

# Quantitative Study on Perception of the Public Space's Morphological Characteristics of Urban Existing Residential Neighborhoods in China Based on Psychophysics

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**Keywords:** Public space of urban residential neighborhood, morphological characteristics, psychophysics.

**Conference topic:** Urban Design: urban morphology, building typology and design/planning.

**Abstract:** In the past 10 years, considerable attention has been paid to the interrelationship between physical environment and human perception, cognition, preference and behavior. This study established the research framework of "physical form – psychological perception" of the public space in existing urban residential neighborhoods by introducing into the theory of psychophysics. Six quantitative indicators were proposed to measure the morphological characteristics of the public space in existing residential neighborhoods in China. The comparative analysis of the spatial vitality of the public space as well as the morphology in the existing residential neighborhoods indicated that four of the indicators were efficient to measure the morphological characteristics of the existing residential neighborhoods which were: the sky view factor, visible ratio, D/H index, and the total depth value index. There was a significant logarithmic relationship with the index of sky view, visible ratio and the D/H through the curve fitting study between the objective attributes of public space morphological features and subjective psychological perception evaluation value of the elderly, which conformed the Steven's law. This would provide a basic data support and more scientific and rigorous research methods for the optimization and transformation in urban existing residential area.

## 1. Introduction

With the acceleration of urbanization, the compactness and the congestion will be an inevitable trend for cities in China and other Asian countries. People's behavior and the perception of the residential environment are being influenced by the dense and vertical living pattern. (Huang Yiru *et al.*, 2016). In China, urban public spaces have become an important places for the daily social activities and participation of the elderly. Its' morphological characteristics as well as the high quality can increase the opportunities of communication among the elderly in residential neighborhoods, and it will play a vital role in regulating the emotional health of the elderly. Existing studies have shown that the changes of building facade, the open space and the sight to the green space have become the key factors affecting users' perception of the space.

Among these factors, the naturalness of residential neighborhoods (Gregory N *et al.*, 2015), the proximity to green space (Mireia Gascon *et al.*, 2018) and other factors can be more effectively in alleviating the physical and mental pressure of the elderly. Expressing perceptual and subjective spatial perception through rational and objective methods have lately received great attention in the field of urban morphology and public health. Based on the psychophysical's "mind-matter" theory, the paper aimed to investigate the relationship of morphological characteristics of the public space in existing urban residential neighborhoods in China and the evaluation of psychological perception of spatial form by the elderly. Through statistical analysis, it aims to find out the relationship between the morphological characteristics of the public space in existing urban residential neighborhoods and the psychological perception of the elderly. Overall, finding out the best threshold of the indicator of the morphological characteristics in the public space in urban residential neighborhoods.

## 2. Methodology

### 2.1. Psychophysics

The goal of psychophysics is to describe the relationship between external physical stimulation and sensation and perception in the form of precise mathematical functions quantitatively. Weber's law, Fisher's law and Stevens' law are the three most classic researches. Spatial form, light, color and sound can be used as physical stimuli to trigger users' psychological perception of shape, brightness and loudness. Physical stimulation is equivalent to the form value of public space in existing urban residential areas, while psychological perception is the perception and evaluation feedback of the perception subject to the form of public space in existing urban residential areas

Modern psychophysics has been applied in the fields of environmental psychology, landscape scenery evaluation and urban spatial morphology. Zhou Yue *et al.* (2012) proposed the algorithms of interface density, near-line ratio based on Weber's Law to describe the overall cognitive difference of street interface; Huang Yiru *et al.* (2016) obtained the relationship model between spatial perception density and "gap-ground sunshine intensity" and "gap-ground sunshine intensity/building number" by regression; Han Junwei *et al.* (2015) found that the relationship between visual entropy and preference value in visual evaluation of pedestrian street landscape conformed to Fichner logarithm law.

In recent years, researchers have been more inclined to study the interaction mechanism between urban form characteristics and environmental perception, cognition, preference and behavior from the perspective of path-finding, location, congestion, security and other spatial organizational structures (Bechtel, 2002; Kubat, 2015), but ignored the impact of interface, enclosure and labeling on users' spatial perception in micro-scale space. In this research, psychophysics was used in the study of the morphological characteristics of the public space in existing urban residential areas in China to seek the quantitative relationship between the attributes and the perceptual response of human beings. Compared with other psychophysics, the main task of psychophysics is to explain the inherent meaning of the mechanism of "environment-psychology-behavior", and to establish subjective views and reflections. The relationship between the characteristics of natural objects is governed by laws. In the process of measurement, the use of physical and mathematical methods can effectively avoid the experimental

errors caused by personal preferences and life experience, only focusing on the evaluation of fitting results, and help researchers simplified the evaluation process.

### 3. Analysis

#### 3.1. Research objectives

As one of the most serious aging cities in China, Tianjin has become a representative research city. According to the spatial distribution characteristics of the elderly population in Tianjin in 2017, Hongqiao District, Hebei District, Hedong District and Nankai District have the highest proportion of the elderly registered population, which were 31.38%, 31.4%, 29.4% and 28.33% respectively. The Zhaohuli residential neighborhood, Xinyuancun residential neighborhood, Santandongli residential neighborhood and Yuxianli residential neighborhood of Tianta Street in Hexi District were selected as the research areas. The information of the four selected districts was shown in Table 1.

#### 3.2. Morphological characteristics attributing to the public space in urban residential neighborhoods

In the field of urban morphology research, the correlation between typical forms of urban residential areas and environmental perception was identified through cross-analysis of different dimensions such as street turning number, environmental diversity, destination accessibility, building height, street width ratio *et al.* For urban designers and environmental psychologists, it is of great significance to do research from the point of micro-scale. According to the visual perception characteristics, this research divided the research interface of public space in existing urban residential areas into the bottom interface (including roads, enclosure greening, etc.), the horizontal enclosure interface and the top interface. By upholding the principles of systematicness, independence, observability and reflecting public aesthetics, this research chose the following six morphological attributes to study:

Table 1. Information of the selected residential areas.

Residential Location	Zhaohuli	Yuxianli	Santandongli	Xinyuancun
				
Basic Information	Construction Year:1986	Construction Year:1985	Construction Year:1991	Construction Year:2000
	Floor area ratio:1.6	Floor area ratio:2.36	Floor Area Ratio:2.23	Floor Area Ratio:2.1
	Ratio of green space:10%	Ratio of green space:20%	Ratio of green space:10%	Ratio of green space:10%
	Aging rate:21%	Aging rate:22%	Aging rate:18%	Aging rate:17%

### (1) Sky view factor

Sky view factor is an important urban morphological parameter as well as an important factor affecting the thermal comfort of urban public space. Its practical significance expresses the degree of closure of urban space. The smaller the value of sky view factor, the more closed the space is. At the same time, the larger the occupied area of buildings entering the visual range of human eyes, the stronger the sense of psychological oppression. In the research, the ratio of the projection area of the sky on the sphere to the whole hemisphere area was calculated by the spherical area ratio method.

### (2) Variation of roofline

The variation of the adjacent roofline reflects the fluctuation degree of the roofline on the top of the building relative to the human viewpoint. For the public space with smaller scale, the larger the fluctuation of the roofline on the top of the building, the more information the fluctuation of the scene reflects, which reflects the richness of the space. In this study, the standard deviation formula  $\rho = \sqrt{\frac{\sum_{i=1}^n (h_i - \bar{h})^2}{n}}$  was used to calculate the variation of roofline. (where  $h_i$  represents the building height and represents the average height of the enclosed building around the public space)

### (3) Spatial openness

The index of D/H can describe people's different spatial openness feelings, which is related to human visual cognitive characteristics. In the research, the D/H index which was proposed by Yoshinobu-ashihara was used as an index to measure the degree of external space openness, which was, the ratio of the distance between observation points and buildings (D) to the height of buildings themselves (H).

### (4) Spatial visibility

The visual part of urban space refers to the area covered by the observer when she/he acts in the city. The higher the visibility of space, the less the occlusion area in the viewer's field of vision, the higher the spatial pleasure. In this study, the calculation formula of Niu Xinyi *et al.* (2011)<sup>1</sup> was used.

### (5) Accessibility of the public space

The study of spatial topology pay attention to the implicit structural characteristics of space. The total depth value represents the convenience of reaching destination. The total depth value of the existing urban residential public space is the sum of the average depth values of each node. The smaller the global depth value, the more convenient the location of the space in the system is.

### (6) First layer interface density

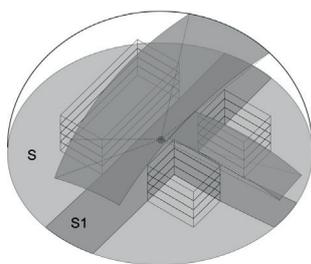
The index of interface density on the first floor is closely related to the degree of dispersion of enclosed buildings around public space in residential areas. The longer the interface is, the

fewer opportunities for the public space to connect with the environment, in the same time the fewer natural light, landscape and a single feeling of external space can be obtained. In this study, the first floor interface density is the ratio of the total length of the first floor interface of all surrounding buildings to the total length of the public space boundary.

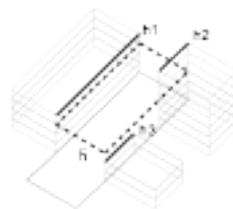
### 3.3. Selection of the Public Space Morphological Index of Urban Existing Residential Neighborhoods Based on Spatial Vitality Index

#### (1) Geographical distribution characteristics of the spatial vitality in residential neighborhoods

According to the behavioral characteristics of the elderly in the public space of residential areas observed regularly and at fixed points in the field survey, the spatial types of high, medium and low vitality indexes were identified and put into ArcGIS system by referring to Jianglei's<sup>2</sup> spatial vitality calculation formula. It was determined that the zones which are graded 10-20 are high vitality, the zones graded 5-10 are medium vitality, the zones graded 1-5 are low vitality.

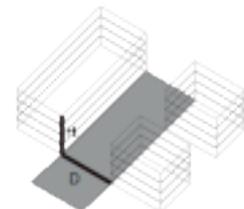


(1) Indicators of Sky View Factor:  $S_1/S$

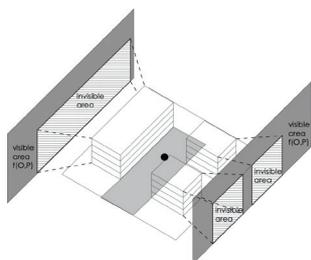


(2) Indicators of variation of roofline:

$$\rho = \sqrt{\frac{\sum_{i=1}^n (h_i - \bar{h})^2}{n}}$$

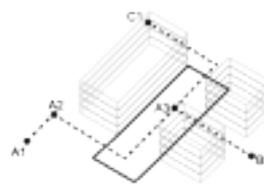


(3) Indicators of spatial openness:  $D/H$



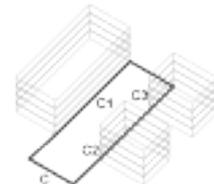
(4) Indicators of spatial visibility:

$$I = (I_a + I_{a+120} + I_{a+240}) / 3$$



(5) Indicators of accessibility:

$$A_1 - A_2 - A_3$$



(6) Indicators of first layer interface density:

$$(C_1 + C_2 + C_3) / C$$

Figure 1. Characteristics attributing to public space morphology in existing urban residential areas.

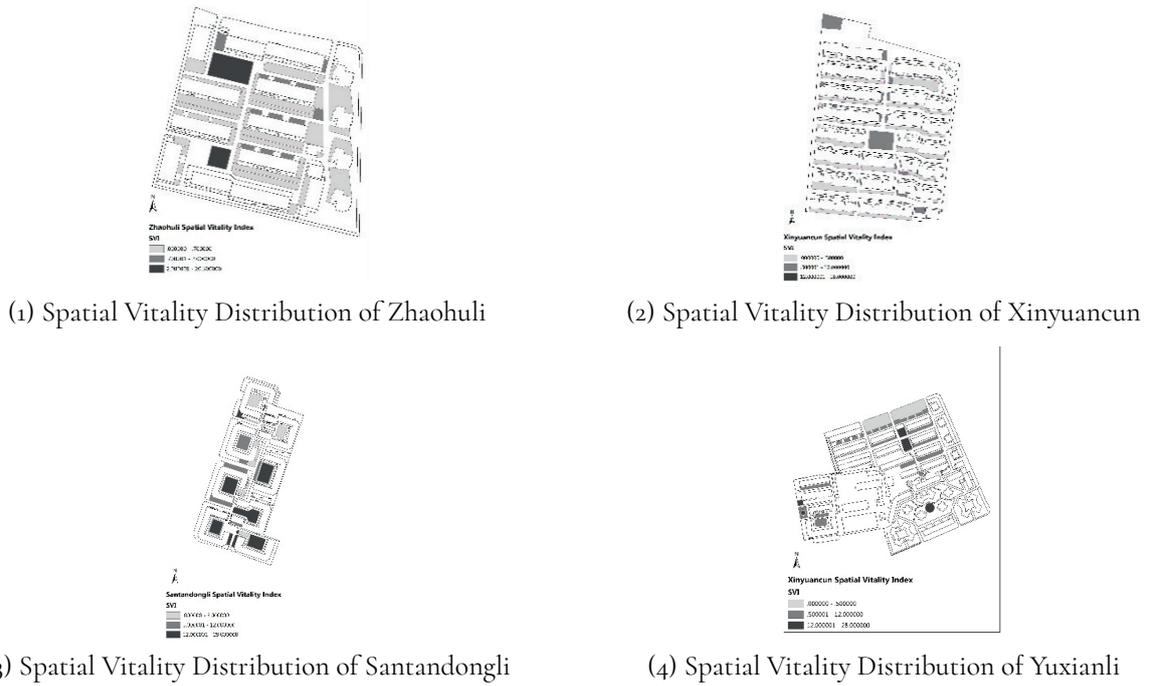


Figure 2. Geographical distribution characteristics of spatial vitality in residential neighborhoods.

Sky view factor						
Variation of Roofline						
Spatial Openness						
Spatial Visibility						
First Layer Interface						
Accessibility						

Figure 3. Morphological characteristics of public space in existing residential areas.

(2) The correlation analysis between the morphological characteristics and the degree of spatial vitality in existing urban residential neighborhoods

The first category: the spatial vitality index had little correlation with the first floor interface density and the variation roofline. According to the distribution law, the spatial vitality index had little correlation with the first layer interface density and the change of roofline. With the increase of spatial vitality index, there was no significant regularity in the change of these two index of the public space in residential neighborhoods.

The second category: spatial vitality had strong correlation with sky view factor, spatial openness, accessibility and spatial visibility. The correlation between spatial vitality index and sky view factor, spatial openness, total depth value and spatial visibility were similar. When space vitality index was low, the morphological characteristics of open sky, spatial openness, spatial accessibility and the spatial visibility were clustered in the first three spatial types. With the increase of space vitality, the spatial type characteristics converged gradually backward to the last three spatial types.

In summary, sky view factor, D/H index, total depth value and the space visibility index had strong impact on the vitality of the public space in existing urban residential neighborhoods, while the correlation between the variation of roofline, the first floor interface density and space vitality were weak. Therefore, this research chose the four highly correlated indicators to quantify the perception of morphological features.

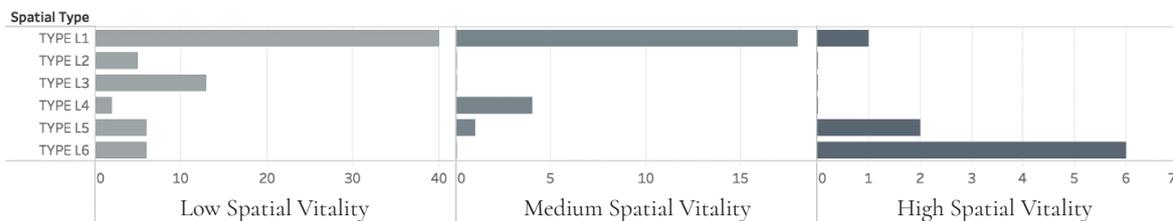
4. Results

4.1. Quantitative Study on Perception of the Public Space Morphological Characteristics in Existing Urban Residential Areas

In order to explore whether there existed the three functional relationships between objective stimulus and subjective perception proposed by psychophysics between stimulus (spatial

Table 2. The correlation degree between spatial vitality and first layer interface density, roof curve value.

First Layer Interface Density and the Spatial Vitality Index



Roof Curve Value and the Spatial Vitality Index

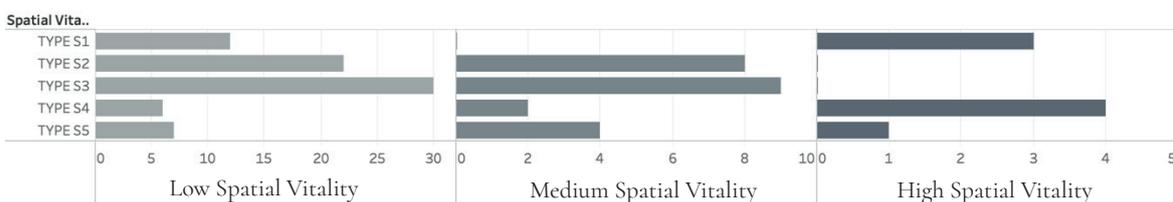
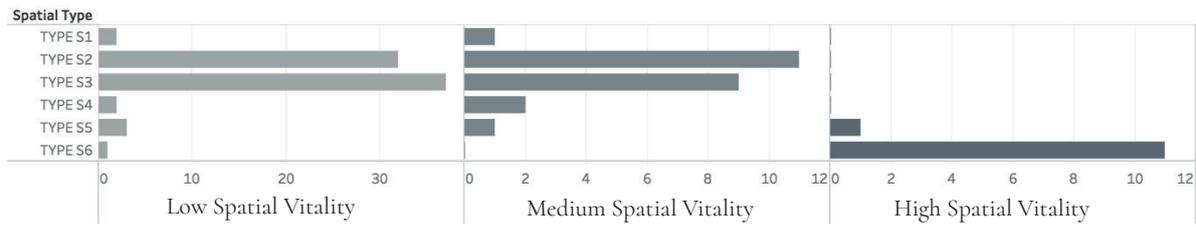
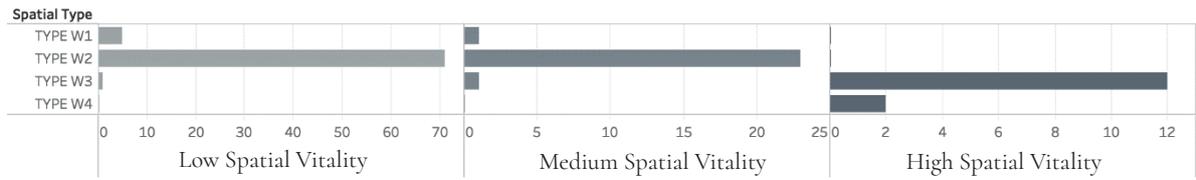


Table 3. The correlation degree between spatial vitality and sky view factor, D/H, total depth value, spatial visibility.

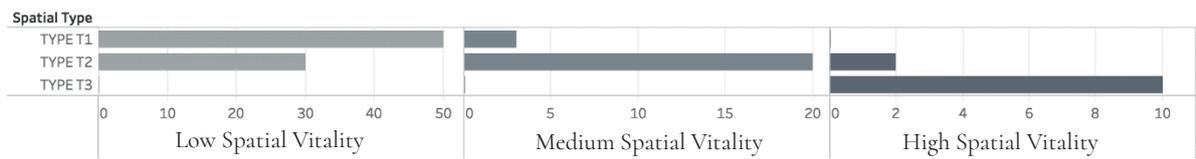
Sky View Factor and the Spatial Vitality Index



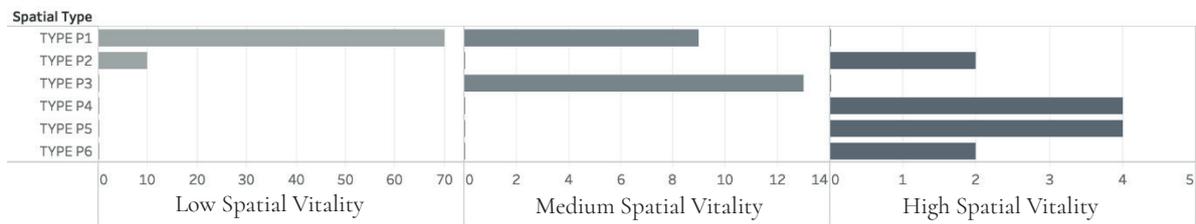
Width/Height and the Spatial Vitality Index



Total Depth Value and the Spatial Vitality Index



Spatial Visibility and the Spatial Vitality Index



attributes) and sensation (evaluation value Table 3. The correlation degree between spatial vitality and sky view factor, D/H, total depth value, spatial visibility. s), 20 high and moderate vitality index public spaces in four residential neighborhoods were selected. Through random invitation to the elderly who were using them. Generally, 30-40 copies of questionnaires were controlled in each residential area, and a total of questionnaires were distributed. 160 questionnaires were selected and 139 valid questionnaires were collected. The questionnaires were formulated by Lickett Scale 7. A total number of 48 elderly people completed the questionnaires. At the same time, in conjunction with the research group of the researcher, a series of symposiums on community public space for the aged were organized. Fifty-six elderly people participated in the perception and evaluation of community public space. Semantic Differential was used to analyze the content of the symposium by comparing the Semantic Differential Scale with the Semantic Differential Scale. With the help of statistical software SPSS, curve fitting were carried out. The results were showed as follows:

### *(1) Curve fitting between sky view factor and sky openness evaluation*

The fitting results showed that the power function relationship between sky view factor and sky openness evaluation was stronger than the linear relationship and logarithmic function relationship. Shown in Fig. 4., and there were significant advantages. Sky openness had a positive effect on the spatial penetration of the subjects. The bigger the front space is, the better the psychological feeling. At the same time, when the sky openness index reached 10%, the user's psychological feeling grew slowly.

### *(2) Curve fitting between D/H and interface space openness evaluation*

The fitting result showed that the power function relationship between aspect ratio and the evaluation of enclosure interface openness was slightly stronger than that between linear and logarithmic functions, as shown in Fig. 4. Spatial aspect ratio had a positive effect on the spatial openness feeling of the subjects. After the index peaking 1.4, the spatial user's openness feeling increases slowly.

### *(3) Curve fitting between spatial visibility and spatial permeability evaluation*

The fitting results showed that the power function relationship between spatial visibility and spatial permeability evaluation was slightly stronger than that between linear and logarithmic functions. The power function model reflected that the degree of public space penetration in residential areas was an important factor affecting the perception of spatial penetration. As the degree of penetration increases, the complexity of spatial interface decreases.

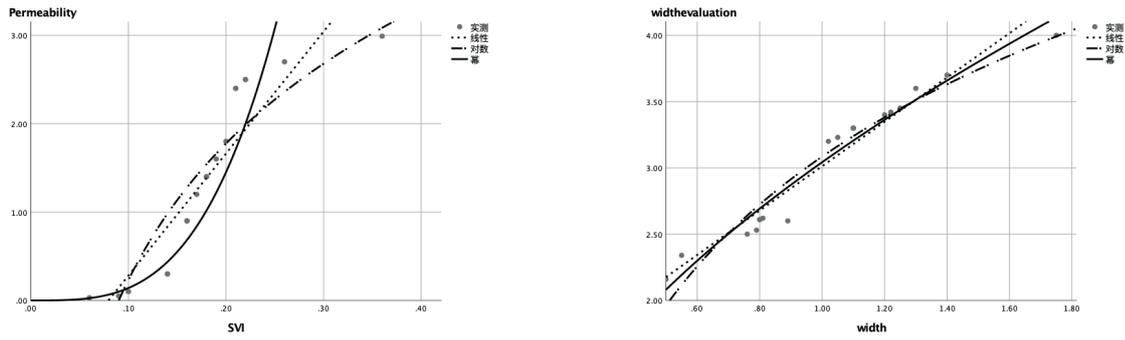
### *(4) Curve fitting between total depth value and spatial convenience evaluation*

The fitting results showed that the linear relationship between global depth and spatial convenience evaluation is stronger than that between logarithm and power function. Global depth had a negative effect on spatial convenience. The lower the global depth, the better the psychological feeling. The linear model reflected that spatial accessibility evaluation would decrease by 1.69 for every increase of global depth.

## 5. Conclusion

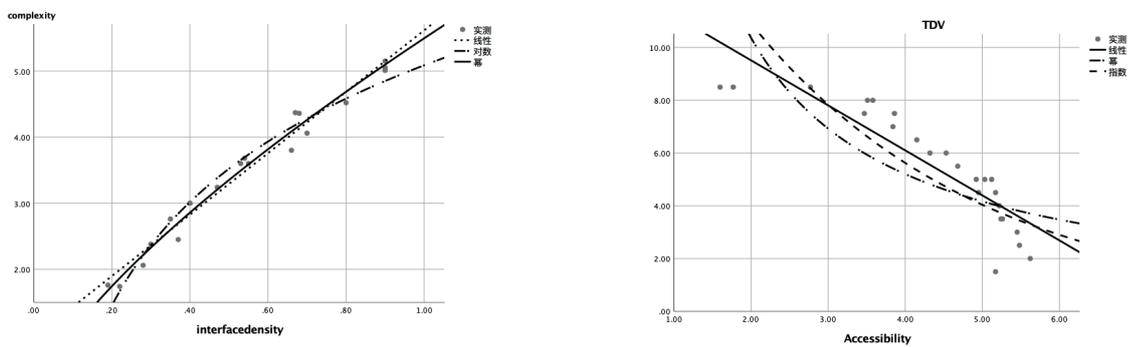
The results showed that the morphological characteristics of urban public space had a significant impact on the spatial perception of the elderly, and the impact can be quantified and described, forming a corresponding relationship function, which is in line with the classical functional relationship of psychophysics. Based on the analysis of the correlation between spatial vitality and public spatial morphological characteristics, it was found that the sky openness, aspect ratio, global depth and spatial visibility have the objective values of physical morphology which are meaningful in the framework of "space-behavior-perception" research.

Sky view factor, D/H and spatial visibility can reflect the positive impact of elderly people on the psychological perception of the public space in existing urban residential neighborhoods: when the stimulus increased in accordance with the geometric level, the perception increases in accordance with the power function level. At the same time, from the trend of fitting



(1) Fitting results of permeability evaluation and sky view factor

(2) Fitting results of spatial openness evaluation and D/H factor



(3) Fitting results of complexity evaluation and spatial visibility factor

(4) Fitting results of convenience evaluation and total depth value factor

Figure 4. Curve fitting results

curve, the psychological perception produced by increasing the shape eigenvalue of the same magnitude tends to decrease gradually, and the total depth value had a negative linear impact on the spatial psychological perception evaluation of the elderly.

## 6. Discussion

In addition, the experimental results showed that the intensity of logarithmic function and power function were similar individually. There may be two reasons: (1) the sample size is not large enough to show a longer function curve, which makes the fitting difference between the two functions incapable of being reflected; (2) the measurement accuracy is not accurate enough, and the subjective perception and psychological quantity collected from questionnaires and interviews are not accurate enough. There were some errors, which affect the later fitting effect.

## Notes

<sup>1</sup> The calculation formula proposed by Niu Xinyi *et al.* (2011):  $I_0 = \frac{O}{N} \times 100\%$ , Among them, O is the observation point, P is any point on the field of view, and N represents the total number of lattices constituting the field of view. Considering that the user is in the public space of the residential area and is affected by the 360 degree viewing angle space, the viewer's viewing

angle range is 120 degrees each time. The final formula for calculating the spatial visibility is:  $I=(I_a+I_{a+120}+I_{a+240})/3$ .

2 Data were provided by Tianjin Committee on Ageing of the Tianjin Government.

3 Referring to the scoring method of vitality index formulated by Jianglei: vitality index  $Y = Y_1$  (number of static activities)+ $Y_2$  (number of interactive activities)+ $Y_3$  (residence time). Among them,  $Y_1$  scoring criteria: the number of people participating in static activities within 15 minutes, each person scored 1 point;  $Y_2$  scoring criteria: the number of interactive activities within 15 minutes, each person scored 1 point;  $Y_3$  scoring criteria: each person staying for 0-1 minutes scored 1 point (time scored 1), each person staying for 1-5 minutes scored 1 point (time scored 3), each person staying for 5-10 minutes scored 1 point (time scored 7.5), each person staying for 10-15 minutes. Personal score is 1 point (time is 12.5), and each person who stays for more than 15 minutes is 1 point (time is 15).

4 Learning from Wu Xi's research: when the boundary surface of public space is equal, the sky openness is positively correlated with the shape ratio of open space. In this research, different types of projection shapes of open sky on the ground were used to refer to the shape types of sky openness.

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