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SPATIAL INFLUENCE ON HUMAN BEHAVIOR IN OPEN SPACE USING THE ENTROPY METHOD: A CASE STUDY OF CAMPUS COMMUNITIES IN HANGZHOU CITY, CHINA

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ABSTRACT: The rapid urbanization of Chinese cities has been resulting to the degradation of urban residential environments. As a representative of green areas, residential open spaces play key roles to balance the needs for both conservation and development. Traditional ways to observe resident's behavior mode only by calculating the absolute population count is not perfect. In order to achieve the goal of public benefits, this study attempts to develop traditional behavior approaches to establish an unconventional determinant factor to enable the examination of temporal regulation, spatial distribution and activity category of residents' behavior through the Behavior Entropy Index (BEI). Through this study, the author hopes to provide recommendations to interrelate the local view into planning process. The data was collected in 6 different residential areas and 4 campuses in Hangzhou. In sum, the result obtained from the study aiming to not only satisfy residents' desire of the improvement of open space but also bring to professional's attention by examining the diversity of user's behavior in the context of residential open space utilization and finding out physical factors which influence their satisfaction and behavior. The samples can be hopefully extended to reasonably represent the overall situation of Yangtze River Delta and provide a valuable reference for other regions of China.

Keywords: Open space, behavioral entropy index, spatial influence

INTRODUCTION

Amerigo and Aragones (1997) addressed that life satisfaction is closely related to residential satisfaction. Urban residential environment plays a vital role in the local society since it is directly relevant to human daily lives. One aspect of the urban residential environment is concerned with open space (Gehl 1987), since it provides diverse benefits and opportunities to people's relaxation that constitutes to mitigating the pressure on urbanites. Consequently, open spaces have been given great importance as one of the indicators of quality of urban environments. People can gain direct benefits from open space service that are related to physical health as well as improved mental health. At the same time, open spaces also contribute indirect benefits to local communities in terms of social, economic and cultural levels.

But traditional planning and design approaches mainly focus on spatial forms and building styles with a viewpoint of visual aesthetics. In addition, local authorities introduce environmental impact assessment into planning and design processes. Though some professionals and experts have begun to convert part of attention to users' subjective evaluation in recent years (Wu 1995; Xu and Yang 1996; Zhu and Wu 2002), Chinese environmental planners and designers are in dilemma, pursuing the maximum monetary profit or realizing the maximum social profit. A preliminary survey concerning the first choice on leisure places conducted in Hangzhou shows that planners should improve the current performance of residential open space to meet residents' desire of leisure.

The above retrospection concerning Chinese residential open space elicits an implication (Yu et al. 2006) that: (1) the traditional top-down approach in residential open space planning and implement should be integrated with scientifically based methods; (2) the functions of the current residential open spaces were mainly provision of green cover, with insufficient concern for human uses such as recreational uses. Recreational uses should be considered and integrated

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into existing and planned residential open spaces; (3) the recently invoked “city beautiful”, or cosmetic approach to residential open space planning and implementation should be stopped; (4) Residential open spaces should be planned as a critical strategic element of ecological infrastructure at both the regional and urban scale during current rapid and extensive urbanization occurring in China.

This research intends to propose a conceptual framework to examine user’s behavior towards their living space and seek spatial factors which influence their views and behavior. Some specific research contributions are described as following: (1) The assessment of residential open space users’ behavior based on the behavioral dynamics model provides a method to observe and examine the intrinsic relationship between temporal, spatial and categorical levels. Based on the entropy theory (Shannon and Weaver 1948; Wilson 1970), this method develops the concept of entropy in the field of environment-behavior, for enhancing outdoor space performance by incorporating the behavioral complexity, differently with the conventional method of population count (Sisiopiku and Akin 2003). (2) The comparison among the common case and the campus case examines the differences in terms of spatial scale and property. Moreover, the correlation analysis and the regression analysis clarify the influence of spatial factors on residents’ evaluation and behavior.

Many researchers manage to explain some special dynamic phenomena in different backgrounds. Brink (1996) uses spatial information as an aid to analyze the maximum entropy image threshold selection. Ichiro (2008) discusses the entropy law in aquatic communities and the general entropy principle for the development of living systems. Roy and Lesse (1981) present appropriate microstate descriptions in entropy modeling.

Since open space is one kind of public facility that is provided to maximize social benefit to the community, it becomes significant to link the professional side with common people. It is expected to provide valuable information for professional practice based on the behavioral model and the study of spatial influence on resident’s satisfaction and behavior.

2. SITUATIONS IN SURVEY AREAS

Residential open spaces in Hangzhou City, China are selected as the study area in this paper. The focus of this research is on some specific spaces that are daily utilized by the users for their recreational purpose, including: neighborhood open spaces, and university campuses. Unlike the US, Europe or Japan, most students in China live on campus as same as residents who live in a neighborhood community. In some regionally central cities, the population of college students is a considerable number. For example, there are more than 600,000 college students in Beijing City, 500,000 in Shanghai City and 300,000 in Hangzhou City, China (National Bureau of Statistics, China 2005). In other words, university campuses should be regarded as a specific type of residential area in China. However, the synthetic consideration of common residences and campuses is still insufficient while related research selects the study areas. As a result, this study makes a comparison and comprehensive consideration on both sides.

The selected residential areas and campuses in Hangzhou city are depicted in Fig. 1.

The two selected campuses, Zi-Jin-Gang Campus and Xi-Xi Campus are suitable to be the typical objects for behavior survey. The former is a representative of the new fashionable type located in the suburban area, while the latter is a representative of the old type located in the central area of the city.

According to the planning transportation system and the current situations in the survey, both the Zi-Jin-Gang campus (Table 1) and Xi-Xi campus (Table 2) are divided into 3 sections (A,B,C) respectively. The partition considered the functions of land, the road level (width) and the traffic control. Section A is the living area (dorm area), Section B is mainly the sports area, and Sections C and D are the study areas.

Fig. 1 Study Area, Hangzhou City
(Rectangle: Residence, Circle: Campus)

Table 1 Area of the Sections of Zi-Jin-Gang Campus

	A1	A2	A3	A4	B1	B2	B3	C1	C2	C3	D1
Total Area (HA)	24.91	10.67	10.44	15.38	8.26	13.79	16.50	17.35	47.43	19.38	14.17
Open Area	0	8.00	0	12.46	8.02	12.27	15.02	15.26	42.69	16.67	0
Description	Null	Dorm	Null	Dorm	Field	Study	Gym	Study	Study	Study	Null

Note: Null denotes under construction

Table 2 Area of the Sections of Xi-Xi Campus

	A1	A2	A3	A4	B1	B2	B3
Total Area	5.27	1.84	3.02	8.47	1.48	2.42	1.71
Open Area	2.72	1.05	1.88	5.14	1.48	2.35	1.36
Description	Dorm	Dorm	Dorm	Dorm	Field	Field	Gym
	C1	C2	C3	C4	C5	C6	
Total Area	2.54	2.45	2.20	3.77	2.70	3.24	
Open Area	1.77	1.62	1.41	2.65	2.69	2.20	
Description	Study	Study	Study	Study	Study	Study	

3. MODEL DEVELOPMENT

People's behavior in open space is diverse in terms of three dimensions - temporal, spatial and categorical. It can be regarded as a kind of complex system that consists of multiple forms. How to characterize the distribution of daily activities in campus open spaces calls for much attention of designers and planners. It seems natural to assume that, if an open space system is a complex system, any internal changes will be reflected in established measures of the complexity of the system (where ‘‘complexity” is seen as a system attribute capturing one or more aspects of the system's structure, function or dynamics) (Parrott 2005). How to measure "complexity" has become a common practice for describing spatial structural property in the fields of urban geography and landscape ecology. One common approach to characterize complexity is to use information-based measures such as Shannon entropy and its relatives to classify a data set according to its degree of order or randomness.

3.1 Method of Behavioral Dynamics Model

The Shannon entropy (Shannon 1948), Hs, of a binary sequence is thus computed as follows:

$$H_s(L) = -\sum_{i=1}^{N} p_{L,i} \log_2 p_{L,i} \qquad (1)$$

Where $H_s(L)$ is the Language Entropy Index,

$p_{L,i}$ is the relative frequency (probability) of the ith language option.

N is the number of language options.

$p_{L,i}$ log2 $p_{L,i}$ = 0 for $p_{L,i}$ = 0. For a random sequence, all words are equally probable (all $p_{L,i}$ are equal), and the maximum value of Hs = log N is obtained. The minimum value, Hs = 0, occurs when one $p_{L,i}$ = 1 and the others are all zero (maximally ordered string).

The behavior of residents in open space includes three levels of characteristics: temporal, spatial, and categorical characteristics. The dynamics of the behavior was examined by employing the idea of Entropy, as follows:

$$BEI = \frac{-\sum_{j=1}^{n} p_j \log_2(p_j)}{\log_2(n)} \qquad (2)$$

where BEI is the Behavioral Entropy Index,

p_j is the relative frequency (probability) of the jth behavioral option.

n is the number of behavioral options.

Division by $\log_2(n)$ serves to normalize the measure into 0-1.

3.2 Result and Analysis of the BEIs

According to the definition of the behavior entropy, the value of BEI stands for the diversity of people's behavior. Take the Temporal BEI for example.

The simple dynamics of population (Fig. 2 and 3) provide insufficient information of students' behavior. It is necessary to explore further into the complexity of students' behavior. The results of a temporal behavioral entropy index revealed that (Fig. 4): (1) Although special affairs or incidents arises the temporal behavioral complexity on the seventh day, the extent should be assessed carefully, instead of only comparing the simple number of population; (2)The weather conditions still influence the temporal behavioral complexity, because rain cuts down the opportunity for outdoor life.

Daily Temporal BEI = f (x_i),

where x_i = hourly accumulative population during the day, i = 1, 2, 3, …, 24.

(The above function is also used in all the BEI calculations)

Total Temporal BEI = f (x_i),

where xi = hourly accumulative population during the 12 weeks (or 6 weeks), i = 1, 2, 3, …, 24.

Temporal BEI of Conditional Random = f (x_i),

where x_i = 1/12, i = 6, 2, 3, …, 18;

x_i = 0, i = 1, 2, 3, 4, 5, 19, 20, 21, 22, 23, 24.

The value becomes 1 if all the periods of the day and night can be used by outdoor activities, and the population distribution is evenly balanced. On the contrary, the value becomes 0 if the outdoor population congregates into only one period or nobody outdoors. As a medium, the value of conditional random becomes approximately 0.78 if the daytime periods from 6:00 to 18:00 are used in balance.

We can also calculate the spatial and categorical BEIs in the same way.

At the spatial (section) dimension:

Daily Spatial BEI = f (x_i),

where x_i = hourly accumulative population in the sub-section, on that day, i = A1, A2, …, C6.

Total Spatial BEI = f (x_i),

where x_i = hourly accumulative population throughout the 12 weeks (or 6 weeks), i = A1, A2, …, C6.

The value becomes 1 if all the sections of the community or campus can be used by outdoor activities, and the population distribution is evenly balanced. On the contrary, the value becomes 0 if the outdoor population congregates into only one section or nobody outdoors. As a medium, the value of conditional random becomes approximately 0.85 if the 75% sections are used in balance.

At the categorical dimension:

Daily Categorical BEI = f (x_i), where x_i = hourly accumulative population of the activity category, on the day, i = Study, View, Ramble, Talk, Play, Party, Sports, Perform, Assembly.

Total Categorical BEI = f (x_i), where x_i = hourly accumulative population during the 12 weeks (or 6 weeks), i = Study, View, Ramble, Talk, Play, Party, Sports, Perform, Assembly.

Categorical BEI of Absolute Random = f (xi), where xi = 1/9, i = Study, View, Ramble, Talk, Play, Party, Sports, Perform, Assembly.

The value becomes 1 if all the categories of the activity can be taken by outdoor people, and the population distribution is evenly balanced. On the contrary, the value becomes 0 if the outdoor population congregates into only one category or nobody outdoors. As a medium, the value of conditional random becomes approximately 0.80 if the 70% categories are used in balance.

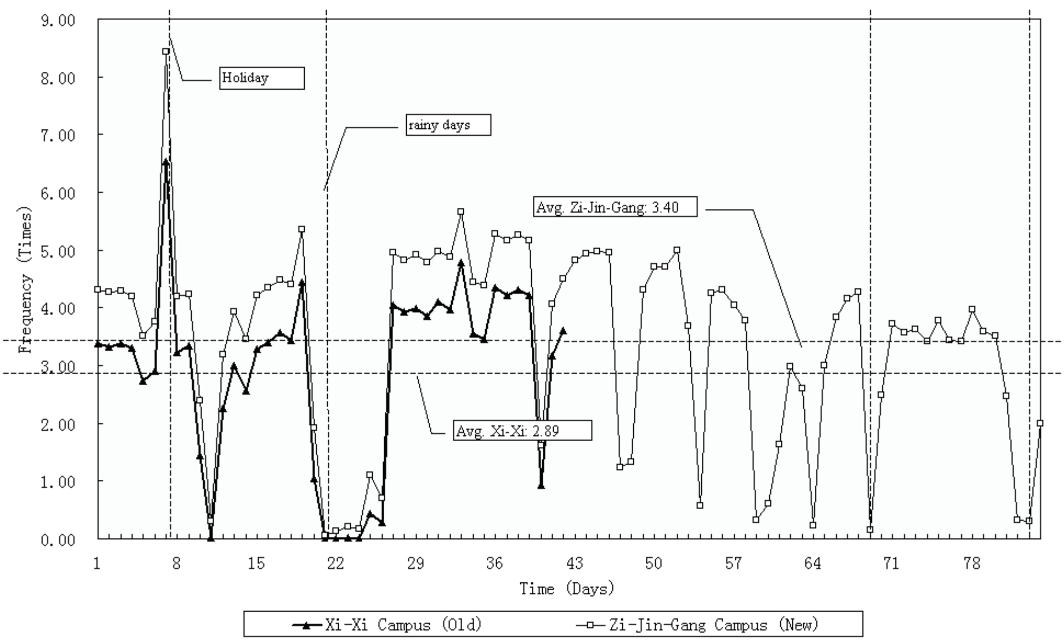

Fig. 2 Average frequency dynamics within a 12-week (6-week) period, measured as the ratio of daily accumulative number of students outdoors to all the samples

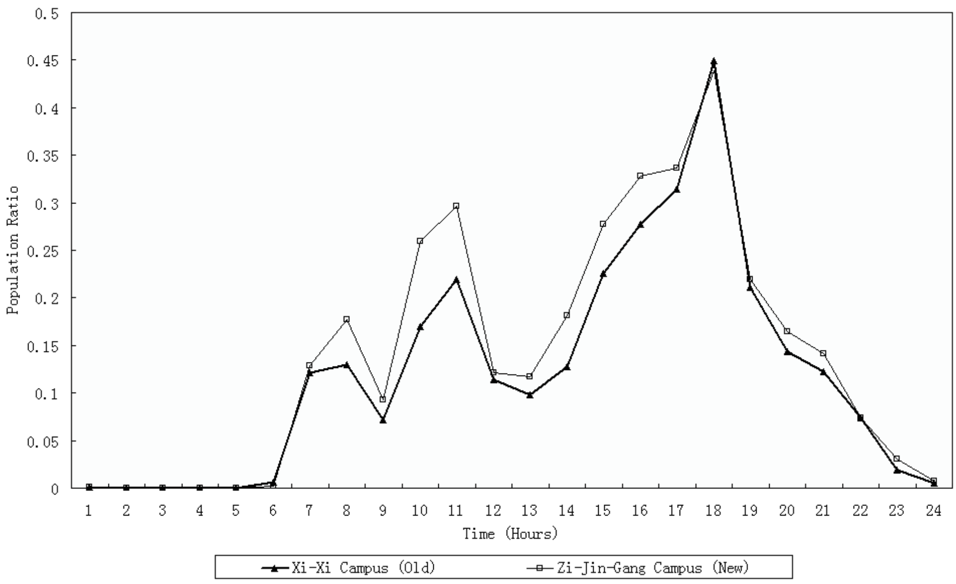

Fig. 3 Hourly population ratio dynamics within a 12-week (6-week) period, measured as hourly accumulative number of people in campus open spaces. Note: the temporal point stands for the end of the hour period, e.g. 12 means the span from 11:00 to 12:00

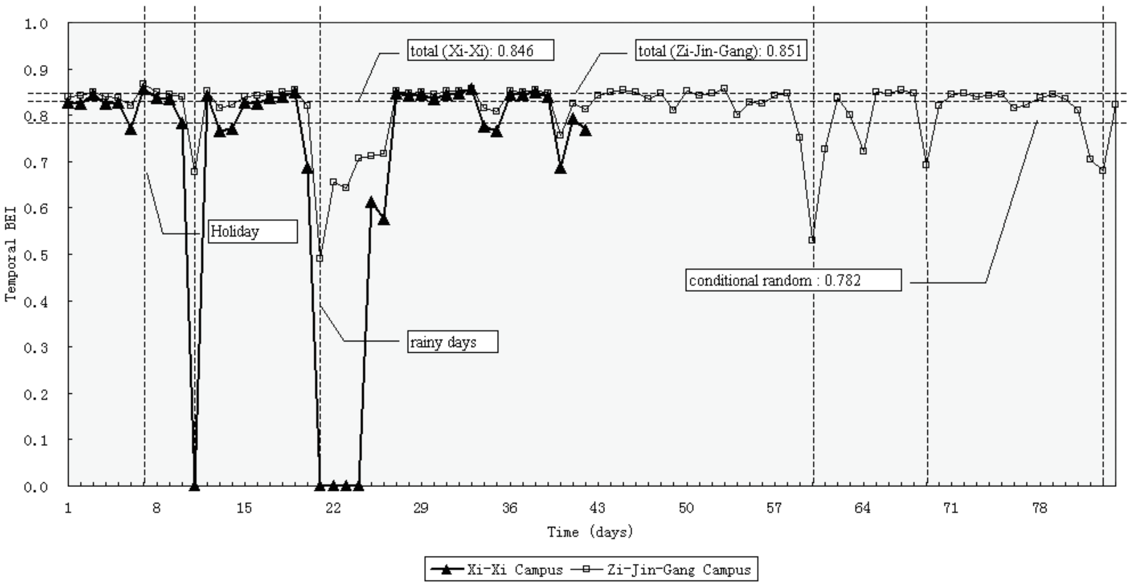

Fig. 4 Total temporal dynamics throughout a 12-week (6-week) period; the daily temporal BEI is measured as hourly accumulative number of people presence on campus

4. SPATIAL INFLUENCE ON SATISFATION & BEHAVIOR

In this session, we'll concentrate on clarifying the influence of spatial factors on residents' evaluation and behavior, and examining the differences in terms of spatial scale and properties by comparing cases among communities and campuses. The spatial factors in this study can be categorized into 18 items (Table 3).

4.1.1 Comparison Analysis

With a comparison of Spatial Indices and Satisfaction Indices within the six communities (Table 4), a conclusion could be drawn that the satisfaction is significantly correlated to the spatial properties of residential open space, the same as the campus case (Table 5). In other words, the relatively new built communities or campuses are generally evaluated higher than the old ones.

While the last community, Xia-Sha Community, should be noted since it is evaluated unexpectedly low although the spatial qualities are not worse. The reason is that open space is also influenced by some external conditions, instead of spatial characteristics. The community of Xia-Sha is located far from urban area, almost more than one-hour drive distance so that people have no abundant leisure time to enjoy open space, which decreases the attractiveness and neighborhood communication. Moreover, many factories are located in the surrounding area. As a result, health of open space is deteriorated on the air, noise and so on.

Table 3 Structure of spatial index system

Spatial Index	Definition	Formula
Neighborhood Park Accessibility Index	Reciprocal of average distance between house and park (/km).	$ParkAccess = \frac{1}{Distance}$
Small Playing Plot Accessibility Index	Reciprocal of average distance between house and plot (/m).	$PlotAccess = \frac{1}{Distance}$
Sports Field Accessibility Index	Reciprocal of average distance between dorm and sports field (/km).	$SportsAccess = \frac{1}{Distance}$
Green Index	Ratio of green area to total open space area	$Green = \frac{GreenArea}{OpenArea}$
Water Index	Ratio of water area to total open space area	$Water = \frac{WaterArea}{OpenArea}$
Road Index	Ratio of main road (bi-way) area to total land area	$Road = \frac{RoadArea}{TotalArea}$
Openness Index	Ratio of open space area to total land area	$Openness = \frac{OpenArea}{TotalArea}$
Car parking Index	Ratio of car parking spaces to total land area	$CarParking = \frac{CarSpace}{TotalArea}$
Bike parking Index	Ratio of bike parking spaces to total land area	$BikeParking = \frac{BikeSpace}{TotalArea}$
Fire Engine Index	Cover rate of fire engine accessible area to total open area	$FireEngine = \frac{EngineAccessArea}{OpenArea}$
Bench Index	No. of benches per 100 square meters (No./ha.).	$Bench = \frac{No.}{OpenArea} \times 100$
Light Index	No. of lights per 100 square meters (No./ha.).	$Light = \frac{No.}{OpenArea} \times 100$
Instrument Index	No. of Instruments per 100 square meters (No./ha.).	$Instrument = \frac{No.}{OpenArea} \times 100$
Display Index	No. of display items (show window) per 100 square meters (No./ha.).	$Display = \frac{No.}{OpenArea} \times 100$
Shop Index	No. of shops per 100 square meters (No./ha.).	$Shop = \frac{No.}{OpenArea} \times 100$
Semi-open Index	Ratio of semi-open area to total open space area	$SemiOpen = \frac{SemiOpenArea}{OpenArea}$
Plaza Index	Ratio of plaza (square) to total open area	$Plaza = \frac{PlazaArea}{OpenArea}$
Blind Index	Ratio of dead angle area to total open area	$Blind = \frac{BlindArea}{OpenArea}$

Table 4 Comparison of Spatial factors and satisfaction of Common Case

		Name of Community					
		Q-H-F	Qiu-Shi	Cai-He	Cui-Yuan	Wen-Xin	Xia-Sha
Spatial Index	1.1. Park Accessibility	0.00	0.00	6.06	7.13	7.65	7.01
	1.2. Small Plot Accessibility	0.11	0.01	0.05	0.06	0.05	0.02
	1.3. Sports Accessibility	0.00	0.00	3.14	4.87	9.23	8.35
	1.4. Green	0.09	0.21	0.29	0.32	0.39	0.35
	1.5. Water	0.01	0.00	0.02	0.03	0.04	0.03
	1.6. Road	0.02	0.08	0.05	0.04	0.04	0.05
	1.7. Openness	0.28	0.55	0.62	0.65	0.75	0.68
	1.8. Car parking	0.01	0.00	0.11	0.14	0.35	0.23
	1.9. Bike parking	0.01	0.06	0.08	0.10	0.26	0.21
	1.10. Fire Engine	0.46	0.84	0.91	0.93	1.00	1.00
	2.1. Bench	0.07	0.01	0.12	0.13	0.15	0.11
	2.2. Light	0.31	0.25	0.26	0.28	0.35	0.30
	2.3. Instrument	0.00	0.01	0.04	0.05	0.06	0.03
	2.4. Display	0.08	0.01	0.03	0.04	0.10	0.06
	2.5. Shop	0.09	0.04	0.06	0.07	0.05	0.01
	2.6. Semi-open	0.12	0.01	0.05	0.06	0.03	0.01
	2.7.Plaza	0.09	0.02	0.05	0.06	0.05	0.02
	2.8. Blind	0.04	0.01	0.02	0.01	0.00	0.00
Satisfaction Index	Applicability	0.19	0.17	0.67	0.71	0.85	0.53
	Amenity	0.54	0.05	0.39	0.64	0.78	0.45
	Health	0.26	0.42	0.36	0.45	0.82	0.20
	Safety	0.16	0.60	0.58	0.64	0.67	0.33
	Community	0.87	0.52	0.68	0.81	0.59	0.09
	Total	0.35	0.23	0.61	0.65	0.77	0.32

Table 5 Comparison of Spatial factors and satisfaction of Campus Case

		Name of Campus			
		ZJU-YQ	ZJU-XX	ZJGSU	ZJU-ZJG
Spatial Index	1.1. Park Accessibility	1.61	2.15	1.27	1.08
	1.2. Small Plot Accessibility	0.01	0.02	0.05	0.06
	1.3. Sports Accessibility	3.09	5.23	0.96	2.51
	1.4. Green	0.32	0.27	0.42	0.55
	1.5. Water	0.02	0.01	0.03	0.08
	1.6. Road	0.12	0.06	0.10	0.09
	1.7. Openness	0.78	0.75	0.84	0.89
	1.8. Car parking	0.06	0.03	0.12	0.10
	1.9. Bike parking	0.03	0.03	0.05	0.06
	1.10. Fire Engine	0.93	0.95	0.96	0.98
	2.1. Bench	0.04	0.04	0.06	0.07
	2.2. Light	0.30	0.35	0.42	0.45
	2.3. Instrument	0.02	0.02	0.03	0.03
	2.4. Display	0.03	0.03	0.06	0.05
	2.5. Shop	0.04	0.06	0.01	0.02
	2.6. Semi-open	0.01	0.02	0.03	0.06
	2.7.Plaza	0.03	0.02	0.04	0.04
	2.8. Blind	0.08	0.05	0.05	0.14
Satisfaction Index	Applicability	0.28	0.37	0.53	0.72
	Amenity	0.19	0.22	0.74	0.92
	Health	0.34	0.58	0.76	0.83
	Safety	0.35	0.41	0.49	0.62
	Community	0.32	0.44	0.46	0.54
	Total	0.41	0.47	0.67	0.75

4.1.2 Correlation Analysis

With a correlation analysis of Spatial Indices and Satisfaction Indices within the six groups (Table 6 and 7), it shows that the satisfaction is significantly correlated to the spatial properties of residential open space and campus.

Table 6 Correlation of Spatial factors and Satisfaction of Common Case

Spatial Index	Satisfaction Index					
	Applicability	Amenity	Health	Safety	Community	Total
1.1. Park Accessibility	.947(**)	.755	.592	.669	-.024	.970(**)
1.2. Small Plot Accessibility	-.084	.241	-.376	-.796	.892(*)	.082
1.3. Sports Accessibility	.804	.823(*)	.845(*)	.614	-.195	.925(*)
1.4. Green	.865(*)	.636	.782	.889(*)	-.419	.840
1.5. Water	.909(*)	.925(**)	.668	.467	.086	.975(**)
1.6. Road	-.209	-.566	.120	.582	-.808	-.375
1.7. Openness	.798	.504	.762	.957(*)	-.556	.724
1.8. Car parking	.834(*)	.896(*)	.895(*)	.558	-.241	.890(*)
1.9. Bike parking	.703	.753	.962(**)	.655	-.456	.769
1.10. Fire Engine	.722	.377	.682	.985(**)	-.592	.642
2.1. Bench	.930(**)	.904(*)	.509	.340	.254	.979(**)
2.2. Light	.405	.845(*)	.593	-.129	.147	.528
2.3. Instrument	.981(**)	.757	.702	.764	-.181	.944(*)
2.4. Display	.336	.813(*)	.472	-.319	-.284	.387
2.5. Shop	-.124	.000	-.600	-.793	.973(**)	-.030
2.6. Semi-open	-.342	.095	-.425	-.923(*)	.925(*)	-.183
2.7 Plaza	-.452	.045	-.389	-.949(*)	.913(*)	-.290
2.8. Blind	-.608	-.346	-.756	-.943(*)	.696	-.498

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

Table 7 Correlation of Spatial factors and Satisfaction of Campus Case

Spatial Index	Satisfaction Index					
	Applicability	Amenity	Health	Safety	Community	Total
1.1. Park Accessibility	-.754	-.867	-.578	-.727	-.467	-.801
1.2. Small Plot Accessibility	.971(*)	.990(**)	.957(*)	.954(*)	.986(*)	.999(**)
1.3. Sports Accessibility	-.472	-.688	-.432	-.419	-.209	-.619
1.4. Green	.936	.950	.963(*)	.929	.742	.921
1.5. Water	.904	.854	.684	.914	.731	.832
1.6. Road	-.148	.048	-.358	-.180	-.499	-.070
1.7. Openness	.922	.964(*)	.772	.908	.716	.931
1.8. Car parking	.695	.861	.661	.650	.473	.813
1.9. Bike parking	.971(*)	.997(**)	.887	.957(*)	.831	.986(*)
1.10. Fire Engine	.977(*)	.906	.767	.981(*)	.893	.944
2.1. Bench	.971(*)	.997(**)	.887	.957(*)	.831	.986(*)
2.2. Light	.969(*)	.963(*)	.987(*)	.956(*)	.941	.988(*)
2.3. Instrument	.980(*)	.902	.810	.876	.709	.949
2.4. Display	.753	.888	.815	.709	.635	.876
2.5. Shop	-.673	-.844	-.617	-.628	-.430	-.788
2.6. Semi-open	.982(*)	.905	.868	.991(**)	.966(*)	.969(*)
2.7.Plaza	.729	.872	.609	.693	.460	.810
2.8. Blind	.658	.563	.345	.687	.467	.527

* Correlation is significant at the 0.05 level (2-tailed)
** Correlation is significant at the 0.01 level (2-tailed)

Table 8 Rotated Component Matrix

Principal Factor	Component 1	Component 2	Component 3
Principal Factor 1:Landscape and Usage			
1.1. Park Accessibility	.998	-.014	.059
2.3. Instrument	.973	-.176	.147
2.1. Bench	.913	.323	.226
1.5. Water	.905	.136	.399
1.4. Green	.895	-.421	.149
1.3. Sports Accessibility	.858	-.130	.497
1.7. Openness	.814	-.576	.070
1.8. Car parking	.790	-.141	.593
1.10. Fire Engine	.769	-.636	-.061
1.9. Bike parking	.689	-.368	.624
Principal Factor 2:Communication			
2.5. Shop	-.138	.983	-.039
2.7. Plaza	-.027	.979	.197
1.2.Small Plot Accessibility	-.097	.970	.221
2.6. Semi-open	-.246	.969	.033
1.6. Road	-.185	-.918	-.349
2.8. Blind	-.591	.754	-.190
Principal Factor 3:			
2.2. Light	.282	.299	.911
2.4. Display	.215	.455	.863

Extraction Method: Principal Component Analysis

Rotation Method: Varimax with Kaiser Normalization

Table 9 Total Variance Explained

Principal Component	Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %
1. Landscape and Usage	8.082	44.899	44.899
2. Communication	6.754	37.520	82.419
3. Information	3.077	17.096	99.515

Extraction Method: Principal Component Analysis.

Table 10 Relative Equation between Satisfaction Index and Spatial Index (Common Case)

Satisfaction Index	Spatial Index			
	Spatial Index Name	Regression Equation	R^2	Sig. (T-Test)
Applicability	Principal Factor 1	$Y=0.279X_1+0.521$	0.975	0.000 0.000
Amenity	Principal Factor 1	$Y=0.216X_1+0.443$	0.733	0.030 0.002
Health	None of Principal Factors is influential.			
Safety	None of Principal Factors is influential.			
Community	Principal Factor 2	$Y=0.227X_2+0.593$	0.661	0.049 0.001
Total	Principal Factor 1	$Y=0.188X_1+0.488$	0.757	0.024 0.001

4.1.3 Principal Component Analysis

With a Principal Component Analysis as Table 8and 9, the above 18 spatial factors were classified into three principal factors. According to the influence on people's activity, the first and second factors may be defined as the Landscape + Usage Factor and the Communication Factor.

The first factor mainly comprises the spatial ratio of green, water and openness, the distance to the neighborhood park and the sports area, the facility and parking. All of them are related to the landscape and personal usage of the open space. The second factor mainly comprises the spatial ratio of plaza and semi-open space, the distance to the small plot, and the ratio of main bi-way road and blind area. They are related to the neighborhood communication.

4.1.4 Regression Analysis

With a regression analysis of Spatial Indices and Satisfaction Indices within the six groups (Table 10), the corresponding equations were built up for the further examination concerning the spatial influence on people's satisfaction. Applicability is influenced by the Principal Factor 1 (Landscape + Usage Spatial Factor); Amenity is also influenced by the Principal Factor 1; Community is influenced by the Principal Factor 2 (Communication Spatial Factor); Total Satisfaction is influenced by the Principal Factor 1.

4.2 Spatial Influence on behavior

4.2.1 Comparison of Spatial Characteristics and BEI

With a comparison of Spatial Indices and Behavioral Indices within the campus sections (Table 11 and 12), a conclusion could be drawn that the behavior is significantly correlated to the spatial properties of campus open space.

4.2.2 Correlation of Spatial Characteristics and BEI

With a correlation analysis of Spatial Indices and Behavioral Indices within the six groups (Table 13), it shows that the behavior is significantly correlated to the spatial properties of campus open space.

Temporal BEI is influenced by the accessibility of small plots for students' activities, the ratio of semi-open space and plaza, and the number of facilities. On the contrary, in the open spaces without building cover, the excessive openness and greenness seems to break the balance of people stay there, although the number of people increases. For example, the sports fields are much uncovered than other districts so that many people take part in public sports activity, but the timing people choose is very few, only in the morning exercising or evening sports.

The categorical BEI is influenced by the accessibility of small plots, the ratio of semi-open spaces and plazas, and the number of benches and lights.

Population ratio is influenced by the ratio of water area and the number of facilities.

4.2.3 Regression of Spatial Characteristics and BEI

With Table 14 the corresponding equations were built up for the further examination concerning the spatial influence on people's behavior on campus.

Based on the regression equations, some estimation of BEIs are available with the simulation of certain conditions. For example, with the simulation of green ratio 50% and light distance 20 m, the temporal BEI will be decline from 0.769 to 0.579 as the accessibility of small plots decreases from 0.1 to 0.01 (Fig. 5), distance to small plots from 10 to 100 meters.

Table 11 Comparison of Spatial factors and Behavioral Indices of Zi-Jin-Gang Campus

Spatial Index	Name of Section							
	A2	A4	B1	B2	B3	C1	C2	C3
1.1. Park Accessibility	1.20	1.33	2.59	3.05	7.62	8.01	42.34	20.67
1.2. Small Plot Accessibility	0.04	0.06	0.00	0.03	0.00	0.03	0.08	0.08
1.3. Sports Accessibility	5.11	2.58	100	3.26	1.68	1.21	1.69	1.12
1.4. Green	0.31	0.32	0.44	0.59	0.82	0.75	0.56	0.42
1.5. Water	0.02	0.07	0.02	0.12	0.01	0.03	0.24	0.15
1.6. Road	0.05	0.13	0.09	0.11	0.05	0.07	0.12	0.08
1.7. Openness	0.75	0.81	0.97	0.89	0.91	0.88	0.90	0.86
1.8. Car parking	0.01	0.05	0.00	0.02	0.02	0.01	0.04	0.03
1.9. Bike parking	0.08	0.11	0.01	0.01	0.01	0.02	0.15	0.12
1.10. Fire Engine	1.00	1.00	1.00	0.85	0.30	0.82	0.91	0.80
2.1. Bench	0.03	0.03	0.02	0.01	0.00	0.01	0.05	0.04
2.2. Light	0.40	0.45	0.27	0.43	0.05	0.57	0.78	0.35
2.3. Instrument	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.00
2.4. Display	0.05	0.07	0.05	0.02	0.00	0.01	0.09	0.08
2.5. Shop	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
2.6. Semi-open	0.01	0.02	0.01	0.01	0.00	0.03	0.06	0.04
2.7.Plaza	0.01	0.02	0.00	0.01	0.00	0.00	0.05	0.05
2.8. Blind	0.01	0.00	0.00	0.12	0.38	0.25	0.00	0.16
Temporal BEI	0.873	0.873	0.657	0.568	0.000	0.792	0.840	0.806
Categorical BEI	0.636	0.727	0.155	0.603	0.000	0.704	0.848	0.759
Population Ratio	0.061	0.132	0.309	0.010	0.000	0.032	0.401	0.072

Table 12 Comparison of Spatial Factors and Behavioral Indices of Xi-Xi Campus

Spatial Index	Name of Section												
	A1	A2	A3	A4	B1	B2	B3	C1	C2	C3	C4	C5	C6
1.1. Park Access	1.65	3.23	3.26	3.07	1.69	3.08	4.11	5.29	6.94	4.96	18.34	100	18.25
1.2. Plot Access	0.00	0.03	0.04	0.05	0.00	0.01	0.01	0.05	0.05	0.10	0.07	0.10	0.10
1.3. Sports Access	2.56	6.17	6.10	3.41	3.36	4.98	5.05	5.18	10.21	6.82	3.36	4.19	5.01
1.4. Green	0.19	0.29	0.24	0.21	0.53	0.59	0.31	0.33	0.28	0.39	0.55	0.85	0.45
1.5. Water	0.01	0.00	0.00	0.00	0.00	0.12	0.00	0.04	0.00	0.00	0.00	0.01	0.01
1.6. Road	0.01	0.08	0.12	0.05	0.00	0.00	0.05	0.06	0.15	0.12	0.05	0.12	0.20
1.7. Openness	0.61	0.65	0.71	0.75	1.00	1.00	0.85	0.78	0.82	0.76	0.79	1.00	0.77
1.8. Car parking	0.01	0.00	0.00	0.02	0.00	0.00	0.06	0.04	0.04	0.04	0.04	0.00	0.05
1.9. Bike parking	0.01	0.03	0.02	0.02	0.00	0.01	0.01	0.04	0.04	0.04	0.05	0.00	0.03
1.10. Fire Engine	0.86	1.00	1.00	0.94	1.00	1.00	0.81	0.93	1.00	1.00	1.00	1.00	1.00
2.1. Bench	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.02	0.02	0.04	0.03	0.02	0.01
2.2. Light	0.32	0.35	0.35	0.35	0.18	0.20	0.25	0.42	0.40	0.45	0.42	0.20	0.45
2.3. Instrument	0.00	0.00	0.01	0.01	0.05	0.07	0.03	0.00	0.01	0.00	0.00	0.00	0.00
2.4. Display	0.00	0.00	0.01	0.00	0.00	0.00	0.02	0.02	0.02	0.04	0.04	0.01	0.03
2.5. Shop	0.01	0.01	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.6. Semi-open	0.01	0.01	0.01	0.01	0.00	0.00	0.01	0.02	0.02	0.04	0.03	0.00	0.03
2.7.Plaza	0.00	0.00	0.02	0.03	0.00	0.00	0.01	0.03	0.05	0.08	0.06	0.02	0.03
2.8. Blind	0.09	0.00	0.00	0.80	0.00	0.07	0.07	0.12	0.00	0.00	0.11	0.00	0.00
Temporal BEI	0.845	0.861	0.861	0.860	0.578	0.665	0.466	0.797	0.766	0.794	0.796	0.795	0.803
Categorical BEI	0.706	0.641	0.631	0.667	0.351	0.287	0.179	0.774	0.784	0.830	0.698	0.781	0.764
Population Ratio	0.01	0.02	0.03	0.11	0.05	0.31	0.01	0.06	0.03	0.05	0.15	0.08	0.09

Table 13 Correlation of Spatial Factors and Behavioral Indices of Campus Case

Spatial Index	Behavioral Index		
	Temporal BEI	Categorical BEI	Population Ratio
1.1. Park Access	.124	.307	.195
1.2. Plot Access	.505(*)	.759(**)	.105
1.3. Sports Access	-.060	-.396	.409
1.4. Green	-.488(*)	-.241	.155
1.5. Water	.089	.184	.598(**)
1.6. Road	.266	.477(*)	.012
1.7. Openness	-.449(*)	-.442(*)	.421
1.8. Car parking	-.004	.253	-.023
1.9. Bike parking	.384	.475(*)	.397
1.10. Fire Engine	.307	.296	.281
2.1. Bench	.359	.460(*)	.541(*)
2.2. Light	.601(**)	.707(**)	.314
2.3. Instrument	-.241	-.653(**)	.448(*)
2.4. Display	.303	.332	.486(*)
2.5. Shop	.402	.163	-.218
2.6. Semi-open	.397	.599(**)	.335
2.7.Plaza	.346	.606(**)	.128
2.8. Blind	-.208	-.135	-.125

* Correlation is significant at the 0.05 level (2-tailed)
** Correlation is significant at the 0.01 level (2-tailed)

Table 14 Relative Equation between BEI and Spatial Indices (Campus Case)

Subjective aspect	Spatial aspect			
	Spatial Index Name	Regression Equation	R^2	Sig. (T-Test)
Y: Temporal BEI (TBEI)	X_1: Plot Access Index	$Y=2.114X_1-0.473X_2+0.464X_3+0.678$	0.615	0.046
	X_2: Green Index			0.009
	X_3: Light Index			0.036
				0.000
Y: Categorical BEI (CBEI)	X_1: Plot Access Index	$Y=3.940X_1-0.631X_2+0.580X_3+0.736$	0.796	0.000
	X_2: Openness Index			0.023
	X_3: Light Index			0.014
				0.007
Y: Population Ratio (PR)	X_1: Water Index	$Y=0.592X_1+3.022X_2+2.660X_3-0.009$	0.674	0.042
	X_2: Bench Index			0.026
	X_3: Instrument Index			0.002
				0.046

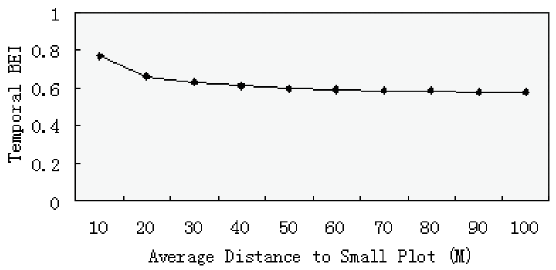

Fig. 5 Plot Accessibility -TBEI relationship
(Simulation: green ratio 50%, light distance 20 m)

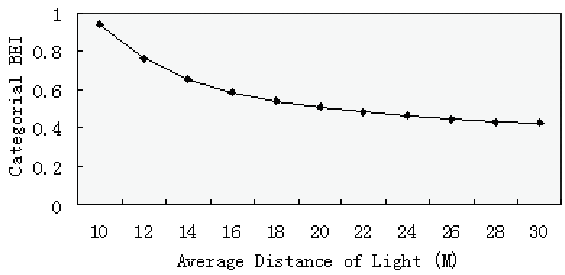

Fig. 6 Light Distance -CBEI relationship
(Simulation: plot access 0.03, open ratio 80%)

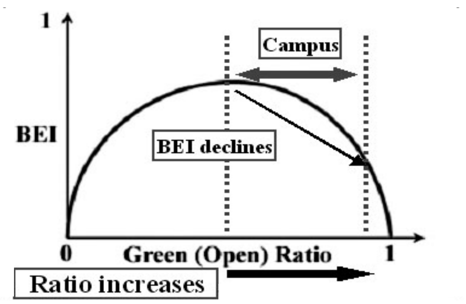

Fig. 7 Green (Open) Ratio- BEI relationship

Similarly, with the simulation of open ratio 80% and the small plot distance 30 meters, the categorical BEI will be decline from 0.942 to 0.426 as the distance of lights increases from 10 to 30 meters (Fig. 6).

From the regression equations in Table 8.3.3., the green and open ratios are negative to the temporal behavior index and the categorical behavior index respectively. For the campus case, the open or green ratio is very high, usually from 0.5 to 0.9. It means that the excessive greenness or openness reduces some options of activity so that behavior diversity will decline. If it increases toward 1, behavior diversity will decline (Fig. 7).

5. POLICY RECOMMENDATION

Through the previous discussion of Section 4, it is confirmed that there are significant relations between spatial features and people's satisfaction and behavior. The 18 items of spatial index system are mainly under the consideration of open space planning, and are also indirectly useful to designers. During a process of open space planning or design, it is an effective approach to improve the satisfaction degree and control users' behavior by changing the spatial characteristics that are influential. The following information can be regarded as an application in the common residential open space case.

5.1 Information for Planning

(1) Neighborhood Park Accessibility

The accessibility of the neighborhood park influences on the total satisfaction and applicability (Table 3). This result means that the average distance of the neighborhood parks to residences should be shortened by adjusting the spatial layout of community. In other words, a park that is located near the community center is better than the other that is located in the corner or along the sideline of the community.

Another important approach is concerned with the entrance placement. Planners may set up a few entrances that are evenly distributed at each orientation (direction) rather than only one entrance. This method can decrease the distance from residences to the park.

(2) Small Playing Plot Accessibility

The accessibility of the neighborhood park influences on neighborhood communication (Table 3). This result means that the average distance of small plots to residences should be shortened by adjusting the spatial layout inside each building group. In other words, for each group, some small plots should be located along the main path that residents pass every day. When they meet with friends and neighbors on the way, these small plots can be used as stopping places for people's talking. If the small plots are not sufficient or located at inconvenient or inaccessible corners, the usage will be decreased so that the neighborhood communication becomes fewer.

(3) Sports Field Accessibility

The accessibility of the sports fields influences on health and total satisfaction (Table 3). This result means that the average distance of the sports fields to residences should be shortened by adjusting the spatial layout inside each building group, and for the whole community. In other words, a main field that is located near the community center is needed, and some small fields or instruments should be set inside each building group. For example, a table-tennis field or a set of physical exercise instruments is suitable to be placed into the space between buildings.

(4) Green Area Ratio

The ratio of green area to the total open space area influences on applicability and safety (Table 3). This result means that the green area ratio should increase by adjusting the spatial layout inside each building group, and for the whole community. In other words, abundant plantation is needed, such as roadside trees, lawn, and shrub. Even at paved plots, planting a few tall arbors is a good means to add more green space. Moreover, liana is also a useful choice to decorate building facades and roofs. This can enforce the impression of green image in open space.

(5) Water Area Ratio

The ratio of water area to the total open space area influences on applicability, amenity and total satisfaction (Table 3). This result means that the water area ratio should increase by adjusting the spatial layout inside each building group, and for the whole community. In other words, some waterscapes or resources are needed, such as ponds, creeks, and spring fountains. Designers should make the best use of natural water systems, especially if there is a river passing the community. Moreover, a water network is better than an isolated water spot even though both areas are equal to each other, since the longer route of the water streamline can bring about more water-intimate spaces. This can sever more residents around the community.

(6) Road Area Ratio (Bi-way motor vehicle)

Although the bi-way road area ratio does not significantly influence on satisfaction, it seems moderately influential on community in a way (Table 3). This result means that the road area ratio should increase by adjusting the spatial layout of the whole community. In other words, bi-way motor traffics should be excluded from the sub-community scale. Planners should organize the major roads at the outer area as much as possible. If it is necessary to permit cars into the central area, one-way road system is more suitable. Excessive motor traffics inside building groups will disturb pedestrian movements of residents who want to visit other sections for neighborhood communication.

(7) Openness Area Ratio

The ratio of open area to the total area influences on safety (Table 3). This result means that the open area ratio should increase by adjusting the spatial layout inside each building group, and for the whole community. In other words, the density of buildings should decrease to a relatively lower degree so that sufficient open spaces are available. Excessively dense buildings increase uneasiness and tension of residents in open spaces.

(8) Car Parking Area Ratio

The ratio of car parking area to the total area influences on applicability, amenity, health and total satisfaction (Table 3). This result means that the car parking area ratio should increase by adjusting the spatial layout inside each building group, and for the whole community. In other words, the car parking area should increase to a relatively high degree so that sufficient parking spaces are available. If there are no enough parking spaces for cars, drivers will possibly occupy roadside spaces and other open spaces that are provided for relaxation purpose.

(9) Bike Parking Area Ratio

The ratio of bike parking area to the total area influences on health (Table3). This result means that the bike parking area ratio should increase by adjusting the spatial layout inside each building group. In other words, the bike parking area should increase to a relatively high degree so that sufficient parking spaces are available. If there are not enough parking spaces for bikes, owners will possibly occupy roadside spaces and other open spaces that are provided for relaxation purposes.

(10) Fire Engine Cover Rate

The ratio of fire engine cover to the total open area influences on safety (Table 3). This result means that the fire engine cover rate should increase by adjusting the spatial layout inside each building group. In other words, planners should organize proper accesses and a road system so that fire engines can reach anywhere when a fire accident happens. If there is some space where fire engines are excluded from, residents will feel dangerous.

5.2. Information for Design

(1) Bench Number and Other consideration

The ratio of the number of benches to the total open area influences on applicability, amenity and total satisfaction (Table 3). This result means that the number of benches should increase by adjusting the spatial design for resting people. In other words, designers should provide more benches everywhere people possibly want to stop a while for viewing, talking or waiting. Of course, the material of benches is also worthy of consideration. For example, wooden benches are favorable for residents although they need more maintenance. In addition, the orientation and the cluster of benches are important. The benches facing landscape or pedestrians are usually favorable. The benches of face to face or in cycle can be used by a group of people who want to discuss together.

(2) Light Number and Other consideration

The ratio of the number of lights to the total open area influences on amenity (Table 3). This result means that the number of lights should increase by adjusting the spatial design for people. In other words, designers should provide more lights everywhere people possibly pass or stop a while for viewing, talking or waiting. Of course, the style of lights is also worthy of consideration. For example, tall lights are erected along the roadside, while low lights are placed near a bench, a bulletin board or a set of instruments. Some decoration lights are suitable to be placed on a tree or embedded in the earth.

(3) Instrument Number and Other consideration

The ratio of the number of instruments to the total open area influences on applicability and total satisfaction (Table 3). This result means that the number of instruments should increase by adjusting the spatial design for people. In other words, designers should provide more instruments not only at sports fields but also at other convenient places. Of course, the category of instruments is also worthy of consideration. Especially at small plots, more playing instruments are placed for children, such as a sand ground and a scrambling barrier.

(4) Display Number and Other consideration

The ratio of the number of displays to the total open area influences on amenity (Table 3). This result means that the number of displays should increase by adjusting the spatial design for people. In other words, designers should provide more displays everywhere people possibly pass or stop a while for assembly. For example, a bulletin board is erected along the roadside or beside a plaza or a square, where residents can get information from the community management office or a hobby club. Moreover, some artistic expositions are placed as a visual focus around the open space.

(5) Shop Number and Other consideration

The ratio of the number of shops to the total open area influences on community (Table 3). This result means that the number of shops should increase by adjusting the spatial design for people. In other words, designers should provide more shops (or a vending booth) everywhere people possibly pass or stop a while for assembly. For example, a food booth and a paper booth is placed along the roadside or beside a plaza or a square, where residents can buy some food and drink and then enjoy them on a bench or lawn. Moreover, these small shops will provide more chances for neighbors' unplanned meeting so that the communication can be enriched.

(6) Semi-open Area Ratio and Other consideration

The ratio of the area of semi-open space to the total open area influences on safety (negative) and community (positive) (Table 3). This result means that the area of semi-open space should be considered properly and carefully by adjusting the spatial design for people. In other words, designers should provide some semi-open space closely connected to open space. For example, a porch of a building and a summerhouse can provide places for people even on a hot day or a rainy day. However, some semi-open spaces far from human sight possibly bring about uneasiness.

(7) Plaza Area Ratio and Other Consideration

The ratio of the area of plazas to the total open area influences on safety (negative) and community (positive) (Table 3). This result means that the area of plazas should be considered properly and carefully by adjusting the spatial design for people. In other words, designers should provide some plazas for assembly or public exercises. On the other hand, the plaza's influence on safety needs further examination. Sometimes these plazas are occupied by young ruffians' fight.

(8) Blind Area Ratio and Other Consideration

The ratio of the area of blind area to the total open area influences on safety (negative) (Table 3). This result means that the area of dead angle should decrease by adjusting the spatial design for people. In other words, designers should decrease the area out of sight. For example, a simple periphery of open space is better than a circuitous boundary. Excessive shrubs will obstruct natural surveillance. And a district enclosed by building facade without direct windows will also be regarded as a dangerous area.

6. CONCLUSION

As a basis for the methodological approach, the present study carried out an empirical study of residential open spaces in Hangzhou city, China. To stimulate public awareness of potential amenity benefit, the open space users as the main stakeholder to consume the service were asked for their opinion as an input for the establishment of a method to quantify the recreational benefit of open space users' behavior through several determinants with very high statistically significant results (Behavioral Entropy Index). With regard to the contribution of methodology, the research has performed an application of Entropy Theory into open space behavior, and try to seek the interrelationship between physical factors and behavior, as well as subjective perception so that several recommendations are put forward.

This study established an unconventional method, Behavioral Entropy Index, to examine the complexity of residents' reaction to physical environments. The results of behavior assessment revealed the following information: (1) It is insufficient to examine the behavioral characteristics only by simply population count. The index of complexity constitutes to clarify the relationship between the temporal, spatial and categorical dynamics;(2)The balance of the temporal, spatial and categorical probability is significant to increase the efficiency of open space utilization; and more options and opportunity for outdoor life are important to increase the complexity of outdoor behavior;(3)The weather conditions hold the balance of outdoor behavior, which provides important information for designers that it is sound to set up more semi-open spaces connected directly with open spaces;(4)The school schedule also influences the balance of outdoor behavior, which provides important information for students' leaders and university organizers that it is considerable to set up more activities not only during off days but also working days.

Some information for environmental improvement is also acquired based on the correlation analysis of spatial influence on satisfaction and behavior:

(1) According to the influence on people's activity, the first and second factors of spatial features may be defined as the Landscape + Usage Factor and the Communication Factor.

(2) Applicability is influenced by the Principal Factor 1 (Landscape + Usage Spatial Factor). Amenity is also influenced by the Principal Factor 1. Community is influenced by the Principal Factor 2 (Communication Spatial Factor). The total satisfaction is also influenced by the Principal Factor 1.

(3) Temporal BEI is influenced by the accessibility of small plots for students' activities, the ratio of semi-open space and plaza, and the number of facilities. On the contrary, the excessive openness and greenness seems to break the balance of people stay there, although the number of people increases.

(4) The categorical BEI is influenced by the accessibility of small plots, the ratio of semi-open spaces and plazas, and the number of benches and lights.

(5) Population ratio is influenced by the ratio of water area and the number of facilities.

Due to the potential of several determinants development, open space users' behavior can lead to the very useful information in order to monitor the change effect to the dependent side. The specific recommendations from the useful findings are as follows:

(1) Correlation between satisfaction evaluation and physical factors shows that it is a suitable way to provide green space, attractive facility and good maintenance inside open spaces;

(2) Both Spatial BEI and Temporal BEI result shows that it is a suitable way to activate unused spaces and vacant land as more as possible, in order to improve the spatial balance for residents' utilization;

(3) Both Spatial BEI and Temporal BEI result also shows that it is a suitable way to provide more semi-open spaces connected directly with open spaces;

(4) Both Categorical BEI and Temporal BEI result shows that it is a suitable way to organize special events during working days.

Based on the above work, there are still some potential aspects to explore in the next stage. What will be happening next? It is significant to apply the entropy methods in other areas and other types of spaces, e.g. parks, plazas, and interior leisure spots. Those different events and people in the spaces will possibly present some new findings. In addition, some related subjects concerning buildings or traffic are also valuable to examine the effectiveness of the entropy method.

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