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CONFIGURATIONAL ANALYSIS ASSOCIATED WITH VERTICAL TRANSITION ON MULTILEVEL PEDESTRIAN MOVEMENT

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Abstract

This article presents the research that attempts to optimize the multilevel model with the additional properties of vertical transition, which are proved to have great impact on the pedestrian movement. The analysis is described through two typical multilevel case studies: the metro station area in Wujiaochang and the metro station area in Xujiahui, both of which are located in the commercial center of Shanghai. Compared to the conventional correction method with vertical transition, the findings show that introducing the types of and topological distances to vertical transition other than spatial configuration as variables into the models can further improve the predictive ability of the pedestrian movement - approximately 50% of the movement can be predicted by these two integrated models in both two case studies. In a further analysis of quantifying the relative significance of these different variables, two-way escalator (ES2) has most effect on the prediction of pedestrian movement among all types of vertical transition, while V_R≥3 is proved to be a variable that has greater impact on predicting pedestrian movement than V_R0.

Keywords: *Multilevel, Pedestrian Movement, Configuration, Vertical Transition*

Theme: *Modelling and Methodological Developments*

1 Introduction

1.1 Background

Driven largely by rapid global population growth and urbanization, China has been experienced an unprecedented boom of the metro construction in the past decades. As a region with the intense socio-economic activities and the heavy traffic, the metro station area in urban center often shows the feature of multilevel routes. The research on the multilevel pedestrian movement in the metro station areas has great significance for improving the regional traffic efficiency, economic activities and urban vitality.

In recent years, researchers have drawn increased attention to the synergistic interactions between the urban spatial structure and pedestrian movement. Space syntax, originally conceived by Bill Hillier, Julienne Hanson and colleagues at the Bartlett, University College London in the late 1970s to early 1980s, is an important theory and method to study the interplay between space and behavior. A number of researches have proved that pedestrian movement is significantly influenced by spatial configuration (Hillier et al, 1987). Integration value that are used to describe its mean depth from other lines within a certain radius is closely related to the urban movement (Hillier, 1996), especially reflected in the two-dimensional level. The 'radius 3 integration' was proved to be the most powerful determinant of pedestrian movement (Penn A. et al, 1998); while the later research (Hillier, and Iida, 2005) showed that the least angle models have the highest correlations with the pedestrian movement by using different concepts of distances in configurational analysis.

However, the predictive ability of the multilevel pedestrian movement based on conventional configurational analysis has been greatly weakened due to the relatively low intelligibility (D Chang & A Penn, 1998) and the inadequate expression of the complex multilevel systems. The users in multilevel systems have to face the more difficult wayfinding tasks due to the more complicated spatial structure, which is difficult to be fully reflected in the space-syntax models. In the study of the interplay between pedestrian movement and spatial form in multilevel areas, therefore, it is proved that such additional spatial factors as vertical transition that have large impacts on pedestrian movement should be involved in the space-syntax analysis of spatial configuration.

1.2 Vertical Transition and Its Additional Properties

In the multilevel system, the vertical transition is considered as an essential and fundamental component, which could connect the routes of different levels and organize the pedestrian movement. Some researches (D Chang & A Penn, 1998; Parvin A., Ye A., and Jia B, 2007; Stephen Law & Yunfei Zhao, 2009; Lingzhu Zhang, Yu Zhuang and Xiaoling Dai, 2012) discussed the role played by the vertical transition on correcting the multilevel models. Their methods reflected the influence of vertical transition on pedestrian movement to some extent, but ignore the following two important issues.

(a).The vertical transitions in metro station areas can be divided into stair, one-way escalator, two-way escalator, and elevator by types, whose impact on pedestrian movement might be various. Stair is the most economical way of all, while escalator is the most popular one for the crowed areas of multilevel, because its continuous operating mode plays a significant role in evacuating and guiding the pedestrian flow. The elevator has low efficiency in carrying passengers, and is often used as barrier-free transport for the disabled in the metro station area. The research above overlooked the differences in the convenience of taking four types of vertical transition.

(b). On the other hand, the influence of vertical transition on pedestrian movement cannot only be reflected in its direct-connected routes, but also might be reflected in other indirect-connected ones, which would further influence the pedestrian distribution in the entire metro station areas. The conventional research ignores this indirect influence, and treats equally all the routes disconnected to the vertical transition. In this paper, these pedestrian routes within study area can be classified and expressed based on the topological distances to the vertical transition.

On this basis, the article reports an investigation on the relationships between the pedestrian movement and additional properties of vertical transition, and further discusses how to optimize the prediction models of multilevel pedestrian movement with the types of and topological distances to vertical transition.

2 Contents and Methods

2.1 Case Selection

This study chose the two typical multilevel cases in Shanghai: metro station area in Wujiaochang and metro station area in Xujiahui, both of which are located in the commercial center of the region. The multilevel pedestrian routes in both cases effectively resolve the pedestrian-vehicle confliction at the intersection of arterial roads on the ground floor, and improve the commercial vigor by directly connecting its surrounding retails and inner commercial space of the shopping mall from the underground floor.

2.2 Study Area

Taking into account the impact of the road network, this article defines the metro station area, the study area in the research, as a collection of all the reachable areas within 10-minute walking distance (500 meters) from the entrances/exits of the metro stations. The scopes of both two cases were calculated by GIS.

(a) Metro Station Area in Wujiaochang (b) Metro Station Area in Xujiahui

Figure1 Study Area

2.3 Study Method

Here we show the study methods. Firstly, following an investigation of pedestrian movement, this study presents two groups of data analyses about the effect of additional properties of vertical transition, including the types of and topological distances to vertical transition, on the pedestrian movement. Secondly, build the multilevel segment map, make the space-syntax analysis and then we get the original multilevel predicting model of pedestrian movement. Finally, build and compare several kinds of improved correctional models on the basis of original space-syntax model, and then further investigate the relative significance of these parameters in integrated models by quantified analysis results.

3. Data Collection and Analysis

3.1 Data Collection

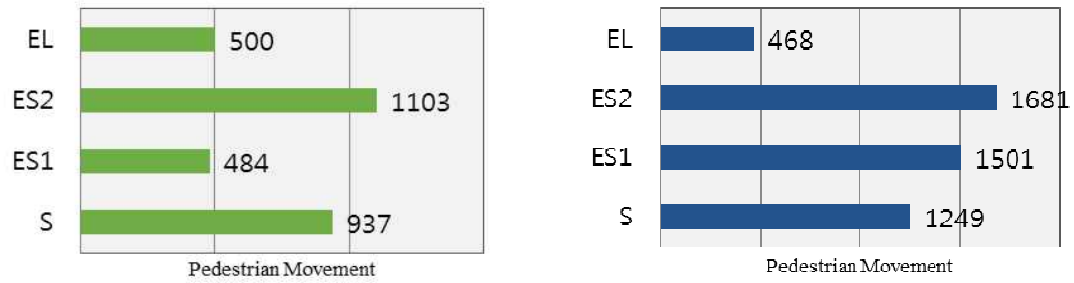
The data of pedestrian movement were collected by using the “Gate Count” method developed by space syntax research. The aim was to investigate the pedestrian distribution on multilevel routes within the study area. The movement surveys of the two cases were respectively conducted in different periods of one working day, which were 8:00 am -10:00am, 10:00 am -12:00am, 00:30 pm -02:30pm, 02:30 pm -04:30pm and 04:30 pm -06:30pm. There were 85 gates observed in the Wujiaochang station area and 99 gates observed in the Xujiahui station area. It took three minutes for observing each gate each time period. The Figure 2 shows the movement data in the working day in both two cases. In order to investigate the relationship between the pedestrian movement and additional properties of vertical transition, two groups of data were analyzed in the following section.

(a) Metro Station Area in Wujiaochang (b) Metro Station Area in Xujiahui

Figure2 Pedestrian distribution on the multiple levels

3.2 Influence Analysis of the Types of Vertical Transition

As mentioned, the vertical transition can be divided into Stair (S), One-Way Escalator (ES1), Two-Way Escalator (ES2), and Elevator (EL) by types. The data analyses of two cases show similar rules: of all the routes directly connected to the vertical transition, the greatest amount of pedestrian were observed on the routes which directly connected to the two-way escalators, followed by the ones connected to the one-way escalators or stairs, while pedestrian flows on the routes connected to the elevators decreased significantly in both two case-study areas. It



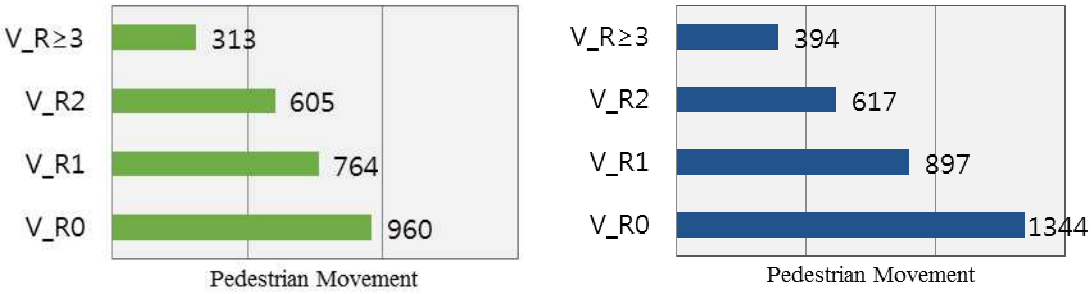
(a) Metro Station Area in Wujiaochang (b) Metro Station Area in Xujiahui

Figure3 The relationship between pedestrian movement and types of vertical transition

seems possible that less pedestrian flow on the routes connected to the ES1 in Wujiaochang case-study area is due to the relatively low number of one-way escalators. It proves that the impact caused by various types of vertical transition on the pedestrian movement is different, and also suggests that the types of vertical transition should be involved in the predicting analysis of pedestrian movement.

3.3 Influence Analysis of the Topological Distances to Vertical Transition

Another set of data is about the relationship between the pedestrian movement and the topological distances to vertical transition. The pedestrian routes within the study areas are classified as four groups by their topological distances to vertical transition: the pedestrian routes directly connecting to the vertical transition (V_R0), the pedestrian routes standing one-step away from the vertical transition (V_R1), the pedestrian routes standing two-step away from the vertical transition (V_R2), and other routes (V_R≥3). The data analyses of the two case-study areas demonstrate that a significant relationship exists between the pedestrian movement of a certain route and the topological distance from this route to its nearby vertical transition. It is clear that the pedestrian volume, which have been observed in both two case-study areas, decreases gradually with increasing topological distances to vertical transitions (within three steps), and the greatest amount of pedestrian flow was on the routes directly connected to the vertical transition. It means that the topological distance to vertical transition should be considered as an important parameter in the multilevel predicting models of pedestrian movement.



(a) Metro Station Area in Wujiaochang (b) Metro Station Area in Xujiahui

Figure4 The relationship between pedestrian movement and topological distance to vertical transition

4. Original Space-syntax Model

4.1 Space-Syntax Analysis

In the space-syntax models, the two broader segment maps of pedestrian routes in the Wujiaochang and Xujiahui cases, including their surrounding route network, were created. The segment lines on the different levels were linked by the lines expressing vertical transition, which describe a 0-step connection between routes. Obviously, this modeling approach is unable to effectively reflect the positive influence of vertical transition on pedestrian movement, as well as the differences of the vertical transition in the types and distance. These limitations require us to develop multilevel predicting model, which could involve more detailed properties of vertical transition. The following angular-analysis results according to the Integration value within 800M area (Integration_R800), which was calculated by Depthmap, were shown in the figure 5.

(a) Metro Station Area in Wujiaochang (b) Metro Station Area in Xujiahui

Figure5 Integration_R800

4.2 Correlation Analysis of Original Space-syntax Model (Model A)

Following the data collection of pedestrian movement, and the space-syntax analysis of two cases, the research proceeds to conduct the regression analysis of original space-syntax model by SPSS.

Firstly, in order to investigate the effect of configurational properties of multilevel systems on the pedestrian movement, the influencing configurational factors were selected by stepwise regression analyses. It is proved that Integration_R800 is the parameter which has the highest correlation with the pedestrian movement in both two case-study areas. It is clear that there is a good linear correlation between the pedestrian movement (Ln) and Integration_R800 by the scatterplot analysis in both two cases. The analysis results of correlations as shown in the Table 1 in both two cases further demonstrate that the integration_R800 is associated with the pedestrian movement, but the Adjusted R-squared of 0.408 in Wujiaochang area and of 0.348 in Xujiahui area, also suggest that there are some limits in predicting the pedestrian movement by using only Integration_R800 in the multi-level systems of metro station areas. The weak relationship between the pedestrian movement and integration mean that additional modeling factors should be taken into consideration in the analysis of pedestrian movement.

Table1 Model A

Cases	R	R^2	Adjusted R^2	Standard Error
Wujiaochang	.643	.414	.408	.701042666
Xujiahui	.593	.351	.348	.663292631

Predictor Variable:（Constant）, Integration_R800.
Predictor Variable:（Constant）, Integration_R800.

5. Correction Models

The positive correlation between pedestrian movement and vertical transition in the previous analysis suggests that the additional properties of vertical transition should be employed in the predicting model. On the basis of original space-syntax models, we build several kinds of correction models by introducing a series of different factors associated with vertical transition. To better examine the correction methods presented in this research, we make a comparative analysis among four models, which are original space-syntax model (Model A), correction model with V_R0 (Model B), correction model with types of vertical transition (Model C), and correction model with topological distances to vertical transition (Model D).

5.1 Correction Model with V_R0 (Model B)

Considering the direct impact of the vertical transition on the pedestrian movement, as demonstrated in the previous analysis, the routes directly connected to the vertical transition have been assigned the value 1 (positive influence), and the value 0 (negative influence) for the remainders of the pedestrian routes in the both two case-study areas. It is apparent that the analysis results of correlations as shown in the Table 2 in both two cases become better, reaching 0.502 and 0.420 respectively in Wujiaochang station area and Xujiahui station area, after adding the V_R0 variable into the regression model with the Integration_ R800.

Table2 Model B

Cases	R	R^2	Adjusted R^2	Standard Error
Wujiaochang	.716	.512	.502	.642885987
Xujiahui	.659	.435	.420	.580820744

Predictor Variable: (Constant), Integration_R800, V_R0.
Predictor Variable: (Constant), Integration_R800, V_R0.

5.2 Correction Model with Types of Vertical Transition (Model C)

To further measure the effect of different types of vertical transition on the pedestrian movement, Stair (S), One-Way Escalator (ES1), Two-Way Escalator (ES2), Elevator (EL) associated with Integration_R800 as the independent variables were together introduced into the multiple regression models. The unnecessary variables would be excluded through the following stepwise regression analyses, which were established on the basis of the model tests and the variable selections. The analyses results of both two case studies show that, in addition to Integration_R800, the variable of two-way escalator (ES2) have greatest impacts on the movement among all types of vertical transition. As well, the quantified data of correlation analysis (Adjusted R-squared: 0.510 in Wujiaochang station area; 0.506 in Xujiahui station area), suggest that the integrated models C, which taking the types of vertical transition into consideration, are more effective than model B in predicting pedestrian movement in both two case studies. This is particularly evident in the multilevel cases of Xujiahui (Table 3).

Table3 Model C

Cases	R	R^2	Adjusted R^2	Standard Error
Wujiaochang	.721	.520	.510	.637514903
Xujiahui	.729	.532	.506	.535858187

Predictor Variable: (Constant), Integration_R800, ES2.
Predictor Variable: (Constant), Integration_R800, ES2, ES1, EL.

5.3 Correction Model with Topological Distances to Vertical Transition (Model D)

Another correctional method has mainly focused on the influence scope of vertical transition on the pedestrian distribution. As mentioned in the previous analysis, the effects of vertical transition on pedestrian movement not merely reflect on its directly connected routes. Therefore, the new model is improved on the basis of model B. All the routes within the study area are expressed as V_RO, V_R1, V_R2, V_R≥3, based on their topological distance to vertical transition. And these routes should be added different weight value to each of them, in order to reflect their different levels of impact on the pedestrian movement. Thus the variables of V_RO, V_R1, V_R2, V_R≥3 associated with Integration_R800 have been put together into the further regression models. By excluding the less-important influencing factors in the following stepwise regression analyses, Integration_R800 and V_R≥3 were selected as the most important variables for the pedestrian movement in both two cases. It is apparent that the integrated model D with Integration_R800 and V_R≥3, comparing with the Model B, show more positive correlations between pedestrian movement (Ln) and the independent variables in both two case-study areas (the Adjusted R-squared: 0.543 in Wujiaochang station area; and 0.446 in Xujiahui station area).

Table4 Model D

Cases	R	R^2	Adjusted R^2	Standard Error
Wujiaochang	.743	.552	.543	.615787431
Xujiahui	.679	.460	.446	.615787431

Predictor Variable: (Constant), Integration_R800, V_ R≥3.
Predictor Variable: (Constant), Integration_R800, V_ R≥3.

5.4 Statistical Significance of Variables

(a) Model C:

For the correction models with types of vertical transition (Model C) of two cases, their F-test results of (53.139 and 20.727 respectively, P<0.001) and the T-test results as shown in table 5 reveal that they are both statistically significant. As well, through the further analysis results, we could quantify the effect of each variable on predicting pedestrian movement, and then acquire an order about statistical significance of variables. Table 5 shows that the variable of Integration_R800 still has most important influence on the pedestrian movement in both two case-study areas. While among all types of vertical transition, two-way escalator (ES2) is proved to be the most important variable for predicting pedestrian movement. In the metro station area of Xujiahui, the integrated model can acquire a greater correlation when associate with the combination of ES2, ES1, EL and configurational property, whose significance ranking of most to least is Integration_R800, two-way escalator (ES2), one-way escalator (ES1), elevator (EL).

Table5 T-test of Model C

Cases	Variables	Standardized Coefficients	t	Sig
Wujiaochang	Constant	1.078	1.458	.148
	Integration_R800	.025	6.310	.000
	ES2	.758	4.660	.000
Xujiahui	Constant	2.991	2.851	.006
	Integration_R800	.018	6.062	.000
	ES1	.774	3.517	.001
	ES2	0.937	4.177	.000
	EL	-1.168	-2.077	.041

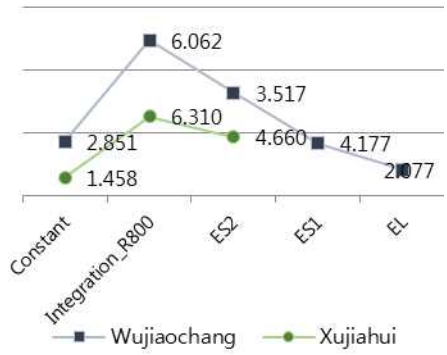


Figure 6 Statistical significance of variables

(b) Model D:

Similar methods were used in the model D in both two case-study areas. The F-test results (60.474 and 32.000 respectively, P<0.001), and the subsequent T-test results (table) of the models D in both two cases, illustrate that the models D of both two cases have significance in statistics. Two sets of quantified analysis data in Wujiaochang station area and Xujiahui station area show a significance order of all independent variables, based on their quantified effect on predicting pedestrian movement. It is clear that, in both two case-study areas, Integration_R800 has the most effect on the pedestrian movement, followed by the variables of V_R≥3, which also occupy a considerable proportion.

Table6 T-test of Model D

Cases	Variables	Standardized Coefficients	t	Sig
Wujiaochang	Constant	2.124	2.700	.008
	Integration_R800	.022	5.702	.000
	V_R≥3	-.769	-5.506	.000
Xujiahui	Constant	2.991	2.851	.006
	Integration_R800	.017	5.368	.000
	V_R≥3	-.742	-5.027	.001

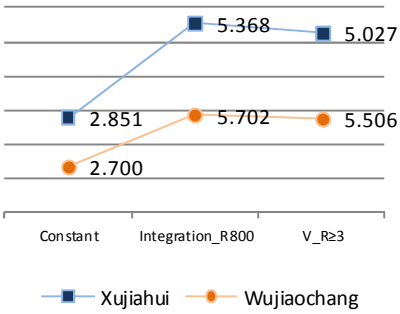


Figure 7 Statistical significance of variables

6 Conclusions

Vertical transitions associated with routes and nodes construct multilevel pedestrian networks in the metro station area. As a fundamental component of multilevel systems, vertical transitions play a vital role in the operation of multilevel systems. However, the conventional space-syntax analysis couldn't fully reflect the effect of vertical transition on the pedestrian movement, which is one of main reason for explaining the weak predictive ability of pedestrian movement based on the conventional space-syntax analysis. There is a need, therefore, to build an improved model involving the detailed properties of vertical transition. On the basis of previous correctional methods with vertical transition, this paper proposes two new modeling methods about introducing additional properties of vertical transition, including the types of and topological distances to vertical transition. Although the two new integrated models show different analysis results in the metro station area of Wujiaochang and Xujiahui, both of them prove that it is feasible to predict multilevel pedestrian movement by introducing the vertical transition into conventional configurational analysis. As well, comparing with the previous correctional models, the improved multilevel models of both two cases have a higher correlation after considering the types of and topological distances to vertical transition.

Specifically, the data analyses of field research show that the pedestrian movement is constrained by the types of vertical transition. If their different impact on the pedestrian movement could be reflected in the models by adding different weight value to them, it is proved that the predictive abilities of multilevel models have been improved (0.510 in Wujiaochang station area and 0.506 in Xujiahui station area). Among all types of vertical transition, the two-way escalator (ES2) is proved to have most effect on predicting pedestrian movement. In the other data analysis, it turns out that, in both two case-study areas, the impact of vertical transition on movement cannot only be reflected on the directly-connected routes, but also on its surrounding routes. By classifying the pedestrian routes in the metro station area based on the topological distances to vertical transition, it is found that V_R≥3 is a variable that has greater impact on pedestrian movement than V_R0. As well, the multilevel models of two cases also could be optimized by introducing both variables of V_R≥3 and Integration_R800

(0.543 in Wujiaochang station area and 0.446 in Xujiahui station area). What's more, among all the models of two multilevel cases in metro station areas, no matter how the independent variables change, Integration_R800 is always proved to have the most significance for prediction of pedestrian movement. It suggests that there are significant correlations always exist between the pedestrian movement and spatial configuration of the multilevel systems.

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References

Chang, D., and P. Penn. 1998 . "Integrated multilevel circulation in dense urban areas: the effect of multiple interacting constraints on the use of complex urban areas." *Environment and Planning B: Planning and Design* 25 : 507–538.

Hillier, B. and J. Hanson. 1984. *The Social Logic of Space.* Cambridge: Cambridge University Press.

Hillier, B., R. Burdett, J. Peponis, and A. Penn. 1987. "Creating life: or, does architecture determine anything?" *Architecture and Behaviour* 3(3): 233-250.

Hillier B. 1996. *Space is the Machine: a Configurational theory of Architecture*. Cambridge: Cambridge University Press.

Hiller, B., and S. Iida. 2005. "Network and psychological effects in urban movement." In *Spatial Information Theory*: COSIT, edited by A.G. Cohn and D.M. Mark. Lecture Notes in Computer Science number 3693, 475-490, Springer-Verlag, Berlin.

Jung, Hye Sun, Young Ook Kim, and Hoon Tae Park. 2009. "Spatial Structure Analysis in Accordance with the Mode of Interconnection between Surface and Underground Pedestrian Networks." *Proceedings of 7th International Symposium on Space Syntax*, Stockholm: KTH.

Lingzhu, Zhang, Yu Zhuang, and Xiaoling Dai. 2012. "A CONFIGURATIONAL STUDY OF PEDESTRIAN FLOWS IN MULTI-LEVEL COMMERCIAL SPACE. Case study Shanghai." *Proceedings of Eighth International Space Syntax Symposium*. Santiago de Chile: PUC.

Penn, A., B. Hillier, D. Banister, and J. Xu. 1998. "Configurational modeling of urban movement networks" *Environment and Planning B: Planning and Design* 25 : 59-84.

Parvin, A., A. Ye, and B. Jia. 2007. "MULTILEVEL PEDESTRIAN MOVEMENT: does visibility make any difference?" *Proceedings of Six International Symposium on Space Syntax*, Istanbul, Turkey.

Stephen, Law, and Yunfei Zhao. 2009. "Exploring Multi-layered Hyper Dense Urban Environments through Spatial Analysis." *Proceedings of 7th International Symposium on Space Syntax*, Stockholm: KTH.