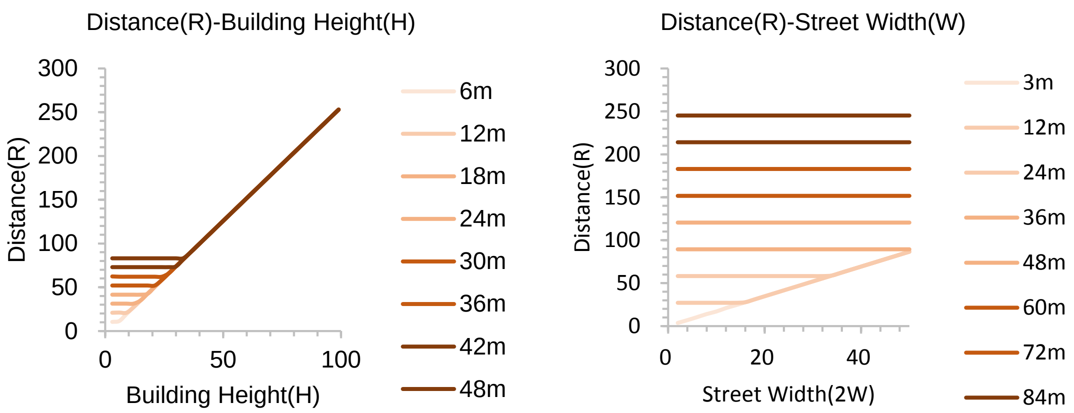
We have analyzed the regularities between H and W and R and displayed the results in Figure 10. We have found that in the case of a certain street width the distance from the view point to the real height area (R) is initially unchanged as H increases and then it increases gradually with the increases of H. This means the perspective drawings change gradually from Fig.13(a) to Figure 13(c), Figure 13(b) is the turning point.



(a) (b)

Figure 11. (a) the relationship between diatant (N) and building Height (H);
(b) the relationship between diatant (N) and street width (W)

In the case of a certain building height, when the building height is less than a certain value, the distance from the view point to the real height area (R) is initially unchanged as W increases, then it increases gradually. This means the perspective drawings change gradually from Figure14(c) to Figure 14(a), Figure 14(b) is the turning point. When the building height is more than the certain value, the R keeps unchanged as W increases, for example, the perspective drawings in Fig.8, when the building height is 60m, as the street width increases the skyline of the building never exceeds the turning point.



(a) (b)

Figure 12. (a) the relationship between diatant (R) and building Height (H);
(b) the relationship between diatant (R) and street width (W)

Here we need to describe the turning point in the drawings above and then we can draw the following formula for R and H and W. In the case of a certain street width, when the building height (H) is equal to or less than the turning point, the perspective drawings are like Fig.13(a), Fig.13(b) Fig.14(a) and Fig.14(b), this means R is equal to N, so we can get the Formula (2). When the building height (H) is more than the turning point, the perspective drawings are like Fig.13(c) and Fig.14(c), this means R is more than N, we can get the Formula (3).

In the case of a certain building height, when the street width (W) is less than the turning point, the perspective drawings are like Fig.14(c), this means R is more than N, in the meanwhile, R is only related to H, so the relationship is Formula (3). When the street width (W) is equal to or more than the turning point, the perspective drawings are like Fig.14(a), this means R is equal to N, so the relationship is Formula (2).

$$\mathbf{R=\sqrt{3}W} \tag{2}$$

$$R=\frac{3}{2}\sqrt{3}H-2.4\sqrt{3} \quad (3)$$

Here we need to discuss the value of the turning points to improve the formula application scope.

If R=N

$$\frac{3}{2}\sqrt{3}H-2.4\sqrt{3}=\sqrt{3}W$$

$$H=\frac{2}{3}W+1.6$$

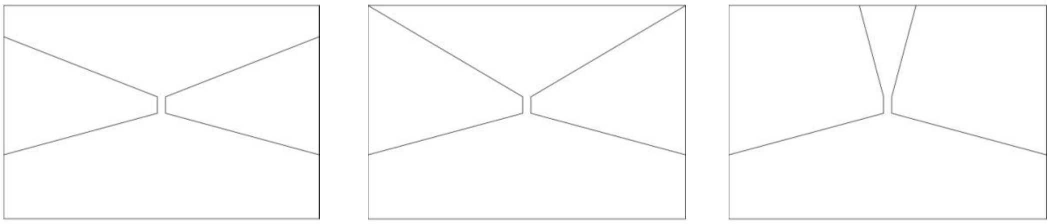
If R=N， there is another situation as shown in Fig.13(a) and Fig.14(a).

$$H<\frac{2}{3}W+1.6$$

If R>N

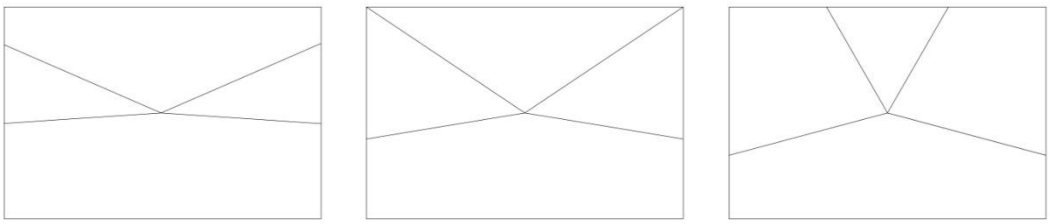
$$H>\frac{2}{3}W+1.6$$

The R is less than N according to Fig.5.



(a) H<2/3W+1.6 (b) R=N 时，H=2/3W+1.6 (c) R>N 时，H>2/3W+1.6

Figure 13. The same street width but a different building height. Streetscapes can be divided into three categories (a)broad, (b)critical state and (c)upright according to the relationship between the building height and the street width



(a) H<2/3W+1. (b) R=N 时，H=2/3W+1.6 (c) R>N 时，H>2/3W+1.6

Figure 14. The same building height but a different street width. Streetscapes can be divided into three categories (a)broad, (b)critical state and (c)upright according to the relationship between the building height and the street width

So we improve the formula as below:

When H≤2/3W+1.6

$$R=\sqrt{3}W \quad (4)$$

When H>2/3W+1.6

$$R=\frac{3}{2}\sqrt{3}H-2.4\sqrt{3} \quad (5)$$

4.3. Angles experiment

In order to find the method to judge how the height of an object in the perspective refers to the real height of the building in the city, we have made the angles experiment to study the regularities of H-α, W-α; H-β, W-β, α is the angle between the bottom boundary of the building and the centerline, β is the angle between the skyline of the building and the centerline. On the basis of the 4.2 experiment. We have calculated α and β of each model and recorded the values in Excel.

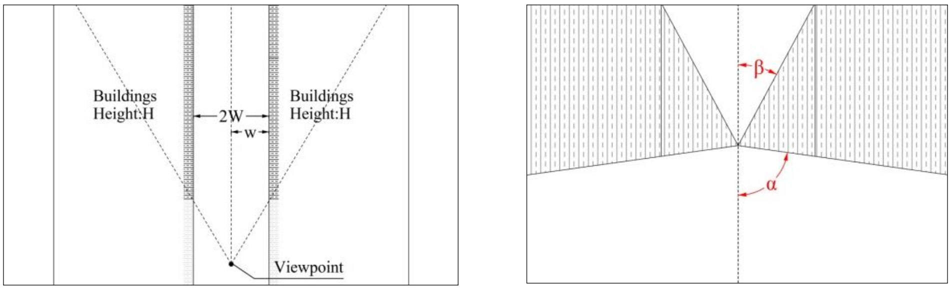


Figure 15. The defination of angle α and angle β

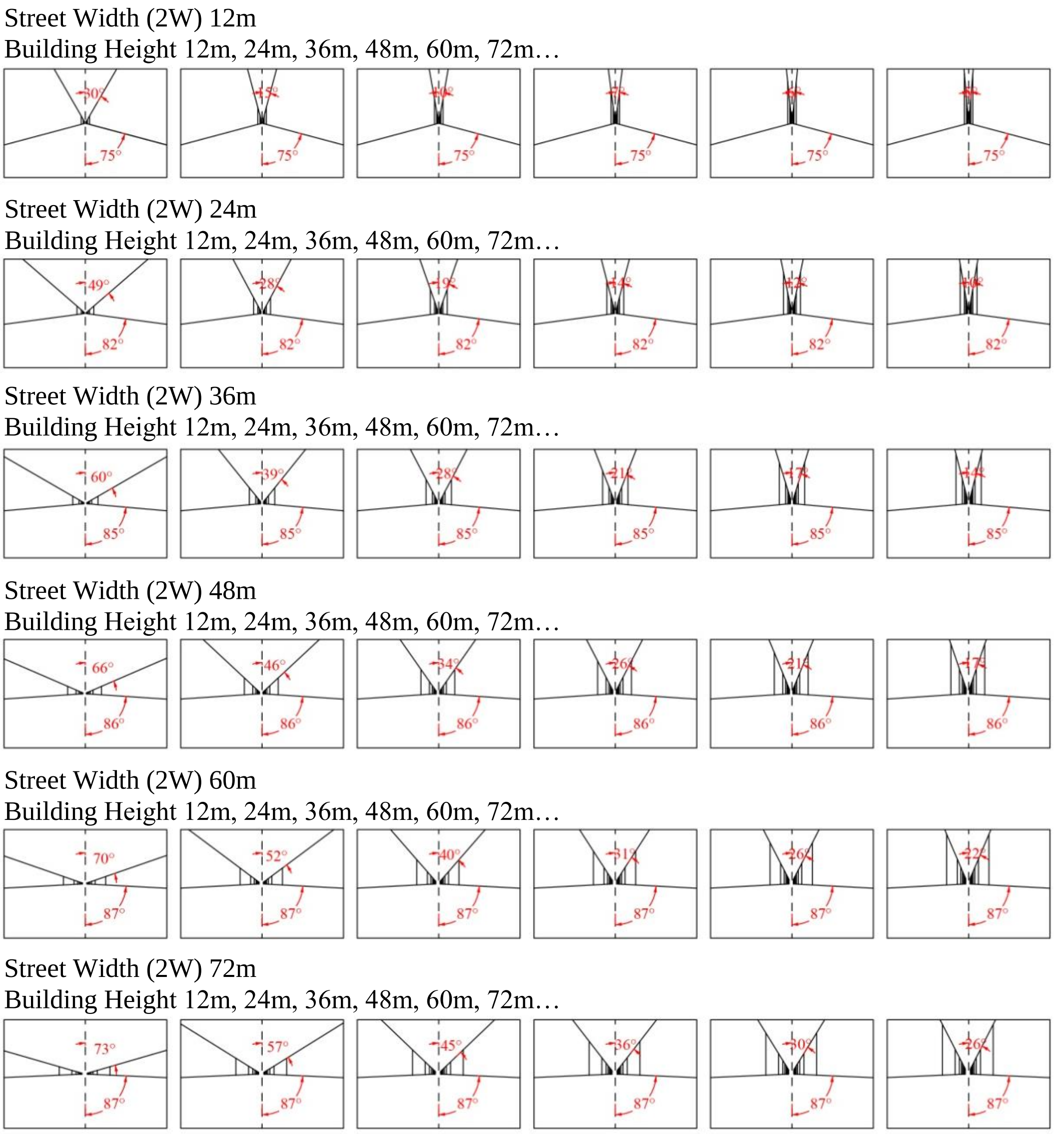


Figure 16. The α and β values of perspective drawings of the different street width and the building height

4.4. Analysis of H-α, W-α; H-β, W-β

We have analyzed the regularities between α and H and W and displayed the results in Fig.17. We have found that α is only effected by the street width (W), α increases with the increases of W.

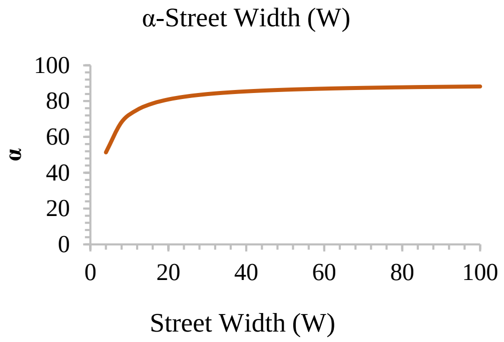
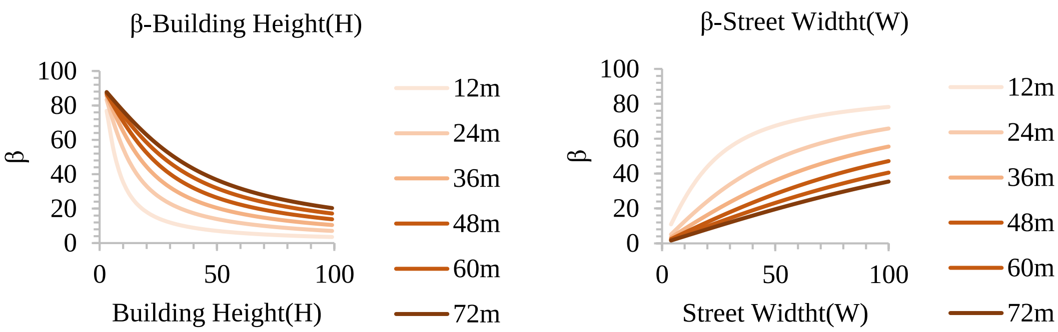


Figure 17. The relationship between α and the street width (W)

We have analyzed the regularities between **β** and H and W and displayed the results in Fig.18. We have found that **β** is effected by the building height (H) and the street width (W).



(a) (b)

Figure 18. (a)The relationship between β and the building height (H);
(b)The relationship between β and the street width (W).

Through the rules presented in Fig.17 and Fig.18, we further study the geometric relationships between W and H and **α** and **β**. For example, the perspective drawing as show in Fig.19, the angle between the bottom outline of the building and the center line is **α** and the angle between the skyline of building and the center line is β, the viewpoint height is h, the vanishing point is O, the person's site is A; we extend the bottom outline and make a horizontal line through point A to intersect with it, the intersection point is B, so the length of line AB is the street width (W), according to the geometry, we get:

$$\mathbf{W=h*tan\alpha} \tag{6}$$

We extend the building skyline and make a vertical line through point B to intersect with it, the intersection point is C, then we draw a horizontal line through the point O, intersect with line BC at point D, the length of line BC is the building height (H), the length of line BC is equal to the sum of the length of line BD and DC.

$$\mathbf{H=L(bc)=L(bd)+L(dc)}$$

$$\mathbf{L(bd)=h}$$

$$\mathbf{L(od)=W=h*tan\alpha}$$

$$\mathbf{L(dc)=h*tan\alpha/tan\beta}$$

$$\mathbf{H=h(\frac{tan\alpha}{tan\beta}+1)} \tag{7}$$

In addition, we can figure out α and β according to the formula (6) and (7).

$$\boldsymbol{\alpha = \arctan \frac{W}{h}} \tag{8}$$

$$\boldsymbol{\beta = \arctan \frac{W}{H-h}} \tag{9}$$

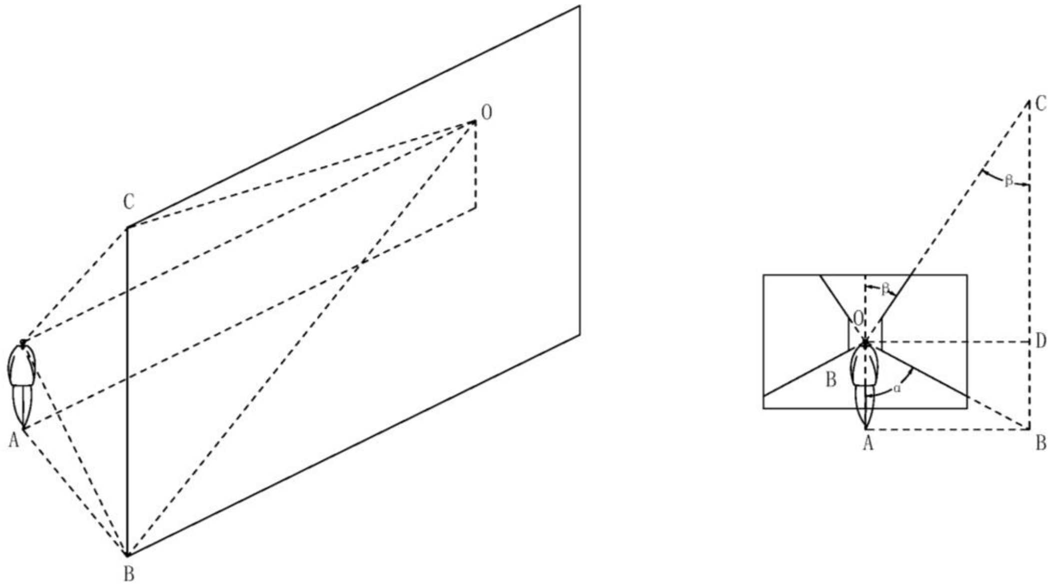


Figure 19. The geometric relationships between W and H and **α** and **β**

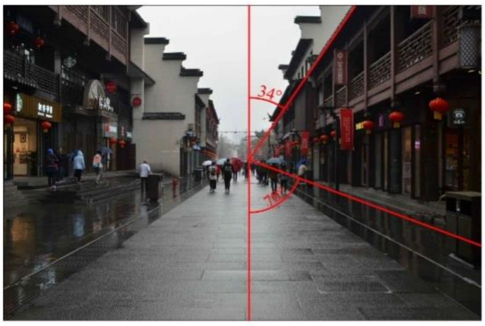
5. Test and application

The quantitative approach developed above will be applied to quantify the streetscape images of the real world to verify its effectiveness and a case has been developed to explain how to apply the approach.

5.1 Verifying the approach of judging how the height of an object in the perspective refers to real height of the building in the city.

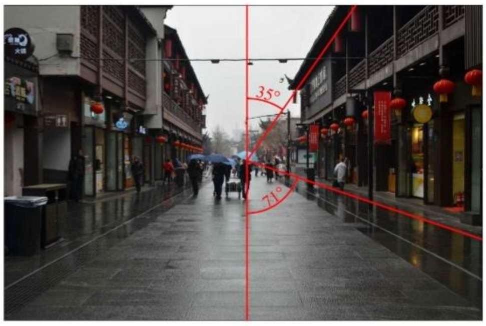
Through the angle formula we know that the real height and real weight are only related to the angle α and β and the camera's height. According to the principle of the equivalent focal length the angle α and β will not change with the focal length of the camera. So, we only need to keep the camera level when shooting. We have chosen several roads in Nanjing to take photos and used a laser rangefinder to measure the distance from the camera to the building and the height of the buildings. Then we have drawn the bottom building outline and skyline, and we have measured the angle α and β. According to the angle α and β we can look up the corresponding W and H in Figure 16. Also, we can figure out W and H according to the angle formulas. Finally, we have calculated the error between the calculated value and the actual measured value. The results are shown in Figure 20.

Through the verified results in Fig.19 we have found that when the street width and building are too large, there is a large error between the calculated values and measured values. Comparing Fig. 20(e) with Fig.20(f), we have found that 1° change will bring a great change of W. Through analyzing the growth rate of α with W, we have found that when the angle α is more than 80 degrees (street width >20m), the growth rate is very slow which means the accuracy of the measuring approach and the real width will decrease.



Confucius Temple	Measured	Calculated	Error
	W=4.6m H=7.7m	W=4.4m H=8.1m	W:4.3% H:5.2%

(a)



Confucius Temple	Measured	Calculated	Error
	W=4.5m H=7.7m	W=4.6m H=8.2m	W:2.2% H:6.5%

(b)

NanJing University	Measured	Calculated	Error
	W=8m H=11m	W=6.9m H=9.6m	W:13.7% H:12.7%

(c)

NanJing University	Measured	Calculated	Error
	W=14m H=23m	W=13m H=19.5m	W:7.1% H:15.2%

(d)

He Xi New Town	Measured	Calculated	Error
	W=61m H=67m	W=45.8m H=44.3m	W:24.9% H:33.9%

(e)

He Xi New Town	Measured	Calculated	Error
	W=40m H=63m	W=30.5m H=61.5m	W:23.8% H:2.4%

(f)

Figure 20. Verifying the measuring approach in the real word.

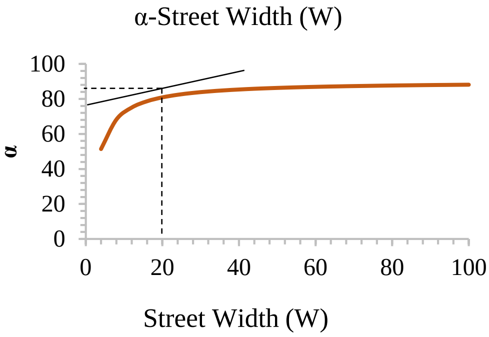


Figure 21. The analysis of the growth rate of α with W

5.2. Application

We developed a digital model in Rhino to explain how to apply the approach developed above. In the case, we need to design a new building according to the streetscape we want it to be. The street width is 12m, the existing building's height is 12m, point O is the viewpoint, the width of the new building's red line is 100m, the distance between the viewpoint and the red line is 200m, the distance between the center line of the road and the red line is 18m (Fig.23).

If we want a new building does not arise in the streetscape the image is shown in Fig.22(a). The β of the new building should be more than the β of the existing building. First, we figure out the β angle of the existing building according to the Formula (9):

$$\mathbf{\beta=arctan\frac{W}{H-h}=arctan\frac{6}{12-1.6}\ 29.982°}$$

Then the β of the new building should more than 29.982°.

$$\mathbf{\beta=arctan\frac{W}{H-h}>29.982°}$$

$$\mathbf{\frac{W}{H-h}>0.577}$$

if the W =18m,

$$\mathbf{H<32.8m}$$

If we want to see the complete skyline of the new building the streetscape image is shown in Fig.22(b). The β of the new building should be less than the β of the existing building.

$$\mathbf{\frac{W}{H-h}<0.577}$$

At the same time, the skyline of the new building should not exceed the frame of the image, we can figure out the maximum height of the new building according to the Formula (5):

When H>2/3W+1.6,

$$\mathbf{R>\frac{3}{2}\sqrt{3}H-2.4\sqrt{3}}$$

$$\mathbf{H<82.4m}$$

if the W =18m,

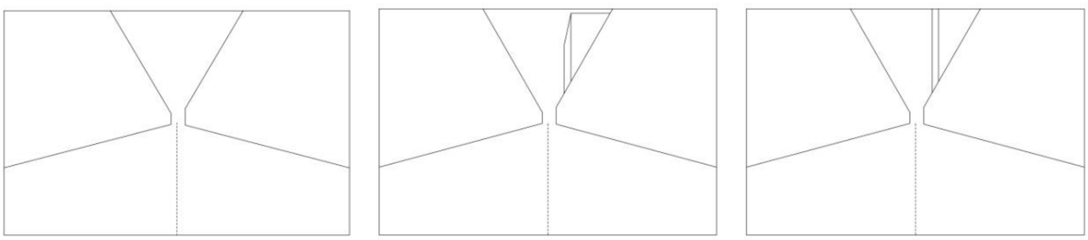
$$\mathbf{32.8m<H<82.4m}$$

If we want the streetscape the image is shown in Fig.22(c). The skyline of the new building will exceed the frame of the image, we can figure out the minimum height of the new building according to the Formula (5):

When H>2/3W+1.6,

$$\mathbf{R<\frac{3}{2}\sqrt{3}H-2.4\sqrt{3}}$$

$$\mathbf{H>82.4m}$$



(a) H<32.8m (b) 32.8m<H<82.4m (c) H>82.4m

Figure 22. The perspective drawings of the different building height

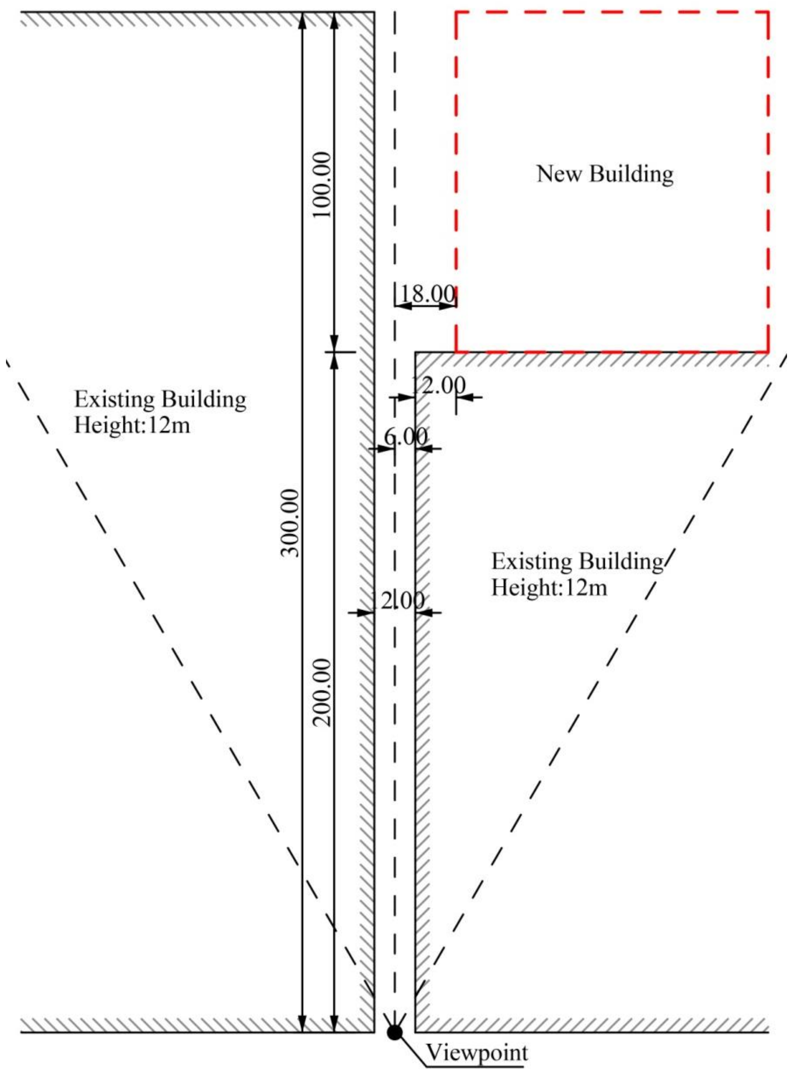


Figure 23. The plan of the case

6. Conclusion and discussion

This research has taken the street space as the research object and started from the people's perception of the streetscape, on the basis of reviewing the relevant literature on streetscape research, through the method of using computer digital models to simulate the streetscape seen by people, an experimental platform for quantifying street space has been developed to study the regularities between the configurations of the street space.

Through the experimental results, we have found that the street width and the building height play an important role in shaping the overall characteristics of the street view, if the street width and building height satisfy the formula $H<2/3W+1.6$, the perspective drawings are like in Fig 13(a), it looks very broad, when the street width and building height satisfy the formula $H>2/3W+1.6$, the perspective drawings are like in Fig 13(c), it looks very upright. Meanwhile, we have figured out the needed distance from the viewpoint to the point so that we could see the completed skyline of the building no matter what scale of the street is.

Also, through the angle experimental results, we can judge how the street width and the building height in the perspective refer to the real scale in the city. But when the street width is more than 20m this method will have a big error. In contrast, we have accurately sketched the streetscape images based on the street width and the building height.

Through the qualitative and quantitative analysis of the street space, this research has developed a quantitative approach of measuring the streetscape to help urban designers sketch streetscape images quickly and accurately and to optimize the plane according to the law of perspective drawings.

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Illustrations

Figure 1. Dürer's Perspective Machine (Source from Albert Perez-Gomez. Architecture Representation and the Perspective Hinge [M]. Boston: The MIT Press. 2000)

Figure 2. Two-dimensional perspective drawings are used to express three-dimensional space.

Figure 3. Viewing angle of photo is affected by the camera's focal length and camera's frame. (a) The relationship between the camera's focal length and Viewing angle. source from https://zhidao.baidu.com/question/1821986652365632108.html, (b) The camera's frame usually has two specifications and the aspect ratios are all 3:2. (source from blog.163.com/xiayu_0629)

Figure 4. The viewing angle and frame of photo and people. (a) The range of people's vision. (b) The red line represents the boundary that people can normally see.