Research on the correlation between pedestrian density and street spatial characteristics of commercial blocks in downtown area: a case study on Shanghai Tianzifang

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ABSTRACT
Taking Shanghai Tianzifang as an example, this study attempted to utilize theories, such as the Space Syntax Theory, to build a multivariate model with street spatial characteristics as variables, and investigate the correlation between street spatial characteristics and pedestrian density in commercial blocks using multivariate regression analyses of the variables in this model. First, in terms of commercial use characteristics, this study examined how pedestrian density is affected by three variables: store density, over flow ratio of store-front space, and density of building exits and entrances. Next, in terms of structural characteristics, this study probed the relationship between commercial pedestrian density and three other variables: street integration, height of buildings on both sides of the streets, and the stores’ distance from block entrances. Last, a multivariate regression analysis was conducted on the research data of the six variables. The results validated that four of the variables are correlated with commercial pedestrian density, in the order of their degree of influence: street integration, store density, density of building exits and entrances, and height of buildings on both sides of the streets.

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1. Introduction
1.1. Research background and purpose
Compared to large-scale urban commercial complexes, traditional commercial blocks in a city center attract enormous crowds because of their own numerous features. Commercial crowdedness is a key indicator of business development. Commercial pedestrian density formed in a specific commercial block is influenced by multiple factors.

During the process of being remodeled from a residential to a commercial block in the past decades and because of its inherent lilong street spatial structure, the Tianzifang Lilong S has reached a state where the old and the new street spaces coexist. This study separated the characteristics of a symbiotic old and new street space into two: commercial use, as represented by three variables, namely, store density, over flow ratio of store-front space, and density of building exits and entrances; and structural, as represented by another three variables, namely, height of buildings on both sides of the streets, street integration, and the stores’ distance from block entrances. Although new commercial features are ever-changing, the structural characteristics of street space, similar to genes, are relatively stable. This study attempted to build a multivariate analysis model between pedestrian density and these six variables, by investigating...
quantitatively each variable, and conducted a multivariate regression analysis of the quantified variables to explore patterns and relationships between the street spatial characteristics of lilong blocks and commercial pedestrian density. This study hopes to provide insights regarding the future development of similar open commercial blocks.

1.2. Past research

This study is a basic research on the relationship between the spatial configuration of urban neighborhoods and human behaviors. Several previous studies have utilized the quantitative analysis method to examine the relationship between the street spatial characteristics and human behaviors, such as commercial, residential, and even criminal behaviors.

Among previous studies on commercial behaviors is Park et al.’s (2012) examination of the constituent factors of vibrancy in a commercial area; they found a positive correlation between commercial vibrancy and the relevant elements of pedestrian space; and a negative one between vibrancy and the relevant elements of parking space that obstructs pedestrian space. Meanwhile, Suzuki et al. (2014) investigated the aggregations of commercial facilities near stations and extracted store density, street integration, and distance from station as three variables of street spatial characteristics. Bai (2018) analyzed pedestrian space, extracted the factors stimulating merchandise streets, and performed a quantitative univariate regression analysis on stores, parking lots, and public facilities. Takahashi et al. (2005) analyzed and explored mainly the relationship between store density and specific pedestrian features, as well as the exclusive behaviors of visitors.

Concerning residential behaviors, Yoshihara, Tanaka, and Inachi (2016) focused on the connection between the amount of resident activity and characteristics of physical environment as well as evaluations on the neighborhood impressions of streets packed with wooden structures. Their conclusions were based on a multivariate regression analysis.

Regarding other studies on the relationship between human behaviors and street space, Zeng, Mao, and Huang (2014) studied the street grid structure and criminal incidents, including robbery, snatch, and theft cases, and adopted the space syntax theory to analyze the connection between the characteristics (eg, intelligibility) of street space and crime rate.

By drawing on the findings of the studies mentioned above, this study attempted to build a model that investigates the relationship between the street spatial characteristics of open commercial neighborhoods and pedestrian density to answer the following questions: What are the variables through which street spatial characteristics influence human behaviors, that is, specifically pedestrian density in this study, and to what extent do they impact pedestrian density? This study employed the space syntax software, Depthmap, to administer an axial analysis and calculated the integration of Tianzifang Lilong Block. Meanwhile, SPSS (Statistical Product and Service Solutions) was used to analyze the association of six variables of street spatial characteristics and to apply a multiple linear regression model, so as to determine the correlation and degree of influence between street spatial characteristics and pedestrian density.

2. Research overview

2.1. Overview of research target place

Tianzifang is a lilong block, a State-Level 3A Tourist Destination, located north of Taikang Road in Luwan District (now Huangpu District) of Shanghai. In 1930, the first batch of residential buildings, named Zhichengfang, was completed. Tianzifang has embarked on a cultural, artistic journey since 1998 when the artist Yifei Chen first moved to and established his studio in Tianzifang, which, in turn, prompted the transformation of lilong buildings into studios and stores. Because of its prominence brought by the art industry, Tianzifang attracts a multitude of art shops and, eventually, grows into its present form as an inclusive neighborhood of culture, art, and commerce.

The structure of Tianzifang Block has a typical, hierarchical Shanghai lilong feature that progresses from a main lane, to sub-lanes, and, finally, to residences. In this type of spatial structure, areas of the main lane, sub-lanes, and residences interconnect with one another to build the entire block space. As indicated in Figure 1, the urban road is completely public; the main lane is a partially shared space; sub-lanes are partially private; and residences are completely private. A spatial hierarchy with progressive privacy, such as that seen in the “urban road-main lane-sub-lane-residence” order is a typical spatial characteristic of lilong.

2.2. Research methods

2.2.1. Research procedures

As shown in Figure 2, a statistical and characteristic analysis was, first, conducted on the density of commercial pedestrians in Tianzifang. Then, street space characteristics were divided into two categories, namely, commercial and structural, and were investigated accordingly. Next, variables were determined and then statistical and initial analyses were conducted. Last, conclusions were drawn by building a multivariate model and conducting a multiple linear regression analysis.
2.2.2. Selection of variables

Street integration is a fundamental quantified tool to predict the distribution of pedestrian density in a neighborhood, but it does not measure other non-planar compositional variables that affect the commercial pedestrian density. Therefore, besides street integration, this study also includes five other variables and tries to build a multivariate model to investigate the relationship between street spatial characteristics and pedestrian density, including store density, height of buildings on both sides of the streets, density of building exits and entrances, overflow ratio of alleyways occupied, and the stores’ distance from block entrances.

Figure 1. Illustration of the Hierarchical Structure of Lilong Block.

Figure 2. Illustration of the Research Procedures and Selection of Variables.
Figure 3. A Survey Map of Tianzifang Block.

Figure 4. Illustration of the Photographic Statistical Method of the Number of Pedestrians.
3. Statistics of pedestrian density

The data on the number of pedestrians in the Tianzifang Block, as shown in Figure 3, used in this study were collected on four different days, with measurement times around 11 a.m. and 3 p.m. Regarding the statistical methodology, lilong alleyways were divided into many sections based on points of divergence; 11 people photographed and recorded these alleyways and sections simultaneously. As demonstrated in Figure 4, photographs were taken at a four-step interval. The number of all pedestrians recorded over the course of four days were summed and divided by the area of their corresponding alleyways. The resultant average of number of people was the pedestrian density of each section. The pedestrian density was calculated based on the sum of pedestrians from eight measurements, instead of the actual number of people during a given time period, to avoid the influence of specific times.

As indicated by Table 1 and Figure 5, in terms of date, more people flock the area during weekends. In terms of time, the number of people in the afternoon is about twice that in the morning. According to the distribution chart, Main Lane 274 sees the most visitors, followed by Main Lane 248; sub-lanes see fewer visitors.

Table 1. Bar Graph of the Number of Pedestrians in the Order of Investigation Dates.

| Investigation Date | Number of Commercial Pedestrians |
|--------------------|---------------------------------|
| 8/11/2016 (Thur)   | 342                             |
| 8/12/2016 (Fri)     | 216                             |
| 8/13/2016 (Sat)     | 635                             |
| 8/14/2016 (Tues)    | 886                             |

Figure 5. Distribution Chart of Pedestrian Density in Tianzifang.
4. Extraction of variables of commercial characteristics

Commercial characteristics are concerned with the new street spatial characteristics formed by remodeling residential blocks into commercial ones. Since the residential-to-commercial renovation began, small-scale stores have aggregated in the Tianzifang Block. These small-scale stores achieve their commercial remodeling through fragmentation and renovation of residences as well as the renovation and utilization of neighborhood streets. This chapter will investigate density of stores, overflow ratio of store-front space, and density of building exits and entrances.

4.1. Density of commercial stores

The fragmentation and renovation of residential buildings by a multitude of small-scale stores have changed vastly the quantity and density of buildings in Tianzifang. Approximately six types of commercializing renovation of the residences are identified in the Tianzifang Block; these are listed in Table 2.

Almost all of the bottom floors of the buildings in the Tianzifang Block are for commercial purposes, and most of the second, third, and fourth levels are used as commercial stores as well. When quantifying the store density, the concept of attenuation is introduced into the number of stores on each floor. As illustrated in Figure 6, ground floor is equivalent to 1 store; second floor, 1/2

Table 2. Partition Methods of Small-Scale Stores.

| Basic Form               | Remodeled Form                  |
|--------------------------|---------------------------------|
| Transected-Main-Lane Type| Front-and-Back-Partition Type    |
| Top-and-Bottom-Shared Type| Top-and-Bottom-Separated Type    |
| Left-Through-Right Type  | Front-Through-Back Type          |

Figure 6. Illustration of the Calculation Method of Store Density.
store; third floor, 1/4 store; nth floor, \((1/2)^{n-1}\) store, which means that store density is calculated by \(X = \Sigma_n - (1/2)^{n-1}/L^n\) (n is the floor number and L refers to the length of the building facade).

The results in Figure 7 were obtained by calculating the Tianzifang stores according to the formula 1 above.

As can be observed in Figure 7, the distribution of stores in Tianzifang follows the original structure of old residential blocks, where most stores are located in several sub-lanes, especially on the northeast side and near the entrance on the southwest side; a few of these stores are located sparsely along the main lane.

### 4.2. Density of building exits and entrances

As shown in Table 3, the internal structure of Tianzifang residences have changed after remodeling. These single buildings that were originally individually divided underwent some free fragmentation and recombination. The original independent partition system which can be seen from Wang and Chen (1987), was destroyed, thereby changing the traffic flows inside these residences to a great extent. The immense changes in the internal flows of these buildings have huge impact on the road network structure of Tianzifang. This study referred to this type of change as a change in the density of building exits and entrances.

![Figure 7. Distribution Chart of Store Density in Tianzifang.](image-url)

#### Table 3. Six Types of Remodeled Building Exits and Entrances.

| Type                        | Image                                                                 |
|-----------------------------|----------------------------------------------------------------------|
| Front-Through-Back Type     | ![Image](image-url)                                                  |
| Connected-At-Far-Ends Type  | ![Image](image-url)                                                  |
| Cut-Through-Corners Type    | ![Image](image-url)                                                  |
| Left-Through-Right Type     | ![Image](image-url)                                                  |
| Straight-To-Artery Type     | ![Image](image-url)                                                  |
| Cross-Building Type         | ![Image](image-url)                                                  |

*This equation was lifted from Takahashi et al. (2005).*
During the research process, it was found that for each store, the ratio of people coming in to and out of the main lanes and onto sub-lanes through the doorways is approximately 1:2; the ratio of people coming in to and out of the city arteries onto lilong alleyways through the doorways is around 1:3. Therefore, if the degree of influence of the doorway of a regular store on the road network is set to be 1, then the influence of a building doorway connecting to a sub-lane is assigned to be 1, and the influence of a building doorway connecting to a main lane is assigned to be 2, and that of a doorway connecting to a city artery is assigned to be 3, which leads to the results outlined in Figure 8.

Figure 8. Distribution Chart of the Density of Building Exits and Entrances.

Figure 9. Illustration of the Commercial Overflow of Store-Front Space.
4.3. Overflow ratio of store-front space

Although stores are not allowed by law to spread out commodity shelves, desks, and chairs on the sidewalks of commercial streets, it is conducive to a vibrant commercial atmosphere of that neighborhood. “Commercial overflow” is a form of positive occupancy, which privatizes a portion of the public space but not a form of claiming ownership, since the rights to own and use these alleyways belong to all residents in Tianzifang. This concept is a ubiquitous feature of stores in the Tianzifang Block as it attracts visitors and invigorates the commercial atmosphere in such way. In the Tianzifang Block, the use of store-front space is flexible. There could be, for example, desks and chairs, billboards, and commodity shelves. Such space affects pedestrian density and, on top of that, is used as a means to attract pedestrian attention. As demonstrated in Figure 9, the overflow ratio of store-front space refers to the proportion of public area being occupied by private properties in front of a store. This study quantified this behavior of commercial overflow and simulated the degree of influence of an occupied store-front space on pedestrian density. The calculation formula is as follows: overflow ratio of store-front space = projected area of objects for commercial occupancy/area of lilong streets.

As can be observed in Figure 10, in the Tianzifang Block, the commercial overflow ratio is high on the north and west side and in the southwest corner near the intersection with Taikang Road.

5. Structural characteristics of street space

This chapter presents the quantification of the influence of structural characteristics of a neighborhood space on the distribution of pedestrian density using three variables: street integration, which is a structural characteristic of the invisible planar topological relationship of streets; the height and width of streets, which are scale features that are relatively intuitive to the human cognition; and the impact of city arteries connected to Tianzifang on its pedestrian density through mainly the influence of primary and secondary block exits and entrances.

5.1. Street integration

The relationship of spatial elements is determined by their compositional structures. Space Syntax is a theoretical methodology that enables an objective, quantified analysis of space by converting a series of spatial relationships into many measurable variables and then investigating them in that way. Integration is a crucial variable in Space Syntax Theory that measures the level of spatial accessibility. In this study, integration is used as a variable to measure how the road network structure formed by urban roads, main lanes, and sub-lanes affects the flow distribution of pedestrians in Tianzifang.

The results of the axial analysis on the Tianzifang neighborhood using the software Depthmap are Figure 11.

Overflow Ratio of Store-Front Space

Figure 10. Distribution Chart of the Overflow Ratio of Store-Front Space.
The integration of sub-lanes on the south side and main lanes of Tianzifang is relatively high, indicating an elevated level of accessibility of these areas. On the west side and in the northeast corner, integration is low, indicating a low level of accessibility.
5.2. Height of buildings on both sides of the streets

The measurement and calculation method of height of buildings on both sides of the streets, by taking the average of the sum of the heights of all building facades on both sides of that street as the height of buildings on both sides of that street, is demonstrated in Figure 12. The distribution of the average height of buildings on both sides of the Tianzifang lilong streets is as shown in Figure 13.

5.3. Distance between stores and block entrances

There are four main entrances that connect the Tianzifang Block to the city's primary and secondary arteries: three on the south side, connecting to Taikang Road, a primary artery, and one connecting to Jianguo Middle Road, a secondary artery. According to statistics, the ratio of the pedestrian density in the south part of Tianzifang, south of the primary artery Taikang Road, over that in the north part of Tianzifang, south of the secondary artery Jianguo Middle Road, is approximately 3:2.

Figure 14. Illustration of the Calculated Distance Between Stores and Block Entrances.

Figure 15. Distribution Chart of the Distance from Stores to the Block Entrances.
Therefore, as indicated in Figure 14, to quantify the influence of different entrances on the pedestrian density inside Tianzifang block, the value distance from block entrances is assigned through the formula below:

Distance from Block Entrances \( L = LA \times 3 + LB \times 2 \) (LA is the store’s actual distance from the primary artery, Taikang Road; LB is its distance from the secondary artery, Jianguo Middle Road)

The distribution of the stores’ distance from block entrances is shown in Figure 15. In the central part, northeast corner, and west part of Tianzifang, the impact of city artery on pedestrian density is limited. By contrast, the pedestrian density in the south part and northwest corner of Tianzifang, near primary and secondary entrances, is influenced heavily by city arteries.

6. Multiple regression analysis

This study establishes a multiple linear regression model by setting the statistic pedestrian density across four days as the dependent variable, and store density, integration, density of building exits and entrances, overflow ratio of store-front space, height of buildings on both sides of the streets, and distance from block entrances as six independent variables. The results, as shown in Table 4, indicate that the multivariate correlation coefficient between pedestrian density and these six variables is 0.544; there is a significant correlation between the distribution of pedestrian density and store density, integration, density of building exits and entrances, and height of buildings on both sides of the streets. Moreover, the distribution of pedestrian density is positively correlated with street integration and density of building exits and entrances, and negatively correlated with store density and height of buildings on both sides of the streets. The degree of importance to the spatial elements is sorted and shown in Table 5, with store integration being 35%, store density being 27%, density of building exits and entrances being 21%, and height of buildings on both sides of the streets being 17%. The results also show that there is no significant correlation between pedestrian density and the overflow ratio of store-front space or between pedestrian density and the distance from block entrances.

7. Conclusions

This study investigated six variables that influence the commercial and structural characteristics of the street space in Tianzifang, established a multivariate regression model on the relationship between these variables and pedestrian density, confirmed that there is a correlation between street spatial characteristics of Tianzifang and the distribution density of pedestrians, and drew the following conclusions:

There is a significant correlation between the distribution of pedestrian density and store

| Table 4. Results of the Multiple Linear Regression Analysis. |
|---------------------------------------------------------------|
| Dependent Variable                                           | Pedestrian Density |
| Multiple Correlation Coefficient R²                            | 0.544              |
| Independent Variables                                        |                   |
| Store Density                                                | −2.857            |
| Integration                                                  | 3.652             |
| Density of Building Exits and Entrances                       | 2.170             |
| Overflow Ratio of Store-Front Space                          | −1.296            |
| Height of Buildings on Both Sides of the Streets              | −1.772            |
| Distance from Block Entrances                                 | −1.105            |

| Table 5. Proportions of the Degree of Influence of Each Variable. |
|------------------------------------------------------------------|
| Degree of Influence on Pedestrian Density                        |
| Store Density                                                   | 27%               |
| Integration                                                     | 35%               |
| Density of Building Exits and Entrances                          | 21%               |
| Height of Buildings on Both Sides of the Streets                 | 17%               |
density, integration, density of building exits and entrances, and height of buildings on both sides of the streets in the Tianzifang commercial block, which used to be a residential neighborhood. There is no significant relationship between the distribution of pedestrian density and the store’s occupancy rate of shared streets and its distance from block entrances.

There is a positive correlation between the distribution of pedestrian density and integration as well as the density of building exits and entrances; and a negative correlation between pedestrian and store densities. Moreover, after sorting their importance to the spatial elements, the integration was found to have the greatest influence on the distribution of pedestrian density, followed by store density. Additionally, the density of building exits and entrances alters the structure of the road network to a certain degree, which, in turn, influences the distribution of pedestrian density in the streets. Last, the height of buildings on both sides of the streets also affects the distribution of pedestrian density to a certain extent.

8. Prospect
The multivariate regression analysis used in this study verified that there is a correlation between commercial pedestrian density and four variables, namely, store density, integration, density of building exits and entrances, and height of buildings on both sides of the streets. The following points can be considered for future studies:

The majority of the neighborhoods that are converted from traditional residential areas into commercial ones have a hybrid purpose, that is, both for commerce and residence. The multivariate regression model can be diversified further if residential pedestrian density is introduced as a variable.

Future research may examine whether the traditional characteristics of neighborhoods and architectures in a traditional residential block are a significant factor influencing pedestrian density.

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