中国の住宅団地における屋外行動に関する研究：滞留行動に及ぼす物理的環境の影響

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住宅団地の屋外空間における活動は、住民同士の社会的交流を促し、ひいては住民の心身の健康増進が期待できる。しかし中国においては1998年以降の住宅政策の変更によって、これまで良好であった近隣交流の急激な減少が問題になっている。本研究は、天津市に新しく建設された4住宅団地における屋外行動の観察調査を通して、それを促す物理的環境要因を明らかにする。住宅団地内の屋外空間を代表する33のサブスペースを定め、それぞれについて、10-20分間ずつ10回（3週日及び2週末の午前と午後）観察調査を行い、計7668の通過及び滞留行動を記録した。住民の滞留行動を説明する物理的要因として、接近性（5変数）、設え（4変数）、空間形態（2変数）の3要因を定め、全ての行動および短停留行動・静的行動・動的行動のカテゴリー別の重回帰分析を行い、影響する物理的要因がそれぞれ異なることを明らかにし、それらの滞留行動を促す計画のための基礎的知見を得た。

キーワード：住宅団地、屋外空間、滞留行動、物理的要因、重回帰モデル

Study on Outdoor Activities in China's Residential Communities: Influence of Physical Characteristics on Staying Activities

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Outdoor activities in residential communities may promote social interactions between neighbors, helping maintain the residents' physical and mental health. However, it has been said that social interactions in China's residential communities have drastically decreased due to the housing policy change in 1998. This paper aims to elucidate relevant factors of the physical environment that enhance residents' outdoor activities via an intensive survey in four newly developed residential communities in Tianjin. Prior to the intensive survey, 33 representative subspaces of all outdoor spaces were defined. For each subspace, the residents' staying activities as well as passing activities were observed 10 times where each session lasted between 10-20 minutes (morning and afternoon on three weekdays and two weekends), providing a total of 7668 behaviors. For the physical environment, we postulated three physical factors, accessibility, facility, spatial configuration; and defined five, four, and two variables, respectively. Linear regression analysis using these variables reveals that the magnitude of the effects of physical factors varies by activity categories including all activities, occasional stoppings, sedentary activities and vigorous activities. The results of this study provide basic knowledge on the design of residential communities to promote staying activities.

Keywords: residential community; outdoor space; staying activities; physical factors; regression model

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1. Introduction

There is a growing body of evidence that improving a neighborhood's physical environment can increase health (e.g., Belon et al., 2014) or active lifestyles (Ferdinand et al., 2012). Approaches targeting the influence of physical environment on activities have been evaluated from several perspectives, including health outcomes (Zick et al., 2009) or quality of life (Edwards and Tsouros, 2006). It has been suggested that activities in a community may positively impact community health.

China's residential communities have changed drastically since the Chinese government initiated a commodity housing policy in 1998. Before this policy, most Chinese citizens from the same company lived in houses provided by governmental organizations, but afterwards new communities were developed as commodities, and many people with different backgrounds started to buy these houses. It has been said that social interactions in these new communities have drastically decreased due to the increased diversity and unfamiliarity with neighbors (Sun, 2010).

Semenza (2005) indicated that activities in residential communities promote social interactions and mutual support between neighbors, helping maintain residents' physical and mental health as well as prevent crime within a community. This study examines the link between community environment and outdoor activities to address the issue of how to encourage residents to partake in various outdoor activities within their communities.

Dahlgren and Whitehead (1991) postulated that whether an individual, group, or whole community will be active is influenced by a variety of factors at different levels, including individual determinants, social environment, and built environment. However, this study does not discuss individual determinants or the social environment because China's society had developed homogeneously until 1980s, limiting significant cultural or socioeconomic differences without ethnic disparities. Thus, we have focused on the effects of the built environment, namely the objective physical characteristics, on outdoor activities of residents, especially activities that provide opportunities for social interactions.

Research regarding the relationship between physical environment and activity has employed multiple approaches. Some physical characteristics such as accessibility (Alfonzo, 2005; Franzini et al., 2010) and environmental supports (Robinson et al., 2014) have been demonstrated to affect people's activities. However, the effects of physical characteristics in the context of Chinese society have yet to be explored in depth. This paper aims to elucidate relevant factors of the physical environment that enhance residents' outdoor activities via an intensive survey of newly developed residential communities in China. We also examine the physical characteristics of outdoor spaces that affect activities of different activity categories.

2. Field Survey

To discuss the effects of physical factors on residents' activity in a scientific manner, a reliable data collection method must be applied. Several methods have been proposed to examine outdoor activities, including statistical analysis using quantitative and qualitative data collection through interviews, observations, and document analysis (Kawulich, 2012). Actual activity information contains both qualitative content (e.g., occurrence location) and quantitative content (e.g., the number of participants). Therefore, an intensive field survey is conducted to collect data with useful direct first-hand information about space use via a systematic observation method.

The survey sites were selected from the residential communities in Tianjin, China because it is one of the first cities to implement the commodity housing policy. It has developed many new residential communities with various physical layouts. In addition, we collaborated with a research group from Tianjin University, who has previously conducted several surveys on the residential communities with us.

2.1 Community Selection

The newly developed residential communities were identified by the documents of Tianjin's urban planning (Du et al., 2004), and their general physical features were examined using Google aerial photographs. There are two basic types of community physical layouts: one where buildings divide outdoor spaces into several similarly sized pieces and peripheral vehicle roads do not disturb interior pedestrian paths and the one with a large central space surrounded by smaller spaces that are usually separated by vehicle roads. We then examined other data for each community (e.g., size and population). Similarities between size and population were considered to compare the physical differences of outdoor spaces. Based on these considerations, we selected four candidate communities for each type of physical layout (i.e., a total of eight).

A pilot survey in the candidate communities was conducted in March 2013. Comparatively young communities generally have inactive outdoor space usage due to unfamiliarity within the community and immature social networks. Thus, we selected the four older communities: Xiangshuiyuan (XS), Fangshuiyuan (FS), Tianhuali (TH), and Jiuhuali (JH), while excluding the four younger ones (Table 1). In addition, general maps of the selected communities were drawn based on aerial photographs and improved through the onsite pilot survey.

2.2 Selection of Subspaces through a Preliminary Survey

Because observing all the outdoor spaces in these four communities is infeasible and many outdoor spaces have similar physical characteristics, next representative spaces to observe were selected. First, we defined an area of subspaces by behavioral barriers such as building walls and/or edge of wide roads/water using general community maps. This yielded a total of 111 subspaces (20–40 subspaces for each community). Then we conducted a preliminary survey to observe and record the basic physical characteristics[1] with regard to outdoor activities. Based on these records authors discussed and determined the representative subspaces according to their similarities. Eventually 33 subspaces were selected for the intensive survey (Figure. 1).

2.3 Intensive survey

Considering the influences of climate and weather, the intensive survey was conducted on 12 clear days between 10 and 30 October 2013. The survey had two steps: investigate the physical environment and observe outdoor activities[2].

We investigated the physical environment of each subspace initially using an environment datasheet to collect the data with a detailed site plan, information of the physical elements, and facilities. On the other hand, activity data were recorded using an activity observation datasheet (Figure 2), which is a synthesized tool for behavioral mapping and a statistical activity observation system named SOPRAC (Mckenzie and Cohen, 2006).

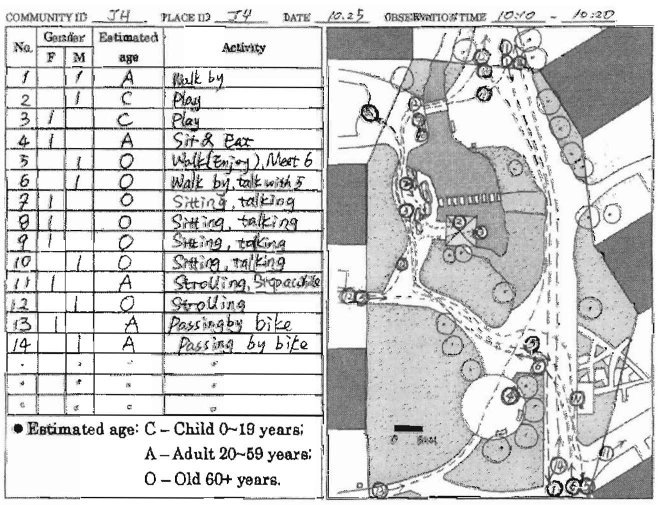
Table 1. Basic Information of Selected Communities

	XS	FS	TH	JH
Established Year	2002	2002	1998	1999
Population	4300	3500	8000	3800
Area (M^2)	1211	1065	1553	1062

The data included information such as activity contents, users' behavioral maps, and individual attributes (gender and estimated age). A typical observation session lasted about 10 minutes, but depending on the subspace size some sessions lasted about 20 minutes. Each subspace was observed twice (once in the morning and once in the afternoon) on five different days (three weekdays and two weekends). Thus, ten activity observation datasheets were collected for each subspace.

2.4 Categorization of Outdoor Activities

The 330 activity observation datasheets (33 subspaces × 10 times) contained data for 7668 users' activities, which were generally divided into passing and staying activities. In the


COMMUNITY ID JH PLACE ID J4 DATE 10.25 OBSERVATION TIME 10:10 ~ 10:20

No.	Gender F	Gender M	Estimated age	Activity
1		1	A	Walk by
2		1	C	Play
3	1		C	Play
4	1		A	Sit & Eat
5		1	O	Walk(Enjoy), Meet 6
6		1	O	Walk by, talk with 5
7	1		O	Sitting, talking
8	1		O	Sitting, talking
9	1		O	Sitting, talking
10		1	O	Sitting, talking
11	1		A	Strolling, [illegible]
12		1	O	Strolling
13	1		A	Passing by bike
14		1	A	Passing by bike

● Estimated age: C – Child 0~19 years; A – Adult 20~59 years; O – Old 60+ years.

Figure. 2. Example of Activity Observation Datasheet.

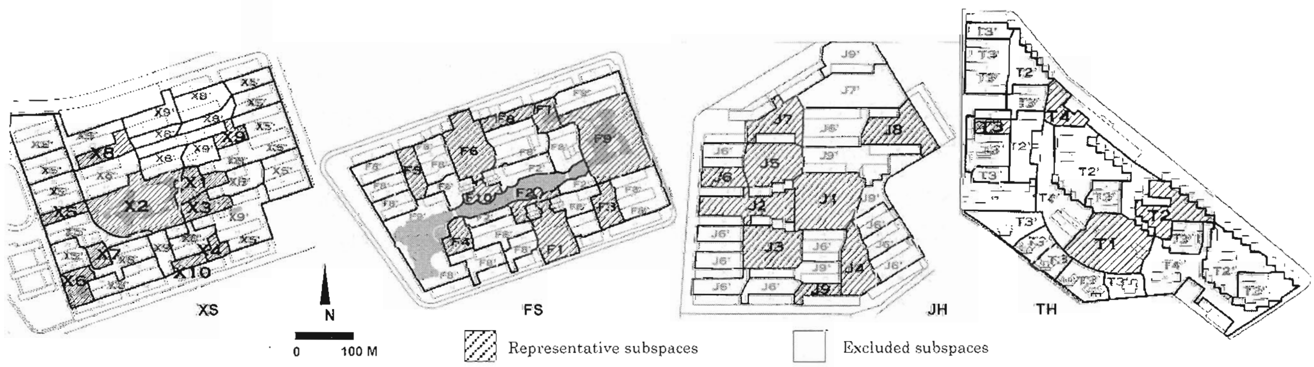


Figure. 1. Selected Subspaces in the Four Communities.

former, a user traverses through a subspace, whereas in the latter, a user stops or remains in a subspace. Hanazato and Kim (2011) also grouped observed activities into passing and staying activities, and argued that staying activities are more related to social life. Similarly, we hypothesize that a staying activity may contribute to social interactions.

Furthermore, we proposed a more detailed categorization of outdoor activities as shown in Table 2. There are three subcategories: 1) occasional stoppings refer to activities that users stop in the subspace for a short time (less than 1 minute); 2) sedentary activities refer to such activities as sitting, standing that users remain in a subspace more than 1 minute without locomotion; and 3) vigorous activities refer to such activities as exercise, playing football that users remain in a subspace more than 1 minute with locomotion.

As mentioned previously, this study focuses on staying activities. At first the number of users involved in staying activities was calculated according to activity observation datasheets. However, the numerical data of staying activities for individual subspaces cannot be directly compared because the community populations differ. Therefore, we used the proportion of the number of users to the total community population to determine the density of staying activities (DSA).

Since we can distinguish subcategories of staying activities based on the activity observation datasheets, it is possible to evaluate DSA data for each category (Table 2), which were treated as dependent variables (DVs) in the regression analysis.

Table 2. Categorization of Outdoor Activities

Category	Subcategory	N	%
Passing activities	Cycling through	1452	19
	Walking through	3413	44.5
	Strolling	936	12.2
Staying activities	Occasional stoppings	854	11.1
	Sedentary activities	292	3.8
	Vigorous activities	721	9.4
Total		7668	100

3. Variables of Physical Characteristics

Previous research has used various constructs to examine the physical characteristics associated with activity (e.g., accessibility (Alfonzo, 2005; 2008; Franzini et al., 2010), walkability (Leslie et al., 2007), facility (Prins et al., 2011), and spatial configuration (Sailer and McCulloh, 2012). However, the literature does not clearly differentiate many of these constructs. This study emphasizes the characteristics of a subspace (e.g., accessibility, facility, and spatial configuration). Table 3 shows major variables and their definitions as they are treated as independent variables (IVs) latter.

3.1 Accessibility Variables

The current study assesses accessibility at two levels: the community-level and the subspace-level. The community-level accessibility discusses the location of a subspace in a community, while the subspace-level accessibility discusses the spatial component associated with accessibility.

3.1.1 Community-level Accessibility

Community-level accessibility refers to the easiness of access from a point to a target subspace. There are two start points considered: community entrances and residential buildings.

For the former one, a space syntax method namely visibility graph analysis (VGA) is used to measure accessibility from community entrances. There are many methods of space syntax, within which only VGA can examine accessibility from a point, namely visibility step depth (VSD). A common software of space syntax – UCL depthmap (Pinelo and Turner, 2010) can generate graph with VSD data from a particular entrance based on site maps. VSD illustrates the number of visual steps necessary to go from one to another in the graph. An analysis point is a symbolized square generated by a grid, whose spacing is fixed as 20 centimeters in this research. We then use the VSD graph to calculate spatial visibility step depth (SVSD) as a measure of accessibility from community entrances.

The start point is set to the center of an entrance. Each visual step is shaded separately in the graph, and multiple VSD graphs are generated because multiple entrances typically exist for a community. In order to synthesize the VSD data of each entrance into one graph, the weight of significance of each entrance was used to assess VSD from all entrances (EVSD). We presume that more passengers passing through an entrance increase the likelihood of its significance. Therefore, we estimated number of passengers in each entrance by the result of passing activity observation in the subspaces which is directly connected to the entrance, and the weight of significance of an entrance is calculated by the ratio of passengers of an entrance to the total. However, EVSD is for an analysis point, and there are many points in a subspace. We, therefore, calculated the spatial visibility step depth (SVSD) using the average value of EVSD of all points inside a subspace.

By contrast, accessibility from residential buildings uses common measures of accessibility and distance (Makri and Folkesson, 1982). Since there are several buildings in a community, the accumulative distance (AD) is proposed as a measure of accessibility from residential buildings. AD was calculated from the shortest distances for every building in a community.

3.1.2 Subspace-level Accessibility

Subspace-level accessibility refers to the spatial characteristics of a subspace, which can be generally examined by three variables: visual accessibility, physical accessibility, and vehicle intervention.

First, the visual accessibility of a subspace (VAS) is defined as a measure of the spatial component associated with effectiveness with which vision can travel. In our definition of visual accessibility, a subspace is considered as a whole. Thus, some general considerations to measure VAS are proposed: total length of openings (Lo), and evenness of the openings' distribution (EOD). These are supposed to be positively related to a higher density of staying activities. A stable assessment for Lo and EOD was used by projecting the openings onto the sides

Table 3. Variables of Staying Activities and Physical Characteristics

Factors			Variables	Explanation	Operational Definition
Dependent variables (DVs)	Density of staying activity (DSA)	All staying activities	DSA_A	Density of all staying activities	$DSA_n=\Sigma(P_n/P)$ P: Community population; P_n: Number of users of different staying activities per hour in subspace N.
		Activity categories	DSA_O	Density of occasional stops	
			DSA_S	Density of sedentary activities	
			DSA_V	Density of vigorous activities	
Independent variables (IVs)	Accessibility	Community level	SVSD	Spatial Visibility Step Depth: Visibility step depth from all community entrances of a subspace using the space syntax (VGA) method	$SVSD=\sum_{i}^{m}(\sum_{i}^{n}VSD_n\times W_n)/m$ m: Number of analysis points inside a subspace; n: Number of community entrances; VSD_n: Visibility step depth of an analysis point from entrance N; W_n: Weight of significance of entrance N.
			AD	Accumulative Distance: Accumulative distance of shortest routes from every building	$AD_n=\sum D_n$ AD_n: Accumulative distance of subspace N; D_n: Shortest distance from a building to subspace N (m).
		Subspace level	VAS	Visual Accessibility of a Subspace: How easy a subspace can be seen or found by people	$VAS=Lo\times EOD$ Lo: Total length of openings (m); EOD: Evenness of openings' distribution. (Sources: Fig. 3; Table 3)
			PAS	Physical Accessibility of a Subspace: How easy a subspace can be approached by people	$PAS=N\times EED$ N: Number of entrances of a subspace; EED: Evenness of entrances' distribution. (Sources: Fig. 3; Table 3)
			VIS	Vehicle Intervention Score: Evaluation of different conditions of vehicle roads connected to a subspace	Intervention of vehicle roads: 0(None), 1(adjoin), 2(go through)
	Facilities		SC	Seating Capacity: How many people can sit simultaneously	$SC=N+Ls/0.6$ N: Number of individual seats; Ls: Length of long benches.
			PO	Playing Objects: Number of playable physical elements, including play equipment, climbable rockery, etc.	Evaluated by environment datasheets
			EEC	Exercise Equipment Capacity: How many people can use items simultaneously	Evaluated by environment datasheets
			SAC	Shops and Activity Centers: Number of shops and activity centers whose entrances face to the subspace	Evaluated by environment datasheets
	Spatial configuration		AUZ	Area of Usable Zone: Paved ground with wider than three meters	Evaluated by site maps (m^2)
			WLR	Width to Length Ratio: Spatial width to length ratio	$WLR=W/L$ W: Shorter side of a rectangle; L: Longer side of a rectangle. (Sources: Figure 3)

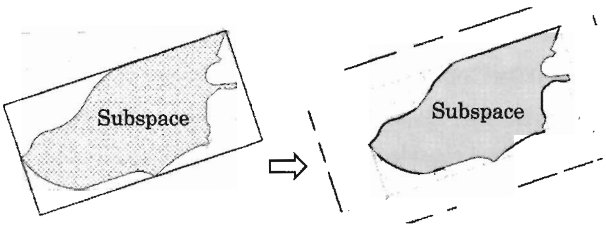


Figure. 3 Example of Projecting Subspaces' Openings onto Sides.

Table 4. Measuring Evenness of Openings' Distribution

	Distribution of sides with openings (or entrances)				
	1 side	2 sides		3 sides	4 sides
	⊔	∟ ┐	[ ]	[┘	┌ ┐ └ ┘
EOD / DE	1	1.5	2	2.5	3

of a rectangle, which reflects a subspace's shape in plan (Figure 3). The rectangle has the nearest area with original size, where the projected Lo can be calculated. Moreover, we defined general rules to assess EOD (Table 4). Finally VAS is statistically examined by multiplying Lo and EOD.

Second, the physical accessibility of a subspace (PAS) is defined as a measure of the spatial component associated with easiness of approach to a subspace. Therefore, the entrance is a crucial factor of physical accessibility. Similar to visual accessibility, two considerations were determined to calculate PAS quantitatively: the number of entrances (N) and evenness of entrances' distribution (EED). With the site maps, N was calculated, while EED was examined by projecting entrances on the same rectangle of a subspace in Figure 3. Two attributes are considerable: distribution of the sides with entrances (e.g., DE), and number of entrances on each side (e.g., NE). DE was measured in the same manner as EED (Table 4). On the other hand, some rules were proposed to measure NE. For instance, if there is only one entrance on a side, NE = 0 and if there are two entrances on a side, NE = 0.2. If there are three or more entrances on a side, NE = 0.4. With these rules, EED was calculated by the sum of NE and DE. Finally, PAS was quantitatively examined by multiply N and EED.

Third, vehicle intervention was discussed by previous researches that a vehicle road could be an accessibility barrier (Aytur et al., 2008; Clark and Hutton, 1991). A measure of vehicle intervention (i.e., the vehicle intervention score (VIS)) was used to show the degree of barrier to safe access to a subspace. (Table 3).

3.2 Facility Variables

There are general rules for choosing influential facility items recorded on the environment datasheets; each item must be strongly correlated with staying activities but uncorrelated with other items. Thus, Table 3 contains four important items: 1) seats, 2) playing objects, 3) exercise equipment, and 4) shops and activity centers.

Measures of seats or exercise equipment (e.g., seating capacity (SC) or exercise equipment capacity (EEC), respectively) evaluate how many people can use the items simultaneously. Measures of playing objects (PO) or shops/activity centers (SAC) assess the number of the item in a subspace. Notably, SAC combines shops and activity centers together. Similar to the findings of Tachibana (2009), shops promote activities among neighbors. Additionally, activity centers play the same role in China.

3.3 Spatial Configuration Variables

To explore variables of spatial configuration, two items were extracted. The first is the usable zone area, which is related to ground usage of subspaces. The second is the spatial width to length ratio (WLR), which shows the degree of spatial integration.

There is increasing evidence that ground usage can either encourage or discourage activities (Frank and Engelke, 2001). We applied this concept to the spatial configuration of a subspace, and the area of different ground usage. We proposed four ways of measuring the area: total area of subspace, the area of subspace excluding surface of the water, the all paved area, and the area of usable zone (paved area with more than 3m width[3]) to explain observed staying activities. We selected the area of usable zone (AUZ) which showed highest correlation coefficients with the observed staying activities.

As discussion of spatial configuration, the area is not enough. For instance, even if two different subspaces have the same area, some staying activities may vary due to the shape of a space. We postulate that if a space is closer to square, it is more integrated. We, therefore, used WLR of a rectangle (Figure 3) to explain spatial integration. A higher value of WLR denotes a better spatial integration (Table 3).

3.4 Selection of Independent Variables

The data of 11 variables for each of 33 subspaces were calculated using investigated data of physical environment (Table 5). A general consideration to choose IVs is that they are not highly correlated with each other in correlations.

Table 6 shows the correlation coefficients between VAS and PAS, as well as PAS and AUZ are quite high (0.68 and 0.60 respectively), therefore we removed PAS from candidate variables for linear regression.

4. Results

We examined the proposed variables concerning three factors (accessibility, facilities, and spatial configuration). Linear regressions were conducted to build models for different staying activities. First, we estimated the density of all staying activities. Then we estimated staying activities by each of three activity categories. Variables of physical factors were treated as independent variables (IVs), while the densities of different staying activities were treated as dependent variables (DVs).

4.1 Explanatory Model for All Staying Activities

The general consideration to choose significant IVs is that regression is best when the IV is strongly correlated with DVs (Tabachnick and Fidell, 2014). Therefore, the coefficient of determination (R^2) was used to sort variables for all staying activities. Individual IV's were tested by IBM SPSS Regression at the beginning, and the best R^2 was selected. Then we gradually added other variables into the regression one by one. Every time a new IV was added, the IV that results in the best regression was chosen. Figure 4 presents the change of R^2 for all staying activities in the process, suggesting that four significant IVs (AUZ, SVSD, WLR, and PO) are proper combination of IVs because R^2 does not increase significantly after PO, even when new IVs are added into the model. With these four IVs, we conducted a standard multiple regression (Table 7). The result indicates that about 63% of the variability in density of all staying activities (DSAa) can be predicted by the regression model below:

$$DSAa = 5.69 + 0.005 \times AUZ - 2.24 \times SVSD + 8.63 \times WLR + 3.36 \times PO$$

As expected the area of usable zone (AUZ) can be considered as most significant variable for all staying activities with the smallest p value, and biggest squared semi-partial correlations

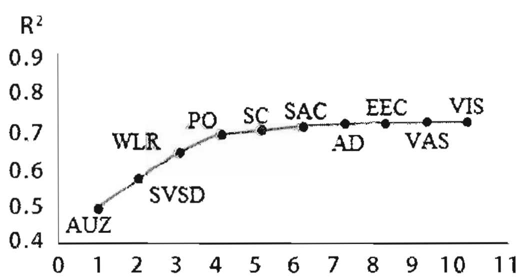


Figure. 4 Change of R^2 Value with Different Size of IVs.

Table 5. Data of Variables in 33 Subspaces.

	SVSD	AD	VAS	PAS	VIS	SC	PO	EEC	SAC	AUZ	WLR
J1	2.00	3620	269	25.2	0.00	20.0	1.00	7.00	0.00	1270	0.77
J2	2.38	4280	191	16.0	0.00	48.0	0.00	0.00	0.00	1350	0.26
J3	2.25	4290	168	16.0	0.00	16.0	0.00	0.00	0.00	321	0.69
J4	2.42	5080	298	30.4	0.00	32.0	1.00	0.00	0.00	1320	0.45
J5	2.38	4090	228	30.4	0.00	12.0	0.00	0.00	0.00	965	0.73
J6	2.98	5580	104	6.60	0.00	12.0	1.00	0.00	0.00	454	0.43
J7	2.86	5460	249	12.0	2.00	6.00	0.00	2.00	0.00	315	0.59
J8	4.23	5870	181	14.5	2.00	12.0	1.00	0.00	1.00	392	0.54
J9	2.50	6010	44.4	4.00	0.00	0.00	0.00	0.00	0.00	34.0	0.33
T1	2.58	7320	372	30.4	1.00	42.0	1.00	16.0	1.00	1810	0.90
T2	4.00	9440	120	7.60	2.00	0.00	0.00	0.00	0.00	0.00	0.44
T3	3.11	13600	14.9	2.40	1.00	15.0	0.00	0.00	0.00	372	0.42
T4	2.46	13300	316	16.0	2.00	2.00	0.00	0.00	1.00	0.00	0.75
F1	2.35	6180	211	20.4	0.00	12.0	0.00	0.00	2.00	1740	0.76
F2	2.45	5820	294	7.50	0.00	2.00	0.00	0.00	0.00	170	0.20
F3	2.90	7580	171	20.4	0.00	6.00	1.00	0.00	0.00	562	0.74
F4	2.95	6330	325	10.8	0.00	12.0	0.00	7.00	0.00	630	0.71
F5	3.10	6540	269	30.4	0.00	8.00	0.00	3.00	0.00	440	0.38
F6	1.73	4720	240	25.2	0.00	22.0	1.00	0.00	2.00	1570	0.56
F7	3.55	6410	157	10.8	0.00	8.00	0.00	6.00	0.00	450	0.72
F8	3.60	5420	47.5	4.00	0.00	1.00	0.00	0.00	0.00	128	0.22
F9	2.45	6050	343	26.4	0.00	18.0	0.00	0.00	0.00	0.00	0.72
F10	2.45	5660	257	7.50	0.00	10.0	0.00	0.00	0.00	485	0.35
X1	2.31	5970	348	25.2	0.00	16.0	2.00	0.00	0.00	997	0.72
X2	2.85	5460	444	20.4	1.00	110	0.00	0.00	0.00	821	0.40
X3	2.58	6760	240	18.6	0.00	8.00	0.00	0.00	0.00	285	0.26
X4	4.55	9180	143	16.0	0.00	12.0	0.00	0.00	0.00	183	0.67
X5	4.53	8270	71.4	4.00	1.00	4.00	0.00	0.00	0.00	320	0.27
X6	4.46	9720	62.8	13.0	0.00	16.0	0.00	0.00	0.00	568	0.61
X7	4.53	8340	139	3.00	1.00	8.00	0.00	0.00	0.00	265	0.73
X8	2.83	7180	138	7.50	0.00	9.00	1.00	0.00	0.00	459	0.25
X9	1.77	7940	154	12.0	2.00	0.00	0.00	0.00	1.00	0.00	0.48
X10	4.55	5970	118	6.60	1.00	12.0	0.00	0.00	0.00	383	0.27
Mean	2.99	6770	204	15.2	0.48	15.5	0.30	1.24	0.24	578	0.52
SD	0.86	2290	105	8.98	0.76	20.2	0.53	3.32	0.56	519	0.20

Table 6. Correlations between Independent Variables.

	IVs										
	SVSD	AD	VAS	PAS	VIS	SC	PO	EEC	SAC	AUZ	WLR
SVSD		.36	.50	-.47	.24	-.16	-.25	-.11	-.31	-.38	-.13
AD			-.30	-.34	.45	-.24	-.23	-.09	.05	-.39	.07
VAS				.68	-.02	.52	.24	.36	.16	.39	.34
PAS					-.24	.36	.39	.31	.26	.60	.48
VIS						-.03	-.14	.00	.23	-.31	.04
SC							.09	.16	.00	.47	.02
PO								.19	.17	.46	.24
EEC									.10	.42	.46
SAC										.45	.31
AUZ											.33

Table 7. Standard Multiple Regression of Selected IVs on Density of All Staying Activities.

	DV	IVs					
	DSAa	AUZ	SVSD	WLR	PO	B	sr^2
AUZ	.69					0.005**	0.10
SVSD	-.52	.30				-2.24*	0.064
WLR	.48	-.24	-.003			8.63*	0.056
PO	.56	-.37	-.088	-.11		3.36*	0.051
						Intercept=5.69	
Mean	7.55	578	2.99	0.52	0.30		R^2=.68
SD	6.97	519	0.86	0.20	0.53	Adjusted R^2	R^2=.63 R=.82***

***p<.001, **p<.01, *p<.05

(sr^2). Notably another variable of spatial configuration, WLR also contribute significantly to all staying activities, which implies that spatial configuration is the most influential factor to all staying activities. In addition, SVSD and PO have the next significance, which suggests that accessibility and facilities may mediate statistically significant differences for all staying activities.

4.2 Explanatory Models for Different Activity Categories

Assessments on the different activity categories can indicate different activity needs. With similar analysis, significant IVs for each of activity categories were identified. As a result, three, four, and three IVs were found to contribute to occasional stoppings, sedentary activities, and vigorous activities, respectively. Table 8 shows general outcomes of standard multiple regression with these IVs.

Table 8. Standard Multiple Regression of Selected IVs on Density of Staying Activities in Different Activity Categories.

Physical environment factors / variables		Occasional stoppings		Sedentary activities		Vigorous activities	
		B	*p*	B	*p*	B	*p*
Community-level accessibility	SVSD	-.94	.026	-.74	.045		
	AD						
Subspace-level accessibility	VAS						
	PAS						
	VIS	.76	.098				
Facilities	SC			.043	.005		
	PO			1.80	.003	2.44	<.001
	EEC						
	SAC			1.45	.010		
Spatial configuration	AUZ	.002	.003			.002	.001
	WLR					3.77	.014
Adjusted R^2		.399		.595		.700	
Intercept coefficient		4.32		2.73		-1.78	

Judging from adjusted R^2 value, the regression models' variability in densities of occasional stoppings, sedentary activities, and vigorous activities are about 40%, 60% and 70% respectively. We consider that the different value of adjusted R^2 among the activity categories may due to their dependences on the physical environment. For instances, occasional stoppings such as brief meetings or stoppings, mainly occur during passing activities, which associate little with the physical environment. Whereas, sedentary activities such as sitting, and vigorous activities like sliding, are associated with the affordance of benches, play equipment and so on.

4.2.1 Explanatory Model for Occasional Stoppings

For occasional stoppings, the adjusted R^2 value indicates that nearly 40% of the variability in density of occasional stoppings (DSAo) can be predicted by the regression model below:

$$DASo=4.32+0.002\times AUZ -0.944\times SVSD+0.756\times VIS$$

The area of usable zone (AUZ) is the most significant variable to occasional stoppings. Further, the Spatial Visibility Step Depth (SVSD), which indicates distances from community entrances, is associated with number of passengers. Existence of many passengers may increase chances of occasional stoppings

Table 9. Standard Multiple Regression of Selected IVs on Density of Occasional Stoppings.

	DV	IVs				
	DSAo	AUZ	SVSD	VIS	B	sr^2 (Unique)
AUZ	.55				0.002^{**}	0.20
SVSD	-.48	.33			$-.944^{*}$	0.10
VIS	.02	.24	-.14		.756	0.055
					Intercept=4.32	
Mean	3.19	578	2.99	0.48	Adjusted R^2	R^2=.46 R^2=.40 $R=.68^{***}$
SD	2.31	519	0.86	0.76		

$^{***}p<.001$, $^{**}p<.01$, $^{*}p<.05$

such as brief meetings or stoppings. Similarly an increase in vehicle intervention (VIS) may increase more interruption in passing activities, which may result in brief stoppings.

4.2.2 Explanatory Model for Sedentary Activities

For sedentary activities, the adjusted R^2 value indicates that nearly 60% of the variability in density of sedentary activities (DSAs) can be predicted by the regression model below:

$$DASs=2.73+1.8\times PO +0.043\times SC +1.45\times SAC -0.74\times SVSD$$

Table 10. Standard Multiple Regression of Selected IVs on Density of Sedentary Activities.

	DV	IVs					
	DSAs	PO	SC	SAC	SVSD	B	sr^2 (Unique)
PO	.54					1.80^{**}	0.14
SC	.43	-.06				$.043^{**}$	0.12
SAC	.46	-.10	.057			1.45^{*}	0.10
SVSD	-.50	.20	.15	.28		$-.74^{*}$	0.055
						Intercept=2.73	
Mean	2.13	0.30	15.5	0.24		Adjusted R^2	R^2=.65 R^2=.60 $R=.80^{***}$
SD	2.53	0.53	20.2	0.56			

$^{***}p<.001$, $^{**}p<.01$, $^{*}p<.05$

The results shown in Table 10 clearly indicated that facilities for playing, shopping and seating are major variables to explain sedentary activities. This result may be well understood by considering the affordance of benches, playing objects (for a person who are watching children's play), or shops. Although SVSD, which is associated with number of passengers, is statistically significant, it seems less important with lowest squared semi-partial correlations (sr^2). Interestingly, variables of spatial configuration such as AUZ, which is major factor in the model for all staying activities, was not included in this model.

4.2.3 Explanatory Model for Vigorous Activities

For vigorous activities, the adjusted R^2 value indicates that about 70% of the variability in density of vigorous activities (DSAv) is predicted by the regression model below:

$$DASv=-1.78+2.44\times PO+0.002\times AUZ+3.77\times WLR$$

Table 11. Standard Multiple Regression of Selected IVs on Density of Vigorous Activities.

	DV	IVs				
	DSAv	PO	AUZ	WLR	B	sr^2 (Unique)
PO	.70				2.44***	0.16
AUZ	.69	-.42			.002**	0.12
WLR	.51	-.17	-.25		3.77*	0.064
					Intercept=-1.78	
Mean	2.23	0.30	578	0.52		R^2=.73
SD	2.90	0.53	519	0.20	Adjusted R^2	R^2=.70 R=.85***

***$p<.001$, **$p<.01$, *$p<.05$

Table 11 reveals that PO contributes significantly to vigorous activities. However, the two variables of spatial configuration (AUZ and WLR) almost have the same importance with their high sr^2, which implies that facilities and spatial configuration are both significant to vigorous activities. The reason may be that playing objects (PO) and area of usable zone (AUZ) are associated with such vigorous activities as sliding, or playing games. Higher score of WLR increase the likelihood of spatial concentration and capacity, which may hold more people doing such group vigorous activities as playing football.

5. Discussion and Conclusions

Our findings suggest that the physical characteristics of community are related to the density of different staying activities (DSA). Variables of the physical environment are related to staying activities, but the magnitude of the effect differs significantly by activity category.

Spatial configuration is the most influential factor for occasional stoppings and vigorous activities, but it is not for sedentary activities. This suggests that the size and shape of the space associate little with sedentary activities.

There is a reduction of significance of accessibility from occasional stoppings to vigorous activities. This implies that accessibility is not influential for long time staying (sedentary activities and vigorous activities). The reason may be that residents are familiar with subspaces in their small communities, which make accessibility insignificant to residents' choice of staying.

Facilities are important for sedentary activities and vigorous activities, but not occasional stoppings, which is associated little with the affordance of facilities. Whereas, sedentary activities like sitting and vigorous activities like sliding are associated with the affordance of such facilities as benches and play objects.

Besides the above result, this study made a considerable contribution to field research method.

First, we developed a systematic observation method, which includes time arrangement consideration, simple and effective recording way, as well as systematic method of extracting useful data. This could be widely applicable for accumulating evidence-based activity data in a field survey.

Second, we proposed some physical measures which were found to relevant to people's activities: 1) the SVSD which stems from Visibility Step Depth (VSD) in space syntax method, can explain visual depth (psychological distance) from multiple start points to a target point or a space, 2) area of usable zone (AUZ) which is defined by necessary ground surface and width of space for staying activities, was verified with its great effects.

In summary, we found relevant variables of the physical environment for different staying activities. On our premise that staying activities contribute to social interactions, the current results suggest that space design concerned with promoting staying activities may increase social interactions. Furthermore, community design targeted at promoting staying activities might be more effective if the design is tailored to a particular activity category. Therefore, our results can be a first step to create a guideline for community design for promoting social interactions between neighbors, and consequently create opportunities for accumulating evidence-based activity data to modify community design.

Notes

1) The basic physical characteristics of subspaces include size, boundary conditions (facing to buildings, roads or water), existence of such physical elements as paly equipment, benches, lampposts.

2) The temperature during the observation time (9:00-17:00) was 13~20℃. Considering the influence of time of the day on outdoor activity, we divided observation time into 4 time periods (9:00-10:30, 10:30-12:00, 13:00-15:00, and 15:00-17:00), and observed each subspace more than 2 times in every time period.

3) Nishide (1985) suggested that a distance exceeding three meters is a public distance for Asian people. Hence, this paper defines pave ground more than three meters wide as a "usable zone".

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