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Research On The Relevance Between Mixed-use Complex and User Behaviour Based On Three-dimensional Spatial Analysis

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Abstract Under the dual pressure of population growth and land shortage, three-dimensional development is the inevitable choice for cities in China. In such a scenario, a mixed-use complex has considerable potential in its realization and research. Based on space syntax and the three-dimensional visibility graph analysis, this paper describes the spatial and functional layout of the Shanghai Super Brand Mall and studies the relationship between spatial visibility and user behaviour through linear regression analysis and correlation analysis. This paper studies three different types of user behaviour, namely, path selection, staying selection, and store selection, and finds that spatial visibility and accessibility have different effects on user behaviour depending on the type and purpose of the activity. This paper reveals the influence of spatial and functional layout on user behaviour and puts forward the corresponding design strategy under the three-dimensional environment.

Keywords Three-dimensional Visibility Graph Analysis, Space Syntax, Mixed-use Complex, Spatial Layout, User Behaviour

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1. Vertical City and Mixed-use Complex

Chinese urbanization has developed rapidly in the 21st century. According to data released by National Bureau of Statistics in February 2018, the urbanization rate of China has reached 58.52% (Stats.gov.cn, 2018). This figure is expected to grow rapidly to 70% in 2030 (Pan et al., 2015). However, increased population concentration puts considerable pressure on the urban environment. The urbanization of China presents two major trends. On the one hand, the continuing growth of population forces cities to provide spaces and facilities for 10 million more people every year. On the other hand, the shift from increment development to stock development results in less developable land for urban construction in future. The conflict between reduction of construction land and increasing demand for construction area pushes the city into high-density development. Urban structures are thus transformed from horizontal to vertical. Furthermore, the vertical layout of the city affects the citizens' lifestyle. In such a context, former experiences of urban design on horizontal dimension might not keep pace with the needs of designing vertical spaces in high-density urban development (Wang et al., 2015). Therefore, in order to better adapt the urban environment to the changes of the citizens' lifestyle, research and discussion on the relevance between the vertical urban environment and user behaviour is essential.

Mixed-use complexes are an important component in modern urban organization. These complexes provide good potential for realizing vertical urbanism (Dong, 2011). A mixed-use complex is a city within the city. The introduction of urban public spaces within the mixed-use complex integrates the base surface of urban public activities into the organization of the mixed-use complex (Wang et al., 2013). Hence, mixed-use complexes are the perfect subjects for discussing the relevance between the urban vertical layouts and user behaviour.

2. Spatial Structure and Spatial Cognition

The relevance between spaces is the fundamental means to construct spatial cognition (Dalton et al., 2005). Users' cognition is determined by spatial relevance, and it can directly influence their behaviour. We therefore suggest that spatial relevance may generate significant influence on user behaviour. User behaviour in mixed-use

complexes may be guided by various factors such as different height of spatial base surfaces, complicated spatial structure, and gaps between accessibility and visibility. In addition, user behaviour can also be affected by different purposes. Thus, the influence of spatial relevance on user behaviour should be studied under the different types of user activities.

Based on the different behavioural characteristics in the mixed-use complex, user behaviour is identified as one of three types: walking, staying, and shop-entering. "Walking" presents users' choice on path, while "staying" presents their choice on behaviour, and "shop-entering" presents their choice on store. The former two are related to a user's cognition of public spaces, and the latter is influenced by the user's perception of the store.

3. Methodology of Three-dimensional Spatial Analysis

To ensure the coherence of units, public spaces investigated in this study are divided equally into 1512 grids via the visibility graph analysis (VGA) modelling method. The studies on spatial relevance are therefore transformed into studies on grids' relevance. The interfaces of stores in cases are transformed into 698 interface points. A total of 270 of these stores' entry are selected as study subjects.

Depthmap is introduced in the physical connection analysis of public spaces in this study. A model of the case's indoor accessibility is built. Vertical transportations connecting different floors are presented as "links". Accessibility R50m is presented by numbers of accessible points in 50 m. Global integration presents the complete accessibility. The accessibilities of stores' entries are presented by those of their located grids. The physical connection between spatial grids and urban spaces are shown in entries' accessibility. It is calculated from accessibilities between entries and grids, which are adjusted by weights taken from the proportion of population passing those entries.

The 3D visibility analysis method by Lu and Xu (2017) is used in the analysis of spatial visibilities. The general visual relations of public spaces are modelled for analysis. The results are shown as integrations of spaces, with adjustment of weights taken from sight length and elevation angle, while in the analysis of stores' spaces, the visual relations from public spaces to stores' interfaces are calculated in the model.

4. Empirical Study of Shanghai Super Brand Mall

This study selected Shanghai Super Brand Mall as the object of empirical research. Shanghai Super Brand Mall is strategically located in the heart of Lujiazui CBD, Pudong, adjacent to the Pearl Ring (pedestrian skybridge system) (Figure 1). This mixed-use complex was invested in and developed by the Thai Chia Tai Group and designed by famous American architects: the Jerde Partnership. The building has a length of 270 m and a width of 121 m. It covers an area of 31,000 m^2 and has a construction area of 240,000 m^2. It has three underground floors and ten floors above ground, with a total height of 53.4 m. It has diverse businesses, including catering, retail, entertainment, service offerings, and offices.

There are four main reasons for choosing Shanghai Super Brand Mall as the research object:

(1) Its large construction area and the visibility of

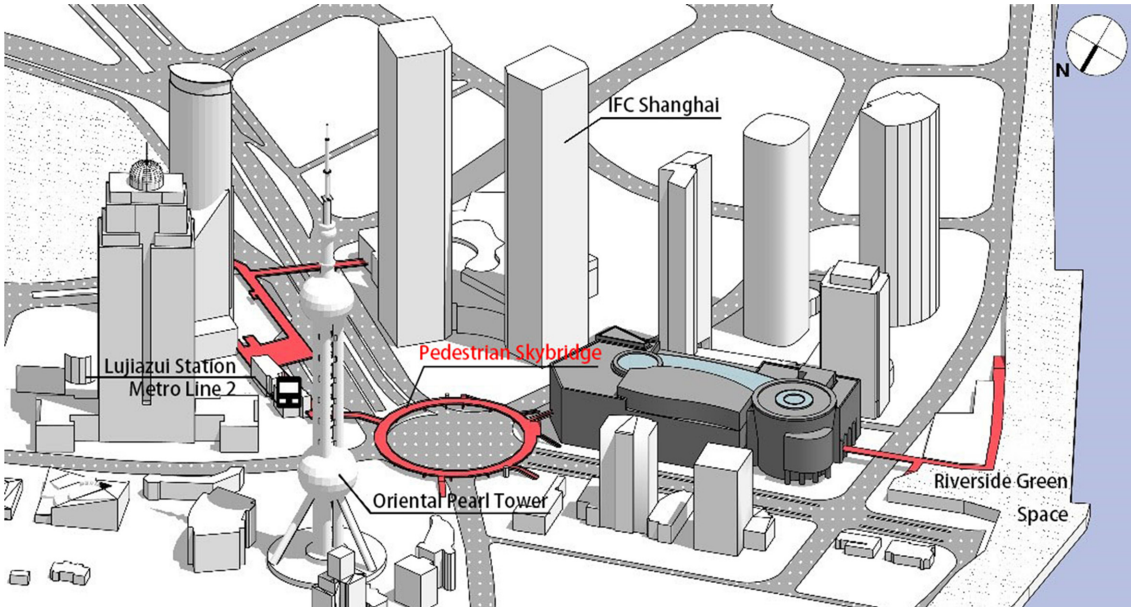


Figure 1. Surroundings of Shanghai Super Brand Mall.

internal space changes considerably, which provides sufficient samples of different spaces for analysis;

(2) It has main entrances from L1 to L3 floor with large flow, hence the distribution of internal passenger flow and spatial accessibility are relatively uniform.

(3) It is located in the core area of Lujiazui CBD, where the passenger flow is extremely high, and its main customer group contains a large number of tourists, which reduces the interference from the strong target group.

(4) Its rich format and the regular pattern between visibility and business layout can be explored through comparative analysis of different types of businesses.

4.1. Path Selection Study

In the study of path selection, "visitor flow in public space" indicates users' path selection. The field surveys chose multiple time periods from the afternoon to the evening in the holiday. Investigators measured the 3-minute sectional visitor flow of the public space in Shanghai Super Brand Mall. A total of 163 sections were recorded. Then, the data was averaged and converted into "visitor flow in public space".

In the quantitative analysis, Statistical Product and Service Solutions (SPSS) software was used to analyse the correlation. A multiple linear regression model was established using the "visitor flow in public space" as the dependent variable and the position factors as the independent variables. The specific variables are as follows. (Table 1)

The R Square of the linear regression model is 0.405, and the adjusted R Square is 0.404 (Table 2). The model has relatively strong explanatory power, which indicates that the position factors of the public space can sufficiently explain the distribution of visitor flow in the mixed-use complex. After adjusting the parameters according to the collinearity diagnosis, the two factors of "public space's accessibility R50m" and "layer" are removed. Correlation analyses reveal that the physical connection of spaces is crucial to the impact of visitor flow, and visual connection plays an auxiliary role. (Table 3)

Comparing the visitor flow with the position factors, there are four areas that do not match the conclusions of the above model. (Table 4) After sorting the factors of the special areas (Figure 2), the following results are shown.

(1) Format, visibility, and accessibility should be kept in balance. A significantly low value in one of these three levels can result in low visitor flow. For example, near the atrium of the north side, the accessibility is similar to other areas in the same floor, but the visibility is significantly reduced, and the visitor flow is also significantly reduced.

(2) A format with strong attraction can largely guide the visitors' path selection. For example, the main store on the B1 floor and the food court on the B2 floor attracted a large number of visitors.

Table 1. Variables of Path Selection Study

Object	Evaluation Index	Quantitative Meaning
Path Selection	Visitor Flow in Public Space	The number of people passing through the section of public space per unit time
Position Factors	Public Space's Visibility	Visibility closeness centrality, the ability of an accessible point in public space to be seen by other accessible points in public space
	Public Space's Global Accessibility	Metric node count, the ability of an accessible point in public space to reach all accessible points in public space
	Public Space's Accessibility R50 m	Metric node count R50m, the ability of an accessible point in public space to reach other accessible points in public space within a radius of 50 m
	Layer	The layer where an accessible point in public space is located
	Public Space's Accessibility from Entrances	Metric node count R50m of entrances, the ability of an accessible point in public space to reach every entrance of the building

Table 2. Multiple Linear Regression Model of Path Selection Study

Summary of Multiple Linear Regression Models									
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
a	.637a	.405	.404	.4267	.405	256.672	5	1506	.000
b	.634b	.402	.401	.4278	.402	337.605	3	1508	.000
c	.613c	.375	.375	.4370	.375	453.556	2	1509	.000

Predictors:: (constant), public space's visibility, public space's global accessibility, public space's accessibility R50m, layer, public space's accessibility from entrances
Predictors: (constant), public space's visibility, public space's global accessibility, public space's accessibility from entrances
Predictors: (constant), public space's global accessibility, public space's accessibility from entrances

Table 3. Correlation between Visitor Flow in Public Space and Position Factors

Correlations			
Independent Variable	Pearson Correlation	Sig. (one-tailed)	N
Public Space's Visibility	.327**	.000	1512
Public Space's Global Accessibility	.551**	.000	1512
Public Space's Accessibility R50 m	.432**	.000	1512
Layer	–.541**	.000	1512
Public Space's Accessibility from Entrances	.552**	.000	1512

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

Table 4. Factors of Special Areas in Path Selection Study

Number	Location	Visibility	Accessibility	Accessibility from Entrances	Business Attraction	Visitor Flow
1	Surrounding of High-level Atrium	High	Low	Low	Middle	Low
2	North-side Atrium	Low	Middle	Middle	Low	Low
3	Ramp from L3 to L4 floor	High	High	Middle	Low	Middle
4	B1 and B2 floors	Low	Low	Middle	High	High

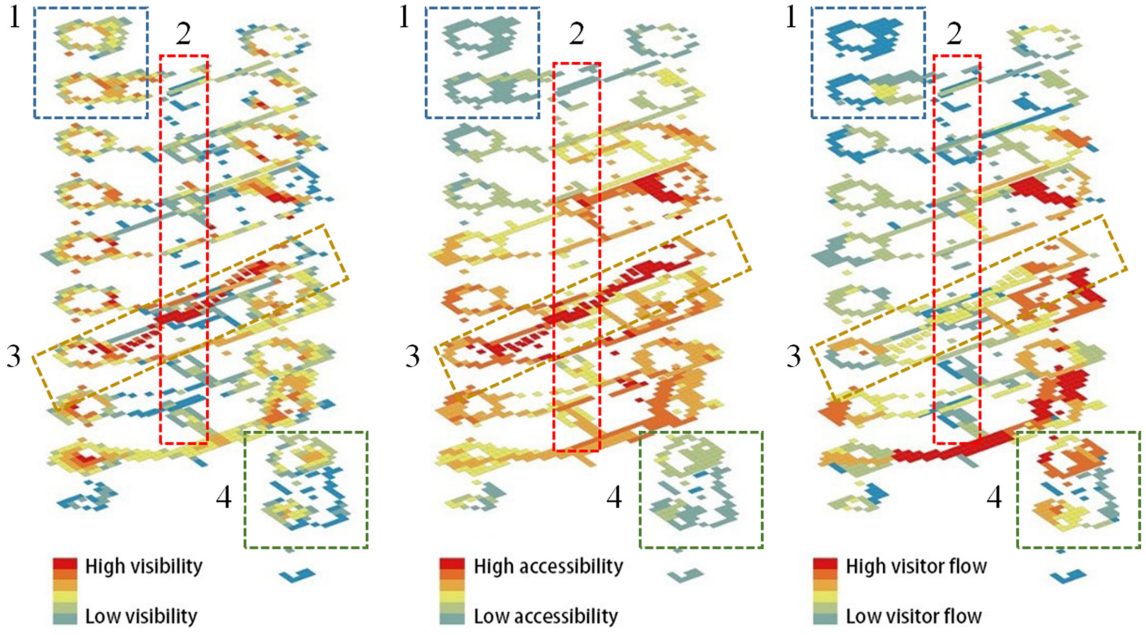


Figure 2. Location of Special Areas in Path Selection Study.

(3) When the physical connection and visual connection of the public space are separately enhanced, the visitors' path selection cannot be guided. For example, the visibility near the high-level atrium is significantly improved comparing with the nearby public spaces, but the accessibilities of them are similar. Hence, the visitor flow around the high-level atrium is not improved.

4.2. Staying Selection Study

In the study of staying selection, first divide the staying activities into active staying and passive staying. Active staying means that visitors choose the stop position independently, which is affected by their spatial cognition. Passive staying is limited by facilities and visitors cannot choose their stop position (Figure 3). Therefore, when analysing the influence of spatial structure on staying selection, the relationship between active staying and position factors should be analysed primarily.

In the field surveys, 786 visitors' staying activities in public spaces are recorded. From the record results, 89% are passive staying, 11% are active staying, and there are only a few users interacting with public spaces.

The independent variables are the same as the study of path selection, since the research objects are public spaces.



Figure 3. Active Staying and Passive Staying.

In the correlation analysis between active staying and position factors, "public space's visibility" is significantly positively correlated with the density of active staying. Although the "public space's global accessibility" is also significantly positively correlated with the density of active staying, the correlation is significantly weaker than the "public space's visibility" (Table 5). This finding indicates that visitors are more willing to stay in areas with better visibility.

In the correlation analysis of passive staying and position factors, all the position factors are not significantly correlated with the density of passive staying (Table 6). The scatterplot of the relationship between visibility and staying activities shows that the higher the visibility, the more active staying happens, and the number of instances of passive staying does not change or even partially decrease (Figure 4). This finding suggests that the influence of the facilities on user staying selection is decisive. To improve the users' experience, the facilities that guide the passive staying should be combined with spaces that users choose actively.

One of the surveys finds a large number of visitors gathering near the west side atrium of the L1 and L2 floors, far exceeding the staying data of other periods and areas. The analysis finds that a large number of visitors are attracted when activities are held on L1 floor. These visitors choose to gather where they can easily see the event, accounting for more than 75% of the recorded active staying in the recording period (Figure 5). This finding shows that interesting visual focus points can trigger active staying.

4.3. Store Selection Study

In the study of store selection, different business formats engender different kinds of visitor behaviour. Hence, it is necessary to analyse according to the classification of

Table 5. Correlation between Density of Active Staying and Position Factors

Correlations			
Independent Variable	Pearson Correlation	Sig. (one-tailed)	N
Public Space's Visibility	.193**	.000	1512
Public Space's Global Accessibility	.083**	.001	1512
Public Space's Accessibility R50 m	.058*	.011	1512
Layer	–.016	.271	1512
Public Space's Accessibility from Entrances	.020	.217	1512

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

Table 6. Correlation between Density of Passive Staying and Position Factors

Correlations			
Independent Variable	Pearson Correlation	Sig. (one-tailed)	N
Public Space's Visibility	–.034	.095	1512
Public Space's Global Accessibility	.039	.065	1512
Public Space Accessibility R50 m	.035	.090	1512
Layer	–.006	.414	1512
Public Space's Accessibility from Entrances	–.020	.222	1512

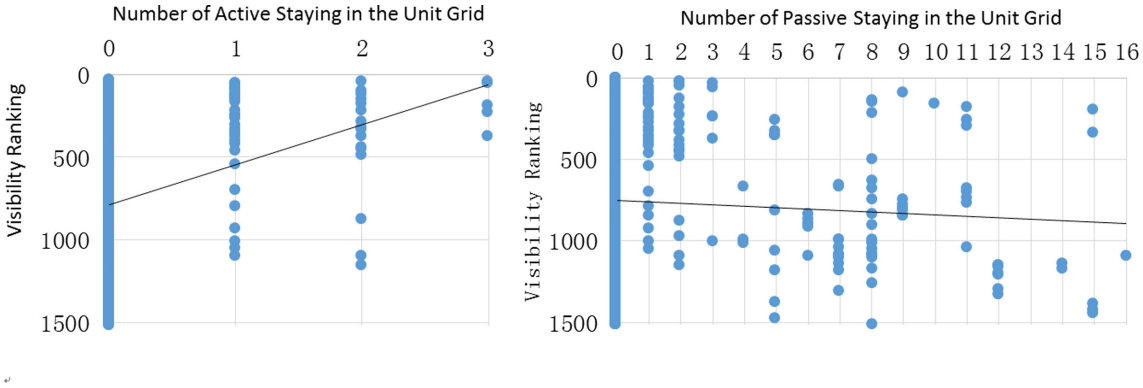


Figure 4. Visibility and Staying Activities.

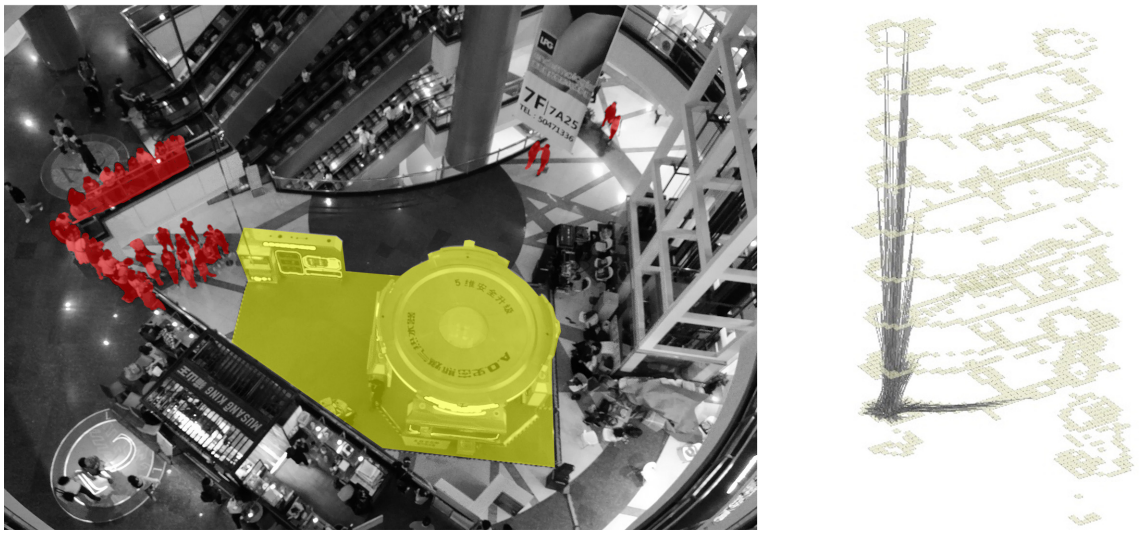


Figure 5. Visual Focus Points Triggered Active Staying.

business formats. There are 270 store entrances in the Shanghai Super Brand Mall. 175 of them belong to clothing retail, while 47 belong to catering. Entrances of other formats total no more than 20 (Figure 6). Hence, this study mainly focuses on the catering and clothing formats. In field survey, it was found that the anchor stores and general stores in the clothing format also cause different visitor behaviour. Thus, these two types of store are also analysed separately.

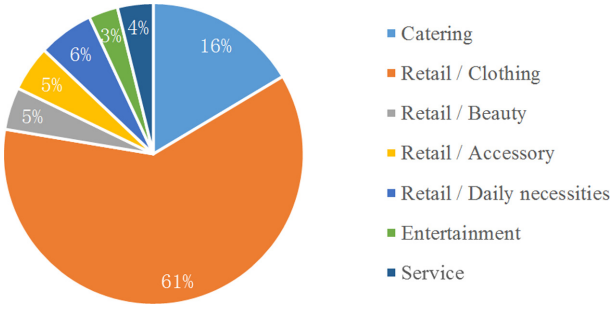


Figure 6. Proportion of Store Entrance's Format.

In quantitative analysis, store selection is represented by custom flow. During the field survey in Shanghai Super Brand Mall, 47 catering store entrances and 174 clothing store entrances are chosen. Three-minute custom flows in several time periods from the holiday afternoon to the evening are recorded. Then, the data are averaged and converted into the store custom flow per unit time. The store's custom flow is used as the dependent variable in SPSS analysis, and the store's location and other factors are taken as the independent variables. A multiple linear regression model is established to analyse the correlation. Specific variables are listed in Table 7.

The R Square of catering store's custom flow in the multiple linear regression model is 0.209, while the adjusted R Square is only 0.043 (Table 8). This finding indicates that all independent variables cannot explain the distribution of a store's custom flow. During the survey, it is also found that when choosing a catering store, visitors are always influenced not by the location or the size of the store but first by the format.

Table 7. Research Variable of Store Selection

Research Object	Evaluating Index	Quantification Meaning
Store Selection	Store's Custom Flow	The number of custom entering the store entrance per unit time
Position Factor	Store Entrance's Visibility	Visibility closeness centrality, The ability of the store entrance's target point to be viewed by the public space accessible point.
	Store Entrance's Global Accessibility	Metric node count, The ability of the nearest public space accessible point at the store entrance's target point to reach other accessible points.
	Store Entrance's Accessibility R50 m	Metric node count R50m, The ability of the nearest public space accessible point at the store entrance's target point to reach the accessible point within 50 meters.
	Number of Layers	The store entrance's floor.
	Entrance's Accessibility	Metric node count, The ability of the nearest public space accessible point at the store entrance's target point to each entrance.
	Store Entrance's Cross-section Custom Flow	The cross-section custom flow of public space where store entrance's target point is.
	Anchor Store's Accessibility	The distance between the store entrance's target point and the anchor store's interface point.
Non-position Factor	Store Area	The total area of a store for business.
	Interface Length	The open interface length of store to public space.

Table 8. Multiple Linear Regression Model for Catering Store Selection

Summary of the Multivariate Linear Regression Model									
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Chang Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.457a	.209	.043	4.9842	.209	1.256	8	38	.295

Predictors: (constant), store's visibility, store's global accessibility, store's accessibility R 50 m, number of layers, the entrance's accessibility, store area, interface length.

After correcting the model of the general clothing stores according to the collinearity diagnosis, three autocorrelated variables are removed: "store's global accessibility", "number of layers" and "entrance' accessibility". The R Square of linear regression model decreased 0.006, while the adjusted R Square increased by 0.008 (Table 9). This finding shows that "the store's global accessibility" in Shanghai Super Brand Mall has no direct impact on the store's custom flow. In the correlation analysis, it is found that "the anchor store's accessibility" is the most significant positive correlation with the custom flow among position factors. "The store entrance's accessibility R50 m" is the second (Table 10). This finding shows that the pass-through formats such as general clothing store are not able to attract most of the custom flow in the mixed-use complex because of its weak attractiveness. They can

Table 9. Multiple Linear Regression Model for General Clothing Store Selection

Summary of the Multivariate Linear Regression Model									
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.608a	.370	.329	3.7467	.370	8.992	9	138	.000
2	.603b	.364	.337	3.7236	.364	13.442	6	141	.000
3	.593c	.352	.329	3.7456	.352	15.412	5	142	.000

Predictors: (constant), store entrance's visibility, store entrance's global accessibility, store entrance's accessibility R50m, layer, entrance's accessibility, anchor store's accessibility, store entrance's section custom flow, store area, interface length.
Predictors: (constant), store entrance's visibility, store entrance's accessibility R 50m, anchor store's accessibility, store entrance's section custom flow, shop area, interface length.
Predictors: (constant), store entrance's accessibility R 50m, anchor store's accessibility , store entrance's section custom flow, store area, interface length.

Table 10. Correlation between Custom Flow and Position Factors of General Clothing Store

Relevant				
Independent Variable		Pearson Correlation	Sig. (one tail)	N
Position Factor	Store Entrance's Visibility	.090	.137	148
	Store Entrance's Global Accessibility	–.085	.153	148
	Store Entrance's Accessibility R 50m	.231**	.002	148
	Number of Layers	–.244**	.001	148
	Store Entrance's Accessibility	.143*	.042	148
	Anchor Store's Accessibility	.499**	.000	148
	Store Entrance's Cross-section Custom Flow	.173*	.018	148
Non-positional Factor	Store Area	.476**	.000	148
	Interface Length	.369**	.000	148

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

only attract nearby visitors.

After correcting the model according to the collinearity diagnosis, six variables are removed: "store's accessibility", "Store's Accessibility R50 m", "number of layers", "store entrance's accessibility", "store area", and "interface length". The R Square of linear regression model (Table 11) decreased to 0.114, while the adjusted R square increased to 0.063. The results of the correlation analysis show that "the store entrance's visibility" and "the entrance's cross-section custom flow" determine "the anchor store's custom flow", and the visibility is the most significant correlation (Table 12). When visitors see the anchor store's entrance, the possibilities of choosing to enter the store are significantly enhanced.

5. Summary of Layout Strategies

To guide visitors' behaviour better through space layout and format layout, this study proposes following layout strategies for different behaviours for design reference.

To guide visitor's path selection, it is necessary to balance the relationship among the visibility, accessibility and format near the path where visitors are expected to gather. The following are specific suggestions: 1) guide custom flow to enter from multiple bases to improve the accessibility of entrance; 2) improve global accessibility

Table 11. Multiple Linear Regression Model for Anchor Clothing Store Selection

Summary of the Multivariate Linear Regression Model									
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.716a	.512	.283	7.325	.512	2.231	8	17	.078
2	.631b	.398	.346	6.994	.398	7.615	2	23	.003

Predictors: (constant), store entrance's visibility, store entrance's global accessibility, store entrance's accessibility R50 m, number of layers, the entrance's accessibility, store entrance's cross-section custom flow, store area, interface length.
Predictors: (constant), store entrance's visibility, store entrance's cross-section custom flow.

Table 12. Correlation between Custom Flow and Position Factors of Anchor Clothing Store

Relevant				
Independent Variable		Pearson Correlation	Sig. (one tailed)	N
Position Factor	Store Entrance's Visibility	.571**	.001	26
	Store Entrance's Global Accessibility	.479**	.007	26
	Store Entrance's Accessibility R50 m	.455**	.010	26
	Number of Layers	–.119	.281	26
	Store Entrance's Accessibility	.259	.101	26
	Store Entrance's Cross-section Custom Flow	.470**	.008	26
Non-positional Factor	Store Area	–.008	.484	26
	Interface Length	.061	.383	26

by controlling spatial connections; 3) ensure a reasonable public space scale, and guide the path selection by controlling visibility; 4) set the format by position factors reasonably, and use the high-attraction format to lead visitors.

To guide visitor's stay selection, it is necessary to improve the spatial visibilities and staying attraction abilities of the public spaces where visitors are expected to stay. The following are specific suggestions: 1) improve the visibility of the public space to the visual focus point, and specifically increase the incidence rate of the active activities; 2) arrange facilities such as seats in areas where visitors are expected to gather, and improve the visibility of these areas and the spatial experience of visitor when they stay passively.

To guide visitor's store selection, it is necessary to adopt different measures according to the store type. The following are specific suggestions: 1) enhance the attractiveness of the target-type stores, such as catering, entertainment, and service; 2) place the anchor retail stores in the best position of visibility and accessibility; 3) place the general retail stores near the anchor retail stores or in a better position of accessibility locally.

6. Spatial Design to Guiding Visitor Behaviour

The target of space design is to design as per visitors' behaviour and feelings. Visitors' requirements of building space change with the dramatic change of urban spatial structures. Thus, designers should guide visitor's behaviour via spatial structure design. Through 3D spatial analysis, designers can effectively predict visitors' behaviour selection tendencies during the design phase. The economic benefits of each function space in the mixed-use complex can be maximized while meeting visitor's most direct requirements and special feelings.

For example, in Shanghai Super Brand Mall, visitors can be guided by the following layout improvements: 1) enhance the attractiveness of the store on the north side, as well as introduce the anchor retail store, and open the north interface of the south atrium to attract visitors to the north atrium; 2) organize activities on the ramps from L3 to L4 given its superior visibility, open the ceiling, and convert the traffic space into a city plaza; 3) adjust the seat layout, and set seats in high-level atriums with high visibility but low accessibility and custom flow, thus improving the custom flow in a high-level area and satisfying visitors' staying needs; 4) change the stores on the ramp from L3 to L4 into targeted stores, and increase the density of stores to form a cluster of stores. Increase the pass-through clothing retail format stores around Uniqlo on the B1 Level. To maximize the value of the anchor store, the structure should be transformed from a single store layout into mesh layout, where an anchor store core is surrounded by general stores.

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References

Dalton R C, Hölscher C, Turner A. (2005). "Space Syntax and Spatial Cognition". In World Architecture, 11, 41-45;

Hexuan Dong. (2011). Urban Three-dimensional Design: Space Structure based on Multi-level Urban Base. Nanjing: Southeast University Press;

Jiahua Pan, Houkai Wei. (2015). China Social Security System Development Report No.8. Beijing: Social Sciences Academic Press (China);

Yi Lu, Shuchen Xu. (2017). "Three-dimensional Visibility Graph Analysis and its Application". In World Architecture, 5, 44-49;

Zhendong Wang, Yinpu Wang. (2015). "Research on Vertical Space System of Mixed-use Complex". In Architectural Journal, 2, 35-38;

Zhendong Wang, Yun Zhang. (2013). "Research on Combined Space of Mixed-use Complex". In New Architecture, 3, 162-165. http://www.stats.gov.cn/tjsj/zxfb/201802/t20180228_1585631.html