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A QUANTIFICATION ANALYSIS OF CAMPUS BEHAVIORAL DYNAMICS USING THE INFORMATION ENTROPY

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ABSTRACT: Measuring complexity of the dynamic system has become a common practice for describing spatial structural properties in the fields of urban geography and landscape ecology. In China, college campuses can be regarded as a kind of complex system since the campuses accommodate multiple functions, such as education, research, leisure, residence and so on. Considerably diversified human activities are daily performed in campus open spaces. How to characterize the distribution dynamics of daily activities calls for much attention of architects and planners. Nonetheless, the resultant dynamics of human activities is often irregular and patchy, giving rise to intricate distribution patterns that can be difficult to characterize. Herein, the issue of characterizing the temporal-spatial-categorial Diversity of Activity Distribution (DAD) in open spaces was addressed and a method of quantifying the complexity of patchy activity dynamics was proposed. The method was inspired by information-based measures of entropy, and the proposed Behavioral Entropy Index (*BEI*) can distinguish the distribution of activities in open spaces between simple (convergent) and complex (random) temporal-spatial-categorial mosaics. The method was demonstrated using sample data through a survey on two typical college campuses at Hangzhou City, China. The results show that the *BEI*s effectively illuminate the behavioral dynamics, rather than the conventional index of absolute population or simple percentage; moreover, proper facilities, natural environments and campus management all facilitate improving the behavioral complexity.

Keywords: Campus open space, behavioral dynamics, temporal-spatial-categorial complexity, entropy

INTRODUCTION

Nowadays a great deal of campus construction in China necessitates the development of new analytical methods that allow for an effective and proper treatment of human activities and environmental conditions. Most architects and planning theoreticians are familiar with traditional methods concerning spatial formation, landscape aesthetics, transportation network and so on. However, Chinese college campuses contain multiple functions, such as education, research, leisure, residence and so on, accommodating diversified human activities. Hence, as an assumption, it is accepted that these campuses should be regarded as complex systems of human behavior. How to effectively characterize the distribution of daily activities in this kind of complex system calls for much attention of designers and planners, who aim at creating proper environments to accommodate the various needs of the people on campus.

Here, we introduce a new measure from the field of ecosystem to characterize patchy dynamics of daily activities in campus open spaces. This measure has been successfully employed in research regarding complexity of landscape ecology and urban transportation; and it originates from the Information Entropy Theory. This study takes into account the three-dimensional nature of time-space-category fluctuations of human daily activities. It can be defined as Diversity of Activity Distribution (DAD) with temporal-spatial-categorial data sets in which the state of a two-phase spatial mosaic (example, presence/absence data) has been recorded at regular intervals over time. The DAD is similar to many information-based measures based on Shannon Entropy and can distinguish between simple (convergent) and complex (random) temporal-spatial-categorial distributions with Behavioral Entropy Indices (*BEI*s). It also allows for the detection of certain spatiotemporal patterns such as space-time cycles. In this paper, the general characteristics of the measure are demonstrated,

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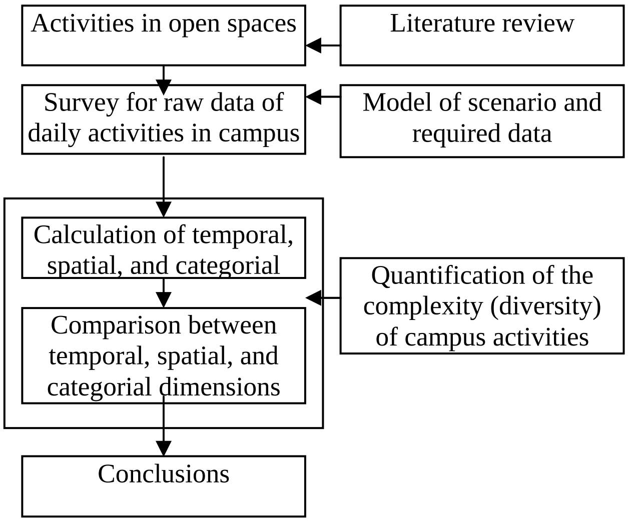

Fig. 1 Framework of quantification of the complexity (diversity) of daily activities in campus open spaces

followed by an analysis of human activity dynamics generated by the individual-based, multi-purpose data. Although the measure was developed specifically for the treatment of campus cases, it is promisingly applicable to other social systems concerning open spaces, where appropriate data exist.

For planners, how to determine this kind of changing activities and the relationship with physical environments is an intractable problem. There is valuable use in the methodology based on the above qualities since it can examine the variable ratio among diverse activities. As a result, it indicates relevant advantages of the entropy method in the field of planning. The research structure is illustrated as Fig. 1.

LITERATURE REVIEW

Since Shannon (1948) introduced the entropy theory into information science and Wilson (1970) subsequently applied it into the field of urban issues, measuring complexity has become a common practice for describing spatial structural properties in the fields of urban geography and landscape ecology. Configurable models in open spaces serve to study not only the temporal variations in population fluctuations, but also a population’s variability in space, across different geographical locations. There are many examples where the introduction of a spatial dimension can radically change the predictions of standard, spatially-implicit models of population dynamics, such as the Lotka-Volterra equations and their derivatives, giving rise to co-existence not predicted by non-spatial equivalents and to intricate spatial patterns of abundance (Sole and Bascompte 1998, Lundberg et al. 2000). For example, Petrovskii et al. (2004) shows that spatial desynchronisation of population densities serves to decrease global extinction probabilities. Similarly, metapopulation and predator–prey models based on coupled map lattices (Sole and Goodwin 2000) or coupled diffusion systems (Medvinsky et al. 2002) have generated a gamut of intriguing patterns including spatial chaos and spiral waves that correspond to the synchronous and asynchronous spatial oscillations that have been observed for certain natural populations. Other models, based on individual-based or cellular automata approaches, have also demonstrated the importance of local interactions in space on population dynamics (Durrett and Levin 1994; Kawata and Toquenaga 1994). In these models, the resulting spatiotemporal dynamics is usually irregular and patchy, corresponding well to many known patterns of vegetation dynamics. Such patch dynamics can be depicted by discontinuous mosaics of occupied and unoccupied regions over a landscape, the shapes and locations of which may change over time.

The study of complex spatiotemporal patterns has a long history, dating at least to Turing and his original studies of spatial structure in reaction–diffusion systems (Turing 1952). In ecology, a large number of models combining a spatial diffusion process coupled to local interaction dynamics (predator–prey, host–parasitoid) have been used to reproduce Turing-like spatial structures (Sole and Bascompte 1998, Wilson 2000; Medvinsky et al. 2002). The study of these models has led to examinations of the conditions that give rise to spatiotemporal chaos in these systems, and the development of analytical tools that can be used to characterize the observed spatiotemporal dynamics (Medvinsky et al. 2002). Such tools include statistics-based spatial analysis (for a review, see Dale et al.2002) as well as spatial versions of the common tests for chaos, such as Lyapunov exponents (Sole and Bascompte 1995) and the correlation dimension (Petrovskii et al. 2003).

The question that is addressed here is how to quantify, or characterize, the dynamics of patchy spatiotemporal mosaics of activities. Such mosaics may or may not show signatures of chaos. Unlike spatial point data that can be studied as a realization of a Poisson process, mosaics consist of patches that have recognizable shapes and surface areas. It is, therefore, the patch dynamics that becomes the phenomenon of interest and thus spatial statistics based on point processes that reduce data to dimensionless events in space are not applicable (Dale et al. 2002). Similarly, analytical measures such as spatial autocorrelation, Lyapunov exponents and correlation dimensions that treat continuous variables in space are also not applicable. Early ecologists developed methods of characterizing spatial mosaics based on comparing the distribution of patch lengths along a transaction to the expected distribution for a random mosaic (Pielou 1969). More recently, the study of patch dynamics has been the object of many studies in landscape ecology, and various authors have used techniques such as fractal analysis or landscape metrics (O'Neill et al. 1998, Ricotta 2000; Moser et al. 2002) to describe the complex spatial patterns that occur on a landscape. In all of these cases, the indices describe characteristics of a spatial mosaic, but do not consider a temporal component. Studies of changing landscape patterns involve calculating the indices for images of a landscape taken at several different times in history and then observing how these indices vary over time.

CHARACTERISTICS OF CAMPUS RESIDENTS' BEHAVIOR

Temporal Characteristics

People visit open spaces in different timings according to their own preference and willingness, which can be observed hourly, daily, weekly, seasonally, annually, even with a whole lifetime. In this study, a period throughout 6 weeks was taken as the sample of behavioral data. The regulation at daily and hourly levels confirmed the diversity of temporal characteristics.

Spatial Characteristics

The distribution of people's activities is also different in terms of their own demands. For example, children like sand grounds and sports instruments, students often gather on a plot of lawn, while the aged usually prefer a seat under a tree. In fact, the spatial characteristics are closely connected to the category of activity.

Categorial Characteristics

Open space provides a mixture of opportunities to visitors, not only the direct benefit to the pleasure of sensory contact with nature but also contribute to the social and cultural meanings to the people in the community. As the results, there are varieties of activities that visitors could perform at site. Greatly simplified, Gehl (1987) categorizes the different activities in open space into necessary, optional and social activities. Following that, in general, a variety of activities can be grouped to be three types of activities that can be described as Table 1.

METHODOLOGY OF BEHAVIORAL ENTROPY MODEL

Since people's behavior in open space is diverse in terms of temporal, spatial and categorical dimensions, it can be regarded as a kind of complex system that consists of multiple forms. 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"? In the fields of urban geography and landscape ecology, one common approach is to use information-based measures such as Shannon entropy and its derivatives to classify a data set according to its degree of order or randomness.

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

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

where $p_{L,i}$ log*2* $p_{L,i}$ = 0 for $p_{L,i}$ = 0. For a random sequence, all words are equally probable (all *pL,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).

According to the classification mentioned in Part 2, the behavior of residents in open space includes three levels of characteristics: temporal, spatial, and categorical characteristics. In order to investigate the complexity of campus activities at these different dimensions, herein, the Shannon Entropy is developed with normalization. The dynamics of the behavior is examined by employing the idea of Entropy, as shown by Eq. 2.

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

where *BEI* is the Behavioral Entropy Index, p_j is the relative frequency (probability) of the j^{th} behavioral option. *n* is the number of behavioral options. Division by $\log_2(n)$ serves to normalize the measure into the range from 0 to 1.

According to the definition of the Behavioral Entropy Index, the value of *BEI* is to stand for the complexity of people's behavior, which may be interpreted as the diversity of campus activities.

Table 1 Category of activity

Category of Activity	Description and Example
1. Necessary	Description: Necessary activities include those that are more or less compulsory. Because of necessity, the incidence is influenced only slightly by the physical conditions. These activities will take place throughout the year, under nearly all conditions, and are more or less independent of the exterior environment. The participants have no choice. Example: going to school or to work, shopping, waiting for a bus or a person, running errands, distributing something.
2. Optional (Individual)	Description: Optional activities are those pursuits if there is a wish to do so and if time and place make it possible. These activities take place only when exterior conditions are optimal, when weather and place invite them. This relationship is particularly important in connection with physical planning because most of the recreational activities that are especially pleasant to pursue outdoors are found precisely in this category of activities. These activities are especially dependent on exterior physical conditions.
2-a Studying	Example: Reading a book or newspaper, or writing something.
2-b Viewing	Example: standing or sitting and sunbathing, enjoying life.
2-c Rambling	Example: taking a walk to get a breath of fresh air.
3. Social	Description: Social activities are all activities that depend on the presence of others in public spaces. Social activities occur spontaneously, as a direct consequence of people moving about and being in the same spaces. This implies that social activities indirectly supported whenever necessary and optional activities are given better conditions in public spaces.
(Group)	There are a limited number of people with common interests or because people "know" each other, or they often see one another.
3-a Talking	Example: greetings and conversations, communal activities
3-b Playing	Example: Play game, such as chess, card or a physical game
3-c Party	Example: Gathering with food, drinks
(Public)	In city streets and city centers, social activities will generally be more superficial, with the majority being passive contacts - seeing and hearing a great number of unknown people. But even this limited activity can be very appealing.
3-d Sports	Example: exercising, playing ball with known or unknown people.
3-e Performing	Example: making a performance, presentation, lecture or speech.
3-f Assembling	Example: dealing at a flea market, a public affair,

At the temporal dimension, 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.

At the spatial (section) dimension, 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 categorial dimension, 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.

According to the above explanation, the entropy value effectively describes the extent of behavioral complexity with a convergent number, instead of a series of ratio results. Since the proposed quantitative method can exceed those conventional calculation based on simple percentage, it is suitable to fulfill the purpose of this study, i.e. examining the dynamic characteristics of daily activities in open spaces.

DATA COLLECTION

In this research, two campuses were selected as the study case of behavioral survey in 2005. As the largest campus and the multiversity campus in China, Zi-Jin-Gang campus and Xi-Xi campus of Zhejiang University, Hangzhou City, are suitable to be the typical objects due to the reason that the two campuses are well designed as a major representative of different social background. The former is a representative of the new fashionable type located in the suburban area, and the latter is a representative of the old type located in the central area of the city.

Structure of Questionnaire

Both qualitative and quantitative approach has been adopted in this study so that the major concerns of users' behavior could be captured simultaneously with users' preference and attitude while they take part in events. Approximately 400 interviewees were randomly selected through a multiple-choice response format of questionnaire sheets that were provided with specific answers form to clarify the ambiguous answers. In order to acquire a general consciousness, both undergraduates and postgraduates were selected around two campuses of Zhejiang University for this case study. The 15 investigators from different colleges visited most of dorms, classes and open spaces, and asked their classmates and friends to answer and deliver the questionnaire forms. They also kindly explained the structure and the meanings of all the options, in order to facilitate respondents understanding.

The questionnaire survey consists of two sections. The first section was a screening survey that includes questions about socio-demographic information; the second section provided information about users' activity diary on campus. Finally, a total of 105 and 98 effective questionnaires (from Zi-Jin-Gang and Xi-Xi respectively) with completed data (a continuous duration of six weeks) were applied to investigate the activity dynamics of campus users. A table summarizing the socioeconomic profile of the interviewees is as Table 2.

General Information of Zi-Jin-Gang Campus and Xi-Xi Campus

Zi-Jin-Gang campus

The campus of Zi-Jin-Gang is the new territory of Zhejiang University and is to be the future main body of the university. At present, the total land area is approximately 2 million square meters, where approximately 13,000 students are studying and living. The campus was founded in the year of 2000 and is still being built. According to the planning transportation system and the current situations in the survey (Fig. 2), the campus is divided into 4 sections (A, B, C, D) and 11 sub-sections (A1, A2, A3, A4, B1, B2, B3, C1, C2, C3, D1). 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 area (Table 3).

The students' dormitories are all located in the northern part of the campus, with a relatively high density of buildings and more service facilities. The

Table 2 Samples and response of the questionnaire

Campus	No. of Distributed	No.of Valid Response	Response Rate (%)	Gender (M): (F)	Avg. Age	Academic Level (U): (P)
Zi-Jin-Gang	204	105	51.4	66: 39	20.3	77: 28
Xi-Xi	201	98	48.8	65: 33	22.5	51: 47
Overall	405	203	50.1%	131: 72	21.4	128: 75

Table 3 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 4 Area of the sections of Xi-Xi campus

	A1	A2	A3	A4	B1	B2	B3
Total Area (HA)	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 (HA)	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	

main types of open space comprise the roadside plots with good pavement, and the green courtyards enclosed or partially enclosed by buildings with good plantation.

The sports facilities are all located between the dormitory area and the academic area, with a relatively low density of buildings and more sports instruments. The main types of open space comprise the sports fields with good pavement or grass, and the green areas with excessive woods.

The academic buildings are all located in the central and southern parts of the campus, with a beautiful landscape of buildings and waterscape. The main types of open space comprise the small plots and semi-open spaces with good pavement and facilities near the buildings, and the lawn along the waterfront.

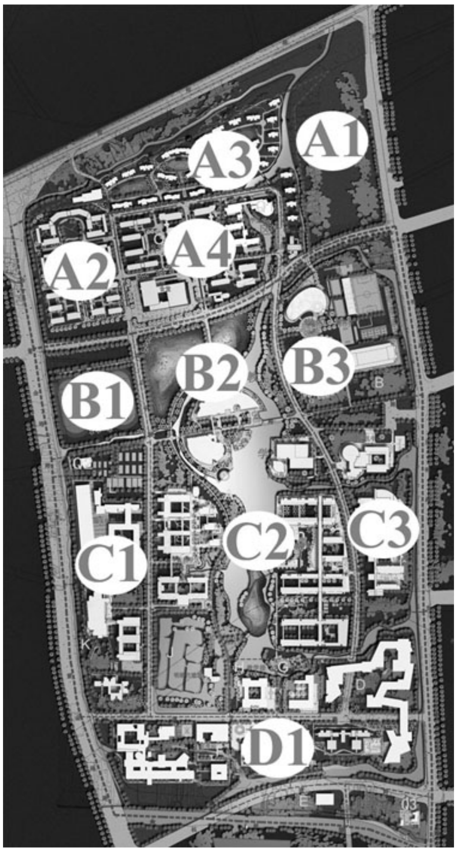

Fig. 2 Partition of Zi-Jin-Gang campus

Xi-Xi campus

The campus of Xi-Xi is one of the old areas of Zhejiang University and was founded since 1952. At present, the total land area is approximately 0.41 million square meters, where approximately 10,000 students are studying and living. According to the planning transportation system and the current situations in the survey (Fig. 3), the campus is divided into 3 sections (A, B, C) and 13 sub-sections (A1, A2, A3, A4, B1, B2, B3, C1, C2, C3, C4, C5, C6). 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 is the academic area (Table 4).

RESULTS OF BEHAVIORAL DYNAMICS MODEL

Results of Temporal Behavioral Dynamics Model

The population of the students who appear in the campus open space could be examined and compared at a temporal level (dimension) as Fig. 4 and 5.

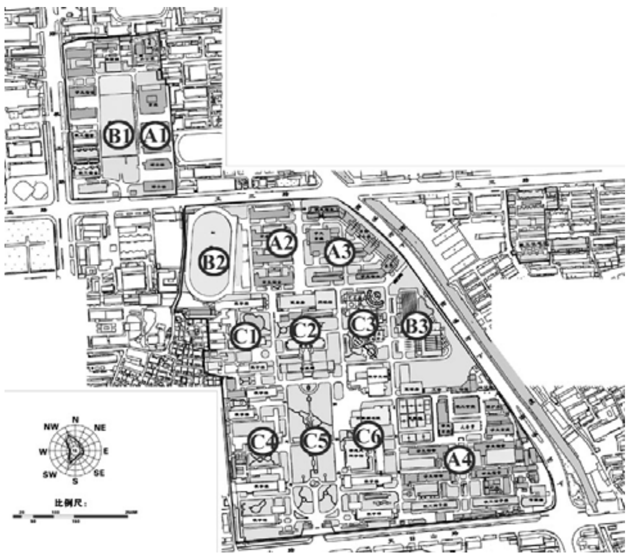

Fig. 3 Partition of Xi-Xi campus

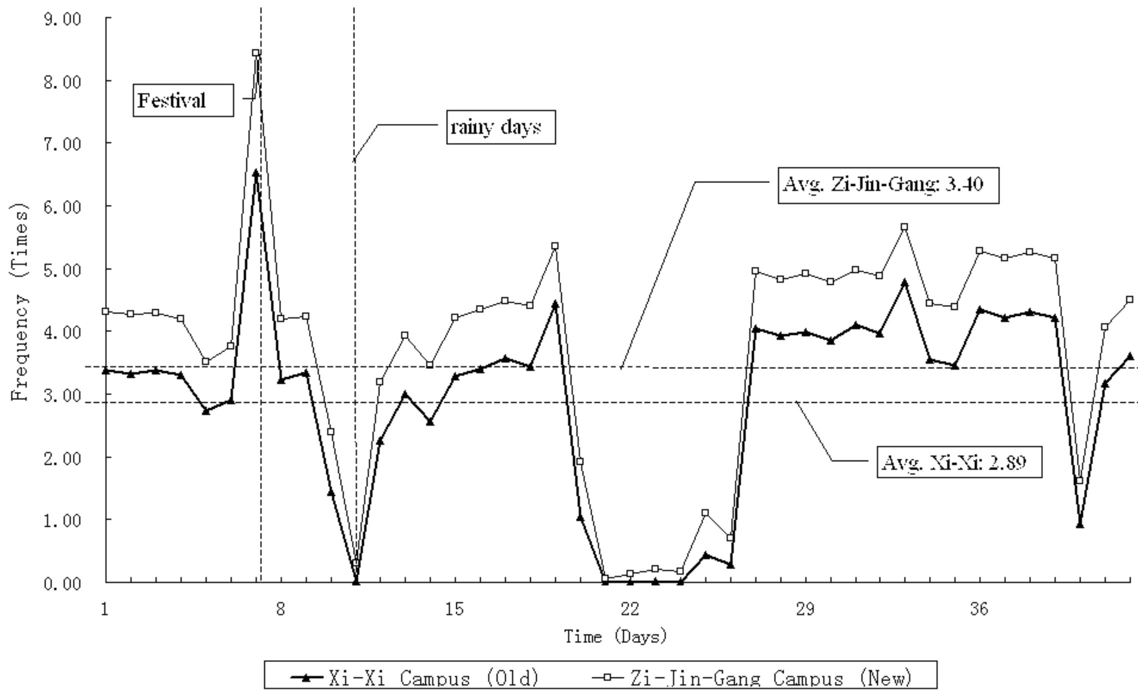

Fig. 4 Average frequency dynamics within the 6-week period, measured as the ratio of daily accumulative

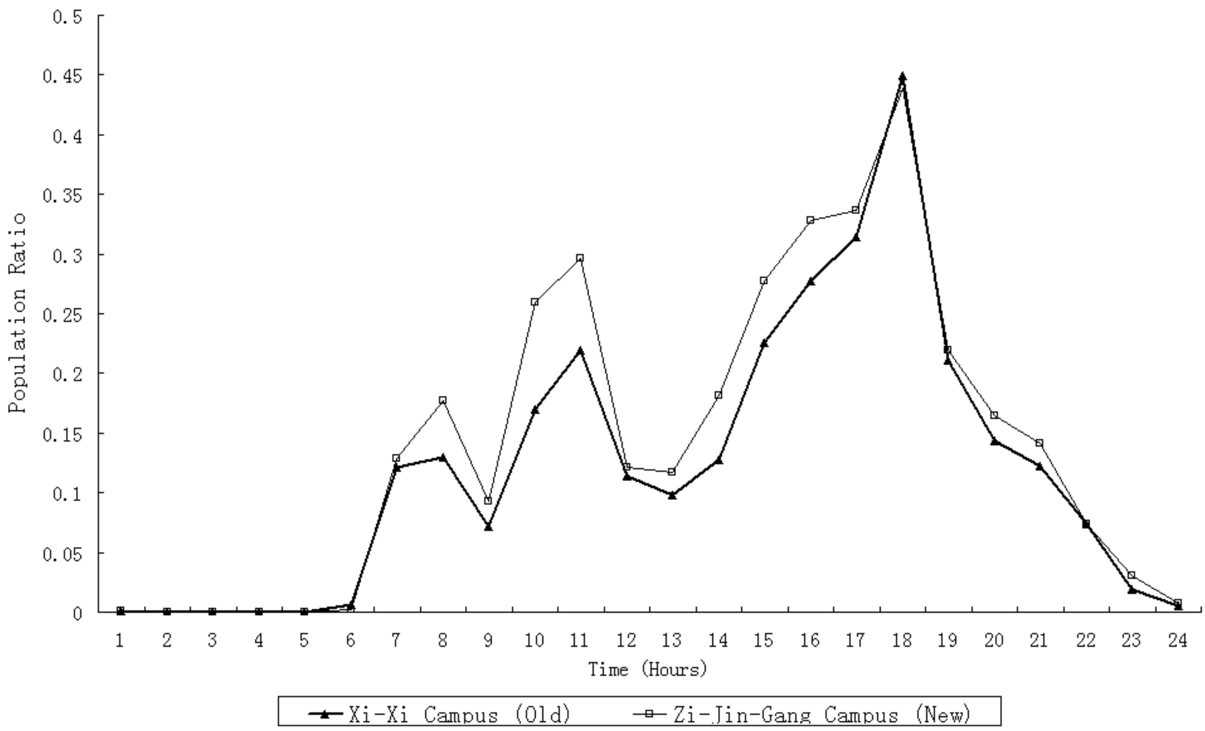

Fig. 5 Hourly population ratio dynamics within the 6-week period, measured as hourly accumulative number of people in campus open spaces. Note: the temporal point stands for the end of the hour period, e.g. 12 means the span from 11:00 to 12:00

On the one hand, from the daily frequency dynamics (Fig. 4), the weather variation influences the population fluctuation with a serious extent, since the population in open space would descend to a trough (valley) as a result of rainfalls. In addition, the special affairs or incidents stimulate the population to a great increment. For

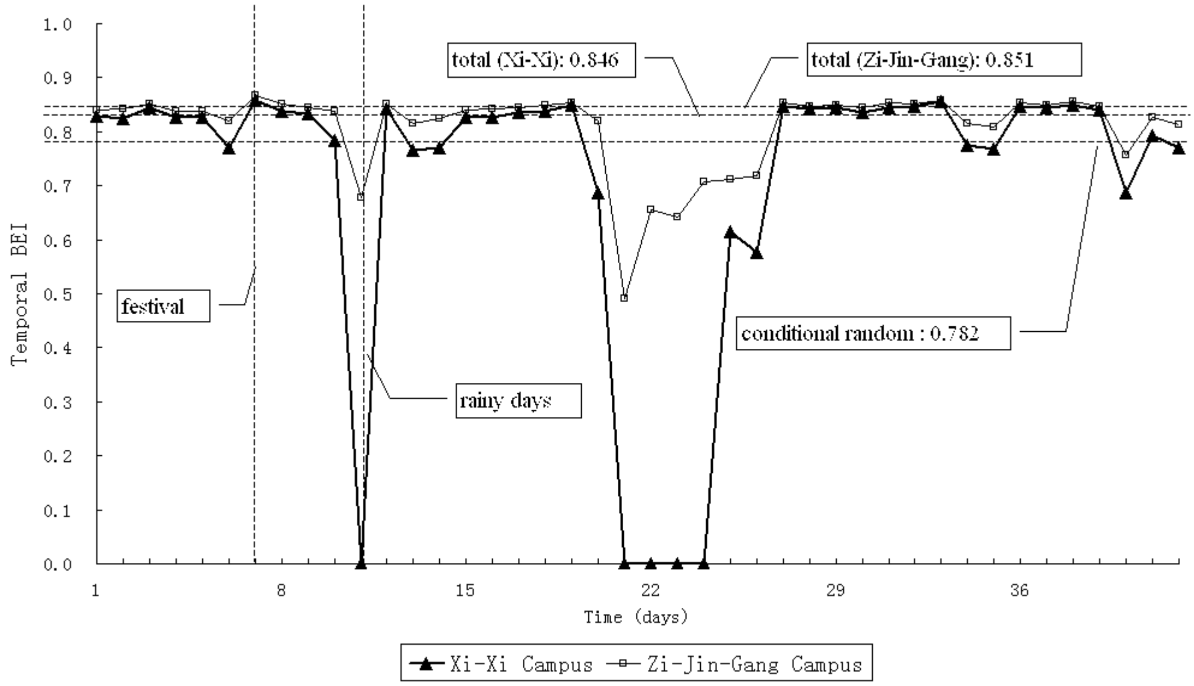

Fig. 6 Total temporal dynamics throughout the 6-week period; the daily temporal *BEI* is measured as hourly accumulative number of people presence on campus

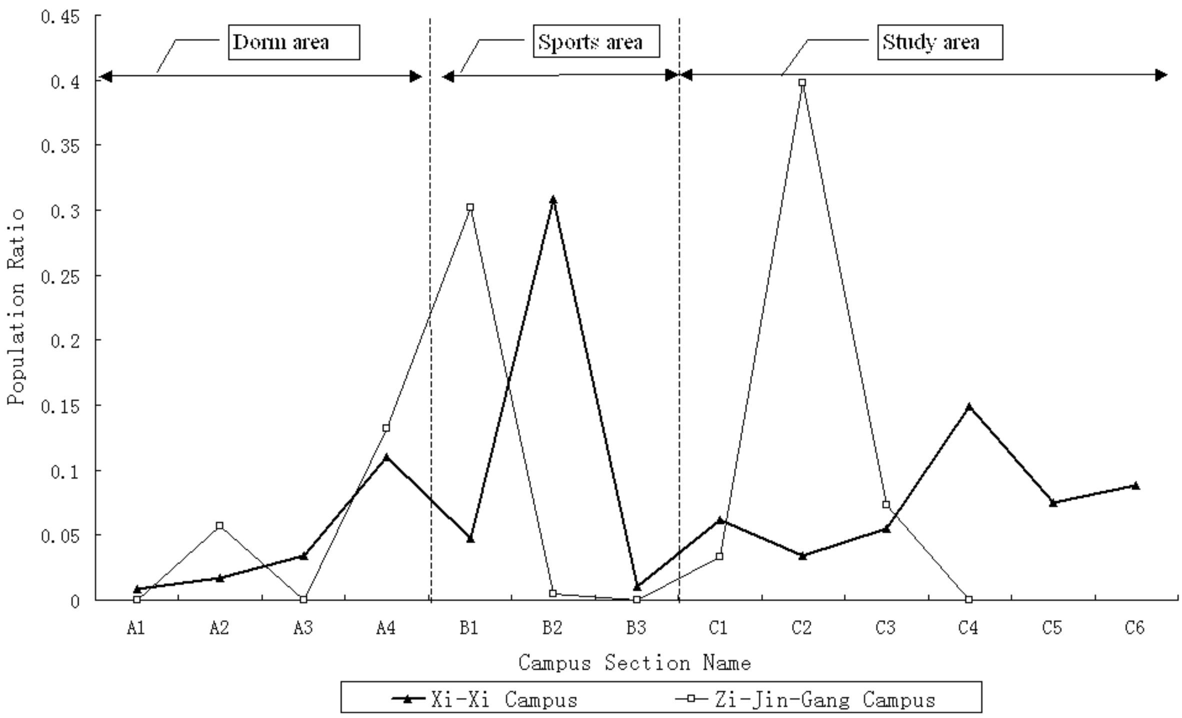

Fig. 7 Spatial population dynamics within the 6-week period, measured as accumulative number of people presence in each section of campus open spaces

example, the apex appears on the seventh day, the Chinese traditional holiday, when people go outdoors to enjoy the moon light and family ties (friendship).

On the other hand (Fig. 5), from the hourly temporal dynamics, the outdoor population ratio rises to the wave crest at p.m. 17 to 18, and the morning period nearly to lunch is also observed many populations. As the common sense, night is not a sound timing for outdoor life and consequently the outdoor population ratio declines to zero.

With a comparison between the old campus and the new campus, it shows that the population in the new campus open space is more prominent at the temporal dimension than that in the old campus.

However, the simple dynamics of population 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. 6):

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.

The weather conditions still influence the temporal behavioral complexity, because rain cuts down the opportunity for outdoor life.

$$TBEI = \frac{-\sum_{j=1}^{n} p_j \log_2(p_j)}{\log_2(n)} \qquad (3)$$

where *TBEI* is the Temporal Behavioral Entropy Index,
p_j is the relative frequency (probability) of the j^{th} behavioral option.
n is the number of behavioral options.
Division by $\log_2(n)$ serves to normalize the measure into 0-1.
(The above function is also used in all the *BEI* calculations)

Daily Temporal $BEI = f(x_i)$,
where x_i = hourly accumulative population during the day, $i = 1, 2, 3, \ldots, 24$.

Total Temporal $BEI = f(x_i)$,
where x_i = hourly accumulative population during the 6 weeks, $i = 1, 2, 3, \ldots, 24$.

Temporal *BEI* of Conditional Random $= f(x_i)$,
where $x_i = 1/12$, i = 6, 7, 8, …, 18;
$x_i = 0$, $i = 1, 2, 3, 4, 5, 19, 20, 21, 22, 23, 24$.

Results of Spatial Behavioral Dynamics Index

Like the temporal case, the population of the students who present in the campus could be examined and compared at a spatial level (dimension) as Fig. 7. On the one hand, from the spatial dynamics, the location influences the population changes with a serious extent, since the population in open space would converge at the sports field and the study area with a good landscape view, where are laid out large numbers of open spaces with facilities. The areas under construction are inaccessible for outdoor activities.

As mentioned above in the temporal section, the results of a spatial behavioral entropy index (Fig. 8) revealed that:

Contrasted with the few population and the low temporal *BEIs* in rainy days, the spatial *BEIs* rises. The contrastive results imply that spatial behavioral complexity could not be simply examined by population. In other words, more population does not absolutely bring out more complexity.

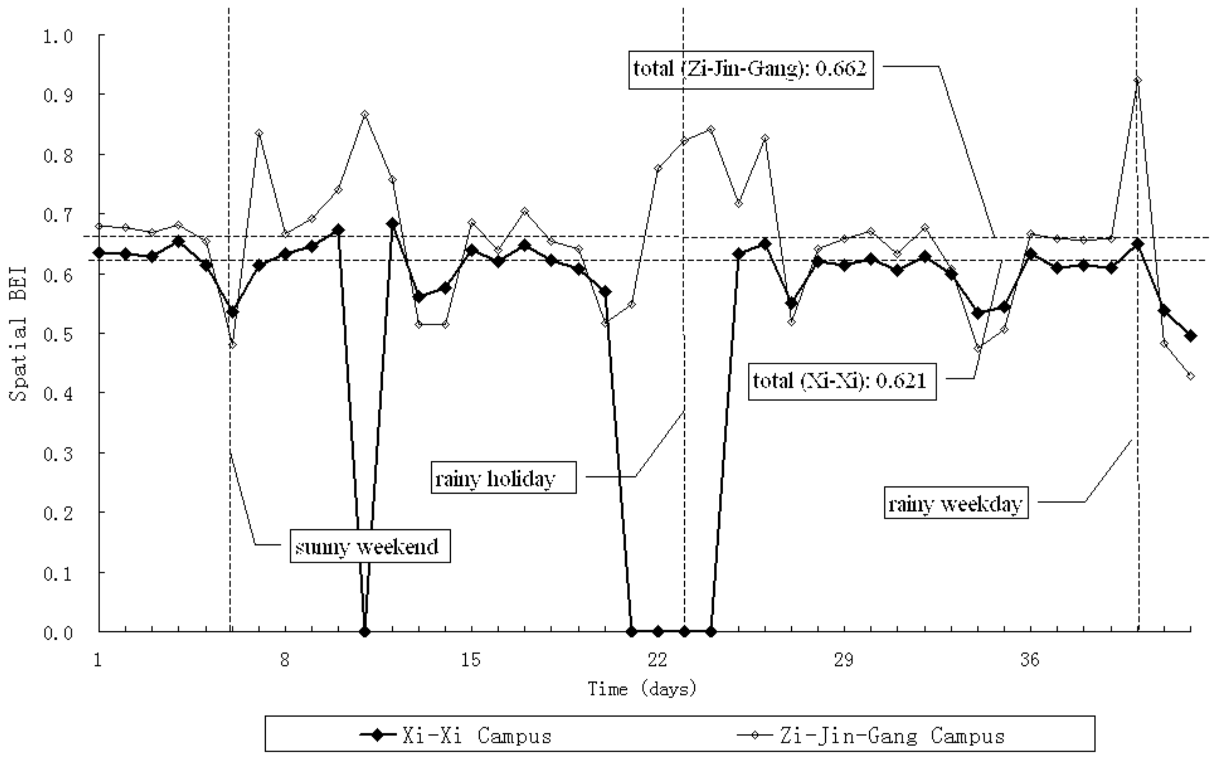

Fig. 8 Total spatial dynamics throughout the 6-week period; the daily *BEI* is measured as hourly accumulative number of people in campus open space

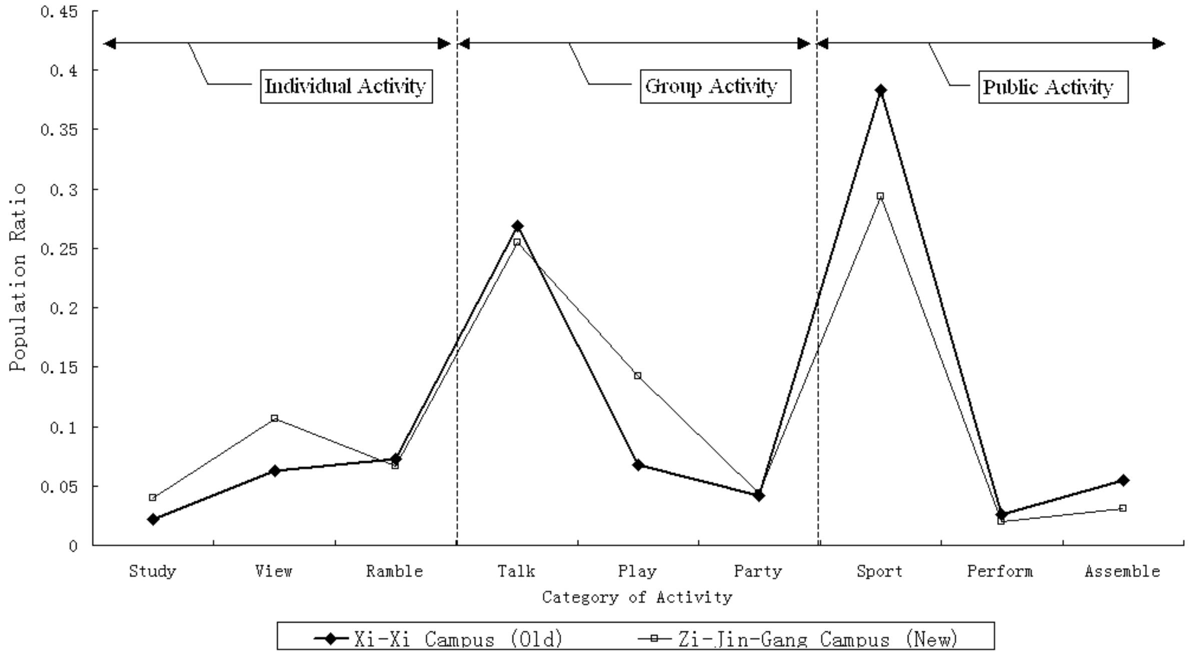

Fig. 9 Categorial population dynamics within the 6-week period, measured as accumulative number of people in each section of campus open space

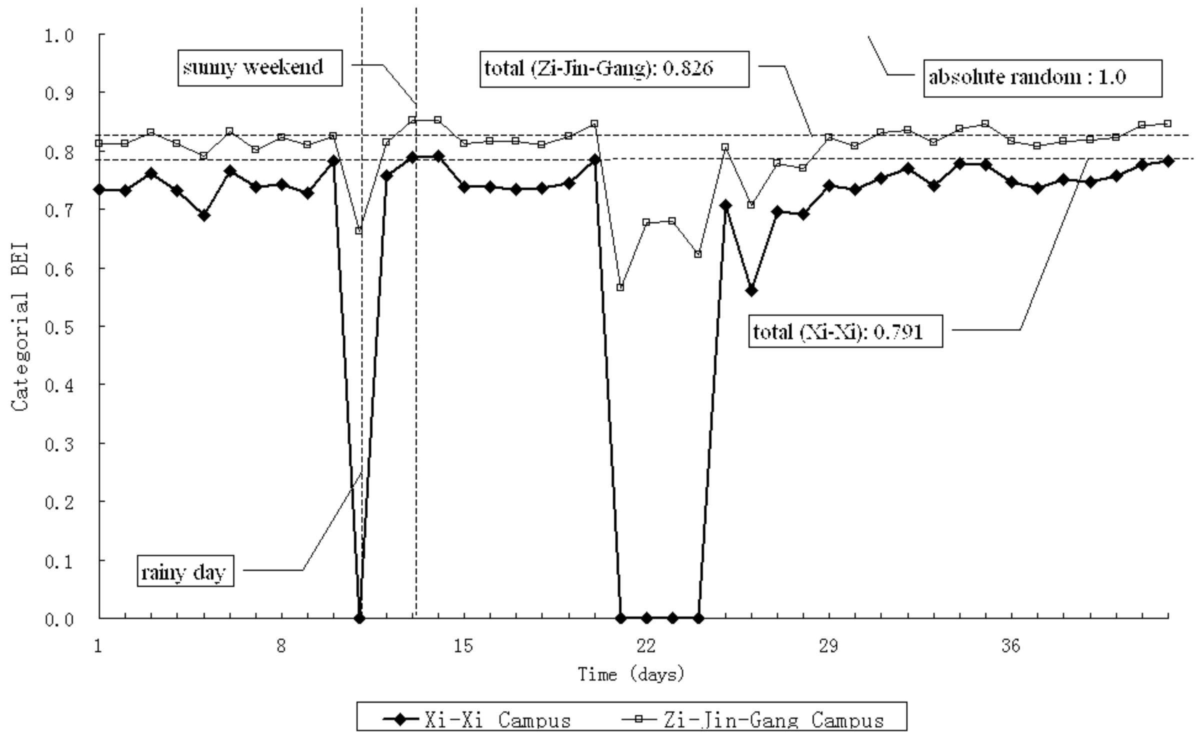

Fig. 10 Total categorial dynamics within the 6-week period; the daily *BEI* is measured as hourly accumulative number of people in campus open spaces

The weather conditions still seriously influence the complexity of spatial behavior, because rain cuts down the opportunity for some given open spaces, e.g. the sports space. As a result, the complexity of location decision increases since people are provided relatively balanced probability of going somewhere. It is also confirmed by the *BEIs* of sunny weekends that are very low as the class is off, the sports and leisure decision increases. Therefore the choice on activity places becomes simple.

The obvious difference between the two campuses from the 21st day to the 24th day confirms that the semi-open spaces influence human behavior because they are extensively built around most sections of Zi-Jin-Gang campus while few are found in Xi-Xi campus.

Note:

$$SBEI = \frac{-\sum_{j=1}^{n} p_j \log_2(p_j)}{\log_2(n)} \quad (4)$$

where *SBEI* is the Spatial Behavioral Entropy Index, p_j is the relative frequency (probability) of the j^{th} behavioral option.
n is the number of behavioral options.
Division by $\log_2(n)$ serves to normalize the measure into 0-1.

Daily Spatial $BEI = f(x_i)$,
where x_i = hourly accumulative population in the sub-section, on that day, $i = A1, A2, \ldots, C6$.

Total Spatial $BEI = f(x_i)$,
where x_i = hourly accumulative population throughout the 12 weeks (or 6 weeks), $i = A1, A2, \ldots, C6$.

Results of Categorial Behavioral Dynamics Index

Similarly, the population of the students who present in the campus could be examined and compared at a categorial level (dimension) as Fig. 9. From the categorial dynamics, the category of activity influences the population changes with a serious extent, since the population in open space would converge at sports and talking, while holding a party or assembly seems not to take an important place among daily life.

As mentioned above in the previous sections, the results of a categorial behavioral entropy index (Fig. 10) revealed that:

Contrasted with the similarly equivalent temporal *BEIs* in unrainy days whether weekdays or weekends, the categorial *BEIs* of sunny weekends rise. The contrastive results imply that categorical behavioral complexity is subject to some compulsory schedule. For example, students must spend more time in study on weekdays so that other activities are cut down. The weather conditions still seriously influence the categorial behavioral complexity, because rain cuts down the opportunity for some given activity, e.g. parties, performance or assembles . As a result, the complexity of activity decision increases. It is also confirmed by the *BEIs* of unrainy weekends that are very high as almost all activities could be held so that the choice of activity content becomes diverse.

$$CBEI = \frac{-\sum_{j=1}^{n} p_j \log_2(p_j)}{\log_2(n)} \quad (5)$$

where *CBEI* is the Categorial Behavioral Entropy Index, p_j is the relative frequency (probability) of the j^{th} behavioral option.
n is the number of behavioral options.
Division by $\log_2(n)$ serves to normalize the measure into 0-1.

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

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

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

ANALYSIS OF INTERACTION BETWEEN BEHAVIORAL DYNAMICS

Analysis of Temporal-Spatial Behavioral Dynamics

Temporal-spatial

The relation between time and space was checked with a temporal-spatial behavioral index (Fig. 11). The behavioral complexity reaches the peaks at 14:00 and 19:00, when the activities are distributed in all the campus sections as a relatively even balance. But they are seriously uneven in the early morning and the suppertime.

Spatial - temporal

The relation between time and space was also checked with a spatial-temporal behavioral index (Fig.12). The behavioral complexity at the temporal dimension reaches the peaks at the Dorm Areas and followed by the Academic Areas. But they are seriously uneven in the sports areas.

The results imply the positive impacts of distance to dorm, facilities (light and bench), waterscape, small plot and semi-open space on the spatial-temporal *BEI*. It is an implication that more provision of these physical factors should increase the behavioral complexity and consequently improve the utilization efficiency of open space at the temporal dimension.

Analysis of Temporal – Categorial Behavioral Dynamics

Temporal – categorial

The relation between time and category was checked with a temporal-categorial behavioral index (Fig.13 and

14). The behavioral complexity reaches the peaks at 14:00 and 19:00, when the category of activities is diverse as a relatively even balance. But they are seriously uneven in the early morning, the dinner time and after 20:00 (Fig.13).

Categorial - temporal

The Categorial - Temporal index shows that there are two categories of activities are taken extensively in a whole day, i.e. individual rambling and group talking. On the contrary, public activities are taken place only during fewer timing (Fig. 14).

Moreover, there is an obvious difference between the two campuses. The viewing activity of Zi-Jin-Gang

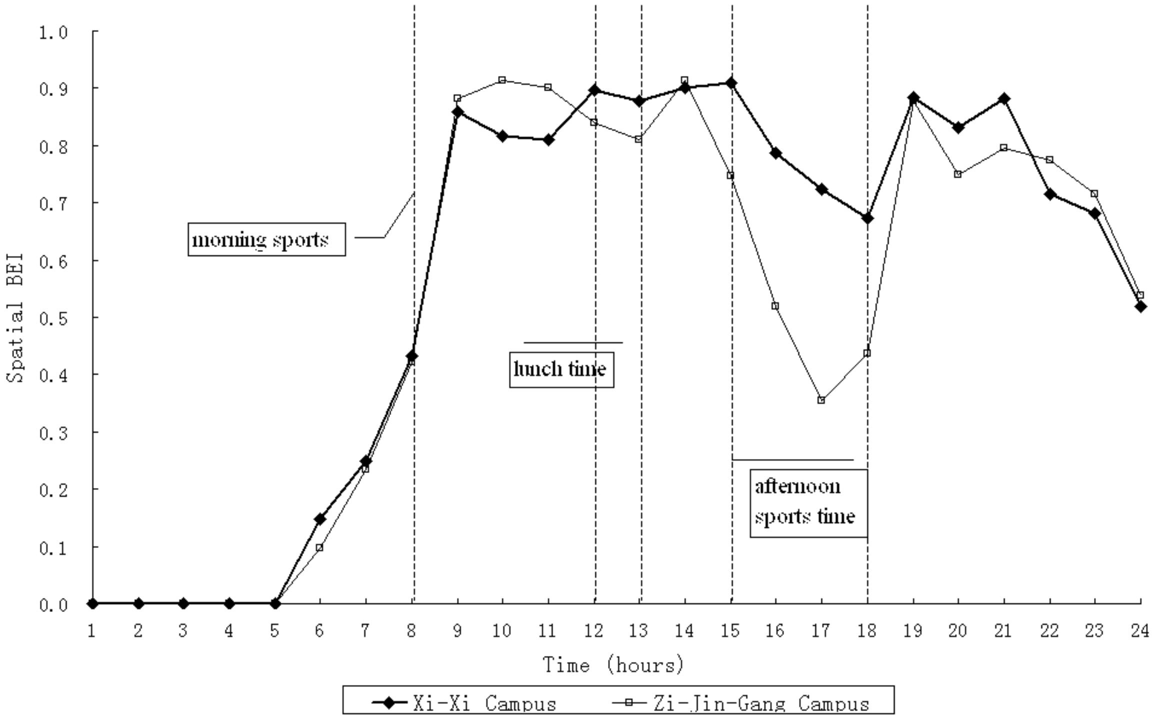

Fig. 11 Temporal-spatial dynamics at the 24-hour scale; the *BEI* is measured as hourly accumulative number of people presence in campus open space

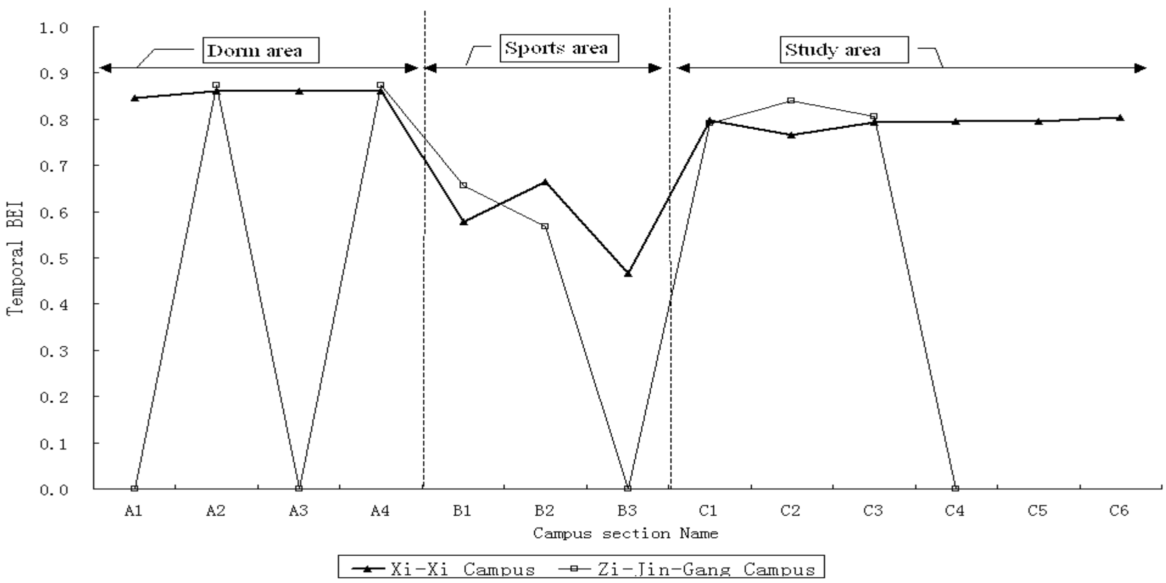

Fig. 12 Spatial-temporal dynamics at the 11-section (13-section) scale; the *BEI* is measured as hourly accumulative number of people presence in campus open spaces

campus (the new campus) is taken much more extensive than Xi-Xi campus (the old campus) at the temporal dimension. That confirms that the landscape in Zi-Jin-Gang Campus is more beautiful and extensively distributed than Xi-Xi campus.

Hence, designers should improve the old campus with more landscape elements not only for the academic areas but also for the dormitory areas or the sports areas.

Analysis of Spatial – Categorial Behavioral Dynamics Indices

Spatial – categorial

The relation between time and category was checked with a spatial-categorial behavioral index (Fig.15 &16). The behavioral complexity reaches the peaks at C1, C2 and C3, especially C2, the central study area of Zi-Jin-Gang Campus, where diverse activities are taken place (Fig.15). But fewer category is held at B1 (the sports field), and none at the three under-construction sections

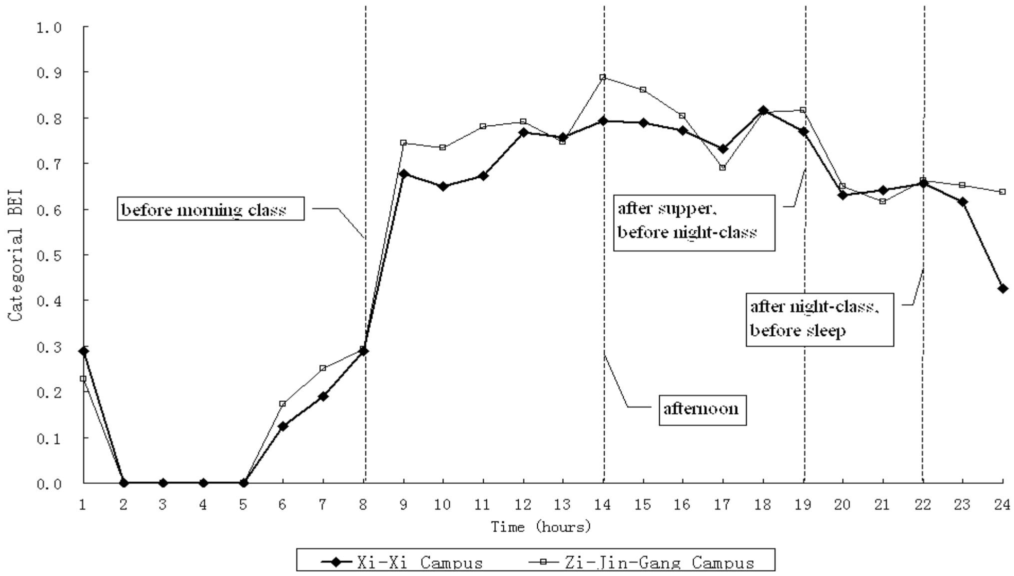

Fig. 13 Temporal-categorial dynamics at the 24-hour scale; the daily *BEI* is measured as hourly accumulative number of people presence in campus open spaces

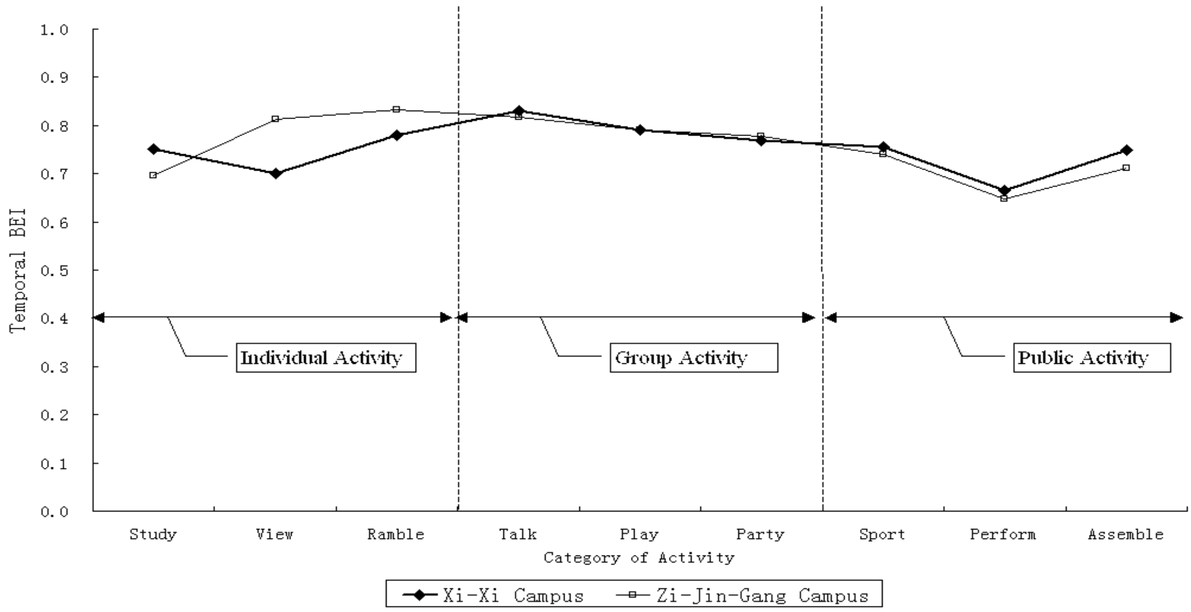

Fig. 14 Categorial-Temporal dynamics at the 9-category scale; the daily *BEI* is measured as hourly accumulative number of people presence in campus open spaces

of Zi-Jin-Gang campus (A1, A3, D1 (C4)).

The results imply the positive impacts of facilities (light and bench), waterscape, small plot and semi-open space on the spatial-categorial *BEI*. It is an implication that more provision of these physical factors should increase the behavioral complexity and consequently improve the utilization efficiency of open space.

Categorial - spatial

The Categorial - Spatial index (Fig. 16) shows that there are two categories of activities are taken extensively on campus, i.e. individual rambling and group talking. On the contrary, sports is taken place only in one or two locations. The results mean that some activities are diversely distributed around the campus sections, while others converge into a few specific

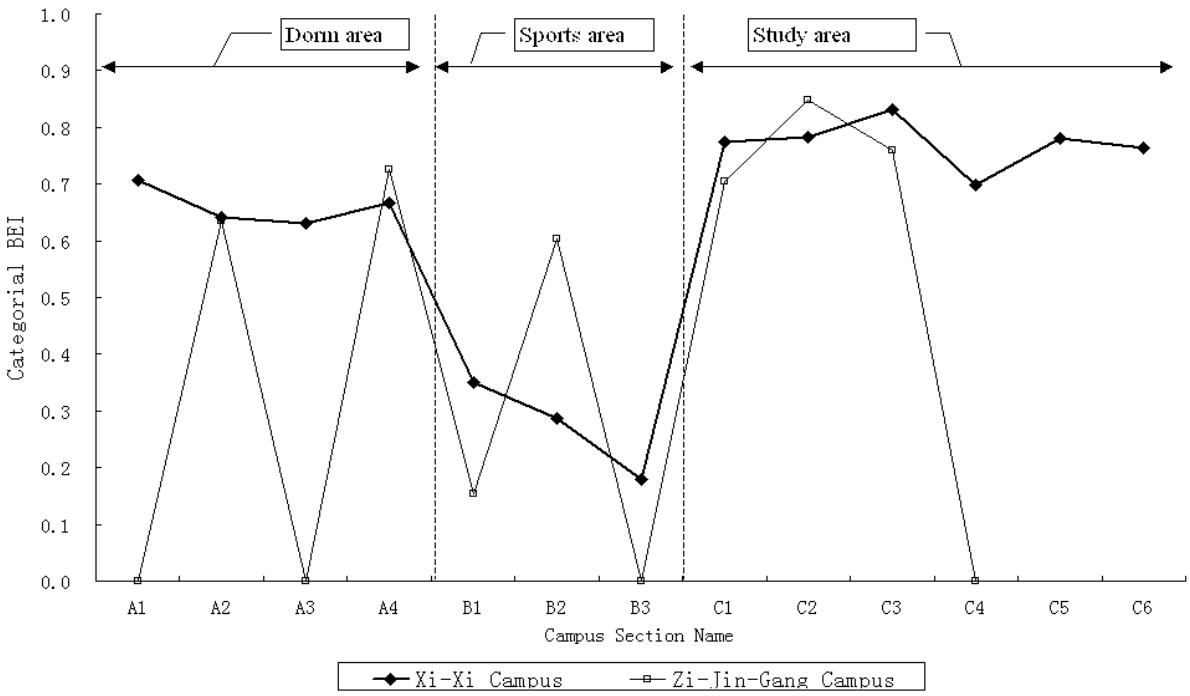

Fig. 15 Spatial-categorial dynamics within the 11-section (13-section) scale; the daily *BEI* is measured as hourly accumulative number of people presence in campus open spaces

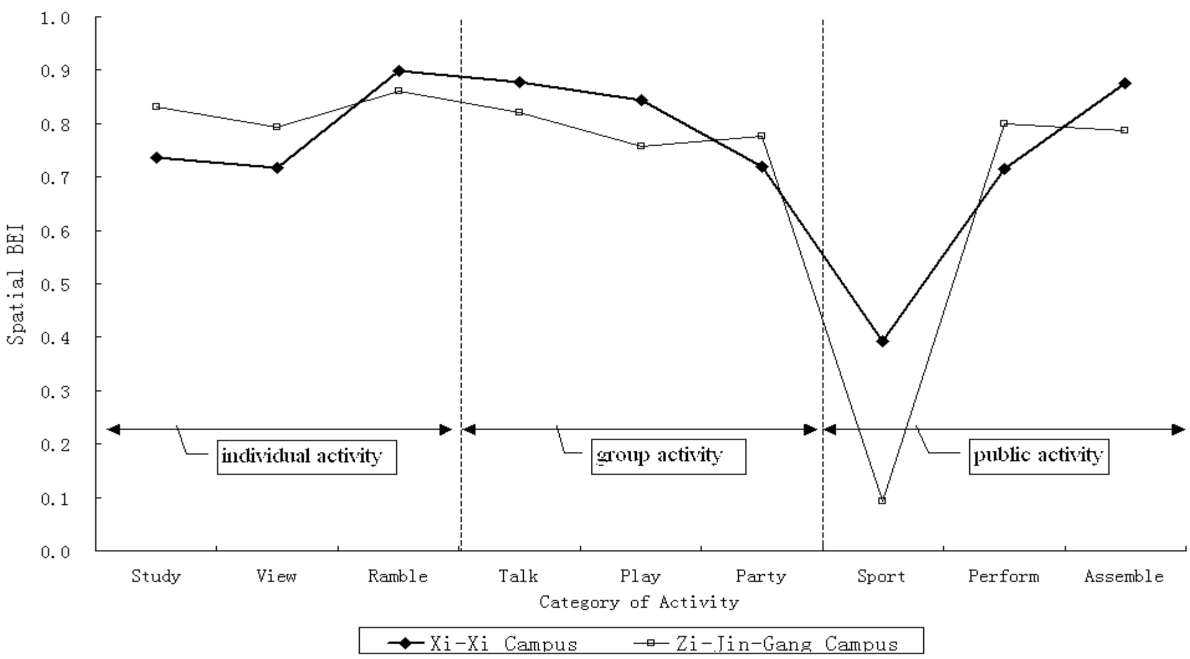

Fig. 16 Categorial-Spatial dynamics at the 9-category scale; the daily *BEI* is measured as hourly accumulative number of people presence in campus open spaces

sections.

Some useful information may be extracted from the above results that:

For individual rambling and group talking, designers should consider to provide more physical conditions at most locations.

If possible, designers may complement some small-scale sports fields inside the dorm areas and the academic areas. That constitute to students' sports activity on the spot.

The following is a brief summary of findings incorporating all significant highlights from the analysis.

The activity distribution balance of different types is significant to increase the entropy result of open space utilization;

The Number of option and opportunity for outdoor life are important to increase he entropy result of outdoor behavioral complexity.

The weather conditions determine the entropy result of outdoor behavior.

The school schedule of off days and working days also influences the entropy result of outdoor behavior.

CONCLUSIONS

The significant quantity of campus construction in China necessitates the development of new analytical methods that allow for effective and proper treatment of human activities and physical (objective) conditions. This is exactly the challenge that is faced by architects and planning theoreticians who are familiar with traditional methods, e.g. spatial formation, landscape aesthetics, transportation network and so on. The measure presented here, is inspired by the work of other scientific fields, and applies an information-based complexity to the analysis of multi-dimensional data on campus lives. With regard to users' behavior on campus, this study established the unconventional methods, the Behavioral Entropy Model, to examine the complexity of residents' reaction to physical environments, i.e. behavioral diversity.

The study comes up with concrete conclusions based on the results of analysis. The results of behavior assessment revealed the following information:

It is insufficient to examine the behavioral characteristics only by simply population counting and percentage. The Behavioral Entropy Index constitutes to clarify the relationship between the temporal, spatial and categorical dynamics.

These conclusions are substantiated based on the results of the findings and analysis. 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.

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.

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.

Finally, the *BEI* model was developed specifically to deal with the characterization problem related to campus activity data. However, its application is not restricted to this limited example.

Some extensible work of the current study should be further done. For example, we plan to apply alternative approaches to quantify the interaction between human behavior and physical factors.

Further concrete directions of the study are stated as follows:

The research area was limited due to the incomprehensive samples of the behavioral survey that only touched two campuses. There is still a need to reinforce the reliability and extension for the overall city. The comparison between different residences and campus, even other specific open spaces should be taken into the model, in order to find more powerful information for planners and designers, as well as residents themselves.

The samples also need to be extended with a complement of more residential areas, not only Hangzhou City but also other local cities in China, since the country is so large that the natural conditions and social conditions are diverse in terms of the location. The fact brings out more diversity of residential open space lifestyles.

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