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Aesthetic Evaluation of Commercial Rooftop Plants Based on Beauty Degree Evaluation Method: A Case Study of Chengdu City, China

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Abstract

Rooftop greening not only has ecological benefits such as energy savings, water conservation and air quality improvement but also has aesthetic and social benefits, especially for the rooftops of commercial complexes, which should meet people's demand for beauty while satisfying sustainable urban development. In this paper, 80 samples of ten commercial rooftops in five old urban areas of Chengdu, China, were selected as the research objects, and the beauty values of different roof types and different plant community types were quantified by the aesthetic evaluation method, and the factors influencing the beauty values were investigated. The results showed that the highest average SBE value was for plant ornamental roofs (0.635), followed by recreational roofs (0.080), and the lowest average SBE value was for sports and fitness (−0.555); Mixed needle-broad communities had the greatest average SBE value (0.330), followed by mixed bamboo-broad communities (0.094), while pure bamboo forests had the lowest average SBE value (−0.716). The rooftop plant community's aesthetic value was highly significant and correlated positively with the type of roof, the community's growth type, its vertical structure, and the number of plants in the community.

Keywords

Commercial Rooftops, Plant Communities, Beauty Degree Evaluation

1. Introduction

With the development of social processes, the expansion of urban land, the accentuation of population concentration benefits, and the increasing tension of green space, the once neglected rooftop space began to gradually gain attention

and development. According to incomplete statistics, the green roof areas of Beijing, Shanghai, Shenzhen, Chengdu, Chongqing, etc. have exceeded 1 million·m^2, while Chengdu ranks first with a total of over 3 million·m^2 [1]. Rooftop greenery is not only a direct participant in urban environmental improvement, but also an invisible booster to promote people and nature, create restorative landscapes, and enhance people's mood pleasure, therefore, how to use rooftop space to create satisfactory landscape effects needs to be explored and researched by everyone's joint efforts.

Scenic beauty estimation procedures (SBE) based on public judgment are the most widely used method for evaluating visual resources of landscape. The method is based on psychophysics, which understands landscape and landscape aesthetics as a stimulus-response relationship, and allows the test subjects to rate different landscape pictures one by one according to their own criteria. Finally, the beauty degree scale of the landscape is obtained [2] [3], and the use of this method for the beauty degree evaluation of public green space and plant community landscapes has provided a scientific and effective basis for the improvement and transformation of different types of urban green space plant landscapes in recent years [4]. It can not only evaluate large samples but also save time. At the same time, it can accurately show people's visual perception of the plant landscape. At present, it is considered one of the best methods to evaluate landscape aesthetics in the world.

At present, the beauty evaluation method has been widely used in urban forests, urban parks, urban waterfront spaces, and other green spaces, and the research on roof aesthetic evaluation is relatively small. The plant layout on the roof is different from that on the ground, and different types of roofs also have differences in plant selection. Therefore, through the beauty evaluation method, this paper explores the differences in beauty between different types of roofs and different types of plant communities and finds the factors that affect their variables, so as to provide advice and a reference for the selection of commercial roof plants in Chengdu.

2. Methodology

2.1. Overview of the Study Area

Chengdu, with a total size of 14,335 square kilometers, is located in central Sichuan Province, in the western portion of the Sichuan Basin, between longitudes 102˚54'E and 104˚53'E and latitudes 30˚05'N and 31˚26'N. In the Yangtze River's higher reaches, Chengdu serves as an important species gene pool and green ecological barrier. Its flat topographic conditions are suitable for large-scale urban development and expansion, and commercial building construction is an important part of urban planning, while the rich plant species and suitable climate in Sichuan Province provide favorable conditions for green roof diversification.

The scope of this research includes Chengdu's five old urban areas: Jinjiang

District, Qing yang District, Jinniu District, Wu hou District, and Cheng hua District (Figure 1). Before October 2005, the five urban areas (including the High-tech District) had achieved 300,000 m^2 of new green roofs (50,000 m^2 for each district), 120,000 m^2 of vertical greening (20,000 m^2 for each district), and 60,000 m^2 of green wall construction (10,000 m^2 for each district). In comparison to the new city.

The five urban areas are more densely populated and have more environmental problems. This is due to a lack of land resources in the oldareas, which rarely builds 12-story or 40-meter-lower buildings.

2.2. Sample Classification and Sample Selection

The survey selected 10 rooftops in the region that were built after 2000 (because

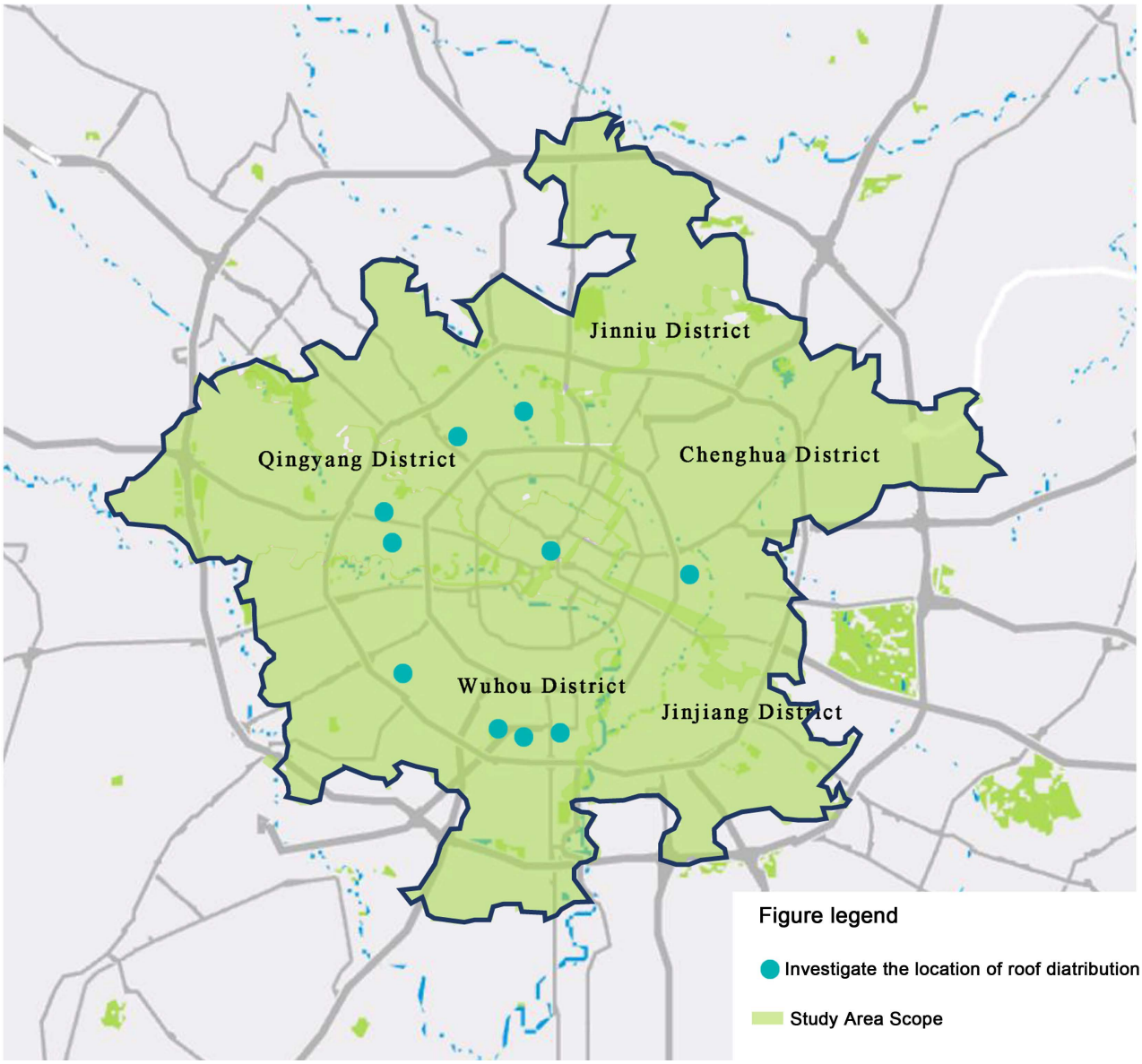


Figure 1. Scope of the research area and sample distribution.

the technical guidelines for green roofs and vertical greening in Chengdu (for trial implementation) were promulgated in 2001), with a commercial area of 100,000 square meters or more, with external green roof space and a variety of community types: Sample 1 (Joy City), Sample 2 (Yintai Center in 99), Sample 3 (Fuli Shopping Plaza), Sample 4 (Jinniu CapitaLand), Sample 5 (Jinsha International Mall), Sample 6 (Longhu-Xichen Tianjie), Sample 7 (Perennial Qingyang Plaza), Sample 8 (Renhe New Town Mall), Sample 9 (Wanxiang City), and Sample 10 (Youfang Shopping Center) were used as the study subjects (**Figure 1**).

The current situation of the site and the characteristics of the plant community arrangement were combined based on a comprehensive survey of commercial rooftops in Chengdu, and from May to June 2022, a typical sampling method was used to set up 10 m by 10 m sample plots with an area of 100 m^2 [5], eight for each roof, and the 80 sample plots were numbered in the order of LA1 to LA8, LB1 to LB8, and LJ1 to LJ8. The ten roofs were clustered into three clusters based on the ratio of green space to pavement, the complexity of the plant community structure, and the main functions of the roofs (**Figure 2**): within the boundaries of the "5" scale, the ten sample sites were divided into three clusters, with sample 1, 8, 3, and 5 clustered into cluster 1. It is observed that Cluster 1 is rich in plant layers, mostly "tree-irrigation-grass" complex structures, the sample square green area is more than 55%, and the main function of the roof is plant landscape; Cluster 2 includes Sample 4 and 7, and it is observed that Cluster 2 sports facilities occupy 70% or more of the area, with more than three

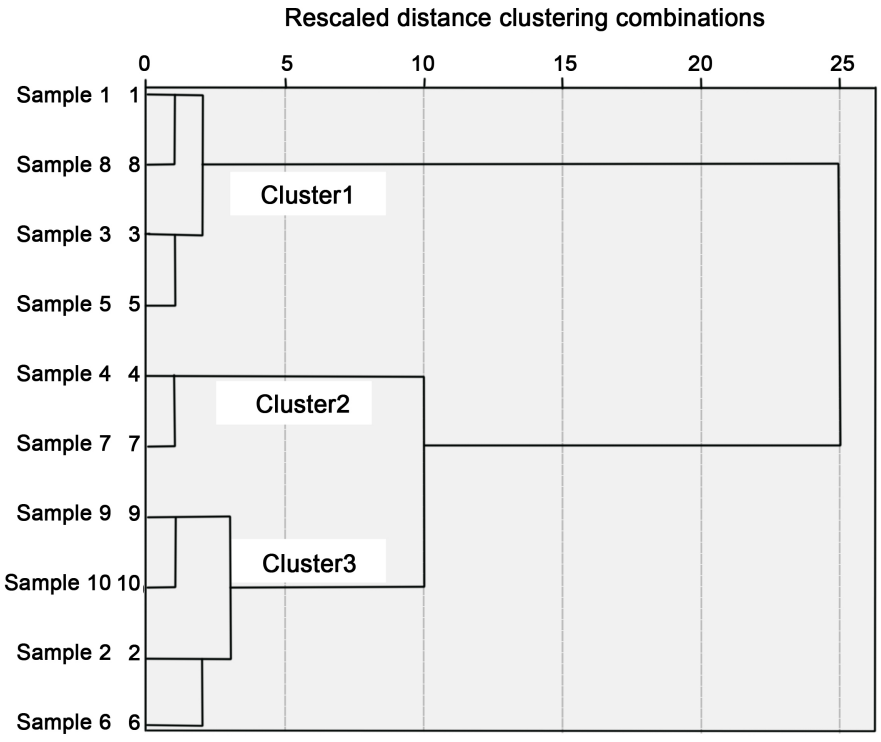


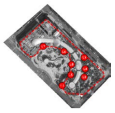
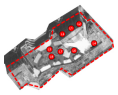
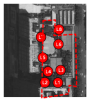
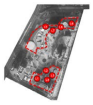
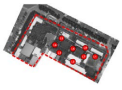
Figure 2. Cluster analysis based on plant compound structure, green space percentage and roof use function.

sports items and fewer plant species; Cluster 3 consists of samples 9, 10, 2, and 6, and it is observed that Cluster 3 is dominated by large paved areas, and the vertical structure of plants is primarily a "irrigation-grass" double-layer structure. These four roofs' primary functions are recreation and dining. As a result, the ten roofs were divided into three categories based on the vertical structure of plants, the proportion of green space, and the main functions of the roofs: Sports and fitness roof, ornamental plants, and recreation, with the area and samples of each roof distributed as follows (Table 1).

2.3. Scenic Beauty Estimation Procedures

Numerous studies have found no significant difference in results obtained by using photographs taken in the field as a medium for evaluating landscape quality and those obtained by being in the field [6]. Photographs of sample plant communities were taken with the same camera in clear, well-lit weather from 9:00 to 16:00 in May-June 2022. Daniel and Boster proposed that the number of photographs chosen for evaluation is determined by the diversity of the community landscape, and that one photograph of a single landscape is sufficient [7]. After removing photographs with obvious non-landscape factors, insufficient information, or obvious light spots or backlighting from each sample site, one photograph that could reflect the entire landscape of the plant community in the sample site was selected as the evaluation object, totaling 80 photographs. Web-based questionnaires have become the most commonly used type of questionnaire due to the rapid development of the Internet in recent years, yielding more scientific and reliable results [8]. In this study, a web-based questionnaire was sent to the raters in the form of a beauty rating questionnaire via the

Table 1. Commercial situation and sample selection in five urban areas of Chengdu.

Roof sample (area/m^2)	roof category	quad select	The square distribution	Roof sample (area/m^2)	roof category	quad select	The square distribution
Sample 1 (18,555)	Plant ornamental	LA_1~LA_8		Sample 6 (9749)	Leisure and entertainment	LF_1~LF_8	
Sample 2 (4606)	Leisure and entertainment	LB_1~LB_8		Sample 7 (3143)	Sports and Fitness	LG_1~LG_8	
Sample 3 (6993)	Plant ornamental	LC_1~LC_8		Sample 8 (3852)	Plant ornamental	LH_1~LH_8	
Sample 4 (11,898)	Sports and Fitness	LD_1~LD_8		Sample 9 (10,257)	Leisure and entertainment	LI_1~LI_8	
Sample 5 (13,351)	Plant ornamental	LE_1~LE_8		Sample 10 (4048)	Leisure and entertainment	LJ_1~LJ_8	

Note: The sample roof area is derived from studio drawing measurements.

Questionnaire Star platform. A 7-point rating scale from 1 to 7 (representing extremely dislike, very dislike, dislike, average, like, like very much, and like very much, respectively) was used as a measure, with higher values indicating more beautiful and popular scenery and lower values indicating less beautiful and popular scenery. Judges score the questionnaires, and finally, the questionnaires are collected and sorted.

To eliminate differences in evaluation criteria among different judging groups, the standardized Z value of the plant community was obtained by averaging the standardized values of all evaluators for each photograph using the standardized beauty formula, which is the standardized beauty value (SBE value) of the plant community, thus reflecting the aesthetic characteristics of the landscape of each plant community and the judges' aesthetic tendency. The following is the calculation formula:

$$Z_{xy} = \left(R_{xy} - R_y\right) \Big/ S_{xy}$$

$$Z_x = \sum_y Z_{xy} / N_y$$

where Z_{xy} is the yth rater's evaluation standardized value of the xth photo, and R_{xy} is the yth rater's rating value of the xth photo. Ry is the mean of all the rating values determined by the yth rater; S_{xy} is the standard deviation of all the rating values determined by the yth rater; Z_x is the landscape standardized score of the xth photo; and N_y is the total number of raters [9].

3. Results and Discussion

3.1. Questionnaire Reliability and Validity and Test of Variance

Through a large number of online questionnaires, 397 rating forms were finally collected and collated; 7 invalid forms were excluded, and a total of 390 valid questionnaires were finally obtained. The distribution of the sample shows that the proportion of males is 51.1% and the proportion of females is 48.9%, which is basically in line with the results of the 7th census of Chengdu: the male population is 10,522,641, accounting for 50.26%; the female population is 10,415,116, accounting for 49.74%; in terms of age, 20 years old to 40 years old has the highest proportion of 79.50%; The proportion of people 40 years old and 60 years old is 15.80%; the proportion of people under 20 years old and over 60 years old is 3.20% and 1.50%, respectively; the proportion of landscape architecture, urban and rural planning, related design majors, and other majors is 46.80% and 53.20%, respectively.

The reliability and validity analysis using SPSS 24 reveals (**Table 2**, **Table 3**) that the standardized Cronbach's alpha is 0.979, indicating that the questionnaire's overall reliability is very high. According to the findings of the following exploratory factor analysis, the coefficient result of the KMO test is 0.938, and the coefficient of the KMO test takes values ranging from 0 to 1. The higher the value is, the more reliable the questionnaire is. This test's significance is infinitely close to zero. Because the original hypothesis was rejected, the questionnaire has high validity.

Table 2. Overall reliability statistics.

Alpha	Alpha based on standardized terms	Number of items
0.979	0.979	80

Table 3. Overall validity test table.

KMO		0.938
Bartlett's sphericity test	Approximate cardinality	31439.622
	Degree of freedom	3160
	Significance	0.000

3.2. Analysis of Beauty Evaluation Results

According to the analysis of the plant communities based on the SBE values of all the judges, there were 43 communities with SBE values of greater than or equal to 0 (relatively good landscape quality), accounting for 53.75%, and 37 communities with SBE values of less than 0 (relatively poor landscape quality), accounting for 46.25%. The top five communities were as follows: LH3 > LA4 > LH2 > LH6 > LA1, primarily in Sample 1 and Sample 8 roofs; the bottom five communities were as follows: LG5 > LG4 > LG1 > LG8 > LD7, primarily in Sample 7. LH3, with an SBE value of 0.798, is the plant community with the highest beauty degree value. This is a mixed evergreen deciduous broad-leaved community of tree, shrub, and grass species (**Figure 3**), with the dominant species being purple-leaved plum, chickweed maple, and golden string willow. Throughout the plant space landscape, the canopy line and seasonal phase changes were implemented. The community with the lowest LD7 beauty degree value of −0.543 is an irrigation-grass broad-leaved evergreen community (**Figure 4**), with a single tree species composition, primarily moonflower and calyx distance flowers, and a small percentage of green space.

The average SBE value of the three types of roof communities was 0.635 for plant ornamental roofs, 0.080 for recreational roofs, and −0.555 for sports and fitness roofs (**Table 4**), with sports and fitness roofs having the lowest average SBE value of the communities. There were 16 sport and fitness roofs, with the top five plant communities being LD1 > LD6 > LD2 > LD5 > LD3. Sport and fitness roof communities all had SBE values less than 0. There was one tree-irrigation-grass type structure plant community, one tree-irrigation, two irrigation-grass, and one tree-grass among these five plant communities. The top five plant communities were LH3 > LA4 > LH2 > LH6 > LA1, which was the same as the overall SBE value ranking, demonstrating that plant ornamental roofs had the largest effect on the average SBE value. There were 21 plant communities with SBE values greater than 0, and all five of these plant communities had the "Trees-Shrubs-Groundcovers" structure. There were 32 recreational rooftops,

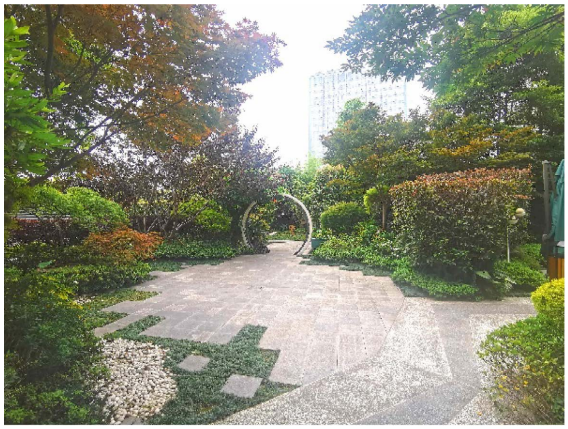


Figure 3. Plant community LH3.

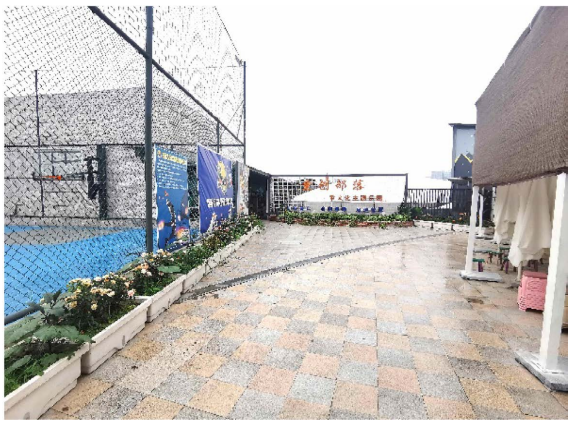


Figure 4. Plant community LD7.

Table 4. Analysis of SBE values for different roof types of beauty.

Roof Type (Average SBE value)	Sample Square	All Judges SBE Mean	Roof Type (Average SBE value)	Sample Square	All Judges SBE Mean
1) Exercise and fitness (−0.555)	LD1~LD8	−0.368	3) Square leisure class (0.080)	LH1~LH8	0.635
	LG1~LG8	−0.742		LB1~LB8	0.096
2) Plant ornamental category (0.635)	LA1~LA8	0.384		LF1~LF8	0.063
	LC1~LC8	0.002		LI1~LI8	0.170
	LE1~LE8	−0.325		LJ1~LJ8	0.119

Note: SBE value > 0 represents relatively good landscape quality, SBE value < 0 represents relatively poor landscape quality; the higher the SBE value the better the landscape quality.

and the top five communities were: LI6 > LB5 > LJ5 > LJ2 > LJ1, with SBE values greater than 0. One of these five plant communities had a "Trees-Shrubs-Groundcovers" structure, whereas the other four had an "Shrubs-Groundcovers" structure.

In terms of different community types (Table 5), mixed coniferous communities had the highest mean SBE value (0.330), followed by bamboo mixed communities (0.094), and pure bamboo forests had the lowest mean SBE value (−0.716), and the mean SBE values of different community types were ranked as follows: mixed coniferous communities > bamboo mixed communities > evergreen deciduous broad-leaved mixed communities > pure shrub communities > deciduous broad-leaved communities > evergreen broad-leaved communities > pure bamboo forests.

3.3. Analysis of Factors Affecting SBE

Correlation analysis of the beauty SBE values with roof type (X1), community growth type (X2), community vertical structure (X3), number of community plants (X4), community mean diameter at breast height (X5), community mean height (X6), and community tree to shrub ratio (X7) was carried out in SPSS 24.0. It was found that the beauty was correlated with X1 ($r = 0.448$, $P < 0.01$), X2 ($r = 0.320$, $P < 0.01$), X3 ($r = 0.295$, $P < 0.01$), and X4 ($r = 0.386$, $P < 0.01$) (Table 6, Table 7); there was no correlation with the mean diameter at breast height (X5), mean height (X6), and tree to shrub ratio (X7).

Regression analysis using the beauty SBE value as the dependent variable, roof type (X1), community growth type (X2), community vertical structure (X3), number of community plants (X4), community mean diameter at breast height (X5), community mean height (X6) and community tree to shrub ratio (X7) as independent variables showed (Table 8) that: roof type ($\beta = 0.383 > 0$, $P < 0.05$), community vertical structure ($\beta = 0.284 > 0$, $P < 0.05$) and community mean height ($\beta = 0.290 > 0$, $P < 0.05$) could significantly and positively affect SBE. the following regression equation was derived between the variables: $SBE = -1.114 + 0.221 \times X1 + 0.090 \times X3 + 0.112 \times X6$.

Table 5. Analysis of SBE values of the beauty of different community types.

Community type (number of sample squares)	Community vertical structure	Average SBE values for different vertical structures of the same community type	Average SBE values for different community types	Community type (number of sample squares)	Community vertical structure	Average SBE values for different vertical structures of the same community type	Average SBE values for different community types
Evergreen deciduous broad-leaved mixed	Trees - Shrubs - Groundcovers	0.089	0.057	Bamboo-broad hybrid	Trees - Shrubs -Groundcovers	0.112	0.094
	Trees-shrubs	0.004			Shrubs - Groundcovers	0.048	
	Trees - Groundcovers	−0.169		Needle-broad hybrid	Trees - Shrubs -Groundcovers	0.330	0.330
	Shrubs - Groundcovers	0.088		deciduous broad-leaved	Trees -Groundcovers	−0.233	−0.233
Evergreen broad-leaved	Trees - Shrubs - Groundcovers	−0.407	-0.309	Pure bamboo forest	Bamboo forest	−0.716	−0.716
	Trees-Shrubs	−0.152		pure shrubs	pure shrubs	−0.019	−0.019
	Shrubs - Groundcovers	−0.298					

Table 6. Description of categorical and continuous variables.

Variables	Different classification cases	Value performance
X_1	1 = "Exercise and fitness" 2 = "Plant ornamental category" 3 = "Square leisure class"	1, 2, 3 only means classification, not assignment
X_2	1 = "Pure bamboo forest" 2 = "pure shrubs" 3 = "deciduous broad-leaved" 4 = "Evergreen broad-leaved" 5 = "Bamboo-broad hybrid" 6 = "Needle-broad hybrid" 7 = "Evergreen deciduous broad-leaved mixed"	1, 2, 3 only means classification, not assignment
X_3	1 = "Bamboo forest" 2 = "pure shrubs" 3 = "Shrubs - Groundcovers" 4 = "Trees - Groundcovers" 5 = "Trees-shrubs" 6 = "Trees - Shrubs - Groundcovers"	1, 2, 3 only means classification, not assignment
X_4	/	The larger the value, the greater the number of plants in the sample community
X_5	/	The larger the value, the larger the average diameter at breast height of the sample community
X_6	/	The higher the value, the higher the average height of plants in the sample community
X_7	/	The greater the ratio, the greater the number of trees in the sample community

Table 7. Correlation analysis of SBE fairness with other factors.

	SBE	X_1	X_2	X_3	X_4	X_5	X_6	X_7
SBE	1							
X_1	0.448**	1						
X_2	0.320**	0.181	1					
X_3	0.295**	−0.020	0.591**	1				
X_4	0.386**	0.484**	0.273*	0.112	1			
X_5	−0.135	−0.232*	0.174	0.121	−0.360**	1		
X_6	−0.063	−0.080	−0.024	0.125	−0.265**	0.435*	1	
X_7	−0.081	0.024	−0.067	0.203	−0.217	0.214	0.572**	1

Table 8. Regression analysis of SBE fairness with other factors.

Impact Factor	Unstandardized coefficient		Standardization factor Beta	t	Significance	Covariance statistics	
	B	Standard Error				tolerances	VIF
(Constant)	−1.114	0.234		−4.764	0.000		
X_1	0.221	0.064	0.383	3.450	0.001	0.702	1.424
X_2	0.017	0.038	0.057	0.444	0.658	0.516	1.937
X_3	0.090	0.039	0.284	2.290	0.025	0.563	1.777
X_4	0.000	0.000	0.130	1.097	0.276	0.613	1.630
X_5	−0.028	0.028	−0.115	−1.001	0.320	0.657	1.522
X_6	0.112	0.048	0.290	2.349	0.022	0.567	1.762
X_7	−0.091	0.042	−0.257	−2.141	0.036	0.600	1.668

Dependent variable: SBE.

4. Conclusions

This article analyzed the aesthetic perception of 80 quadrats of business roofs in Chengdu using the SBE beauty rating method. The data indicated that the average SBE value of plant decorative roofs was the greatest among all roof kinds, at 0.635; recreational roofs came in second, with an average SBE of 0.080; and sports and fitness had the lowest average SBE value of the community, at −0.555. From each roof: the average SBE value of sample 1 is 0.384; the average SBE value of sample 2 is 0.096; the average SBE value of sample 3 is 0.002; the average SBE value of sample 4 is −0.368; the average SBE value of sample 5 is −0.324; the average SBE value of sample 6 is −0.063; the average SBE value of sample 7 was −0.742; the average SBE value of sample 8 is 0.635; the average SBE value of sample 9 is 0.170; the average SBE value of sample 10 is 0.119. In conclusion, the average SBE value of the ten roof plant communities was sample 8 > sample 1 > sample 9 > sample 10 > sample 2 > sample 3 > sample 6 > sample 5 > sample 4 > sample 7.

There were large differences in the SBE values of different types of communities: the highest mean SBE value was for mixed coniferous communities (0.330), followed by mixed bamboo and broadleaf communities (0.094), and the lowest mean SBE value was for pure bamboo forests (−0.716), and the mean SBE values of different community types were ranked as follows: mixed coniferous communities > mixed bamboo and broadleaf communities > mixed evergreen deciduous broadleaf communities > pure shrubs > deciduous broad-leaved communities > evergreen broad-leaved communities > pure bamboo forests. In summary, the SBE evaluation results show that the mixed coniferous community has a better landscape effect and the tree-shrub-grass community structure is relatively more popular.

The beauty value of rooftop plant communities was highly significantly corre-

lated with roof type, community growth type, community vertical structure and the number of plants in the community; roof type, community vertical structure and the average height of the community could significantly and positively influence the SBE, indicating that people are more satisfied with plant landscapes with rich plant communities and well-defined hierarchical structures.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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