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Pedestrian Distribution in High-Rise Commercial Complexes: An Analysis of Integrating Spatial and Functional Factors

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Abstract

One of the key problems in the design of high-rise commercial complex is how to guide reasonable pedestrian distribution in commercial space. In this study, pedestrian distribution in three high-rise commercial complexes in Shanghai and Hong Kong was studied using spatial configuration analysis software Space Syntax and quantification of physical elements in commercial spaces, such as functional attractiveness, entrances, escalators, level variations and passage width. Additionally, in an attempt to integrate functions with spatial integration and spatial depth, two combination variables, the spatial coefficient of function (IF) and spatial depth coefficient of function (F/D), were proposed. The results of the correlation analysis and multiple regression analyses reflected the following: (1) Regarding the influence on pedestrian distribution, there was a synergistic and complementary relationship between function and space; (2) The comprehensive flow distribution analytic model could successfully interpret flow distribution in high-rise commercial complexes and its R Square ranged up to about 70% in the three cases; (3) The spatial coefficient of function (IF) and spatial depth coefficient (F/D) could effectively integrate functions and spatial configuration, which could help close the gap between over-emphasis on function in commercial research and the lack of consideration of function in space-syntax analysis.

Keywords: High-rise commercial complex, Function, Space, Configuration, Pedestrian distribution

1. Introduction

The high-rise commercial complex is one of the main development forms of urban space where the goal is intensive utilization of urban space and land. When used in combination with rail transit stations, this spatial structure has demonstrated highly three-dimensional and comprehensive features. The rational use of flow resources in rail transit stations and guidance of reasonable pedestrian distribution in high-rise commercial spaces by way of a comprehensible strategy of spatial and functional layout is related to the efficiency of commercial development and space systems, and is also the key to successfully intensive development of high-rise commercial complexes. In present studies, function and space are often considered separately; the quantitative research on the integration of function and space has been one of the difficult points in the research of architectural design. For instance, the relevant research in the field of business pays attention to the attractiveness of anchor stores and sub-anchor stores (Konishi & Sandfort, 2003) and adopts a combination of different formats to enhance shopping centers' attractiveness (Wang & Wang, 2010). In the study of Space Syntax, function can be reflected in different spatial configurations, and the configurational theory of Space Syntax was proven to be the most powerful in explaining the laws of space and function in real-life applications (Hillier, 2008).

However, the dualistic view of space and function has caused some practical problems. For instance, in the studies of Carter and Vandell (2005), Nie and Jia (2011) and other scholars, it was confirmed that pedestrian distribution differences mainly caused by spatial configuration would directly impact the rent of shops and the actual operating income. In addition, analysis of space syntax would not be effective, because the function and the local spatial factors were excluded. For example, the influence of integration on pedestrian distribution would gradually fade out with increasing floor levels (Hossain, 1999); and pedestrian distribution may converge at fake integration cores influenced by starting points, landmarks and people's individual preferences (Langenfeld, 2013).

In studies of functional and spatial combinations, Fong (2005), Jung et al. (2009) and Min et al. (2012) analyzed spatial distribution of different functions, and studied differential effects on human behavior. These researches mainly focused on pedestrian distribution in commercial space on one floor, and lacked insights on how to effectively combine spatial factors and functions to analyze pedestrian distribution. In research on multi-level com-

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mercial complex space, Parvin et al. (2007) and Zhuang et al. (2012) used an integrated analysis model based on integration and other spatial variables, such as the relationship with rail transit stations, floors, vertical traffic, and so on, which could better predict pedestrian distribution, but here also, the influence of function was not taken into account. Fujitani and Kishimoto (2012) confirmed the influence of shopping areas on flow distribution around adjacent commercial space, but the attractiveness of different functions was ignored. These studies all struggle to explain pedestrian distribution and do not readily suggest a guidance strategy for functional and spatial organization of the commercial complex.

2. Research Questions

This research hopes to solve two problems: 1) How to carry out effective quantitative analysis of function and space in a high-rise commercial complex? 2) How do function and space affect pedestrian distribution?

According to relevant research of commercial complexes, functional studies mainly included the type of commerce being undertaken (Fong, 2005; Min et al., 2009) and the size of the shop (Fujitani & Kishimoto, 2012); while spatial analysis included the globe feature and the local feature of space. The global feature of space included spatial depth and integration, and the local features included the relationship with building entrances (Parvin et al., 2007; Zacharias et al., 2007; Zhuang et al., 2012), floors (Parvin et al., 2007; Zhuang et al., 2012), distance to escalators (Parvin et al., 2007; Zhuang et al., 2012; Qiu, 2012), the relationship with the atrium, passage width, etc.

In this study, three rail-transit-adjacent commercial complexes, two in Shanghai and one in Hong Kong, serve as case studies. A series of integration analyses of function and spatial configuration were carried out based on the measurement and analysis of pedestrian distribution, space and function. Pedestrian flow was measured in high-rise commercial space through the "gate count" method. The axial map was drawn based on the Space Syntax theory, and the pedestrian flow of axial spaces was determined by the average weighted value of pedestrian distribution at different observation points according to the passageway length. The Depth Map of the Space Syntax was used to calculate the global integration (Rn) and spatial depth. Hillier and Penn (2004) pointed out that multiple regression models could be made to deal with the factors that were ignored in the Space Syntax. The work of Parvin et al. (2007), Zhuang et al. (2012), Fujitani and Kishimoto (2012) and Guo et al. (2014), etc., SPSS (Statistical Product and Service Solutions) software was used to perform multiple regression analyses for pedestrian distribution, spatial configuration and other spatial variables, returning good results. Therefore, this paper hopes to first propose quantitative measurement methods for functional and spatial factors based on the axis map of Space Syntax and the concept of topological relations, then to conduct correlation analysis and multiple linear regression analysis using SPSS software, and finally, establish a comprehensive analytical model for pedestrian distribution in high-rise commercial complexes.

3. Case Study and Analysis

3.1. Case selection

Three typical rail-transit-adjacent commercial complexes in Shanghai and Hong Kong were taken as research cases: Zhongshan Park Cloud Nine Plaza (ZPCNP) and Hongkou Cloud Nine Plaza (HCNP) in Shanghai, both of which were developed by CapitaLand Group, and Langham Place (LP) in Hong Kong (Table 1). The two commercial complexes in Shanghai have established direct transport links to the adjacent rail transit station at multiple levels, which drives the three-dimensional development of spatial form. As to function, these complexes integrate comprehensive department stores, retail services, catering, entertainment, parking, office and other functional forms, which create one of the one-stop public living spaces with a set of transportation, shopping, entertainment and leisure facilities. Langham Place, a famous high-rise commercial complex, is functionally composed of hotel, office and retail. The shopping center is linked with the MTR stations and other functional units at the underground B2 level, the first floor and the third floor, which shows a highly intensive development characteristic in terms of spatial organization and functional arrangement.

3.2. Field study for pedestrian distribution

Two-day (one weekday and one weekend day) field studies of pedestrian distribution were carried out for each of the three cases, and the weather conditions were fair. A total of 128 observation points and 97 observation points were selected at ZPCNP and HCNP, respectively, and 90 observation points were implemented at LP. Time sampling was used to acquire the flow data in different time periods (Table 2), which could cover the peak hours of pedestrian flow across the whole day. The time-sampling unit was 3 minutes for each observation point and spread across 10 sample surveys over the course of two days. There was a total of 30 minutes for each observation point in the Shanghai cases, and 33 minutes for each observation point at LP. Taking the average pedestrian flow of each time on these two days and converting it into hourly data, yields the pedestrian flow per hour at each observation point (Fig. 1). The axial map was made based on the Space Syntax theory, and the pedestrian distribution of one axial space was calculated by taking the the average of pedestrian flow at different observation points, and varied according to the passageway length.

In addition, in order to obtain the characteristics of consumer behavior in the commercial complex, trace-tracking and questionnaire surveys were carried out. In

Table 1. Overview of Cases

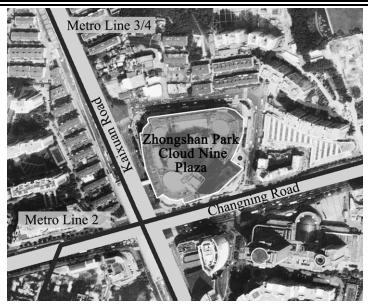
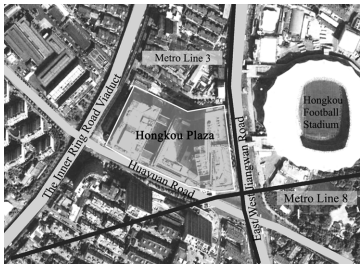
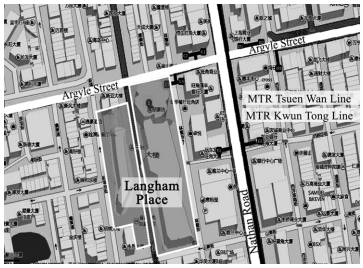
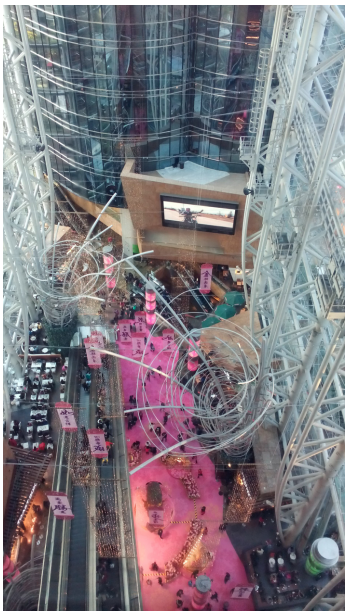
Cases	Zhongshan Park Cloud Nine Plaza (ZPCNP)	Hongkou Cloud Nine Plaza (HCNP)	Langham Place (LP)
Location	 Changning District, Shanghai (near Zhongshan Park)	 Hongkou District, Shanghai (near Hongkou football stadium)	 Youjian Wang District, HongKong
Opening time	December, 2005	December, 2011	October, 2014
Gross floor area	320,000 m^2 (220,000 m^2 commercial area; 24,000m^2 office; 66,000m^2 hotel)	230,000 m^2 (170,000 m^2 commercial area; 60,000 m^2 office)	170,000 m^2 (56,000m^2 commercial area; 66,000m^2 office; 43,000m^2 hotel)
Rail transit	Metro line 2/3/4	Metro line 3/8	MTR Tsuen Wan/ Kwun Tong line
Commercial floor	-2F, -1F, GF, 1~8F	-2F, -1F, GF, 1~5F	-2F, -1F, GF, 1~12F
Entrances	-2F, GF, 1F	-2F, GF, 2F, 3F	-2F, GF, 1F, 3F
Main public space			

Table 2. Research time arrangement

Cases	Content	Field Research Time	Time slot	Investigator
ZPCNP	Pedestrian distribution	Dec 27, 2013 (Friday) Dec 28, 2013 (Saturday)	10:30-11:30, 12:30-13:30, 14:30-15:30, 16:30-17:30, 18:30-19:30	7
	Questionnaire	July 16-17, July 19-20, 2014	13:00-20:00	6
HCNP	Pedestrian distribution	December 29, 2013 (Sunday) December 30, 2013 (Monday)	10:30-11:30, 12:30-13:30, 14:30-15:30, 16:30-17:30, 18:30-19:30	5
	Questionnaire	July 12-15, July 18,2014	13:00-20:00	6
LP	Pedestrian distribution	January 11, 2014 (Saturday)	11:30-12:30, 13:30-14:30, 15:30-16:30, 17:30-18:30, 19:30-20:30	6
		January 15, 2014 (Wednesday)	8:30-9:30, 11:30-12:30, 13:30-14:30, 15:30-16:30, 17:30-18:30, 19:30-20:30	6
	trajectory Tracking	January 11, January 15, 2014	Use the spare time after the investigation of pedestrian flow	6

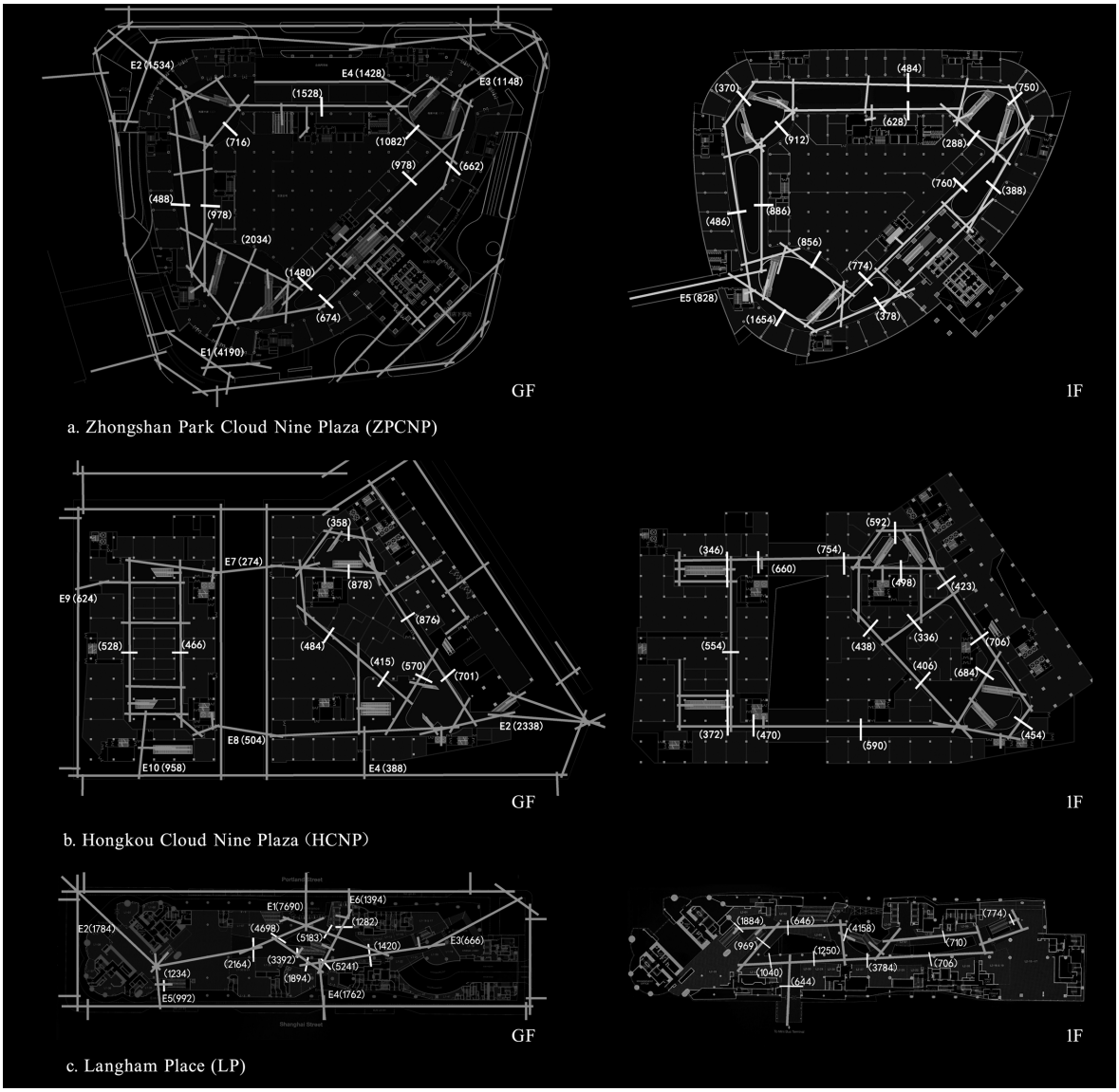


Figure 1. The pedestrian flow and axial map of the ground floor and the first floor in the selected cases.

LP, a trace-tracking survey was conducted after the survey of pedestrian flow, and a total of 290 people were traced. From July 12 to 20, 2014, the questionnaire survey was carried out in ZPCNP and HCNP, and in each case contained at least two working days and two weekend days. A total of 195 valid answer sheets were collected in ZPCNP, and 218 valid answer sheets were collected in HCNP.

3.3. Measurement and analysis of function and space

3.3.1. Measurement and analysis of function

Attractiveness of function (F): Bruwer (1997), Bitgood et al. (2006, 2013), etc. argued that the route choice of customers showed their strong intention. Konishi and Sandfort (2003), Fong (2003), Long and Chai (2006), Fujitani and Kishimoto (2012), and Nie and Jia (2013), etc. also confirmed the effect of attractiveness of function types and sizes on people flow. This paper aims to explore the attractiveness of function through integration of quantitative purpose features, function types and sizes of corresponding shops. Long and Chai (2006) categorized consumer purposes into shopping, sightseeing, entertainment, dining, business, etc. Taking ZPCNP as an example, according to the analysis of the results of 195 valid questionnaires, consumers were divided into the following types: garment accessories (28.83%), department store (14.42%), service class (4.6%), food (33.74%), leisure (11.95%) and other (6.44%), and the proportions of different types assigned as the "attraction weight". The definition of "area scale" was based on the concept of Space Syntax, which was calculated by the sum of the area of all the functional spaces from which pedestrians could see the axial space.

Thus, the calculation method of the function attraction is as follows:

$$F=A*\sum_{i=0}^{m}S_{ai}+B*\sum_{i=0}^{n}S_{bi}+C*\sum_{i=0}^{j}S_{ci}+D*\sum_{i=0}^{k}S_{di}+E*\sum_{i=0}^{l}S_{ei}$$

In the equation, F means function attraction of the axial space; A, B, C, D, E respectively correspond to five function type attraction weights : the clothing accessories, department category, service, food and entertainment, etc. S_a, S_b, S_c, S_d, S_e respectively mean the sizes of store area (according to classification of function format type); m, n, j, k and l respectively stand for the number of stores that need to be counted as representatives of various types of functions along one axial space.

In analysis of function attraction and pedestrian distribution, the correlation coefficients of ZPCNP and HCNP were 0.195 and 0.257, respectively. The correlation coefficient and significant correlations were not high while the correlation coefficient in LP was 0.636, and sig. was 0.000. It indicated the obvious differences between the two cases in Shanghai and LP in Hong Kong, which was attributed to spatial organizational features of the three cases. Therefore, regardless of the spatial organization characteristics, it was difficult to effectively guide the rational pedestrian distribution in the commercial space only through combination of functions.

3.3.2. Measurement and analysis of space

1) Global Spatial Factors

Spatial depth (D): This is different from urban street space, as a high-rise commercial complex is a relatively closed spatial system, and flow in commercial space mainly relies on ingress from building entrance. So the depth related to the entrances of commercial space has become one of the indices for the study of pedestrian distribution. And because of a number of entrances set up in commercial complex, the spatial depth described in this paper was generated from the average value of the relative depth from the measurement point to each main entrance of the building. First, the relative depth of the axial space to the each main entrance was calculated in Depthmap software of Space Syntax, and then the average relative depth was calculated according to the weight coefficients determined by the corresponding percentage of the flow through each entrance. The study found that there was a high negative correlation between spatial depth and pedestrian distribution. The correlation coefficient of ZPCNP, HCNP and LP was -0.543,- 0.542 and -0.658 respectively, and statistically the sig. is 0.000.

Integration (I): Global integration (Rn) and local integration (R3) are in common use as measurements. Since the commercial space of a high-rise complex is a closed spatial system and is within walking distance of consumers, in this paper the global integration was used, which reflected the accessibility and convenience of one axial space in the whole commercial space and was also calculated by Depthmap software of Space Syntax. In correlation analysis, there was no significant correlation in ZPCNP and HCNP. But there was strong correlation in LP; the correlation coefficient and significance were 0.717 and 0.000, respectively. Correlation analysis results indicated strong relationships with the characteristics of the layout in the three cases. For instance, in ZPCNP, there were nine floors above ground, in which the topological relationship of each floor was basically the same and spread around three atrium spaces. The network of underground space was relatively simple. Therefore, the highest global integration in the whole system concentrated on the second and third floors, while it decreased along the high-rise and lower floors gradually. But this actually does not match the pedestrian distribution.

2) Local Spatial Factors

Significant quantitative research on local spatial factors had been carried out. For example, Parvin et al. (2007) proposed: the value of “relationship with building entrances (E)” of the axes directly linked to main building entrances should be 0.7, and all others rest should be 0. The value of “distance to an escalator (T)” of the axes directly connected to escalator should be 1, with the rest set to 0; the value of "level (L)” directly connected with the rail transit station was -1, and the rest on the upper floor levels was 0,1, 2, etc., respectively as the floor increases. Zhuang et al. (2012) also proposed that the value of “relationship with building entrances (E)”of the axes directly linked to building entrances would be set at 1, and the rest would be 0; as to “level (L)”, the value of the bottom floor was 0, the rest increased as the floor increased. This paper tried to carry out quantitative evaluation of the local spatial factors based on above studies.

Relationship with the entrance (E): The building entrance in this paper included both the entrance of the ground floor and the entrance of high-rise complex connecting to rail transit station. Since the entrance has great influence on the flow of axial space that directly connects to it, and the topological distance increased between the axial space and the entrances, the influence of the entrance on the space in question gradually decreased. Therefore, the value relationship with the entrance (E), was refined, and the influence of the entrance distance within 2 steps of the axial flow was considered. The value of the axis that directly connected to main entrance was assigned to 1, while the distance of 1 step (number of topology steps) was assigned to 0.5, and the rest to zero.

Level (L): The value in this paper was not the actual value of the floor, but the relative value. For a rail-transit-adjacent commercial complex, not only the flow at the ground-level floor entrance was great, but there was also a strong flow on the floor connected to the rail transit station.. Therefore, the value of level (L) of axes on the ground floor and the floor directly connected to transit station were assigned to 0, and the rest were assigned

according to their difference. The difference between the adjacent floors was 1. For instance, in ZPCNP, the value of level (L) of axes on the ground floor, the underground B2 floor and the first floor was 0, because the B2 floor and the first floor were directly connected to rail transit station.

Passage width (W): The value was the average width value of the axial space (passage area / channel length), which was obtained by the actual measurement of the drawing.

Relationship with atrium (A): The atrium creates a more abundant spatial experience, which plays a certain guiding role for pedestrian distribution. In this paper, the value of an axis directly connected to atrium was set at 1; otherwise the value was 0.

Distance to escalator (T): In a multi-level commercial space, the significant effect of escalators on pedestrian distribution has been confirmed in the studies of Zhuang et al. (2012) and Qiu (2012). In this paper, the value of an axis directly connected to a bidirectional escalator was set at 1; otherwise, the value was 0. The value directly connected to unidirectional escalator was set at 0.5, otherwise was 0; when the axis was directly connected to multiple escalators in different positions, the values would be added together.

Correlation analysis indicated that in the three cases, the relationship with the building entrance (E) and distance to the escalator (T) showed a strong correlation with pedestrian distribution characteristics; the level (L) and passage width (W) showed a moderate correlation with pedestrian distribution. The impact of the relationship with atrium (A) on pedestrian distribution was difficult to determine independently, because most of the axes were arranged around the atrium.

3.4. Pedestrian distribution analysis based on integration of function and space

3.4.1. Spatial coefficient of function and spatial depth coefficient of function

In this paper, spatial depth (D) showed significant negative correlation with pedestrian distribution in the three cases, and integration (I) showed significant correlation with pedestrian distribution only in LP; different correlations analysis between attraction of function (F) and pedestrian distribution occurred in the three cases. The fundamental reason was that prior research took an independent dualistic view on space and function in commercial complexes, which didn't take into account the differences of functional layout in different spatial locations, and ignored the differences of pedestrian distribution caused by those differences. The research described in this paper attempted to adopt the modification for attraction of function by global spatial factors, and to integrate functions with spatial depth. Therefore, two combination variables, spatial coefficient of function (IF) and spatial depth coefficient of function (F/D), were proposed.

1) Spatial depth coefficient of function (F/D): F/D, the new combination variable integrated spatial depth (D) with attraction of function (F), the attraction parameter of different functions under different spatial depths in commercial complexes, and reflected the effect of function attraction and space resistance of pedestrians in the commercial complex, as measured from the entrance. In this study, correlation coefficients between F/D and pedestrian distribution were respectively 0.708, 0.541 and 0.716 in ZPCNP, HCNP and LP, and the significance was 0.000.

2) Spatial coefficient of function (IF): IF, the new combination variable integrated integration (I) with attraction of function (F), was attraction parameter of different functions under different integrations in the commercial complex. It reflected the synergistic effect of function attraction and space on pedestrians while staying in the commercial complex. In this study, correlation coefficients between IF and pedestrian distribution were respectively 0.268, 0.331 and 0.709 in ZPCNP, HCNP and LP, and the significance was 0.001. The correlation coefficients in cases in Shanghai were relatively low, and this was significantly related to the integration explained above.

Table 3 reflected the correlation characteristics between the space / function and pedestrian distribution (M). Combination variables, spatial coefficient of function (IF) and spatial depth coefficient of function (F/D), could effectively integrate the function and spatial configuration. It seemed to bridge the gap of too much emphasis on the function in commercial studies on one hand, and a lack of consideration of function in Space Syntax analysis on the other hand. Function and space (spatial depth, integration) had a synergistic and complementary relationship in their impact on pedestrian distribution, rather than a simple independent aspect. Therefore, in the analysis of pedestrian distribution, the combination variables (F/D and IF) could be used to replace the attraction of function.

3.4.2. Comprehensive analysis model for pedestrian distribution

In order to further integrate influence of function and

Table 3. The result of correlation coefficients between function / space and pedestrian distribution

		F	E	L	W	A	T	D	I	F/D	IF
Pedestrian distribution	ZPCNP	0.195*	0.600**	-0.407**	0.405**	-0.093	0.492**	-0.543**	0.178	0.708**	0.268**
	HCNP	0.257*	0.568**	-0.292*	0.249*	-0.071	0.543**	-0.542**	0.128	0.541**	0.331**
	LP	0.636**	0.738**	-0.562**	0.346**	0.010	0.478**	-0.658**	0.717**	0.716**	0.709**

The deeper the grayscale, the stronger the correlation; the numbers of samples of ZPCNP, HCNP and LP were respectively 112, 64 and 66.

space on pedestrian distribution, SPSS was used for multiple linear regression analysis. After the model test and variable selection, the best regression model (Table 4) was obtained in the three cases. The spatial coefficient of function (IF), spatial depth coefficient of function (F/D) and other variables could sufficiently explain the pedestrian distribution. The R Square in each case was respectively 67.4%, 73.8% and 70.6% in ZPCNP, HCNP and LP. Due to the influence of space organization, the spatial coefficient of function (IF) showed more obvious influential effect only in LP, while regression models based on the spatial depth coefficient of function (F/D) in three cases showed higher effectiveness.

Significant test, t test and co-linear tests (Table 5) were conducted for the model 1 with the best fitting effect. In ZPCNP: df = 07, F' = 55.372, p = 0.000; in HCNP: df = 58, F' = 32.634, p = 0.000; in LP: df = 62, F' = 49.543, p = 0.000. It could be explained that the model 1 in the 3 cases could meet the requirements of significance test, t-test and co-linear test. The standard coefficient reflected the influence of the independent variables on pedestrian distribution (M), and the multiple linear regression equations of the 3 cases were as follows:

ZPCNP: M = 275.655 + 3.315 * F / D –20.273 * D + 344.259 * E + 255.593 * T

HCNP: M = 646.08 + 2.674 * F / D – 53.733 * D + 199.69 * E + 137.195 * T – 91.232 * L

LP: M = 685.945 + 1.338 * IF + 881.837 * E + 251.185 * T

4. Discussion

In high-rise commercial complexes, when influence on pedestrian distribution is considered, there is synergy and complementary relationship between function and space. A comprehensive analysis model was built based on quantification and integration of function and space in this study, which could explain the pedestrian distribution in the above three cases. R Square respectively reached 67.4%, 73.8% and 70.6%. In addition, about 30% of unexplained pedestrian distribution was greatly related to business brand, space quality and other factors.

This study suggested two new variables, spatial depth coefficient of function (F/D) and spatial coefficient of function (IF), which could effectively integrate the function and spatial configuration. The two new variables could well solve the problems of too much emphasis placed on function in commercial research and too little placed on function in Space Syntax analysis. Spatial depth coefficient of function (F/D) was an attraction parameter of different functions under different spatial depths in a commercial complex, which reflected the effect of function attraction and space resistance on pedestrians while entering the commercial complex. Spatial coefficient of function (IF) was an attraction parameter of different functions under different integration scenarios in a commercial complex, which reflected the synergy effect of function attraction and space on pedestrians while staying in the commercial complex. Therefore, F/D reflected the purpose of shoppers' behavior in certain extent, and it showed good reliability and validity in analysis of pedestrian distribution in different cases. IF was demonstrated as a use-

Table 4. The result of multiple linear regression analysis

Cases	Model	R	R^2	Adjusted R^2	Std. Error of the Estimate
ZPCNP	1	.821	.674	.662	213.434
HCNP	1	.859	.738	.715	156.202
LP	1	.840	.706	.691	514.651
	2	.816	.666	.650	547.939

The dependent variable was pedestrian distribution (M); in model 1 of ZPCNP, the predictor variables were F/D, D, E and T; in model 1 of HCNP, the predictor variables were F/D, D, E, T and L; in model 1 of LP, the predictor variables were IF, E and T; in model 2 of LP, the predictor variables were F/D, E, T.

Table 5. The results of significance test, t test and co-linear test

	Standardized Coefficients			t			VIF		
	ZPCNP	HCNP	LP	ZPCNP	HCNP	LP	ZPCNP	HCNP	LP
Constant				2.095	5.404	6.314			
Spatial depth coefficient of function (F/D)	.409	.555		5.756	6.830		1.656	1.460	
Spatial coefficient of function (IF)			.402			4.812			1.471
Spatial depth (D)	-.157	-.296		-2.081	-3.204		1.870	1.886	
Relationship with the entrance (E)	.241	.187	.467	3.350	2.325	5.611	1.705	1.431	1.457
Distance to escalator (T)	.315	.193	.159	5.342	2.519	2.094	1.142	1.305	1.215
Level (L)		-.225			-2.466			1.836	

ful measure of pedestrians' inclination to stay in the commercial complex, which was greatly influenced by the quality of the spatial environment.

The high correlation between IF and pedestrian distribution reflected the rationality of functional layout and spatial organization in the commercial complex, which could be further confirmed in future research. In single-story commercial spaces, the high correlation between integration and pedestrian distribution has been confirmed (Zhuang et al., 2012; Kong & Kim, 2012), but in multi-level commercial spaces, the influence of integration on pedestrian distribution may gradually fade out due to the space resistance in the vertical direction (Hossain, 1999). Therefore, in high-rise commercial complexes, unique strategies of functional layout and spatial organization are needed in order to form meaningful space images that will effectively attract people (Xu, 2012). For instance, in LP, there were fascinating features such as "Rock Canyon" and "Digital Sky"; in the functional layout there were cinemas, trendy local clothing retailers, food, etc.; and on the ground floor of the giant atrium space (3F), there were multi-floor escalators (3~7F, 7~11F), which could directly take pedestrians to upper floors. Through the use of the above measures, a higher correlation was found between spatial coefficient of function and pedestrian distribution in LP.

In high-rise commercial complexes, we should make full use of the collaborative relationship existing between function and integration, and make full use of the complementary relationship existing between function and spatial depth, to guide reasonable pedestrian distribution. For instance, in high-depth spaces, we could arrange the function with a large scale and strong attractiveness; in low-depth spaces, functions with small-scale and weak attractiveness could be arranged. Because of significant negative correlation between spatial depth and pedestrian distribution, much attention should be given to how to effectively reduce the spatial depth in high-rise commercial complexes. Increasing the number of entrances on different floors would be the most important strategy, which could reduce the spatial depth in the whole commercial complex. If it is impossible to increase the number of entrances, multi-floor escalators could be adopted to reduce spatial depth.

Among local spatial factors, the relationship with the building entrance (E) and distance to the escalator (T) showed a strong correlation with pedestrian distribution characteristics. Therefore, atria and escalators could be arranged near the entrance, so that more passageways could have more direct connections with entrances. Space connected with escalators should have high accessibility within eye-catching areas, especially in the case of multi-floor escalators. Commercial circulation should have fewer levels and have direct connection with escalators, which would help to reduce the spatial depth. Great attention should be paid to the effect of an atrium on spatial atmosphere and traffic guidance. The main vertical transportation space should surround the atrium. In addition, because a positive correlation was found between passage width (W) and pedestrian distribution, the width of the passage could be increased when necessary to guide pedestrians.

5. Conclusions

Through pedestrian distribution analysis of three high-rise commercial complexes in Shanghai and Hong Kong, we found some rules in the individual space choice behavior. The purposes of different behavioral subjects, functional and spatial factors would determine the users' spatial distribution in high-rise commercial space. In addition, based on quantification and integration of function and space, a comprehensive flow-distribution analytic model could well interpret pedestrian distribution in high-rise commercial complexes, and its R Square could be up to about 70% in the above three cases.

The spatial depth coefficient of function (F/D) and spatial coefficient of function (IF) effectively integrate the attraction of function and the global spatial factors (spatial depth and integration). They reflect the synergistic and complementary relationship between function and space on the influence for pedestrian distribution, which could well solve the problems of over-emphasis on the function in commercial research and oversight of function in Space Syntax analysis. According to the correlation analysis and multiple regression model analysis results, F/D was found to indicate good reliability and validity in analysis of pedestrian distribution, and IF was found to be greatly influenced by the quality of the spatial environment.

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