The Relation between Micro-scale Built Environment and Bicycle Related Thefts: A Case Study of Space Susceptible to Crime in Gated Communities of ZS City, China

Abstract: At present, studies of the relations between residential environment and crime have mostly taken whole communities and some larger spatial units as samples, while there are only a few studies of the relations between community's micro-scale environment with crime. The Gated community is a typical community form in Chinese cities, where walls and fences are widely used to separate the internal environment and external streets, and highly stylized buildings and landscapes are adopted in a similar layout. The spatial features of the gated community make it a suitable object to study the role of internal micro-scale environment in criminal activities. Taking a typical gated community in ZS City of China for example, the present paper has probed into the relations between its micro-scale built environment and distribution of electric-bicycle-related thefts. Through long-term observation and investigation, the authors have quantified the environmental features that are closely correlated with the daily activities of residents with Space Syntax theory. On this basis, the authors have compared the difference of environmental features, between spaces with different crime rates according to the crime distribution data from 2014 to 2017 within the community. Our research has found that the micro-scale environmental features within the gated community, such as the local integration of road network, sheltering level of the public artworks and plants, the inter-visibility conditions in the entrance to the apartment buildings, are significantly correlated with the crime rate. Meanwhile, housing/residential clusters, a spatial structure unique to gated communities in China, are characterized by more continuous spatial distribution of crime activities. Therefore, the authors have proposed that emphasis shall be laid on housing clusters of gated communities for better crime prevention and environmental transformation strategies.

Key Words: Crime, Space Syntax, CPTED, Gated Community

1 Introduction

Many studies have tried to explore the relations between environmental features of communities and crime activities, and proposed crime prevention strategies accordingly (Alexander & Martin, 2012; Cozens, Saville & Hillier, 2005; Cozens & Love, 2015; Marzbali et al.,2016). Most of the studies have built on environment-based crime prevention theories, such as Eyes on the Street theory (Jacobs, 1961), Defensible Space (Newman, 1972), Crime Prevention through Environmental Design, CPTED for short (Jeffery, 1971), and Broken Windows theory (Kelling & Wilson, 1982), with the focus on the influence of environmental features of communities on spatial perception, behavior of residents and potential criminals (Sohn, 2016; Cieślak, 2017). However, the existing studies have mostly regarded the community or more extensive urban area at large as a study area to look into the influence of community environment on crime (Sohn, 2016; Breetzke & Cohn, 2013), with only a few studies focusing on the internal areas of communities, small-scaled areas susceptible to crime and micro-scale environmental features. Here in China, gated community

is a major form of newly-built settlements in cities due to the impact of such factors as living tradition and social culture (Huang, 2006；Xu & Yang, 2009；Wang, 2010). Unlike the communities in the cities of the West, which tend to integrate with public streets, Chinese communities often use walls to separate different communities, and traffic and environmental features are discontinued between communities and streets in the cities. Those features of Chinese communities help to exclude the effect of external environment, thus making it possible to specifically study the relations between the environmental features within communities and crime. In addition, recent years have witnessed massive real estate development in China and the improvement of the gated communities' environment. Nonetheless, in terms of security, many gated communities rely on CCTV and patrols solely for crime prevention, without much attention to the role of landscape or spatial design, resulting in a scarcity of empirical studies in this regard.

Consequently, this paper has focused on a typical high-crime gated community in ZS City in the Yangtze River Delta in China in order to study the relations between its internal micro-scale environment and crime distribution. The paper attempts to develop methods to measure the environmental features on micro scale, which might be able to offer new perspectives on the research and design of this field. Given the fact that Space Syntax theory is an important tool in quantifying and analyzing spatial features, the present study perceives it as a theoretical framework. This paper has, in the first place, review the basic application of Space Syntax to the studies of crime in urban communities and elaborate on the fundamental features of gated communities in China. On this basis, the paper analyzes and discusses the relations between the spatial features within communities and crime with crime data and environmental variables in this study. In conclusion, the authors have built on the patterns found from the study to raise some crime prevention strategies for housing/residential clusters, a secondary structure of gated communities.

2 Theoretical Background

2.1 Space Syntax-based Studies of the Relations between Spatial Features of Communities and Crime

Space Syntax theory provides a quantitative method to interpret the interaction between people and built environment on different scales, and it has been widely used in the residential crime studies. The theory derives from Graph theory and Complex System theory and develops the quantitative understanding of the hidden logic and spatial relations behind the real spatial system (Hillier & Hanson, 1984). Hillier and his colleagues proposed the concept of "spatial configuration" to describe such spatial relations, including spatial components and organizational features. For spatial objects on various scales, ranging from a single room to the urban road network, corresponding spatial configuration can be extracted via partition and refinement of spatial relations included in the spatial system (Hillier, 1996). On this basis, Turner developed the software Depthmap for space modeling and rapid calculation of typical configuration variables such as connectivity, integration and choice in Space Syntax theory (Turner, 2004). Starting from the analysis of spatial configuration, lots of scholars have expanded the application of Space Syntax in the crime studies in the environment of community, and the potential relation between accessibility and visibility with criminal activities have been the common focuses.

- Accessibility

Accessibility plays a critical role in crime research in community environment. The accessibility of roads within communities has been found likely to be associated with the routes chosen by the criminals for crime commitment and escape; therefore, it has been a significant strategy to control the highly-frequented roads and access for crime prevention (Newman, 1972). As for Space Syntax, axial analysis (Hillier, 1996; Turner, 2004) and segment analysis (Turner, 2007) have been widely used to the study of relations between accessibility and crime. The majority of the studies have centered on the configurational features of road networks in communities, looking into the inherent relations between such variables as the integration and choice of road networks and distribution of criminal activities. On the one hand, Hillier (1988) studied London, revealing quite early that burglaries took place in areas with relatively lower integration of road networks, i.e., relatively isolated places. On such a basis, Shu (2000) tried to probe into the relations between accessibility of community layout and susceptibility to property crime, such as theft, demonstrating that criminal activities tended to be concentrated in space with relatively lower integration or isolation, such as cul-de-sac, in low-and-middle-income communities. On the other hand, space with higher integration is also likely to gather criminal activities. For instance, Baran, Smith and Toker (2007) studied the correlations between four types of crime, namely theft, robbery, burglary and auto theft, and factors, such as variables of Space Syntax and types of land use. It is found that the overall integration and the above-mentioned four types of crime, and other analysis variables, were positively correlated respectively, indicating that high-crime areas were also the center of public activities in communities. Besides, Nubani and Wineman (2005) concluded that local integration and crime rate were positively correlated, believing that the highly-convenient roads for residents also made it easier for criminals to escape. Moreover, Matijosaitiene (2016) conducted a study in New Haven before coming to a conclusion that auto thefts were correlated with connectivity and depth, while in Kaunas, such a crime was related to integration and depth, highlighting that the relations between accessibility and criminal activities varied from place to place. The above-mentioned researches have noted that the relations between road network accessibility and crime distribution might vary with crime types and background of study areas. Hence, Hillier and Sahbaz (2008) held the opinion that environmental features related to crime risks could not stand alone, i.e. they are interdependent with the context of society and space. It also showcases that each community model might have its own crime-accessibility correlation pattern, which is likely to vary from one community to another. Space Syntax is of high applicability to reveal the correlation pattern in the gated communities in China.

- Visibility

A large number of studies have revealed that visibility conditions in the communities and natural surveillance formed in daily life were closely connected with criminal activities. At the same time, residents' conditions for natural surveillance were highly correlated with design quality of landscape (Yancey, 1972； Kuo, 2003), the luxuriance (Wolfe & Mennis, 2012) and height of landscape plants (Michael, Hull and Zahm, 2001; Donovan and Prestemon, 2012). In

the field of Space Syntax, the Visibility Graph Analysis model, VGA model for short, developed by Turner and his colleagues, serves as a proper tool to simulate the visibility conditions of the environment within the landscape. Such a model was able to quantify the likely impact of visibility on space by analyzing the area that could be seen from a certain spot and the connectivity of lines of sight (Turner, Doxa, O'Sullivan, & Penn, 2001). On that basis, Desyllas, Connoly and Hebbert (2003) were the trailblazers to integrate VGA model with CPTED theory, simulating natural surveillance on traditional street space and university campus of modern times, which revealed significant differences in the variable of natural surveillance between those two places. Kaya and Kubat (2007), and Lee and Ha (2016) tried to apply the VGA model to crime prevention research into such spaces as parks and primary schools with the purposes of identifying the relations between spatial layout, visibility and fear. With regard to the environment of communities, Hu and Wang (2015) analyzed the spatial closure of typical nodes with high crime rate in three communities in Shenzhen, China, with VGA model, where they compared the parameter of visual integration and discussed the correlations between natural surveillance and criminal activities. The aforementioned studies have laid a foundation for the application of VGA model to space on relatively small scale. It is worth noticing that such a model mainly extracts two-dimensional surfaces at equal altitude from the real circumstances for visibility analysis (Turner, Doxa, O'Sullivan, & Penn, 2001). As a result, its applicability might be restricted in some space with an emphasis on vertical height differences. In spite of that limitation, there is great potential to carry out crime study with VGA model based on the micro-scale environmental features. For example, probe into the sense of safety of residents and the possibility for criminals to commit crime by simulating blockage of lines of sights caused by plants and artworks in public spaces.

- Constitutedness

Apart from VGA model, there are also some significant Space Syntax methods based on observation and statistics, and can be specially employed to courtyards or streets in communities. Hillier and Hanson (1984) were the first to propose the concept of "constitutedness", which had defined residential buildings with street-oriented entrance as "constituted", describing the integration of street networks with buildings on micro scale. Such integration can be further applied to characterize the streets under natural surveillance from residential buildings. Shu (2000, P01.3) built on that concept and defines streets with over 75% of buildings whose accesses were facing the public space as "constituted", while others as "unconstituted", in order to explore the impact of entrance layouts in communities on criminal activities. On this basis, Van-Nes and López (2007) systemised the spatial connection between streets and residential buildings. In the towns of Alkmaar and Gouda of the Netherlands, they analyzed the micro-scale environmental features and their possible connections with burglaries and auto thefts, such as constitutedness of private entrances linked with streets, the topological depth of various private and public spaces, and inter-visibility between apartment buildings and streets. Matijosaitiene (2016) combined the aforementioned method with CPTED theory to study robbery and auto theft in New Heaven and Kaunas. Constitutedness of private residential buildings' entrances, inter-visibility and some other variables are used to reflect the level of natural surveillance, and they were found to be correlated with auto

theft. Research into such relevant concepts as constitutedness has enhanced the flexibility of natural surveillance simulation and explored the research potential for micro-scale environmental features of communities However, the methods are mainly practiced in low-and-medium-rise residential buildings in non-gated communities along the streets, without being applied to gated communities and high-rise apartment buildings.

In a nutshell, despite some limitations, Space Syntax theory and analytical methods have shown adaptability and potential in their application to crime research in communities, in particular, to landscape space in communities and space in front of the residential buildings. Relations between humans' perception of the space and environmental features can be extracted with principles of Space Syntax, and converted into simple and effective spatial variables, which supports the quantification of the micro-scale environmental features in the communities.

2.2 Introduction to Gated Communities in China

Modern gated communities, which originated from the United States in the 1960s and 1970s, have been developing by leaps and bounds globally (Blakely & Snyder, 1997; Webster, Glasze & Frantz, 2002). Their key factors generally include enclosure, wall or fence, restricted access, guarded gates, possible surveillance equipment, security personnel and semi-amenities (Blakely & Snyder, 1997; Miao, 2003; Low, 2004). Gated communities were preferable for various reasons, including better privacy, convenience for life and separation from some other social groups, with safety assurance being the most important one (Breetzke & Cohn, 2013).

The development of gated communities in China has been driven by diverse factors, such as demand for safety (Miao, 2003), culture of collectivism (Huang, 2006), and tradition of urban settlements (Xu & Yang, 2009). Since the 1990s, gated communities have been developing rapidly as a standard and major form of newly-built commercial housing (Wang, 2010). Spatially, gated communities tend to cover a large area and are enclosed by continuous walls or skirt buildings along the streets (Miao, 2003). For the sake of practicality, gated communities usually adopt similar form of layout, but are distinguishable with prominent decoration styles for their landscape and architectural design (Wu, 2010). Within the communities, large housing/residential clusters are formed as secondary structure with major roads serving as boundaries (Ministry of Housing and Urban-Rural Development of China, 2016). There are closely-knit paths, space for landscape, and apartment buildings in similar architectural form within clusters. Such a spatial pattern of "enclosure and cluster" is a significant feature of gated communities in China, making it particularly suitable to be the focus of research into crime and micro-scale environmental features of communities. On the one hand, continuous spatial enclosure has led to semi-public-and-semi-private space outside the buildings within the communities, resulting in more or less the same environmental features and limited interference from streets outside of the communities. On the other hand, the continuation of the environmental features within the clusters, and the existence of public landscape for entertainment and motorized lanes have brought about similar behavior and habits of residents within the clusters, which will facilitate the exploration of the inherent pattern. Nonetheless, regarding research into crime in communities, there are only a few number of quantitative studies of the environmental features within gated communities in China.

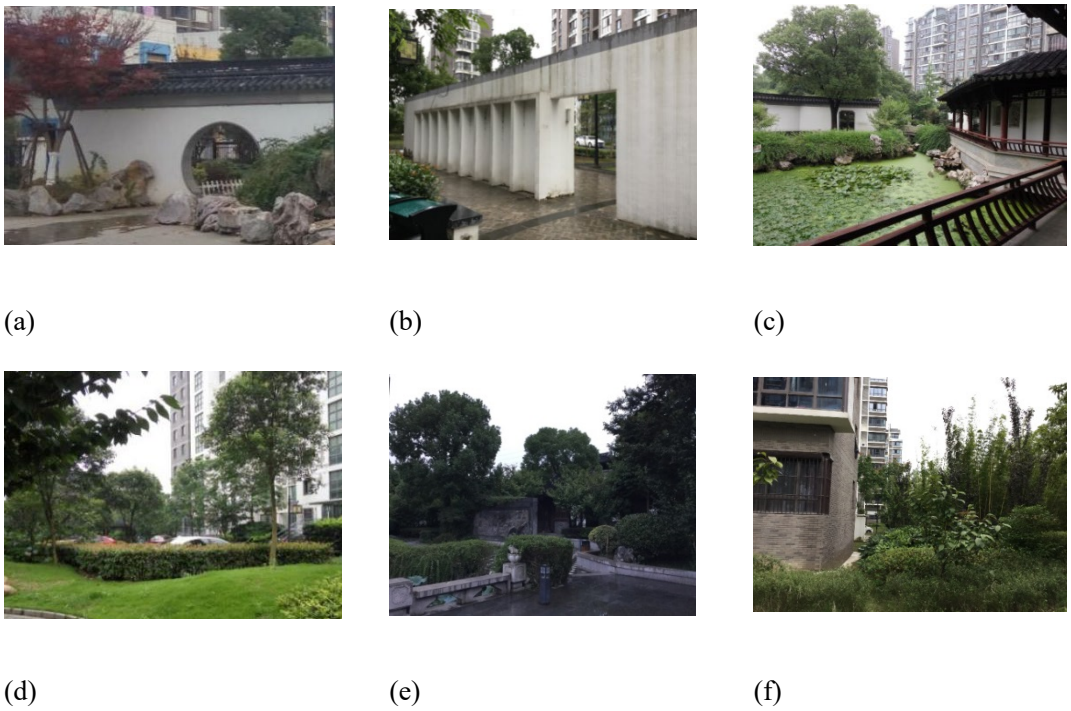
In general, Space Syntax has offered potential methods to identify and study environmental features from the perspectives of accessibility, visibility and constitutedness, making it possible to probe into the relations between the micro-scale environmental features within the communities and crime distribution. But some methods are suitable for street-based non-gated communities in the West, and rarely have they been applied to gated communities prevalent in China. On the basis of the enclosure-and-cluster patterns of gated communities in China, the present study aims to contribute to the study of Space Syntax theory and look into the possible impact of micro-scale environmental features on criminal activities in relatively closed communities.

3 Methodology

3.1 Study Object

The present study has focused on a typical gated community called YCM in ZS City, in the Yangtze River Delta of China. According to the crime heat map analyzed by police department, YCM community has been the high-crime area for thefts of electric bikes and batteries for four years on end. The community was built in 2007, with an area of 3.5 hectares, and typical in-row layout of residential buildings has been adopted. Additionally, the landscape in YCM is in a consistent style of traditional Chinese garden, with abundant shrubs and trees plants, and a diversity of local spaces (Figure 1), being suitable for research into micro criminal space. Based on construction time and residential type, the community can be divided into five zones and the present study covers only Zone I and Zone II that are closely connected by transit, and the public service area between the two. Those three areas are separated from the rest of the community (Figure 2). Zone I and Zone II mainly consist of six-story buildings and 10-to-11-story buildings, with occupancy rate of roughly 80% and relatively well-equipped facilities. The north and east sides of the zones are adjacent to a river, while the south side is enclosed by walls, ensuring a relatively independent space. Such a study area has three accesses in total, which are all guarded by security personnel.

For a better calculation of the environmental variables, the authors have taken into account Hillier's methods to measure residential density in their study of burglary in communities in London (Hillier & Sahbaz, 2008), and regarded each apartment building as the center of a spatial unit, i.e. spaces within 25 meters to the surround buildings, obstructions or the community boundary are counted as one spatial unit. Each unit has been numbered from south to north, 47 units in total (Figure 3). An inventory of environmental factors within each analysis unit and number of crime cases have been made. In light of the partition between roads within the community and the continuation of landscape environment, the above-mentioned units can be further classified into eight natural clusters as indicated in Figure 3. On top of that, the public space outside the apartment buildings, where criminal activities also exist, has been numbered, too, in which No. 48 is the public service area, No. 49, West Gate area in Zone I, No. 50, a small square in Zone I, and No. 51, West Gate area of Zone II.



(a) (b) (c)

(d) (e) (f)

Figure 1. The landscape in YCM

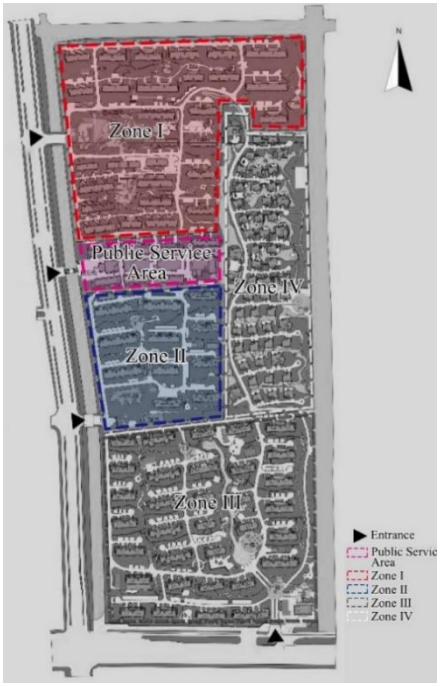


Figure 2 Master plan

Figure 3 Residential clustering

3.2 Theoretical Framework

The present study has built its theoretical framework on Space Syntax theory (Figure 4) in order to explore the relations between four types of environmental features and the distribution of electric bike-and-batteries-related cases, in the gated communities of enclosure and cluster structure. Those four environmental features are related with properties of road network, landscape space, space in front of the apartment buildings, and apartment buildings themselves. The authors have adopted the Axial analysis model of Space Syntax and associated methods to study the accessibility of road network in the community, and employed VGA and constitutedness to study the impact of landscape space, space in front of the apartment buildings and apartment building on natural surveillance formed during the daily life of residents. On such a basis, information about the environmental features and criminal activities has been streamed into corresponding spatial units with purposes of identifying the features that are significantly correlated with the crime rate via ANOVA method.

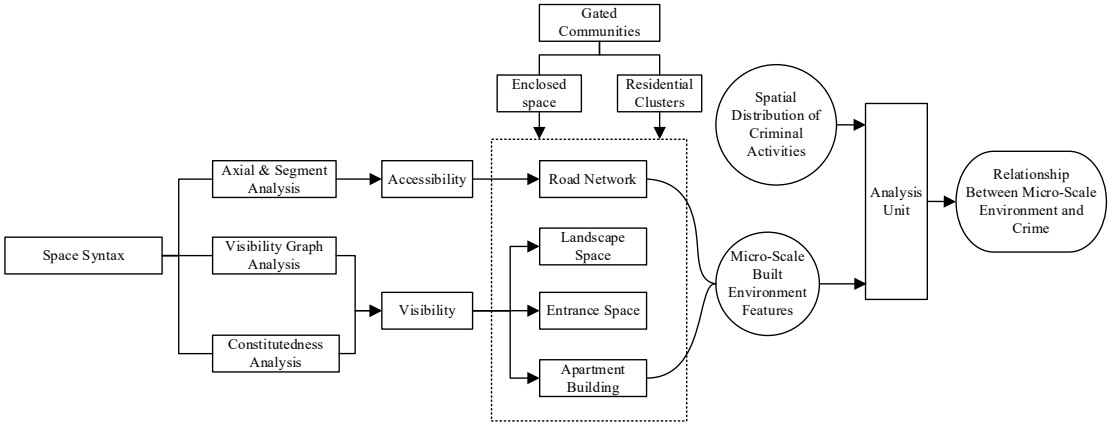


Figure 4 Theoretical Framework

3.3 Crime Data

The crime data on theft in the present study came from the Police Department of ZS city from October, 2014, to September, 2017, with 280 cases in total, among which nine have been excluded due to the lack of relevant case information. As for the rest of the cases, 58 took place in the underground garage. Among 213 cases that happened on the ground, 92 were thefts of batteries, 59 electric bikes, 44 burglaries and 18 thefts from auto. The present study has focused on the electric bicycle related thefts cases, hereinafter referred to as EBRT（Electric Bicycle Related Thefts）, for the reason that they have taken up the largest proportion. All told, 151 EBRT cases have been selected, taking up 53.93% of the cases in total, and 70.89% of the cases happening on the ground.

Our investigation has shown that, as the potential crime target, electric bikes, usually parked by either side of the road leading to the entrance to the apartment building, were in the custody of residents. Considering that the number of electric bikes parked differed dramatically from one

apartment building to another, meanwhile, the number of cases was distinct from working days to weekends, crime rate is used to measure the susceptibility of crime in each analysis unit as precisely as possible. On the basis of the long-term observation of residents' daily life in the community, a typical weekend, December 17th, 2017, and a typical working day, December 21st, 2017, were selected, when data of electric bicycles parked in the analysis units were collected. Those two days enjoyed fine weather, while the residents' behavior was typical. Investigators recorded the number of electric bicycles parked in each analysis unit every two hours from six am to six pm, six times in total. Mean value is taken for each unit as the number of electric bicycles parked there.

Formula for the Rate of Theft

$$\text{Rate of Theft} = \frac{\left(\frac{Cx}{\sum_i Xi} + \frac{Cy}{\sum_i Yi}\right)}{N} * 1000‰ \qquad (1)$$

In this formula, C_x represents the number of two kinds of theft cases on the working day, C_y, the number of those cases during the weekend, X_i, the number of bicycles parked during various periods on the working day, among which i, with the value of one to six, presents the time period for calculation, Y_i, the number of bicycles parked during various periods during the weekend, among which i, with the value of one to six, presents the time period for calculation, and N, the year period for the cases, with day as the unit.

3.4 Spatial Variables

In light of the distribution features of cases, the authors have chosen four types of variables to quantify the micro-scale environmental features of the community, namely, road network, landscape space, space in front of the apartment building and apartment architectural form, which have been further categorized into 14 subcategories (Table 1). Most variables have been acquired via Space Syntax analysis, while a small number of them have been collected through field investigation. The environmental variables of each apartment building have been acquired within the analysis unit, as shown by the example in Figure 5.

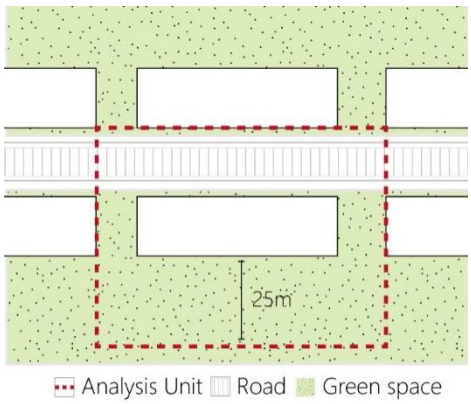


Figure 5 Analysis Unit

1

2 Table 1 Spatial Variables

Category	**Sub-category**	**Description**
Road Network	Global Integration	The average of the global integration value of road segments in the analysis unit, a full-scale calculation
	Local Integration	The average of the integration value of road segments in the analysis unit, with a radius of 3 steps.
	Connectivity	Average number of road segments linked directly with each segment in the analysis unit
	Average Distance Depth	The average of shortest distance from road segments within the unit to the nearest entrance
	Average Topological Depth	The average value of topological depth in the road network of the analysis unit
Landscape Space	Visual Integration	The average of Visual Integration of the space in light of various landscape obstructions in the analysis unit as a whole
	Visual Integration Difference	Difference in the Visual Integration of the community before and after the removal of various landscape obstructions in the analysis unit
	Visual Connectivity	Average visual connectivity of the space in the analysis unit
Space in front of the Apartment Building	Entrance Layout	Features of the road to the cluster entrance in the analysis unit
	Number of Constituted Building Entrances in the Analysis Unit	Number of entrances linked by the roads to the apartment building, in front of and behind the apartment building

	Surveillance by CCTV	Number of CCTV cameras installed in the analysis unit
Apartment Building	Household Estimated in the Building	* Potential flow of people in the analysis unit estimated by the multiplication of entrance number and floor number
	Ratio of Floors Forming Effective Surveillance	Ratio of floors forming effective surveillance to the total number of floors in the analysis unit
	Ratio of Window Area on Standard Floor	Ratio of window Area on the north to that on the south on a standard floor of an apartment building in the analysis unit

Notes: Our calculation is based on the following facts: The apartments in the community are mainly housed in buildings with six floors or less (low-rise buildings) and those with seven to ten floors (high-rise buildings). There are two apartments on each floor, with one lift. The number of entrances equal that of the lifts.

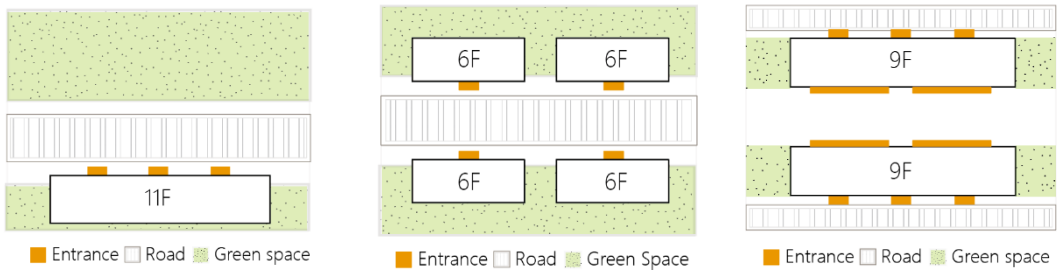
The variables of road network are used to reveal the relations between road network, the apartment building layout, and the distribution of theft cases in the community. Axial model is built based on Space Syntax theory, with the fewest and longest axial lines to represent roads and squares, and the overall integration, local integration, connectivity and topological depth of roads have been further analyzed. Since YCM community is located in a large residential area with well-equipped public facilities in the neighborhood, an area within 30-minutes of walk has been designated as the extended area of the model modelling, to simulate the boundary of daily activities of residents. Furthermore, the meter-based distance between the nearest access to the apartment building and each analysis unit is also taken as a variable in order to compare and analyze the potential relations between spatial depth and criminal activities in the gated community.

The variables of landscape space are employed to analyze the impact of public landscape on the visibility of residents, and the relations between public landscape and theft cases. With the tool of VGA in Space Syntax, the boundary lines of buildings, plants and artworks in public space that clearly obstruct the lines of sight in the community, have been drawn accordingly to build a view model. Specifically, the obstructions include the contour of the apartment building, entrance to the underground garage with plafond, landscape wall, tall trees and some small plant artworks. On this basis, visual integration, visual connectivity and some other variables have been analyzed. Since various landscape artworks and plants have obviously obstructed the lines of sight, the concept of visual integration difference has been put forward, which aims to quantify the impact of those obstructions on the lines of sight by analyzing the changes brought by the removal of the movable obstructions to the visual integration.

The variables of space in front of the apartment building strive to explore the spatial permeation and constitudeness features of buildings and roads within a cluster, including the number of entrances linked with the roads leading to the apartment buildings and the spatial correspondence

of entrances, i.e., the inter-visibility of entrances. Based on the research conducted by Van-Nes and López, the authors have categorized entrances in gated communities with row layout into three types (Van-Nes & López, 2007) (Figure 6). Firstly, most of the high-rise buildings and a few low-rise buildings have street-oriented entrances on the north side, with the other side of the street as landscape space (Figure 6, (a)). Secondly, other low-rise building are located on both sides of the street, with entrances facing each other or are inter-visible (Figure 6, (b)). Thirdly, some high-rise buildings in the public service area have their entrances \ apartment building for residents and for commercial service, respectively, on the two sides of the buildings (Figure 6, (c)). Moreover, the CCTV for surveillance in the streets in front of the apartment building and landscape space have been taken into account, i.e., the number of CCTV cameras in the public space on the ground of each unit has been counted.

The variable of apartment building tries to explain the possible influence of architectural form on criminal activities. Generally, there are two types of apartment buildings in the study area, namely, high-rise buildings and low-rise buildings. The differences between them mainly find expression in the household estimated in the building, the ratio of floors forming effective surveillance, the ratio of window area on standard floor. Research conducted by Hillier has demonstrated that, compared with the density on the ground, vertical high density of the apartment building provided more potential crime targets, rather than creating more natural surveillance, which was not favorable to crime prevention (Hillier & Sahbaz, 2008). To verify such an idea, the largest number of households in the building was taken as one variable. Besides, the ratio of the floor one to three, which formed effective natural surveillance, to the total number of floors, has been calculated in order to gain more insights into the influence of floor number on criminal activities. Besides, as the study area is situated in subtropical monsoon climate zone of the northern hemisphere, the apartment buildings are mostly south-oriented. Consequently, windows with larger area are concentrated in the south for better lighting, while the building entrances, stairs and elevators are usually found in the north. Since electric bicycles tend to be parked by the roadside of the entrance, the differences in windows layout between high-rise buildings and low-rise buildings are assumed to influence natural surveillance and criminal activities. Hence, the variable of the ratio of window area on standard floor has been adopted for investigation.



（a）Entrance on the north side only　（b）Independent entrance to the apartment building　（c） Entrances on both sides

Figure 6 Layout of apartments and entrances to the apartment buildings

3.5 Analysis of Variance

The analysis procedures for micro-scale environmental features and crime data have been displayed in Figure 7. Firstly, the analysis units can be ranked based on the crime rate, and cluster analysis is used to divide units into different crime groups. This is followed by the comparison of the differences in environmental variables via ANOVA analysis in each group. Finally, combining the comparison result, and the location and cluster features of each unit, it is possible to further identify the relations between criminal activities and community environment.

In the first place, two-step cluster method has been employed to analyze the 47 analysis units by perceiving the crime rate, crime case number, and both the crime rate and case number as interval variables. The aim of clustering analysis is to single out the most reasonable grouping pattern to interpret the features of crime data. The groups will be ranked and numbered according to the susceptibility of crime.

Secondly, with the group number as the categorical variable, 15 types of environmental variables as interval variables, one-way ANOVA has been used to find out environmental variables with significant differences between groups. All interval variables have to meet the requirements of normal distribution and homogeneity test of one-way ANOVA. Those that fail to conform with the homogeneity test have been corrected and supplemented with Kruskal-Wallis test. In both ANOVA test and Kruskal-Wallis test, P value has to equal or be less than 0.05, which serves as the criteria for assessing significant differences between groups. Variables with significant differences between groups can be deemed as having significant impact on the theft cases.

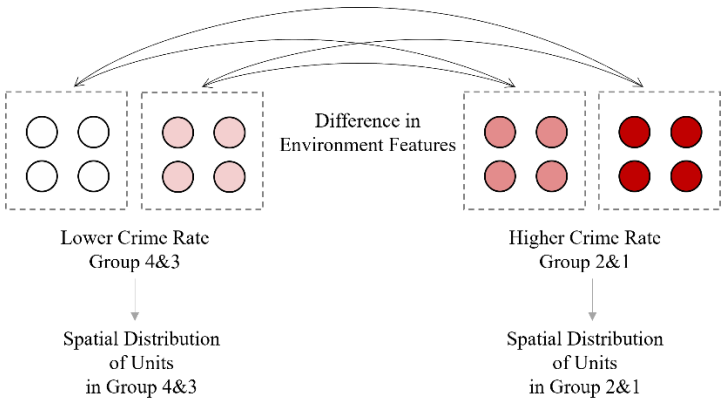


Figure 7 Research Path

4 Results

4.1 Spatial Distribution of Cases

EBRT cases in YCM community are prominently concentrated in certain space. Judging from the kernel density of crime place (Figure 8), areas around Unit 32, 35 and 39 in the north of the

community, Unit 18 and 22 in the middle of the community, and Unit 10 and 11 in the south of the community are all hot spots for thefts cases. Judging from the crime rate of each unit (Figure 9), Unit 32, 35, 39 and 40 are characterized by high theft rate, while Unit 10, 11, 18, and 22 have high crime cases but low theft rate. Furthermore, Unit 2, 9, 15, 16 and 17 have bicycles parked, but no theft cases . The cases are concentrated in certain spaces, showing that their distribution is likely to be related with certain environmental factors in the community.

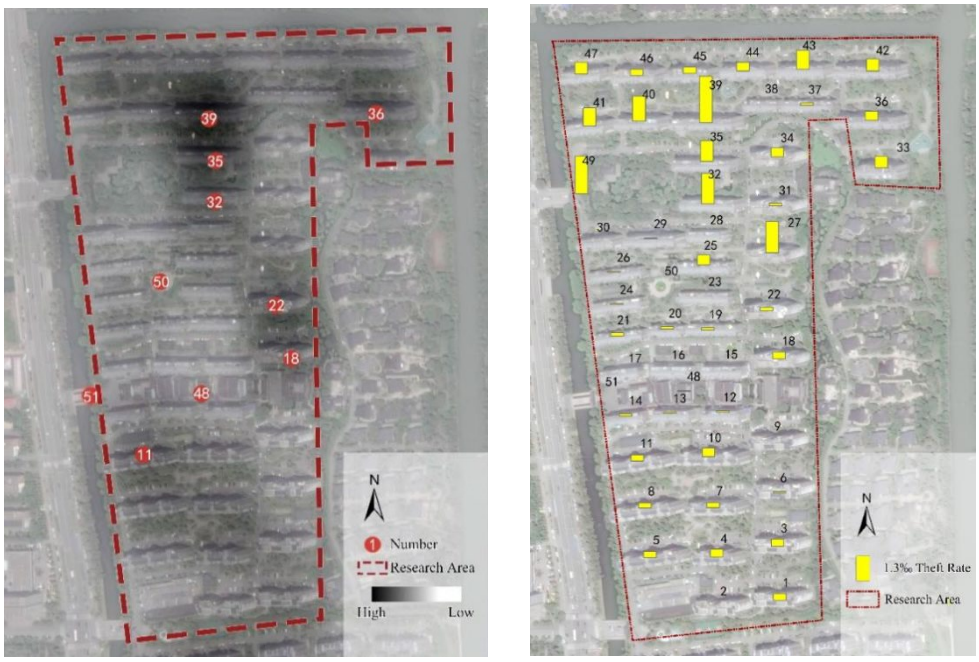


Figure 8 Distribution of EBRT Cases in the Community

Figure 9 Theft Rate in Each Analysis Unit

4.2 Case Grouping and Variance Test

Through data screening and comparison, the crime rate of EBRT cases is found to be more appropriate to describe the spatial distribution features of the crime data (Figure 10). Based on the optimization of two-step cluster analysis result, 47 analysis units have been categorized into four groups (Table 2). Four units have fallen into Group 1, known as the Group with High Crime Rate, 18 into Group 2, Group with Middle Crime Rate, 16 into Group 3, Group with Low Crime Rate, nine into Group 4, Group with Zero Crime Rate. The distribution of units in each group is shown as Figure 11.

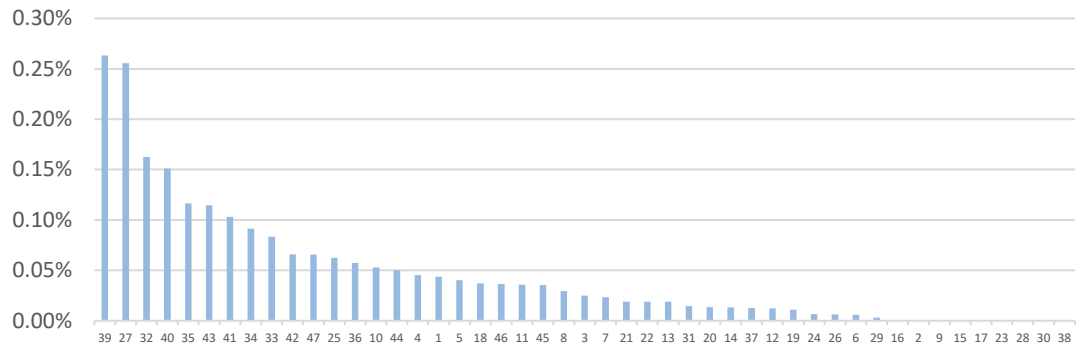


Figure 10 Theft Rate Ranking of the Analysis Units

Table 2 Theft Rate-based Cluster Analysis Grouping Result

Group	Analysis Unit																	
High (G.1)	39	27	32	40														
Middle (G.2)	35	43	41	34	33	42	47	25	36	10	44	4	1	5	18	46	11	45
Low (G.3)	8	3	7	21	22	13	31	20	14	37	12	19	24	26	6	29		
Zero (G.4)	16	2	9	15	17	23	28	30	38									

Figure 11 Spatial Distribution of Analysis Units

Then,14 types of environmental factors have been subject to one-way ANOVA analysis with purposes of finding out if there are significant differences between four groups. Preliminary analysis has demonstrated that there are significant differences between groups in local integration of road network, distance depth, visual integration difference, ratio of floors forming effective surveillance, ratio of windows area on standard floor and entrance layout. Among them, local integration of road network, ratio of floors forming effective surveillance and entrance layout have failed to meet the requirements of homogeneity test of variance analysis, while the rest conformed with the hypothesis of homogeneity (Table 3).

The above-mentioned variables that failed to meet the homogeneity test have been further subject to Kruskal-Wallis test. Ratio of floors forming effective surveillance and entrance layout have indicated significant differences between groups, while there is no significant difference in local integration of road network between groups. For more insights into the subtle differences in environmental variables between groups, all the variables have gone through multiple comparison via LSD (Least-Significant Difference) and Tamhane methods (Table 4). Generally speaking, groups with relative high crime rate and low crime rate have shown significant difference in certain variables.

Table 3 Result of One-Way ANOVA Analysis

Category	Sub-category	Homogeneity Hypothesis	One-Way ANOVA	Kruskal Wallis Test

		P	Homogeneity	F	P	p
Road Network	Global Integration	.374	Yes	1.311	.283	.205
	Local Integration	.000	No	3.081	.037	.219
	Connectivity	.000	No	2.327	.088	.690
	Average Topological Depth	.168	Yes	.872	.463	.165
	Average Distance Depth	.122	Yes	3.592	.021	.022
Landscape Space	Visual Integration	.751	Yes	1.287	.291	.235
	Visual Integration Difference	.295	Yes	5.598	.002	.021
	Visual Connectivity	.132	Yes	2.483	.074	.097
Apartment Building	Household Estimated in the Building	.395	Yes	1.545	.217	.056
	Number of Floors Forming Effective Surveillance	.000	No	5.308	.003	.022
	Ratio of Windows Area on Standard Floor	.076	Yes	3.896	.015	.059
Space in Front of the Apartment Building	Entrance Layout	.000	No	6.974	.001	.001
	Number of Constituted Building Entrances in the Analysis Unit	.807	Yes	.412	.745	.733
	Surveillance by CCTV	.200	Yes	.614	.610	.636

1

2

3 Table 4 Result of Multiple Comparisons

Dependent Variable		Control Group (I)	Compared Group (J)	Mean Difference (I-J)	Std. Error	Sig.
Local Integration	LSD	2	1	.86337056*	.39642968	.035
			3	.60178868*	.24641338	.019
			4	.60145722*	.29278272	.046
Connectivity	LSD	2	3	5.26389*	2.29608	.027
Average Distance Depth	LSD	2	3	92.07972*	32.52232	.007

			4	98.58875*	38.64228	.014
Visual Integration Difference	LSD	1	2	.38109361*	.17887067	.039
			3	.63827875*	.18089187	.001
			4	.65086028*	.19445292	.002
		2	1	-.38109361*	.17887067	.039
			3	.25718514*	.11118271	.026
			4	.26976667*	.13210475	.047
Ratio of Floors Forming Effective Surveillance	Tamhane	3	1	.10125*	.03109	.027
			2	.09347*	.03032	.032
Ratio of Windows Area on Standard Floor	LSD	4	2	.24151*	.07101	.001
			3	.14687*	.07248	.049
Entrance Layout	Tamhane	3	1	.75000*	.19365	.009
			2	.69444*	.20146	.018

a. Kruskal Wallis Test

5 Discussion

5.1 Variables of Road Network

In accordance with the Multiple Comparisons, with regard to variables related to road network structure, significant differences can be found in local integration of road network (between G.2and G.1, G.2 and G.3, G.2 and G.4), connectivity (between G.2 and G.3) and average distance depth (between G.2 and G.3). Furthermore, prominent differences in the aforementioned variables can be seen between Group with Middle Crime Rate (G.2) and Group with Low Crime Rate (G.3). Compared with other groups, Group with Middle Crime Rate (G.2) has showcased higher local integration, connectivity and average distance depth (Table 5), which implies that the space composed of G. 2 is more accessible in the local road network, but far away from the main gates of the community. According to the research into the relations among integration, connectivity and crime by Nubani and Wineman（2005）, road network with high-connectivity and high-integration may also provide convenient escape route for criminals.

On top of that from the perspective of housing/residential clusters, analysis units with middle crime rate are generally situated in the north and on the eastern rim of clusters in the north of the community, far away from the gates, while a small number of them are located on the north and south sides of clusters that are situated in the south of the community, with the main road at the back. Those distribution features have further demonstrated that convenient escape routes are correlated with the overall structure and local space of the community, and with the spatial distribution and

structure of the housing clusters in particular. In gated communities, space closed to the gates or main roads tends to be frequented by security personnel and guards on patrol. While the space deeper in the clusters is less frequented by security guards, but it is also not conducive to the escape of criminals. Therefore, space on the periphery of the clusters but far away from the main gates or main roads is usually weak in crime prevention because of its convenience for criminals to escape and hide.

Apart from the above-mentioned variables, global integration and average topological depth of the road network haven't shown significant differences in Variance Analysis. Regarding global integration, compared with the urban road network outside the community, the road network within the gated community is relatively smaller, with limited connection with the external one. Consequently, the feature of global integration within the gated community might not stand out if they are put into a larger road network model extended area within 30-minutes of walk. Besides, there is also no significant difference in the average topological depth. The different results from the distance and topological depth can lead to the inference that the axial model is not satisfactorily precise for road network within the gated community with limited scale and simple structure, since its topological features are highly replicable as a whole. In a nutshell, it can be necessary to adopt a more precise model on an appropriate scale when studying a relatively closed residential area like YCM.

Table 5 Local Integration of Road Network, Connectivity and Average distance Depth

Group	Local Integration	Connectivity	Average distance Depth
	Mean Value	Mean Value	Mean Value
1	2.7127600	7.0000	357.0533
2	3.5761306	13.0556	440.5510
3	2.9743419	7.7917	348.4712
4	2.9746733	8.1296	341.9622

5.2 Variables of Landscape Space

According to the Multiple Comparisons, in terms of the variables related to landscape space in the community, significance mainly finds expression in visual integration difference. Group with High Crime Rate(G.1) and Group with Middle Crime Rate(G.2) are significantly different from other three groups, and higher the crime rate, higher the value of visual integration difference. (Table 6). Visual integration difference represents the impact of movable landscape or obstructions within the analysis unit on residents' lines of sight. Analysis result has demonstrated that there could be more visual obstructions in the high-crime area. When it comes to spatial distribution, the high-crime analysis units are concentrated in the areas around the access on the north side, where more elements of traditional Chinese gardens can be found in the neighboring clusters. The local gardens

lay great emphasis on winding paths and landscape artworks, so that visitors can experience different scenery as they walk on, leading to a higher density of landscape plants and structures, and a greater diversity of conditions for lines of sight. Take Unit 31, 32 and 35 for example. The dense bushes around the apartment buildings have concealed the electric bicycles behind, and blocked the lines of sight between the main roads in the community and the housing units, reducing natural surveillance formed by the pedestrians (Figure 12, a & b). Likewise, tall arbors have exerted negative influence on surveillance over space in front of the apartment buildings by residents living on the second floor and above. Our statistics analysis and field investigation have revealed that the disadvantages of abundant and highly-dense traditional garden landscape in local style within the YCM community may have outweighed their advantages in crime prevention, which is concordant with the above-mentioned research conducted by Michael, Hull & Zahm (2001).

It is worth further explanation that the landscape of the gated community we have studied is maintained by the real estate management company and maintenance condition is relatively fair, while residents have basically no intervention. In that case, the maintenance condition of the landscape space may not be included in the consideration by the criminals when they identify potential value of crime target. In contrast, to evade the surveillance from both the real estate guards and residents, space with luxuriant plants, and convenient to escape might be more attractive to criminals. Additionally, traditional gardens in the local style stress the importance of privacy offered by the landscape. Large communities especially designed in that way enjoy better cultural tastes and higher quality of environment, but might not be able to meet the needs of public surveillance.

In spite of significant difference in visual integration difference, the variables of visual integration and visual connectivity have not demonstrated any significance, which rejects the initial design. This indicates that, the visual condition difference of different crime rate groups may be small if only considering the defined open space in VGA model, and the accuracy of model analysis need further improvement.

Table 6 Visual Integration Difference and Visual Integration

Group	**Visual Integration Difference**	**Visual Integration**
	Mean Value	Mean Value
1	1.3783025	6.6335550
2	.9972089	6.9276528
3	.7400238	7.1153175
4	.7274422	6.5975133

（a）Analysis Unit 32 and 31　　(b)　Analysis Unit 35

Figure 12 Analysis Units Obstructed Severely

5.3 Variable of Apartment Building

With regard to apartment buildings, it has been found via Multiple Comparisons that the ratio of floors forming effective surveillance is higher in Group with Low Crime Rate(G.3) than those with middle(G.2) and high crime rate(G.1). In addition, compared with Groups with Middle(G.2) and Low(G.3) Crime Rate, the apartment buildings in the Group of Zero Crime Rate(G.4) has a higher ratio of the window area on the south side to the north side (Table 7).

Among the four groups, Groups with High(G.1) and Middle(G.2) Crime Rate are dominated by high-rise apartment buildings, while the proportion of high-rise apartment buildings to the low-rise buildings is closed to 2:1 in the Groups with Low(G.3) and Zero(G.4) Crime Rate (Table 8).

Considering that the two variables related to floors and window areas above keep the same in the high-rise and low-rise apartment buildings respectively and the two types of apartment buildings gather in specific crime groups, it can be inferred that the distribution of criminal activities may be further related to the difference of apartment buildings' types and the architectural form.

Table 7 Ratio of Floors Forming Effective Surveillance and Ratio of Open Windows on Standard Floor

Group	Ratio of Floors Forming Effective Surveillance	Ratio of Open Windows on Standard Floor
	Mean Value	Mean Value
1	.2850	.7494
2	.2928	.6847
3	.3863	.7793
4	.4000	.9262

（a） North-oriented Elevation in Typical High-rise Apartment Buildings

（b）South-oriented Elevation in Typical High-rise Apartment Buildings

Figure 13 Differences in Window Areas between Elevations with Different Orientation in Typical High-rise Apartment Buildings

In terms of the ratio of floors forming effective surveillance, the high-rise building appears in a disadvantage position. Despite the larger number of floors and potential households in high-rise buildings, the number of floors forming effective natural surveillance is the same as that in low-rise buildings, which decreases the ratio of effective floors. Besides, more households living in taller floors might not contribute to the natural surveillance, according to the non-significant result of the household estimated in the building variable. Instead, more households may provide additional potential crime targets to criminals, such as bicycles parked on the ground, which to some degree, corresponds to the opinion of Hillier & Sahbaz regarding density off the ground (Hillier& Sahbaz, 2008).

As for window area, high-rise buildings see a lower ratio of window area on the north to that on the south on a standard floor, while for low-rise building the window areas on both sides are relatively close. The unbalanced windows layout in high-rise buildings indicate a possible poorer natural surveillance on its north side space. Compared to the low-rise buildings, there is more space for structural support and vertical transit on each standard floor for high-rise buildings, and most of the above space is concentrated in the north side (Figure 13, a & b), which reduce the necessity of setting windows. However, the ground level place on the north side is commonly the parking place for electric bikes, and a lack of surveillance may increase the risk of EBRT cases. All in all, probably owing to the differences in architectural form, it can be harder for high-rise buildings to bring the function of residents into full play for forming natural surveillance than the low-rise buildings.

Table 8 Number of High-rise Apartment Buildings & Low-rise Buildings

Group	Number of High-rise Buildings	Number of Low-rise Buildings	Ratio between the Two
1	4	0	0
2	17	0	0
3	10	6	0.6
4	6	3	0.5

5.4 Variable of Space in front of the Apartment Building

According to the result of Multiple Comparisons, there is significant difference between Group with Low Crime Rate(G.3) and Groups with Middle(G.2), and High(G.1) Crime Rate in the variable of entrance layout This indicates that certain organizational forms of roads and buildings within the housing/residential clusters can be related to crime distribution. To be more specific, 90% of the analysis units in the cluster of low-rise buildings located in the middle of the study area, are characterized by low and zero crime rate. There the entrances in the south and the north are facing each other and inter-visible. Clusters where there are more groups with high crime rate and middle crime rate are quite the opposite in that the buildings there are situated on only one side of the road, while the entrances are not inter-visible.

In clusters where entrances are inter-visible, field investigation has found that pedestrians' road are designed separated from motorized vehicles' road, making the clusters more compact. On the one hand, surveillance can be stronger on the pedestrians' road leading to the apartment building entrance, where there are fewer obstructions but more residents coming in and out; meanwhile, residents are allowed to park their electric bicycles in designated space in front of the apartment building (Figure 14.a). On the other hand, the public landscape, plants and artworks are moved to the inner part of the cluster, where the floor has been elevated to create a non- motorized-vehicle-free area for residents to enjoy themselves. Such a layout results in that residents make use of the roads in front of their apartment buildings for mobility and parking, which has reinforced the natural surveillance on both sides of the roads.

On the contrary, the public space of the apartment buildings with their own entrances in the Group with High Crime Rate and Group with Middle Crime Rate is relatively less frequented, leading to insufficient natural surveillance there. Specifically, the apartments in the south and north respectively are not inter-visible due to the following two reason: first, the space for transit and landscape is located on the same side of the building entrance; second, the landscape space is for the residents living on the same side only, to some degree, blocking the surveillance of residents living in the nearby buildings over the electric bicycles parked in front of the building (Figure 14.b). To deep dive into the apartment architectural form of the cluster, it can be concluded that different patterns of natural surveillance have been created on the streets within the cluster where taller and larger buildings prevail, as the overall layout is not compact at all because of the long distance between buildings for better lighting and safety conditions. All in all, the clusters featuring low-rise

buildings and inter-visible entrances are similar to the plane layout of streets outside the community, which is in line with the concept of “main street” proposed by Shu (2000, P01.3), bringing about stronger natural surveillance. In contrast, cluster with only one entrance to the building is more isolated spatially, leading to uncertainty in natural surveillance.

（a）Cluster with Entrances on Both Sides

（b）Cluster with Entrances on North Side Only

Figure 14 Analysis Unit Obstructed Severely

Apart from the variable of entrance layout, the number of entrances linked to the space in front of the apartment building and surveillance by CCTV have shown no significant difference. Since the apartment buildings in this community only have limited number of public entrances, it is difficult for such a variable to reflect the number of residents and their potential movement flow in the analysis unit. That feature is prominently distinct from the research conducted by Van-Nes and others into open neighborhood in the towns of Alkamaar and Gouda (Van-Nes & López, 2007). The number of cameras in the public space of the community has been counted with the variable of “surveillance by CCTV”. There is only a small number of them, which are mostly equipped in the main road, exerting limited influence on the surveillance over the parking space for electric bicycles, which might have reduced the impact of such a variable.

To sum up, even the variable of space in front of the apartment building has been discussed individually, in nature, it is still significantly related to the apartment building and the corresponding

architectural form. Combined with the previous discussion of landscape space and road network, it is demonstrated that housing/residential cluster is a multi-element and closely-knit structure which is very important within the gated community. They have showcased the differences in environmental features there and interpreted the relations between criminal activities and environmental features on a reasonable scale.

6 Conclusion

The authors have tried to build on the discussion above and draw a conclusion to the relations between different environmental features within the gated community and EBRT cases.

The variables regarding the location features of analysis unit in the community, such as the global integration and topological depth of the road network, have not been found to be significantly correlated with the distribution of criminal activities. But the distance-based-depth analysis has implied that there might be higher risks of crime in space far away from the main entrances of the community. Such analysis has shown that the topology-based global variables, for example, global integration and topological depth, might not be capable of revealing the natural movement features of residents in a relatively closed environment as easily as it does in the open streets. One possible reason for that might be as follows: the mobility and route selection of the residents mainly center on the main entrances of the gated community. In the present study, the distance between each housing/residential cluster and the nearest entrance is more or less the same, consequently, residents are allocated a clear and fixed destination for their daily mobility, without many choices of paths they will travel through. It can be concluded from this perspective that the distribution of criminal activities is also closely correlated with the allocated daily routes of residents from the nearest entrance to the inner part of the cluster, but weakly correlated with the inherent features of the road network structure of the community. This finding above has implied that it is necessary to strengthen crime prevention in the space far away from the entrances of the gated community.

For variables reflecting the local features of the environment in the analysis unit and interaction between the residents and the environment aim to study, the local integration and connectivity of the road network, visual integration difference of the landscape environment, layout of entrance to the space in front of the apartment building and apartment architectural form have all shown significant differences between groups. The analysis of four types of environmental features above, from the perspective of local space, has brought more insights into the relations between criminal activities and housing/residential clusters, the secondary structure of gated communities. Each cluster is characterized by clear spatial boundaries, i.e., main roads in the community, and shared public space such as the path in front of the apartment building and landscape for entertainment, and similar spatial perception experience, which is based on the same apartment building type. On this basis, the local environmental features are similar internally but different externally for most clusters, which has found to be significantly correlated with the spatial concentration of criminal activities. For instance, in cluster composed of high-rise apartment buildings, similar conditions for natural surveillance exist in different buildings since they are similar in the number of floors and elevation design. Moreover, the similar roads and landscape layout have led to the same natural surveillance effect on the ground space. In light of the intense patrols and physical shelters, criminals

will, without any doubt, choose clusters with the weakest natural surveillance as a whole so as to reduce the cost of crime commitment. Hence, the homogeneity and diversity of spatial features in the clusters have offered them space for comparison and choice, leading to the concentration of criminal activities in certain clusters. As a result, it is very meaningful to find out and improve the spatial features of clusters with high crime rate. Moreover, the impact of spatial structures and features of the clusters on criminal activities shall be taken into full consideration in the future design of gated communities.

The present research is creative in that it has adopted a new perspective by studying the correlations between the micro-scale environmental features of gated communities and criminal activities via quantitative methods. Given the features of gated communities, i.e., modularization of residential layout, prominent structure of clusters within the community, and relatively weak connection with the external urban environment, the present study has regarded gated community as a type of independent space, where samples of environmental features have been taken from each analysis unit. Possible influence of various environmental factors on criminal activities, and the importance of cluster structure for crime prevention in gated communities have been verified through comparison and analysis of groups with different crime rate and natural clusters there. On the basis of the features of landscape and architectural form, new variables have been put forward, such as visual integration difference, ratio of floors forming effective surveillance, and ratio of the window area on different sides, which, to some extent, have contributed to crime research in gated communities, with sufficient data collection, insightful study, and new ideas for spatial design and crime prevention strategies in newly-built communities.

There is still room for improvement for the present study in that the study area is limited due to the acquisition of data, crime data in particular. Consequently, the universal applicability of some conclusions still needs further verification.

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