Contents

Abstract

Classical investigation of an urban street's enclosure relies on the actual measure of a street's height-to-width ratio. It requires detailed spatial data for both buildings and streets and extensive amount of work. Since there are open-source images of streetscapes available, this study applies image recognition technology to identify street space quality and improve the efficiency of street quality assessment. First, this study develops a method quantifying street trees' shelter coverage and sky exposure at street level with computer vision. The method extracts color from abundant street images from Tencent to calculate the green view index and sky exposure. The program then compares this data to 0the street quality scores marked by professional urban planners and scholars in a local planning school and develops a regression model between marked scores and the variables from computer vision. The significant match between the two sets of results demonstrates that green view index and sky exposure degree are reliable indicators in measuring the human-perceived enclosure. This study then applies its method to evaluate the street enclosure quality across the entire area of Harbin city and identify high-quality street clusters.

Key Words: Green View Index, Proportion of Sky, Perceived Enclosure Degree, Tencent Street Map

1. Introduction

One significant goal of urban design is to create pleasant outdoor spaces(Trancik, R). However, it has long been difficult to measure the quality of urban design in an effective way(Ewing, 2009). Prior research suggests that the enclosure of a place is directly associated to a person's appreciation of that place (Ewing & Clemente, 2013). First, it has been proved by many studies that the degree of enclosure relates to a person's perception of comfort not only in discipline of urban design (Carmona, 2010), environmental psychology (Im, 1984; Kaplpan, 1989) but also visual aesthetics preference (Jacobs, 1993; Moughtin, 2003). Second, the degree of enclosure also relates to a person's sense of safety: a place of appropriate enclosure often has a positive implication that makes people feel safe (Appleton, 1996; Gibson, 2014; Stamps, 2005).

Ewing and Clemente (2013) developed a method of measuring enclosure by assembling a panel consisting of planning experts to evaluate the space quality according to video clips of street views. This method requires extensive human labor. Another option is to measure the height-to-width ratio which requires information of streets' widths and buildings' heights (Alkhresheh, 2007). The height-to-width ratio approach divides the street width by the building height to represent the enclosure of the street. Although this method is straightforward, it ignores the influences of street greenaries, which significantly affect the quality from the pedestrian's perspective.

Using Tencent street view images which present pedestrians' actual perspectives of streetscape, this study develops a more efficient and reliable method to measure streets' enclosure. It establishes a sufficient way to quantify the amount of greenery cover and sky exposure in any given street view image by computer vision. It demonstrates the feasibility of quantifying the pedestrian perceived coverage of street-side trees and exposure of sky at city scale in several ways: 1) obtaining a sequence of street view image from this city's whole urban scope; 2) calculating the amount of green view index and sky exposure; 3) randomly choose 100 (0.5%) images and collecting the sense of enclosure from urban planning experts 4) modeling the relationship between the sky exposure ratio, Green View Index (GVI), and sense of enclosure.

This study's purpose is to advocate a new way of mapping enclosure in urban scale with reliable accuracy. Compare toe the conventional techniques in street measures, it offers many merits. For example, it is more closely related to the pedestrians' perspective, at much lower cost, and can be easily applied to any city as long as there are street view images. It provides a reliable and efficient alternative for planners and policy makers to assess the quality of the built environment.

2. Literature Review

2.1 Evaluation System of Streets Space

Streets construct the most basic element of city pattern (Whyte, 1980; Nichol & Wong, 2004). It constructs the image of the city (Carmona, 2010), gathers people, creates physical settings for activities (Jacobs, 1993), and encourages even more relaxation and entertainment than parks for people (Appleton, 1996).

The street evaluation system often includes five elements, namely image-ability, enclosure, human scale, transparency, and complexity (Ewing & Clemente, 2013). Enclosure is one of the most significant element as it directly affects a person's appreciation of that place. This association has been established and proved in many research fields, including urban design (Carmona, 2010), environmental psychology (Im, 1984; Kaplan & Kaplan, 1989; Jacobs, 1993; Lynch & Hack, 1984), visual study (Moughtin, 2003; Nelessen, 1994; Salingaros, 1999; Stamps, 2005). Enclosure is also related to the sense of security: a place of appropriate enclosure often has a positive implication making people feel safe. (Appleton, 1996; Gibson, 2014; Stamps, 2005).

2.2 Enclosure, Height-to-width Ratio, and Street Trees

The most emphasized method in assessing enclosure of streets has been related to the equation "R = H/W", in which the ratio (R) of the height (H) of the vertical elements (such as buildings and trees) and the width (W) of that space would have large impacts (Bacon, 1974; Alexander, 1977; Jacobs, 1993; Carmona, 2010; Im, 1984; Lynch & Hack, 1984; Moughtin, 2003; Nelessen, 1994). This equation is widely applied in theoretical constructs. For urban street spaces, previous researches suggested a series of desirable height-to-width ratios, ranging from 1:1 (Alexander, 1977), 1:1 to 1:2 (Nelessen, 1994), 1:2 (Moughtin, 2003), 1:3 to 1:2 (Lynch & Hack, 1984), and 2:1 to 2.5:1 (Carmona, 2010).

In addition, Ewing and Clemente (2013) also mentioned that enclosures are impaired by breaks in the continuity of the street wall; which is, the impairments were caused by discontinuities in vertical elements such as rows of trees or buildings that line the street.

Street trees are able to humanize the unpleasant scale of height-to width ratio caused by tall buildings and wide streets (Hedman & Jaszewski, 1984). Horizontally, trees define space by visually enclosing an open area; vertically, trees do so by creating a leaves' and branches' ceiling. A canopy created by trees would provide a perceived smaller space within an actual more spacious space where wide streets or tall buildings would have created an unpleasant-scale space that frighten pedestrians (Andersen & Arnold, 1993). At suburban area where building density is low, street trees play the main role in defining space than building masses.

2.3 Image Segmentation in Urban Studies

Image segmentation is done to decompound an image into meaningful parts for further analysis (Sural, Qian, & Pramanik, 2002). The segmentation can be based on gray-level images and color images (Guo-quan, Zhan-ming, Xiang-wei, & Wei-yi, 2010). Scholars have focused more on color image segmentation, as color images convey more information than gray-level images, and causing more meaningful and robust segmentation (Huang & Liu, 2007). The motivation for using color for segmentation is due to it providing regional information, and when specified appropriately, it relatively insensitive to variations in different illumination conditions and appearances of objects (Rui, Huang, & Chang, 1999).

The color mode or image mode determines how colors combine based on the number of channels in a color model. Different color modes lead to different levels of color details and file sizes (Adobe, 2017). The hue, saturation, and value (HSV) mode is also often called the hue, saturation, and brightness (HSB) model. In the HSV model, hues range from 0 to 360°, and saturation and value range from 0 to 100%.

Street view image is a library of video footage captured by cars driven down the streets (Rundle, 2011), it is able to take the place of in-person audit of urban environment which is costly and time-consuming. Rundle (Rundle, 2011) measured the concordance between

Google Street View and field audit, and proved that using street view image to audit neighborhood environments is feasible. Now, scholars use three main image segmentation methods to read street view images, including Markov Random Field (Xiao, 2009), histogram-based methods (Li, 2015) and convolutional neural network (Badrinarayanan, 2017).

3. Data and Method

This chapter states the method of measuring enclosure and includes the data acquisition and analysis.

3.1 Study Areas and Image Source

This section concentrates on the urban area of data collected from the beltway of Harbin (Fig.1).

3.1.1 Dataset

Data was collected on the proportion of sky and green view index by using 22,518 images of Harbin streetscapes. However, considering the view of streetscapes varies between downtown and the suburbs, this research only focuses on the area by the belt way. The total area of study is 624.64 km^2. Images were sourced from the Tencent Street View (TSV) API and represent a ground-level side-view perspective of city streetscapes.

To download images of streetscapes from TSV, the coordinate of each point was collected and then finished in ArcGIS[1]. The following steps were part of the data collection.

(1) Simplifying the shapefile

Simplify the shapefile with the "Generalize" tool from the Edit Tools in ArcGIS.

(2) Splitting the shapefile

Split the shapefile with the "Split Line at Vertices" tool from the Data Management Tools in ArcGIS.

(3) Grouping lines by length

Divide lines into two groups by length: above 160 m (long group) and below 160 m (short group).

(4) Adding vertices on long group's lines

Use the "Densify" tool from the Editing Tools to add points on those lines longer than 160 m and the distance is 80m.

(5) Extracting the midpoint of short group's lines

Extract the midpoint of those shorter than 160m' lines by "Feature Vertices to Point" from Data Management Tools.

Figure 1:Map of the Road Network in Harbin

[1] The shapefile of Harbin was collected from our school's database.

(6) Calculating the road direction

Calculate the angle between lines and the x-axis by field calculator in ArcGIS.

(7) Extracting coordination

The coordination of all the points are calculated through the “Add XY Coordinates” from the Data Management toolbox, and the attribute table including these coordinates’ information is exported to an external file in dbf format.

3.2 Methods

3.2.1 Download street map

The process of downloading is based on the data API offered by Tencent. To stimulate the view from pedestrians, we need to determine the heading and the pitch of street images. Heading indicates the compass heading of the camera (the heading values range from 0 to 360). Pitch specifies the up or down angle of the camera relative to the street view vehicle. Each image at a resolution of 960 by 640 pixels is at the same heading with each street and a 0° pitch to simulate the view in pedestrians’ eyes.

3.3 Research Variables

3.3.1 Proportion of Sky and Green View Index

A three-dimensional representation of the HSV color space is a hexatone, where the central vertical axis represents the intensity. Hue is defined as an angle in the range $[0,2\pi]$ relative to the red axis with red at angle 0, green at $2\pi/3$, blue at $4\pi/3$ and red again at 2π. Saturation is the depth or purity of the color and is measured as a radial distance from the central axis with value between 0 (at the center) to 100 (at the outer surface). For $S = 0$, as one moves higher along the intensity axis, one goes from black to white through various shades of gray. For a given intensity and hue, if the saturation is changed from 0 to 100, the perceived color changes from a shade of gray to the purest form of the color represented by its hue. As approached from a different angle, any color in the HSV space can be transformed to a shade of gray by sufficiently lowering the saturation.

Sky and plant cover cannot be defined only by hue; they also have a specific range of saturation and value. After many experiments, it was discovered that sky is defined by color: (195 <= hue <= 220 and 70 <= value) or (0 <= saturation <= 75 and 75 <= value). It was also determined that plant cover is defined by the color: (50 <= hue <= 160 and 20<= saturation), (20 <= hue <= 40 and 80 <= saturation and 30 >= value), or (12 <= hue < 24 and 30 <= saturation and 30 > value). These calculations were completed with Python codes. In Python codes, hue, saturation, and value range from 0 to 255. To avoid extracting color from reflective ground, the range of extraction of proportion of sky is 960 by 300 pixels.

With the images segmented by this procedure, plant cover and sky in each image were extracted (Figure 2). The percentage of plant cover and sky in an image were calculated as the total number of image pixels.

1 2 3

Proportion of Sky: 0.240 Proportion of Sky: 0.185 Proportion of Sky: 0.174

GVI: 0.209 GVI: 0.213 GVI: 0.166

Figure 2: Image Segmentation Results

The images in which the proportion of sky is under 5% (Figure 3) were automatically deleted. This situation means this image was taken under roofs or bridges. The number of valid images was 94.

Figure 3:Example of extremely low proportion of sky image

3.3.2 Height-to-Width Ratio

These two variables are functions to test the accuracy of the questionnaire results. This measurement object is the same with the 100 images in the questionnaire. The height is the average height of the defining buildings of the street space, measured from ground to the highest point in the vertical defining wall. Width is the width of the street measured from the face of the buildings on one side of the street to the face of the buildings on the other side. Height and width together produce different values of height-to-width ratio and scale.

3.3.3 Perceived Enclosure Degree

The result of the questionnaire is the perceived enclosure degree. One hundred images were chosen randomly, and senior urban planning students and teachers were invited to judge the images' enclosures. The questionnaire was designed in the semantic differential method; the options were set in five scales. To avoid respondents losing patience, they only needed to answer 25 questions once. The questionnaire received 169 responses, and the average score was used to describe each image's perceived enclosure degree.

To obtain a more accurate result, meaningless feedback was manually deleted. For example, all images were chosen to be the same score or the time of answering questionnaire is under 30 seconds. The number of valid questionnaires was 141.

3.4 Regression Analysis

In this subsection, two linear regression models are described: one for perceived enclosure degree and another for proportion of sky. They are expressed in linear regression form and link the proportion of sky and perceived enclosure degree in the first model. In the second model, the equation links height-to-width ratio, GVI, and proportion of sky.

Model 1:

$$y = a_1 + a_2 x_1 + \varepsilon \qquad (1)$$

where y is the *Enclosure Degree*, x_1 is the proportion of sky, a_1 , a_2 are the regression coefficients, and ε is the error.

Model 2:

$$\frac{1}{x_1} = \beta_1 + \beta_2 e^{x_2} + \beta_3 x_3 + \varepsilon \qquad (2$$

where x_2 is the GVI, x_3 is the height-to-width ratio, b_1, b_2, b_3 are the regression coefficients, and ε is the error.

3.5 Hot Spot Analysis

This study divides the result of enclosure assessment in five categories: 1.0 (very low enclosure), 2.0 (low enclosure), 3.0 (medium enclosure), 4.0 (high enclosure), and 5.0 (very high enclosure). The most human-scale quality enclosure is 3.0.

To make the results more readable, the study then described "enclosure quality" with the following definition:

Enclosure Quality = Abs ([Enclosure Degree,] – 3)

As a result, when quality = 2, that means that the enclosure perceived is the most appropriate, and when quality = 0, the enclosure scale is the most negative.

The purpose of this analysis is to identify the highest quality's cluster. It deploys the hot spot model to identify statistically significant spatial clusters of high values (hot spots in which the high degree of quality area may be between 1.6 and 2.0) and low values (cold spots in which the low degree of quality area may be between 0 and 1.6).

The Getis-Ord local statistic is given as

$$G_i^* = \frac{\sum_{j=1}^{n} w_{i,j}\, x_j - \bar{X} \sum_{j=1}^{n} w_{i,j}}{S\sqrt{\frac{\left[n \sum_{j=1}^{n} w_{i,j}^2 - \left(\sum_{j=1}^{n} w_{i,j}\right)^2\right]}{n-1}}}$$

Where x_j is the attribute value for feature j, $w_{i,j}$ is the spatial weight between feature *i* and *j*, *n* is equal to the total number of features, and:

$$\bar{X} = \frac{\sum_{j=1}^{n} x_j}{n}$$

$$S = \sqrt{-\bar{X}^2 + \frac{\sum_{j=1}^{n} x_j^2}{n}}$$

A high *z*-score and small *p*-value for a feature indicates a spatial clustering of high values. A low negative *z*-score and small *p*-value indicates a spatial clustering of low values. The higher (or lower) the *z*-score, the more intense the clustering. A *z*-score near zero indicates no apparent spatial clustering.

4. Research Finding

This chapter reports results from the variance and regression analysis. Moreover, the Model 1 have been altered in this chapter.

4.1 Quarter Interpretation

In this scatter diagram (Figure 4), the label of each point is the perceived enclosure degree. In this plot, there are some sample outliers that cannot be explained by our models. In the range where proportion of sky < 0.125 and GVI > 0.278, perceived enclosure degrees are often marked as

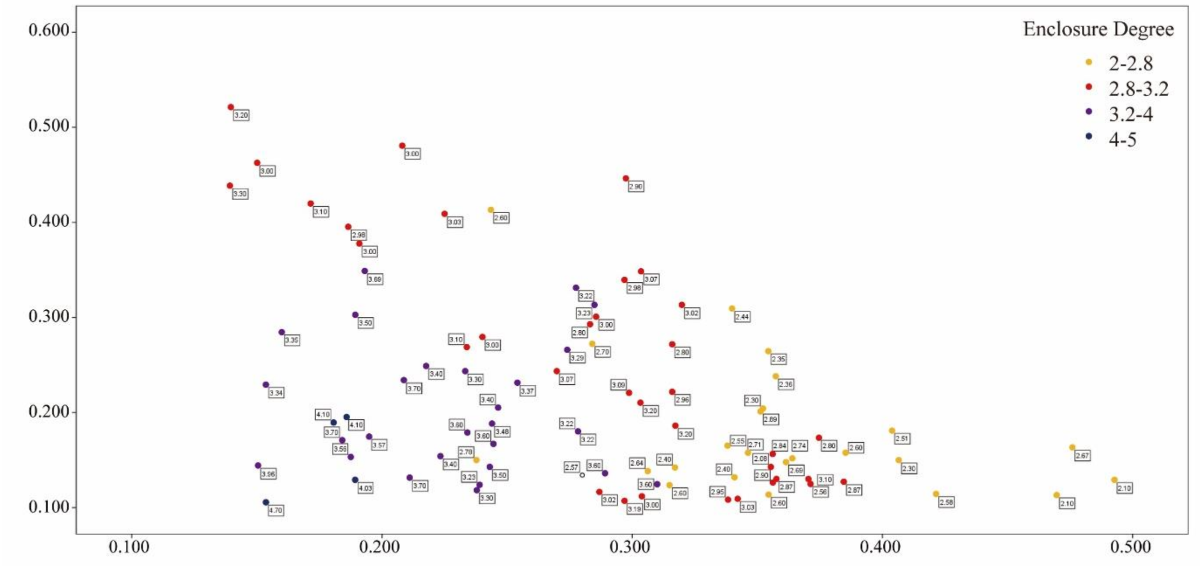


Figure 4:Quater interpretation of Enclosure Degree, Proportion of Sky and Green View Index

3.0 (highest quality). If only judged by the proportion of sky (< 0.125), the enclosure degree from these images should have been marked as 4 to 5, meaning they are very narrow. However, when the images' GVI values are larger than 0.278, the perceived enclosure qualities are better than other images in which the sky ratio is at the same level.

One possible explanation for these outliers having a very low proportion of sky is because of the dense vegetation. The vegetation constructs a narrow but more intimate street interface than buildings, and they are thus marked with scores closer to 3. In other words, the high value of GVI *x* has a greater influence on the enclosure degree.

To make the regression analysis more accurate, this study recalculates the model of enclosure degree and adds the GVI as a new factor.

4.2 Adjusted Model 1

$$y = \alpha_0 + \alpha_1 x_1 + \alpha_2 e^{x_2} + \varepsilon$$

where y is the enclosure degree, x_1 is proportion of sky and x_2 is the GVI.

Table 1: Regression table of model 1

	Enclosure Degree,
α_1	-5.494*** (-113.108)
α_2	-1.521*** (-5.532)
Constance	5.779 (16.381)
Observations	94
R^2	0.651

t statistics in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.0001$

4.2.1 Proportion of Sky is Significant

In Model 1, the pattern of coefficients suggests that proportion of sky has a significant negative impact on the perceived enclosure degree (Table 2). This model demonstrates that when proportion of sky is 57.6%, enclosure degree is 1 (very low enclosure); when proportion of sky is 38.96%, enclosure degree is 2 (low enclosure); when

Table 2: Examples of the Relationship Between Proportion of Sky and Enclosure Degree

			
4	5	6	7
Proportion of Sky: 0.468	Proportion of Sky: 0.202	Proportion of Sky: 0.171	Proportion of Sky: 0.069
GVI: 0.107	GVI: 0.077	GVI: 0.269	GVI: 0.159
Enclosure Degree: 1.802	Enclosure Degree: 2.932	Enclosure Degree: 3.000	Enclosure Degree: 4.000

proportion of sky is 3.47%, enclosure degree is 3 (medium enclosure), and when proportion of sky is 1.61%, enclosure degree is 4 (high enclosure).

Keeping GVI stable, if proportion of sky increases 0.182, enclosure degree will increase by 1.

Keeping proportion of sky stable, a GVI increase from 0 to 0.1 will cause enclosure degree decrease by 0.159. A GVI increases from 0.2 to 0.3 will cause enclosure degree decrease 0.195. GVI increases from 0.3 to 0.4 will cause enclosure degree decrease by 0.215, GVI increases from 0.4 to 0.5 will cause enclosure degree decrease by 0.238, GVI increases from 0.5 to 0.6 will cause enclosure degree decrease by 0.263. To conclude, the higher the GVI, the greater the impact.

4.2.2 Interpretation of Model 1

Table 4 shows three enclosure levels: low enclosure (enclosure degree = 2), medium enclosure (enclosure degree = 3) and high enclosure (enclosure degree = 4). It can be seen that enclosure degree is to the negative ratio of proportion of sky. When there is a higher proportion of sky exposed in the photo, the place is less enclosed. It is interesting to note that Picture No. 5 and Picture No. 6 are of the same enclosure degree, yet the proportion of sky is different. It is because in the scene of photo No.6, the sky mostly is cover by trees. As Ewing & Clemente claimed, trees can make the scale of street more humane (Ewing & Clemente, 2013). From the above photo, it can be seen that using trees, especially fast-growing trees, can improve the enclosure of streets while keeping the built structures the same.

$$x_1 = \beta_0 + \beta_1 e^{x_2} + \beta_2 \ln(x_3 + 1) + \varepsilon$$

Table 3: Regression Table of Model 2

	the reciprocal of proportion of sky
$\frac{1}{1+e^{x_2}}$	-0.354*** (-6.661)
$\ln(x_3 + 1)$	-0.118*** (-6.113)
Constant	0.662 (10.341)
Observations	94
R^2	0.425

t-statistics in parentheses

* *p* < 0.05, ** *p* < 0.01, *** *p* < 0.0001

4.2.3 Proportion of Sky is determined by Ratio

Table 4:Relationship between H-W ratio and Proportion of Sky (Alkhresheh, 2007)

		
H-W Ratio: 1	*H-W Ratio: 0.67*	*H-W Ratio: 0.5*
Proportion of Sky: 0.138	*Proportion of Sky: 0.239*	*Proportion of Sky: 0.290*
		
H-W Ratio: 1.5	*H-W Ratio: 1*	*H-W Ratio: 0.75*
Proportion of Sky: 0.092	*Proportion of Sky: 0.138*	*Proportion of Sky: 0.185*
		
H-W Ratio: 2	*H-W Ratio: 1.33*	*H-W Ratio: 1*
Proportion of Sky: 0.663	*Proportion of Sky: 0.099*	*Proportion of Sky: 0.138*

and Green View Index.

This model justifies the previous study that shows that rows of trees on both sides of a street can both humanize the height-to-width ratio and determine the perceived enclosure in low densities areas (Ewing & Clemente, 2013).

Keeping GVI stable, ratio increases from 0.1 to 0.5 will cause proportion of sky decrease by 0.037. Ratio increases from 0.5 to 1 will cause proportion of sky to decrease by 0.034. Ratio increases from 1 to 2 will cause proportion of sky to decrease by 0.048. Ratio increases from 2 to 3 will cause proportion of sky to decrease by 0.034. Ratio increases from 3 to 4 will cause proportion of sky to decrease by 0.026. Ratio increases from 4 to 5 will cause proportion of sky to decrease 0.022; In summary, the height-

Table 5: H-W Ratio, Green View Index, and Proportion of Sky

			
8	*9*	*10*	*11*
H-W Ratio:1.50	*H-W Ratio: 1.50*	*H-W Ratio:0.517*	*H-W Ratio:1.429*
Green View Index: 0.149	*Green View Index: 0.006*	*Green View Index: 0.101*	*Green View Index: 0.104*
Theoretical Proportion of Sky : 0.114	*Theoretical Proportion of Sky : 0.202*	*Theoretical Proportion of Sky : 0.186*	*Theoretical Proportion of Sky : 0.133*
Actual Proportion of Sky : 0.118	*Actual Proportion of Sky :0.196*	*Actual Proportion of Sky : 0.251*	*Actual Proportion of Sky :0.252*

to-width ratio has a negative influence on the proportion of sky. When the height-to-width ratio is below 1, the higher value has a greater impact; when the height-to-width ratio is above 1, the higher value has a lower impact. This situation can be explained as when the top of building is beyond people's view, the height of the building will not make a significant difference.

Keeping height-to-width ratio stable, GVI increases from 0 to 0.1 will cause enclosure degree to decrease by 0.037. GVI increases from 0.1 to 0.2 will cause enclosure degree to decrease by 0.041. GVI increases from 0.2 to 0.3 will cause enclosure degree decrease 0.045, GVI increases from 0.3 to 0.4 will cause enclosure degree decrease 0.050, GVI increases from 0.4 to 0.5 will cause decrease 0.055, GVI increases from 0.5 to 0.6 will cause decrease 0.061.To conclude, the higher the GVI, the greater impact on the proportion of sky. This is because when the GVI is not high enough, trees are just covering the buildings and will not affect the proportion of sky in people's view. As the area of green is large enough to surpass the buildings and cover sky, it has a significant influence on the proportion of sky.

In other words, the same street, to improve the perceived *Enclosure Degree*, if X_2 is still, X_3 needs increase 56%; if X_3 is still, X_2 needs increase 6.79.

4.2.4 Interpretation of Model 2

Model 2 shows that, if the influence of trees is excluded, the value of *Proportion of Sky* is ultimately defined by the *Height-to-Width Ratio*. From Figure.8 it is clear that when the H-W ratio is same, the proportion of will be same, even if the scale perceived is different.

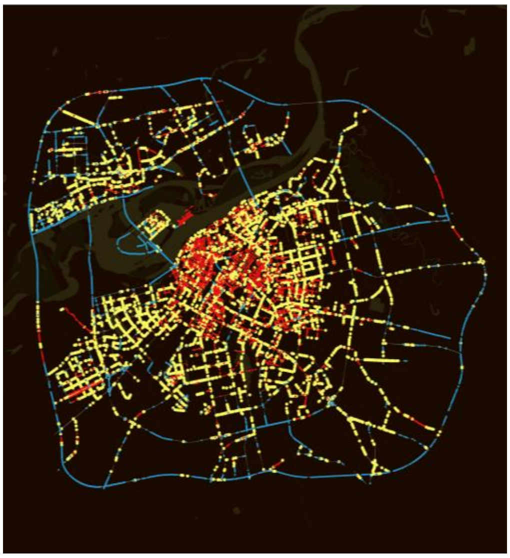
Compare Photo No.8 with No.9 (Table 8), it can be concluded that, with same H-W ratio, *Green View Index* has large influence on *Proportion of Sky*. Conversely, compare No.10 to No.11, we can conclude that with same *Green View Index*, the difference in H-W ratio will not necessary change the *Proportion of Sky* largely. It proves that, *Green View Index* has larger impact than H-W ratio in changing people's visual perception of street *Enclosure Degree*. This finding is consistent with what we found in Model 1.

4.3 Apply the method to Harbin

4.3.1 Urban Structure of Harbin

City of Harbin has a three-ring road structure. Within the 2nd ring (green) it is the 80 city and districts develop before 1980s, with more decent scale. Outside the 2nd ring, especially Songbei New District, Qunli New District, West Harbin New District and the new technology zones in the southwest corner are typically new urban zones developed with vehicle oriented mode.

4.3.2 Distribution of Street Enclosure Degrees



- Extremely high Enclosure Degree
- High Enclosure Degree
- Appropriate Enclosure Degree
- Low Enclosure Degree
- Extremely low Enclosure Degree

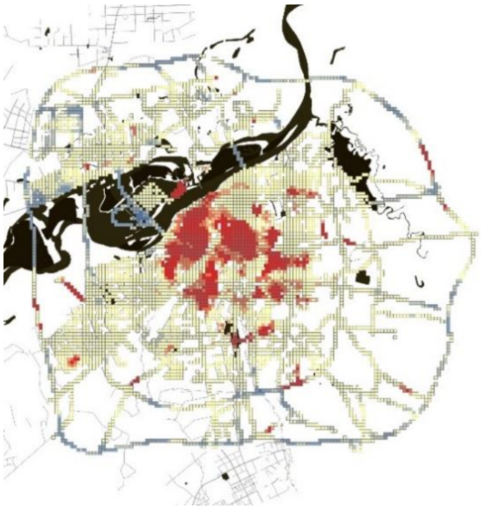
Figure 5: Enclosure Distribution

From Figure 10, it is clear that the area within 2nd ring road are of better enclosure than the new developments. Although the buildings in the old city are lower than new residential towers outside the 2nd ring road, streets are narrower and trees are older and bigger, as a result both *Proportion of Sky* and *green view index* are better. As a result, the street in the old city are more enclosed.

Moreover, from the map it can also be concluded that the enclosure are more homogenous, there is no diversity in terms of enclosure outside the 2nd ring. This could be problematic as the new roads, new buildings are very similar, lacking of identity and diversity.

4.3.2 Cluster of High Enclosure Quality Spaces

Figure 11 shows that there are more high enclosure quality clusters within the 2nd ring than outside. It is consistent with the finding in 4.3.1, which is old city district has better street quality



- Most significant high enclosure *Quality* cluster
- Significant high enclosure *Quality* cluster
- Not significant
- Significant low enclosure *Quality* cluster
- Most significant low enclosure *Quality* cluster

Figure 6: Cluster of High Enclosrue Degree Spaces

in terms of perceived enclosure in average (see Figure 12). Outside the 2nd ring, most roads are of low enclosure quality, except for some area in West Harbin New District, Sun Island, Qunli District and new technology zones.

Figure 13 lists some of the high quality streets in the old city, out of the 2nd ring road, and the bad enclosure streets out of 2nd ring road. It is clear that the good quality streets are shape by either dense trees or streets with fewer lanes.

Low enclosure street segments are concentrated in the 3rd ring road, the beltway and the new avenues in Songbei New Town. From Figure.14 it is clear that it is due to low density buildings, wide vehicle lanes and not enough street trees. The study suggests that by implementing street trees with high and big crown, the sense of enclosure of those streets can be largely improved.

Table 6: High enclosure streets

			
Enclosure Degree : 4.70	Enclosure Degree : 4.10	Enclosure Degree : 3	Enclosure Degree : 3
Green View Index: 0.005	Green View Index: 0.095	Green View Index: 0.318	Green View Index: 0.292

Table 7. Image of high-quality streets outside the 2nd ring of Harbin

		
Enclosure Degree: 3.12	*Enclosure Degree* : 3	*Enclosure Degree* : 3
Green View Index: 0.006	*Green View Index*: 0.552	*Green View Index*: 0.318
Quality: 1.93	*Quality* : 2	*Quality*: 2
		
Enclosure Degree : 3	*Enclosure Degree* : 2.86	
Green View Index : 0.292	*Green View Index*: 0.048	
Quality: 2	*Quality*: 1.85	

Table 8. Image of low enclosure cluster

		
Enclosure Degree : 1.915	*Enclosure Degree* : 1.161	*Enclosure Degree* : 1.724
Quality: 1.06	*Quality*: 0.84	*Quality*: 0.91

5. Conclusion

Quantifying the perceived enclosure degree in cities has been an open challenge due to the difficulty of measuring and collecting compelling data. We have address this challenge by presenting a novel method of quantifying perceived enclosure degree using only open source data and software, while achieving very high throughput at the city extent.

6. Research limited and future

Due to the limitation of the algorithm, in this study the variables of *Proportion of Sky*, green view index are only base on green and blue color segmentations. It is a relative course resolution at global level. The study does not take into account the impact of proportion of street wall, long sight line and other features from classical researches. Future research could develop a more detail and specific recognition that identify those important street characters. It will improve the study with better resolution. Meanwhile, the sample of scores from architecture and planning experts are small.

References

Adobe. (2017). Color modes.

Alexander, C. (1977). A pattern language: towns, buildings, construction: Oxford University Press.

Alkhresheh, M. M. (2007). Enclosure as a Function of Height-to-width Ratio and Scale.

Andersen, P., & Arnold, H. F. (1993). Trees in Urban Design: JSTOR.

Appleton, J. (1996). *The experience of landscape*: Wiley Chichester.

Bacon, E. N. (1974). *Design of cities*: Thames and Hudson London.

Badrinarayanan, V., Kendall, A., & Cipolla, R. (2017). Segnet: A deep convolutional encoder-decoder architecture for image segmentation. *IEEE transactions on pattern analysis and machine intelligence, 39*(12), 2481-2495.

Blumenfeld, H. (1953). Scale in civic design. *Town Planning Review, 24*(1), 35.

Carmona, M. (2010). Public places, urban spaces: the dimensions of urban design: Routledge.

Duany, A., & Plater-Zyberk, E. (1992). The second coming of the American small town. *Wilson Quarterly, 16*(1), 3-51.

Ewing, R., & Clemente, O. (2013). *Measuring Urban Design Metrics for Livable Places*: Island Press.

Ewing, R., & Handy, S. (2009). Measuring the unmeasurable: Urban design qualities related to walkability. Journal of Urban design, 14(1), 65-84.

Gibson, J. J. (2014). The ecological approach to visual perception: classic edition: Psychology Press.

Guo-quan, Z., Zhan-ming, L., Xiang-wei, L., & Wei-yi, W. (2010). Research on color image segmentation in HSV space. *Computer Engineering and Applications, 46*(26), 179-181.

Hedman, R., & Jaszewski, A. (1984). *Fundamentals of urban design*.

HSL and HSV.

Huang, Z.-K., & Liu, D.-H. (2007). *Segmentation of color image using EM algorithm in HSV color space.* Paper presented at the Information Acquisition, 2007. ICIA'07. International Conference on.

Im, S.-B. (1984). Visual Preferences in Enclosed Urban Spaces An Exploration of a Scientific Approach to Environmental Design. *Environment and Behavior, 16*(2), 235-262.

Jacobs, A. B. (1993). Great streets. *ACCESS Magazine, 1*(3).

Kaplan, R., & Kaplan, S. (1989). The experience of nature: A psychological perspective: CUP Archive.

Lennard, S. H. C., Lennard, H. L., & Bert, P. (1987). Livable Cities: People and Places: Social and Design Principles for the Future of the City: Center for Urban Well-Being.

Lorenzo-Valdés, M., Sanchez-Ortiz, G. I., Elkington, A. G., Mohiaddin, R. H., & Rueckert, D. (2004). Segmentation of 4D cardiac MR images using a probabilistic atlas and the EM algorithm. *Medical Image Analysis, 8*(3), 255-265.

Lynch, K., & Hack, G. (1984). *Site planning*: MIT press.

Moughtin, C. (2003). *Urban design: street and square*: Routledge.

Nelessen, A. C. (1994). *Visions for a new American dream*: Planners Press, American Planning Association.

Nevatia, R. (1977). Color Edge Detector and Its Use in Scene Segmentation. *IEEE Transactions on Systems Man and Cybernetics, 7*(11), 820-826.

Nichol, J., & Wong, M. S. (2005). Modeling urban environmental quality in a tropical city. *Landscape and Urban Planning, 73*(1), 49-58.

Rui, Y., Huang, T. S., & Chang, S.-F. (1999). Image retrieval: Current techniques, promising directions, and open issues. *Journal of visual communication and image representation, 10*(1), 39-62.

Rundle, A. G., Bader, M. D., Richards, C. A., Neckerman, K. M., & Teitler, J. O. (2011). Using Google Street View to audit neighborhood environments. American journal of preventive medicine, 40(1), 94-100

Salingaros, N. A. (1999). Urban space and its information field. *Journal of Urban Design, 4*(1), 29-49.

Stamps III, A. E. (2005). Enclosure and safety in urbanscapes. *Environment and Behavior, 37*(1), 102-133.

Sternberg, E. (2000). An integrative theory of urban design. *Journal of the American Planning Association, 66*(3), 265-278.

Sural, S., Qian, G., & Pramanik, S. (2002). *Segmentation and histogram generation using the HSV color space for image retrieval.* Paper presented at the Image Processing. 2002. Proceedings. 2002 International Conference on.

Trancik, R. (1986). Finding lost space: theories of urban design: John Wiley & Sons.

Whyte, W. H. (1980). The social life of small urban spaces.

Xiao, J., & Quan, L. (2009, September). Multiple view semantic segmentation for street view images. In *Computer Vision, 2009 IEEE 12th International Conference on* (pp. 686-693). IEEE.