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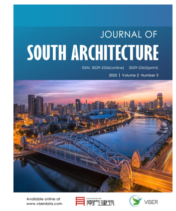

Spatial Improvement Strategies for Commercial Complexes Based on Simulations of Consumer Behavior

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ABSTRACT: Current studies investigating spatial improvement strategies for commercial complexes often fail to address consumer behavior adequately. This paper aims to reveal how consumer activity at a micro level is affected by the spatial environment, ultimately providing insight into strategies that may improve commercial complex spaces through simulated consumer behavior. Empirical data on consumers' spatial behavior from a real case study were collected to estimate behavioral models that could be applied to implement general simulations of consumer behavior. A series of virtual scenes were constructed in which most variables were controlled at the same level to compare specific design modes and techniques, such as the relationship between anchor stores and general stores, different plane forms, and the dynamic line of passenger flow, vertical connections, and entrance locations. Differences in consumer behavior resulting from these optimization strategies, along with guiding principles, were analyzed through individual simulations. The results of the current study provide a more objective reference for the quantitative evaluation of spatial performance.

KEY WORDS: commercial complex; consumer behavior; individual simulations; spatial improvement

Introduction

With thegrowing consumer demand and the upgrading commercial formats, commercial complexes have developed rapidly across China. Taking Wanda Plaza as an example, the first Wanda Plaza opened in 2002. Just 16 years later, in 2018, there were 280 Wanda Plazas opened across China, ranking first in the world in terms of the owned commercial property area. Not only big cities but also many small and medium-sized towns and even villages are actively promoting the development of commercial complex projects. In the face of such widespread and rapid growth, the planning and design of commercial complexes urgently require more scientific theoretical guidance to enhance spatial vitality and consumer experience.

A specific accumulation of research has been conducted on the design of commercial complexes in architecture. Although a relatively comprehensive theoretical system has been established, the specific spatial improvement strategies that can be directly applied in practice are still limited. This is because the design tasks of commercial complexes are highly complex and diverse, making it challenging to summarize the design modes and techniques in terms of guiding principles. Based on the literature summary and interviews with architects, the most

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commonly adopted design modes and techniques include the layout of anchor stores and general stores, the selection of plane form, vertical traffic organization, among others, and their application is reflected in many cases. However, most of these discussions remain at the stage of conceptual explanation and summary of experience. They discuss space from a top-down perspective, focusing on spatial forms for their own sake from the designer's viewpoint, which leads to obvious shortcomings. On the one hand, insufficient attention is paid to consumer behavior, and judgments on how consumers use space are relatively subjective, with little empirical data support based on surveys of consumer spatial behavior. On the other hand, limited by traditional research methods, there is insufficient support for quantitative analysis, lacking both the ability to simulate and predict, and the ability to use quantitative indicators to evaluate the effectiveness of design guidelines.

To address this shortcoming, existing studies have analyzed the characteristics and mechanisms of customers' use of commercial space through quantitative methods from the consumer's perspective. Among them, space syntax is the primary quantitative method, which is often used to analyze the topological structure of various commercial spaces, measure spatial quality using indicators such as depth, integration, connectivity, and visual accessibility, and establish its statistical relationship with passenger flow through correlation or regression analysis.[1-6] Some scholars also use spatial interaction models to analyze the flow of consumers between different commercial locations, and believe that the volume of flow is positively correlated with the attractiveness of the destination and negatively correlated with the distance impedance between the two locations. Specific forms include gravity models [7, 8], Huff models [9], and Competing Destination Models [10, 11]. However, a common problem with these two types of methods is that they can only analyze aggregated passenger flow counts at the collective level of spatial units, but cannot study activity trajectories at the individual level. This neither fully utilizes information nor makes it easier to achieve truly meaningful simulation and prediction. In contrast, some individual-oriented studies employ discrete choice models as quantitative tools to reveal how each consumer makes destination selection decisions within their specific commercial space environment, and use these rules to simulate individual spatial behavior. In foreign countries, such research has yielded promising predictive results across various spatial scales, ranging from downtown business districts [12, 13] to approximately 100-meter-long commercial street segments [14]. In China, this approach has been successfully applied to studies of traditional commercial spaces such as East Nanjing Road in Shanghai [15], Wangfujing Street in Beijing [16], and Guanqian Street in Suzhou [17].

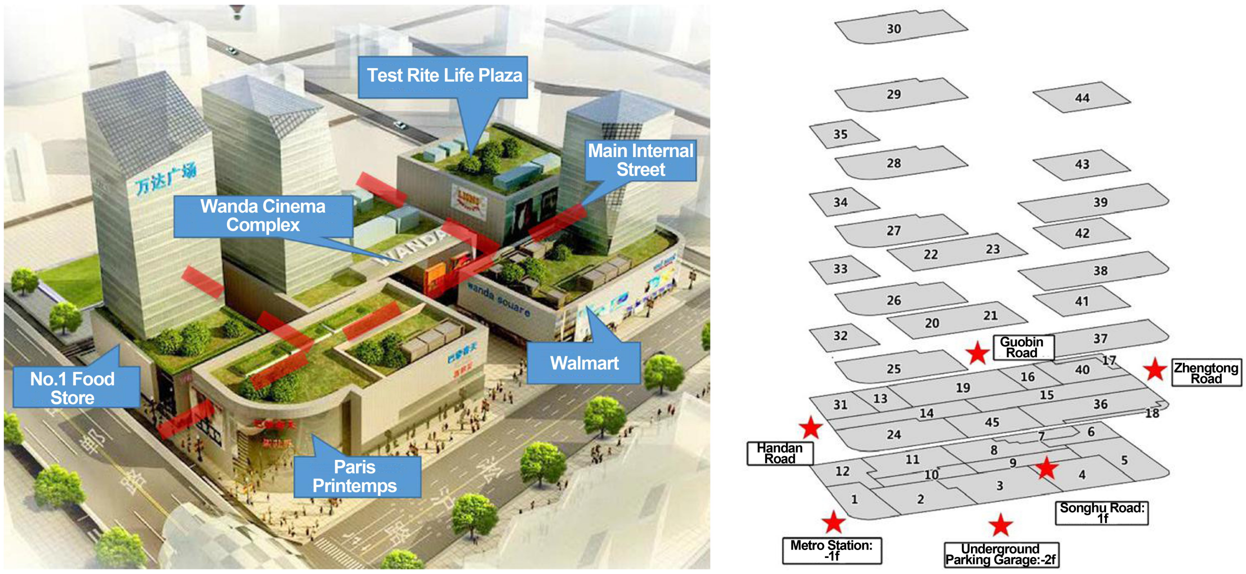
Therefore, this study will continue to adopt the above-mentioned quantitative research method, focusing on individual consumer spatial trajectories, and apply it to the emerging format of commercial complexes. Specifically, the study will construct a consumer spatial behavior model based on empirical data, and on this basis, use "general simulation" technology to predict and quantitatively compare the impact of different design techniques, so as to more scientifically demonstrate the effectiveness of various improvement strategies and provide support for design practice. It is worth noting that although the data of this study come from a specific case, the subsequent analysis will extend beyond this specific case. The "general simulation" adopted is precisely designed to explore the general rules of commercial complex design and make the results more universally applicable.

1 Data and methods

1.1 Data collection

Taking Wanda Plaza in Wujiaochang, Shanghai, as a case study, this research collected consumer spatial behavior data through a questionnaire survey conducted in May 2014. A total of 323 valid samples were obtained. Wanda Plaza in Wujiaochang comprises five buildings, internal and external streets on the ground level, and underground spaces, which are divided into 45 spatial units (Figure 1). The respondents were asked to recall their complete activity trajectory in Wanda Plaza in Wujiaochang that day. Each trajectory recorded the sequence of stops along with information such as the spatial unit, time, type of activity, whether it was planned in advance, and the amount of expenditure.

In terms of sample composition, the gender ratio was 38% male to 62% female, with a majority of respondents (61%) under the age of 30. Most participants were either corporate employees (54%) or students (23%). These demographic characteristics are broadly representative of the consumer population in such commercial settings.



a. Space composition　　b. Spatial units and main entrances

Figure 1　Case study: Wanda Plaza in Wujiaochang, Shanghai

1.2　Research methods

The primary methods used in this study are discrete choice modeling and individual spatial behavior simulation. Discrete choice models are used to reveal the mechanisms underlying consumers' spatial behavior. On this basis, spatial behavior simulation can predict consumers' activity processes in a specific spatial environment.

As the name suggests, discrete choice models are used to explain choice data. The study divides the activity trajectory intoa series of continuous choices: after a stay activity is completed, consumers choose one of 45 spatial units as the destination for the next activity, or select a special option—"Leave (Wanda)"—to mark the end of the trajectory. In this way, 1767 choices were generated for the 323 activity traces, each with 46 options. In a choice, each option *i* will bring a certain utility U_{ni} to consumer *n*, this utility includes two parts: systematic and random. Systematic Utility V_{ni} can be explained by a series of independent variables (x_{ni1}, x_{ni2}, $\cdots$ x_{nik}). For the spatial unit options, these explanatory variables include functional attractiveness and spatial impedance; while for the leave option, they are mainly indicators of consumers' previous cumulative activities. Random error ε_{ni} represents the impact of factors not included in the model and measurement errors, as shown in the following formula, where $b_1 \sim b_k$ are the preference coefficient of each explanatory variable, reflecting the consumer's spatial behavior mechanism.

$$U_{ni} = V_{ni} + \varepsilon_{ni} = b_1 x_{ni1} + b_2 x_{ni2} + \cdots + b_k x_{nik} + \varepsilon_{ni}$$

According to the principle of discrete choice models, consumers will choose the option with the highest utility U_{ni}, but due to the uncertainty of random errors, this will be a choice probability P_{ni}. This research employs the classic Logit model, and the following formula can be used to calculate Pni in a straightforward manner.

$$Pni = \exp(V_{ni}) / \sum_j \exp(V_{nj}) = \exp(b_1 x_{ni1} + b_2 x_{ni2} + \cdots + b_k x_{nik}) / \sum_j \exp(b_1 x_{nj1} + b_2 x_{nj2} + \cdots + b_k x_{nj})$$

For a given set of choice data, the Logit model estimates the optimal values of $b_1 \sim b_k$, such that the choice probabilities computed by the model for the selected options are maximized. On the one hand, these estimation results can provide a quantitative explanation of the relative importance of various environmental factors. On the other hand, they provide predictive capabilities at the individual level: calculating the probability of consumers choosing each option in a new scenario.

On this basis, the study employed the Monte Carlo method to convert probabilities into specific selection results through random sampling, simulating the occurrence process of actual events. For example, if the probabilities of choosing two options A and B are 0.7 and 0.3, respectively, then a uniformly distributed random number can be drawn in the interval of 0~ 1. If the number is exactly less than 0.7, A will be chosen; otherwise, B will be chosen. Although the outcome of each choice is uncertain, the chance of each option being selected conforms to the preset probability distribution. In this research, the distribution is provided by the Logit model, and the Monte Carlo simulation will continuously generate the consumer's next choice results until he chooses "leave". The individual trajectories obtained in this way will be used for further analysis, such as summarizing the passenger flow distribution in each unit and calculating the average number of consumer activities.

To explore the general rules in the planning and design of commercial complexes in more depth and make the research findings more universal, this paper proposes the method of "general simulation". The term "general" refers to the fact that the scene used in the simulation is not a specific and complex real-world built environment, but a simple virtual environment abstracted according to research needs. In the virtual scene, we only focus on the environmental factors of interest and keep all other factors to the same level. The changes in the simulation results observed should be attributed solely to the above-mentioned factors of interest.

2 Consumer spatial behavior model

Thisresearch uses the following variables in the discrete choice model to explain consumers' spatial behavior: (1) functional factors, including the business area of the spatial unit and consumers' familiarity with the unit; (2) spatial factors, including the distance between units, adjacency, and whether backtracking is required. These factors include both horizontal and vertical dimensions. In addition, floor levels are also included in the model as dummy variables; (3) factors related to the "leave" option, mainly the cumulative number of activities and distance; (4) other factors, such as time, whether the activity was planned, individual attributes, etc.

Table 1 Estimation results of the discrete choice model

Variable	Coefficient	P-value
Business area (m^2)	0.000 15	< 0.001
Familiarity[1)]	1.318	< 0.001
Planedistance (m)	−0.126	< 0.001
Vertical distance (layer)	−0.226	< 0.001
Plane adjacency (1-yes, 0-no)	0.149	0.147
Vertically adjacency (1-yes, 0-no)	0.336	< 0.001
Plane backtracking (1-yes, 0-no)	−0.653	< 0.001
Vertical backtracking (1-yes, 0-no)	−0.684	< 0.001
Cumulative number of activities	0.243	< 0.001
Cumulative plane distance (m)	0.008	< 0.001
Cumulative vertical distance (layer)	0.092	< 0.001

Table 1 presents the estimation results for some variables that will play a key role in the simulation. The model demonstratesa good fit, with $R^2 = 0.26$ (McFadden). All variables are statistically significant at the 1% level, except for plane adjacency. From the sign of the coefficient, we can see that consumers prefer spatial units that are large in area, highly familiar, close in distance, and do not require backtracking. As the cumulative number of activities and distance increase, the probability that consumers choose to leave rather than continue further activities increases. These findings are consistent with expectations.

3 Simulation of spatial improvement strategies

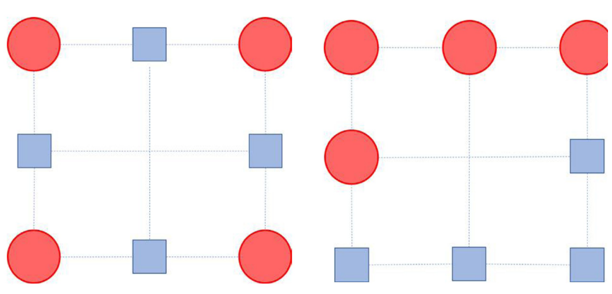
Building on the results of the behavioral model presented in the previous section, this section constructs comparable virtual scenes. It simulates passenger flow distribution based on common spatial layout modes and techniques used in commercial complex design practice. The effects of these design strategies are quantitatively analyzed by comparing the simulation results.

3.1 The relationship between anchor stores and general stores

The design theory of commercial complexes has extensively explored the relationship between anchor stores and general stores, and has formed a widely recognized layout mode: anchor stores arestrategically located at opposite ends to play an anchoring role in guiding customer flow, and general stores are lined along both sides of the pedestrian street corridor connecting the anchor stores, forming a dumbbell-shaped structure.[18-21] Scholars believe that the strong appeal of anchor stores makes consumers willing to walk longer distances. When people pass by general stores on the way to anchor stores, the customer flow of general stores can be increased, thus balancing the distribution of customer flow.

To test the effect of this mode, the research set up two virtual scenes, as shown in Figure 2. The left picture is laid out according to this mode; the right picture reverses the arrangement, with the anchor stores and general stores separately arranged in a centralized manner. The business area of each anchor store in both scenarios is assumed to be 10,000 m^2, while that of each general store is set at 5000 m^2; the familiarity of each anchor store is set to 1, while that of the general store is set to 0. Due to the same spatial layout, the spatial elements such as distance, adjacency, and backtracking are the same. In summary, the differences in consumer behavior between the two scenarios stem from the varying location relationships between anchor stores and general stores.

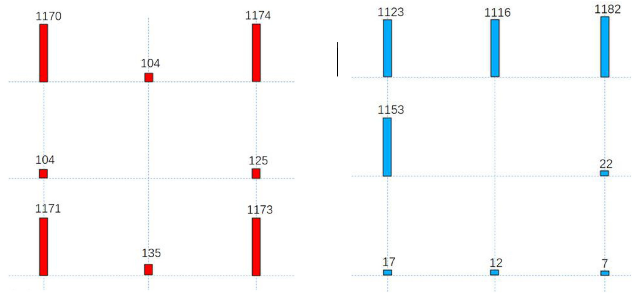
Two scenarios were simulated, respectively, with 1,000 consumers. Each consumer randomly chose two of the four anchor stores as their planned stores. Other anchor stores and all general stores were not included in the plan. Each store is regarded as a spatial unit, and both scenarios have eight units. The average results after 200 simulations are shown in Figure 3. The numbers marked in the figure are the simulated number of visitors for each store. It can be observed that the customer flow distribution patterns in the two scenarios closely align with the distribution patterns of anchor stores and general stores. Anchor stores have a larger customer flow, while general stores have a smaller customer flow.



a. Anchor stores are scattered, and general stores are located on their connecting corridors.

b. Anchor stores and general stores are concentrated separately.

Figure 2 Scenario setting: Layout relationship between anchor stores and general stores anchor store general store



a. Anchor stores are scattered, and general stores are located on their connecting corridors.

b. Anchor stores and general stores are concentrated separately.

Figure 3 Simulation results: Spatial relationship between anchor stores and general stores

The summarized simulation results (Table 2) reveal significant differences in the customer flow distribution of anchor stores and general stores between the two scenarios. The average number of visitors to each anchor store in scenario (a) is slightly higher than that in scenario (b). On the other hand, the average number of visitors to each general store in scenario (a) is significantly higher than that in scenario (b), with a 680% increase. Accordingly, the total customer flow of the eight stores in scenario (a) is also significantly higher than that in scenario (b), with an increase of 11%. It can be seen that the dumbbell-shaped layout model exerts a strong positive effect on general stores, generating a large amount of induced customer flow. Obviously, the increase in customer flow of general stores is due to their special location advantages: in scenario (a), the distance between general stores and anchor stores is closer, and there are more adjacent anchor stores. Therefore, when a large number of consumers attracted by anchor stores choose the next destination, the general stores in scenario (a) are more likely to be selected than those in scenario (b). Considering the impact of planning, when consumers go from one planned store to another, the general store in scenario (a) is more likely to become a stopover point, making its location more advantageous.

Utilizing the relationship between anchor stores and general stores to increase customer flow tothe latter is of vital importance to the comprehensive development of commercial complexes. On the one hand, due to the limited functional appeal of general stores, they are more reliant on external customer traffic. When the external driving force is insufficient, general stores have far weaker risk tolerance and adaptability than anchor stores. Attracting a sufficient amount of customer traffic to general stores is of great significance to their active operations and has become an indispensable condition for their survival. On the other hand, existing research on rent distribution in commercial complexes shows that anchor stores typically pay low rent per unit area, while general stores serve as the primary contributors to overall rental income.[18, 20, 22-25] Since the rent of general stores is closely tied to their customer flow, [26, 27] attracting more consumers to these stores via high-attractiveness anchor stores can increase their customer flow, thereby enhancing the overall rental revenue of the commercial complex through the prosperity of general stores. To sum up, this dumbbell-shaped layout pattern is an effective stragegy and should be actively applied in design.

Table 2 Characteristic indicators of simulation results: Spatial relationship between anchor stores and general stores

	Scenario (a): Anchor stores are scattered, and general stores are in the middle	Scenario (b): Anchor stores and general stores are concentrated separately	Compare: Scenario (b) → Scenario (a)
Total number of stays	5 155	4 633	11% increase
Average number of visitors to anchor stores	1 172	1 144	2% increase
Average number of visitors to general stores	117	15	680% increase

3.2 Plane form: Linear and block

Plane form is a key concern in commercial space planning and design, and it is of decisive significance to the organization of the dynamic line of passenger flow. The research summarizes the plane forms of commercial complexes into two basic forms: linear and block. The former is similar to a traditional commercial street, with a strong orientation and a long circulation path; the latter has no clear orientation, and the dynamic line of passenger flow mainly forms a circular loop. Existing studies have not reached a clear conclusion on the choice between the two forms; however, most studies point out that certain restrictions should be placed on linear planes. For example, some scholars [21, 28, 29] have suggested limits on desirable length for interior shopping streets and have shown a preference for zigzag or curved spatial forms. A case study in Japan found that linear layouts often result in excessive distances between core stores, leading to poor customer return flow. In contrast, ring-shaped layouts reduce the distance between anchor stores and are more conducive to return flow [30].

In this regard, this research set up the virtual scenarios shown in Figure 4: the units in scenario (a) are arranged in a straight line at intervals of 80m, while scenarios (b, c) are arranged at the four corners of a square with a side length of 80m, representing the most linear and the most block-like plane forms respectively. The difference between scenarios (b) and (c) is that the former does not limit the specific path between any two units, and its prototype is an outdoor open space with a high degree of freedom; the latter defines fixed walking paths that consumers can move along, representing a more enclosed space such as an indoor atrium and underground space. The units in the three scenarios are completely homogeneous in terms of functionality, so all the differences in the simulation results are due only to the different plane forms.

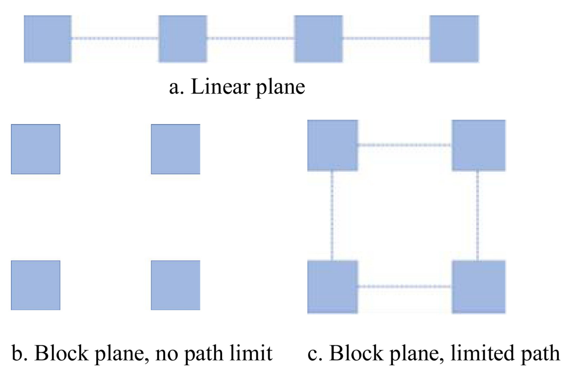
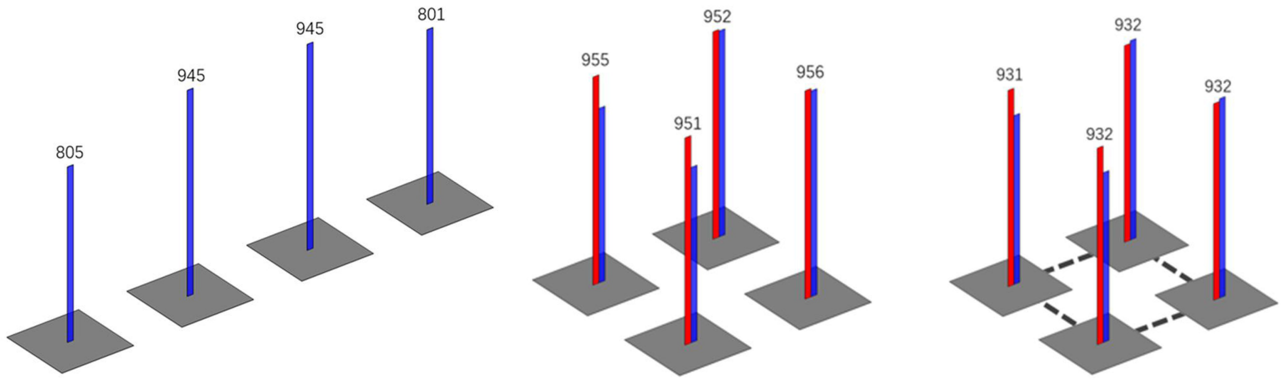


Figure 4 Scenario setting: The plane form and dynamic line of passenger flow of the commercial complex

The above three scenarios were simulated separately with 1000 people, and the results are shown in Figure 5. It can be observed that under the linear plane, the customer flow distribution shows a "less-at-ends, more-in-the-middle" pattern.2) This is due to the difference in location conditions between the edge and the center. In contrast, the locations of the four units in the block plane are equivalent, making their passenger flows almost the same, and the distribution balance is better than that of the linear plane. On the other hand, in Figure 5 (b, c), the height of the red columns in two units (representing the passenger flow under the block plane scheme) is significantly higher than the height of the blue columns (representing the passenger flow under the linear plane scheme, for comparison), while the height of the other two units is the same. This indicates that, given the same number of simulated consumers, the total number of activities under the block plane scheme is higher than that under the linear plane scheme, and the return flow is more effective.



a. Linear plane b. Block plane, no path limit c. Block plane, limited path

Figure 5 Simulation results: Plane form and dynamic line of passenger flow of the commercial complex

The above virtual scene simulation can also be easily extended to more units. Table 3 summarizes thekey indicators from the simulation results of 4, 6, and 8 units. Among them, the Spatial Gini Coefficient reflects the balance of the spatial distribution of passenger flow, with a value ranging from 0 to 1. The lower the value, the more balanced the distribution. It can be seen that the number of activities per person on the linear plane is always the lowest, meaning that the same number of consumers generates the least total stay activities and the worst return flow, which to a certain extent supports the view that "block planes can attract popularity". On the other hand, the Spatial Gini Coefficient of block planes is consistently the lowest, indicating a more balanced distribution of passenger flow.

Table 3 Characteristic indicators of simulation results: Linear and block plane forms

	4 units		6 units		8 units	
	Average number of activities	Spatial Gini Coefficient	Average number of activities	Spatial Gini Coefficient	Average number of activities	Spatial Gini Coefficient
Linear plane	3.496	0.041	3.606	0.061	3.650	0.061
Block plane, no path limit	3.814	0.001	4.027	0.033	3.951	0.026
Block plane, limited path	3.726	< 0.001	3.908	0.032	3.824	0.013

The main factors that determine the differences in the above simulation results are spatial variables such as plane distance and plane backtracking.An analysis of average inter-unit distances shows that units at both ends of the linear plane are significantly farther apart than those in the block plane. Additionally, the possibility of triggering backtracking in all units on the linear plane is higher than that on the block plane. Since distance and backtracking both show negative effects in the behavior model, the utility of the units in the block plane is relatively higher. This gives block layouts a greater advantage in the competition against the "leave" option, retaining more consumers to continue the activity, thus improving the return flow. On the other hand, the horizontal distribution of the aforementioned spatial elements in the block plane is more even, resulting in a more balanced distribution of passenger flow.

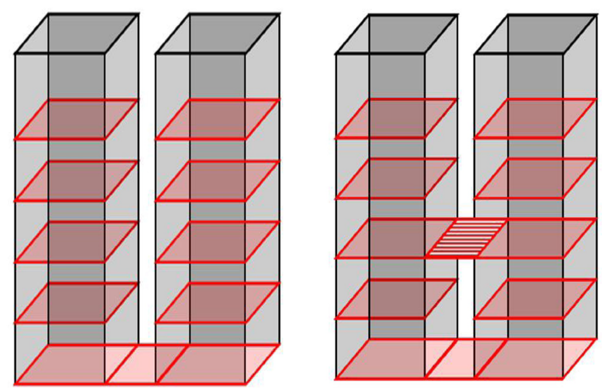
Although the simulation results in this section are more favorable to block planes, linear planes also have their advantages. For example, their simple spatial structure isintuitive and their clear sense of direction is conducive to wayfinding, which is consistent with consumers' image of traditional street space. These cognitive aspects were not incorporated into the model and, therefore, could not be reflected in the behavior simulation. In summary, the design should reflect actual conditions and prioritize block planes when appropriate. When adopting a linear layout, the distance and backtracking problems that long straight passenger flow routes may cause should be fully considered to avoid adverse effects on return flow and passenger flow balance.

3.3 Vertical network connection

In multi-story, multi-building commercial complexes, buildingsare often connected only through the ground floor or underground space. When consumers want to travel from the upper floor of one building to the upper floor of another, they must go through this intermediate level, resulting in reduced convenience and efficiency. This universal problem of upper-level connections is also reflected in this case study of Wanda Plaza in Wujiaochang.[31] Wang Zhendong et al. classified the vertical spatial structure of commercial complexes as tree-shaped and network-shaped structures. They found that, compared to the tree-shaped structure, the network-shaped structure results in greater passenger flow and more uniform passenger flow distribution.[32] A multi-story, multi-building commercial complex connected only by the ground floor is a typical tree-shaped vertical space structure, and adding upper corridors is the most direct way to form a networked connection.

This section examines how the upper corridor, as a vertical network connection, affect consumer behavior. For this purpose, the study establishes the virtual scenarios depicted in Figure 6. Figure (a) and Figure (b) are two 5-story buildings. The only difference between the two is that the former has no corridor, while the latter has a corridor on the 3rd floor to facilitate movement between upper floors. Each floor of each building is a spatial unit with a business area of 3000 m^2. The plane distance between the two buildings is set to 80m.

The above two scenarios are simulated separately using a population of 1000 people. The passenger flow distribution results are shown in Figure 7.The results show that adding a corridor increases the number of stay activities in all 10 units to varying degrees, with the highest increase in the two units located on the 3rd floor, where the corridor is located. The average number of activities per person increases from 4.15 (no corridor) to 4.27 (with corridor). This translates to more than 100 additional activities generated by 1000 consumers, and its value to the commercial complex is self-evident. On the other hand, the spatial distribution Gini coefficient of passenger flow in the scenario without corridors is 0.092, while it drops to 0.086 in the scenario with corridors. Therefore, the setting of corridors can not only improve return flow but also balance the passenger flow distribution to a certain extent. In addition, the research constructed and simulated more scenarios, including adding corridors on different floors and adding multiple corridors. The results show that various corridor settings can improve return flow and balance passenger flow distribution. While the effect improves with more corridors, a noticeable trend of diminishing marginal effect is observed.



a. No corridor b. With corridors

Figure 6 Scenario setting: The upper corridor as a vertical network connection

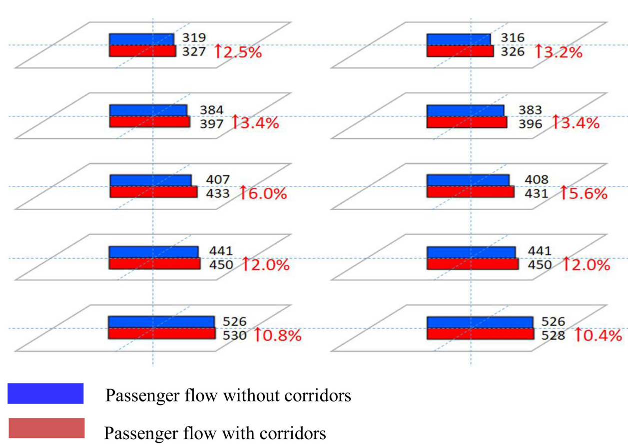


Figure 7 Simulation results: The upper corridor as a vertical network connection

The determining factorbehind the above simulation results is the vertical spatial element. Figure 8 analyzes the vertical distance between every two units and the occurrences of vertical backtracking among every set of three units, before and after the corridor is set up. Calculations indicate that for the scenario depicted in Figure 6, the corridor can reduce the total vertical distance by 34%, thereby decreasing the theoretical possibility of vertical backtracking from 55% to 38%. These changes will enhance the overall utility of the spatial unit, thereby reducing the likelihood of consumers choosing to "leave" and increasing the probability of return visits. On the other hand, the upper floors of the corridor (3rd to 5th floors) benefit more than the lower floors (1st to 2nd floors), and the former is precisely the area with an unfavorable location and relatively small passenger flow, thus playing a role in balancing the passenger flow. In addition, the marginal diminishing trend of corridor benefits can also be explained by the above method. For example, in two seven-story buildings, the total vertical distance between each two units is 406 floors without any corridor. The installation of the first corridor can reduce it by at most 152 floors, and adding a second corridor can only lower it by 16 floors, while the 3rd to 6th corridors can only lower it by two floors each.

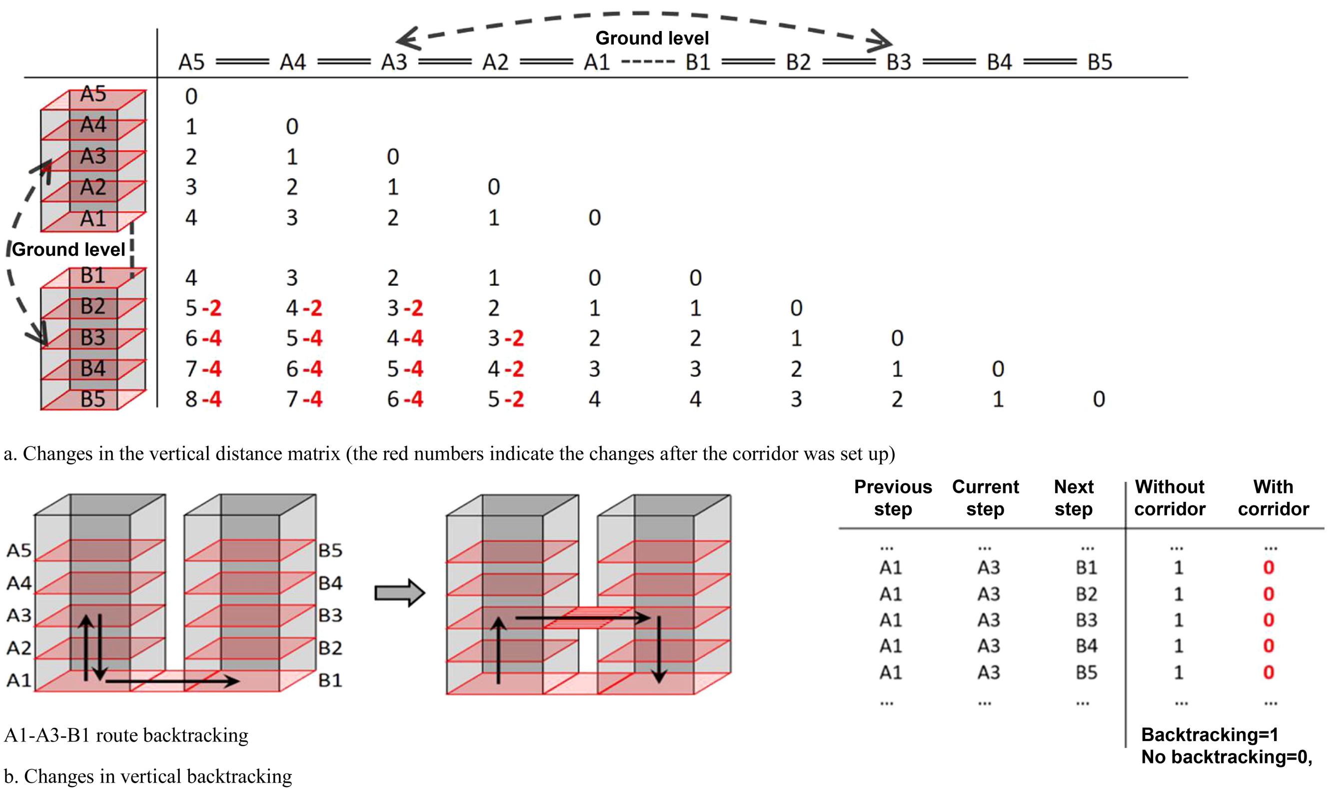


Figure 8 Changes in vertical spatial elements before and after the upper corridor was set up

These corridor effect and diminishing returns closely resemble the characteristics of small world networks [33] proposed by Watts et al. Upper corridors of the commercial complex help transform the originally closed and isolated vertical spatial network into a small world. Although the network density remains low, it can already achieve a good connection effect. In summary, setting up upper corridors in multi-story, multi-building commercial complexes can achieve the convenience of a small world network through limited vertical network connections, thereby improving return flow, increasing vitality, and balancing passenger flow distribution to some extent. It is an effective spatial improvement measure. However, its benefits exhibit clear marginal diminishing returns. Considering the construction cost of the corridor itself, only a limited number of corridors should be added according to the number of vertical floors.

3.4 Entrance settings

The above simulations do not account for entrances; that is, it is assumed that consumers can enter from any location. When using space syntax to evaluate the value of spatial location, the influence of entrances is often ignored, which is inappropriate. In reality, entrances are the entry points for external passenger flow into commercial complexes. Their locations and the volume of incoming passenger flow directly determine the accessibility of the internal space and the distribution of stay activities. Taking Wanda Plaza in Wujiaochang as an example in this research, the heavy passenger flow at the Wujiaochang subway station entrance has a significant impact on the internal spatial location differentiation within the complex. To improve accessibility in less favorable locations, Wanda also added a new entrance to Jiangwan Stadium Station on the opposite side of the existing entrance (Figure 9). This approach, which involves setting up entrances at opposite ends and balancing the inflow between them, is vividly referred to as "passenger flow compression" by some designers. Similar cases can also be observed in Daning International Plaza in Shanghai, which is adjacent to Yanchang Road Metro Station and Circus City Metro Station on the north and south sides, respectively. In addition to being applied to plane layouts, this approach is also applied to vertical space. Since most entrances are located on the ground floor or underground, upper floors tend to have poorer accessibility, and the passenger flow of commercial complexes often decreases with height. In response to this, some commercial complexes have attempted to attract external passenger traffic directly to the upper floors. For example, Bailian Xijiao Shopping Mall and Global Harbor in Shanghai offer rooftop parking, while Dragon Dream Mall in Hongkou features direct metro access to its third and fourth floors.

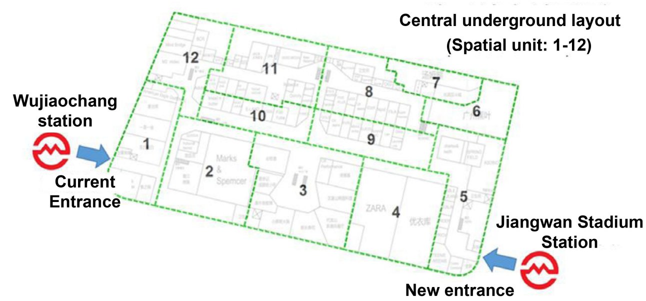
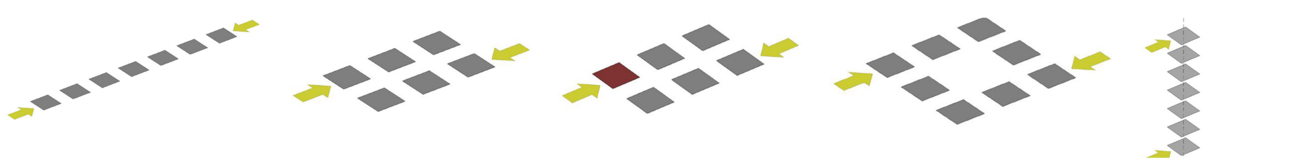


Figure 9 "Customer flow compression" at Wanda Plaza in Wujiaochang

This section focuses on the impact of entrance settings on passenger flow distribution in commercial complexes and the effects of "customer flow compression" measures. Simulation analyses are conducted using five virtual scenarios, as illustrated in Figure 10. Scenario (a) is a linear plane, and scenarios (b) and (d) are both block planes, with 6 and 8 small areas, respectively. All these small areas are functionally homogeneous. Scenario (c) share the same spatial form as scenario (b), but differs in functional appeal - the brown area in the upper left corner is set as the anchor store and is more familiar to consumers than other areas; all of the above scenes are horizontally developed, while scenario (e) is vertically developed, with seven floors, each floor being a unit. Each scenario has two entrances, marked by yellow arrows at the ends, to create a condition of passenger flow compression. The incoming passenger flow ratio of these two entrances can be adjusted, with settings of three scenarios — "100%:0%", "75%:25%", and "50%:50%", among which the "100%:0%" scenario is equivalent to having only one entrance.



a. Linear plane, seven units b. Block plane, six units c. Block plane, six units with different functions d. Block plane, eight units e. Vertically developed

Figure 10 Scenario setting: Initial distribution of incoming passenger flow at the entrances

Three rounds of simulation were performed for each of the five scenarios in Figure 10. Each round used a different initial passenger flow ratio at the entrance, and the number of simulated consumers was 1,000. Figure 11 shows the simulation results for scenario (a), which is the most typical scenario. When onlythe left entrance is active (100%: 0%), the passenger flow distribution shows an evident decreasing pattern—the closer a spatial unit is to the entrance, the more frequently it is visited. The gap between the highest and lowest values is enormous, resulting in a significant imbalance. When 25% of the passenger flow is introduced at the right entrance (75%: 25%), the passenger flow distribution remains unbalanced, but it has been significantly improved compared to the previous scenario. When the inflow at the right entrance is increased to match that at the left end (50% :50%), the spatial configuration become symmetrical from left to right, resulting in a more balanced distribution of customer flow. The other four scenarios also basically reflect this trend, but to varying degrees.

Table 4 Characteristic indicators of simulation results: Initial distribution of incoming passenger flow at entrances

	Spatial Gini Coefficient of passenger flow distribution			Number of activities per person		
	100% : 0%	75% : 50%	50% : 50%	100% : 0%	75% : 50%	50% : 50%
(a) Linear plane	0.40	0.20(↓50%)	0.06(↓85%)	3.63	3.64	3.64
(b) Block plane, six units	0.09	0.05(↓43%)	0.03(↓72%)	4.01	4.01	4.02
(c) Block plane, six units with different functions	0.20	0.16(↓21%)	0.12(↓38%)	4.18	4.19	4.17
(d) Block plane, eight units	0.14	0.08(↓42%)	0.05(↓65%)	3.95	3.95	3.95
(e) Vertical development	0.24	0.22(↓10%)	0.20(↓18%)	4.40	4.40	4.41

Note: The numbers in brackets indicate the reduction in the current result compared to the "100% :0%" scenario (single entrance).

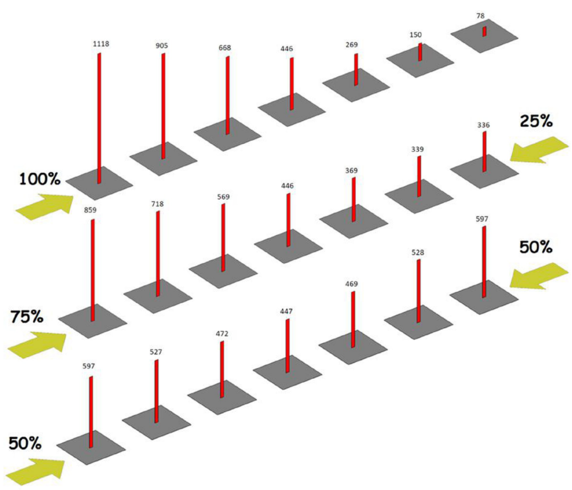


Figure 11 Simulation results: Initial distribution of incoming passenger flow at the entrance (Scenario A: Linear plane)

Table 4 summarizes the Spatial Gini Coefficient and the number of activities per person for each scenario. In each scenario, the single-entrance scenario with an initial passenger flow distribution of "100% :0%" has the highest Spatial Gini Coefficient, indicating the most unbalanced flow distribution, followed by the "75% :25%" scenario. The "50% : 50%" equal entrance passenger flow scenario has the lowest Gini coefficient and the most balanced distribution. The effects of adjusting the initial entrance flow ratio on reducing the Gini coefficient and improving the overall passenger flow balance varies across scenarios: the linear plane scenario (a) has the highest decrease and the most obvious effect, followed by the block plane with no functional difference scenario (b, d), and then the block plane with functional differences scenario (c), while the vertical layout scenario (e) has the lowest decrease and the weakest effect. On the other hand, by comparing the number of activities per person in the three rounds of simulation under each scenario, it was found that the changes were minimal, and the variance analysis showed that the differences were not significant. Therefore, this indicator was marginally affected by the adjustments to entrances. In summary, the "passenger flow compression" strategy primarily has a structural impact on the internal distribution of passenger flows.

Why are the effects of "passenger flow compression" measures so different in different scenarios? The reasons for the uneven distribution of passenger flow are different. For the scenarios (a, b, d), the imbalance mainly stems from the relative proximity of each unit to the entrances. In this case, adjusting the entrances can help reduce the differences, thereby achieving a more balanced passenger flow. Among them, scenario (a) is a linear plane, and the degree of imbalance before adjustment is significant, with the most pronounced effect. The scenarios (b, d) are block planes, and the degree of imbalance before adjustment is not large, so the effect is not as obvious as (a). Scenarios (c, e) are different. In addition to the relative location differences mentioned above, there are absolute differences in functional attractiveness in scenario (c) and absolute location differences between different floors in scenario (e). Here, "absolute" refers to differences that are independent of entrance placement. Even if the entrance settings are changed, they will remain unaffected. In these scenarios, the effect of entrance optimization is not ideal. Although the Spatial Gini Coefficient has also decreased, the imbalance after adjustment is still very high.

In summary, the location of entrances and the volume of incoming passenger flow have a significant impact on the spatial layout and distribution of passenger flow within the commercial complex. In design practice, setting up new entrances at unfavorable locations and introducing a certain amount of passenger flow can have a positive effect on the balanced distribution of overall passenger flow within the commercial complex. The so-called "passenger flow compression" is of practical significance. However, it should be noted that the mechanism of this effect is to reduce the location differences of each internal space relative to the entrances. When the existing imbalance is mainly caused by relative location differences, better results can be achieved. On the contrary, if it is primarily caused by other reasons, such as functional appeal or an unchangeable absolute location (like the floor), the improvement effect will be relatively limited. In addition, the simulation analysis in this section once again demonstrates the advantages of the block plane form, as it can better address the issue of passenger flow imbalance in commercial complexes resulting from the location of entrances and the initial distribution of passenger flow.

Conclusion

The design of a commercial complex is a systematic project that requires guidance from scientific design theory. In response to the problems of a lack of bottom-up empirical analysis and insufficient support of quantitative methods in existing studies, this paper collects consumers' spatial behavior data from the perspective of micro-individuals. A behavioral model is estimated for simulation and prediction. On this basis, the study conducted a quantitative analysis of the effects of four spatial layout modes and techniques for common commercial complexes through the "general simulation" method, and obtained the following conclusions:

(1) The dumbbell-shaped layout, with anchor stores dispersed at the end and general stores located on the corridors connecting them, can improve the overall return flow, especially by providing significant customer flow support to general stores with high rents. This is the layout method that should be adopted.

(2)Compared with linear planes, the block form has a higher number of activities per person, a more balanced passenger flow distribution, and can better deal with the problem of uneven passenger flow distribution at entrances.

(3)For the vertical network connections between multiple buildings, establishing corridors can significantly increase the number of activities, improve return flow, and balance the distribution of passenger flow. Although the effects increase with the number of corridors, it exhibits clear diminishing marginal effects.

(4) The location of entrances and the volume of incoming passenger flow have a significant impact on the distribution of passenger flow within the commercial complex. When the distribution is unbalanced, introducing new entrances at previously unfavorable locations and implementing "passenger flow compression" can help balance passenger flow; however, the degree of improvement varies with specific spatial conditions.

(5) The "general simulation" approach controls for other factors to isolate specific differences and can serve as a useful tool for exploring generalizable design principle in the future.

Sources of figures and tables

The figures and tables in this article are drawn by the author.

Notes

1) In the survey, respondents were asked to name the 10 stores with which they were most familiar. After all data were aggregated into spatialunits, the ratio of the total count in each unit to the number of respondents was the familiarity level.

2) The impact of entrances is not considered here, and the consumer's first step will be to select a unit randomly.

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