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Exploration of a New Method of Spatial Analysis to Predict the Pedestrian Pattern in the Circulation Spaces of Shopping Centers: The Case of Shenzhen

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Abstract

Turner and Penn (1) from UCL have proved that Visibility Graph Analysis (VGA) can be used as a more accurate method to predict the pedestrian distribution in building spaces. However, this methodology neglects certain elements that are of special influence on pedestrian distribution in buildings, especially the entrances and exits. Based on Space Syntax, this dissertation improves on the traditional method of Visibility Graph Analysis, using three shopping centers in Shenzhen as examples, attempts to explore a new parameter – "attenuation index of pedestrians at the entrances and exits" – using relevant data of the entrances and exits of the three cases, and combines it with traditional VGA analysis through weighted calculation, in order to provide more accurate predictions of pedestrian patterns in shopping centers.

Keywords: VGA, Pedestrian movement prediction, Entrances, Visual depth, Pedestrian density, Commercial complex

1. Background

Since the 21st century, commercial complexes have been developed at an unprecedented rate in cities all over the world, especially in Asian metropolises with high population density. In recent years, China has become the country with the largest number of commercial complexes. Commercial complexes often drive the development of urban space; the formation, exploration and influence on commercial activity can reshape the life pattern of citizens and the influence the evolution of urban space (14).

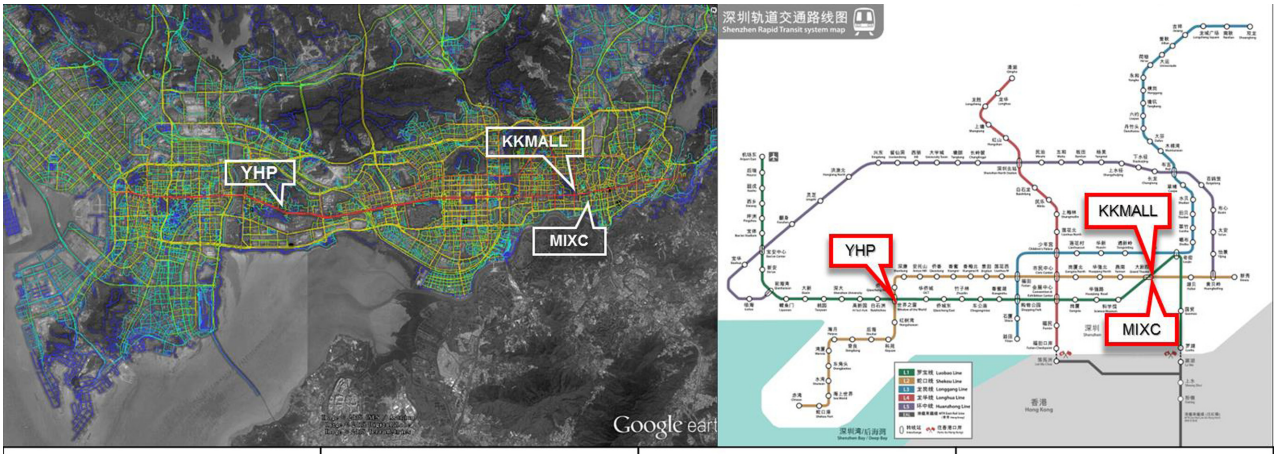
For property developers and operators of commercial complexes, the prognosis of pedestrian distribution is of great importance in estimating spatial value of stores and adjusting retail distribution so as to promote commercial benefits. For users, i.e., the citizens, if the commercial functions are distributed considering the impact of space on pedestrian movement, this will indeed promote the efficiency of the commercial space (19). Therefore, against the background of cities with high population densities and fast-paced urban life, the question of how to provide more accurate analysis and prognosis of commercial space's influence on pedestrian movement is the focus of architectural scholars.

Space Syntax is a theory that combines the methodology of topology based on social logic of space. Its related technology allows us to explore the interrelations between space and the behavior of users through quantitative analysis and description of space configurations (16). In recent years, Space Syntax has been widely applied in the research of spatial structure and the cognitive study of commercial complexes. It can help researchers analyze in what way users' behaviors are influenced by complex spatial systems.

In past research, scholars have discussed the correlation between spatial integration and statistics of pedestrian movement, and most of them have shown that spatial integration is useful in explaining spot surveys of pedestrian movement. Meanwhile, numerous researchers have found that, besides spatial format, there are still many other variables that affect the distribution of pedestrians, to which they also provided improvement. In the research of Zhuang Yu et al. of Tongji University (12), the relationship of rail transit terminals, changes of floors, vertical traffic means and other spatial elements were taken into consideration to optimize the analysis model so as to promote the relevance of its outcome with pedestrian distribution; Xia Zhengwei et al. of Tongji University (11) attempted to demonstrate the coordination and supplementation between business types and functions in their influence on pedestrian movement. Japanese scholar Fujitani et al. studied on the influence of acreage of stores on pedestrians in commercial space (13), just to name a few.

Most of these studies focused on elements other than interior circulation spaces. Indeed, all of these elements are of great importance to pedestrian movements. Objectively

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	MIXC	YHP	KKMALL
Open Year	2004	2008	2010
Gross Floor Area (m²)	188k	135.8k	83.5k

Figure 1-1. Location and Basic Information of Selected Cases.

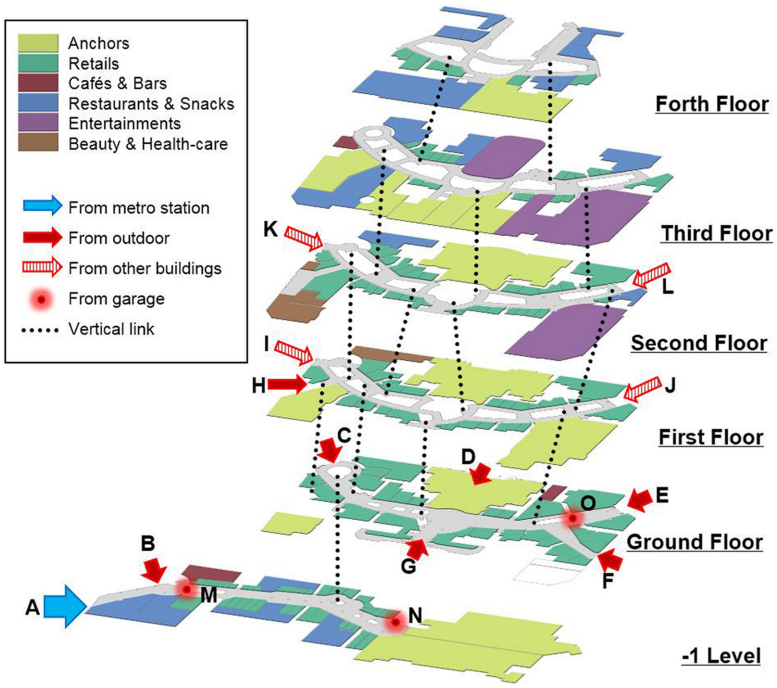


Figure 1-2. Layout of the MIXC Mall, with vertical links and entrances.

speaking, most of the variables like distribution of business, arrangement of acreage and function of a specific store, decoration style and all the other customized visual elements can be adjusted during later commercial operation. But, from the perspective of commercial operation, operators expect to rationally improve their profits through control of pedestrian distribution by spatial format (18).

As a result, this dissertation attempts to explore how to improve the accuracy of Space Syntax analysis on predicating pedestrian movements in commercial complex through interior circulation flow. In this research, entrances and exits of shopping centers will be taken into consideration as spatial elements, which are less affected by commercial operation.

Taking certain special elements (like commercial campaigns, landscape, decoration, lights, background music and air conditioner) out of the picture, and seeing these only through the perspective of space, the accessibility of a point in space is decided by the visual depth of its distance from different entrances and exits and its position in

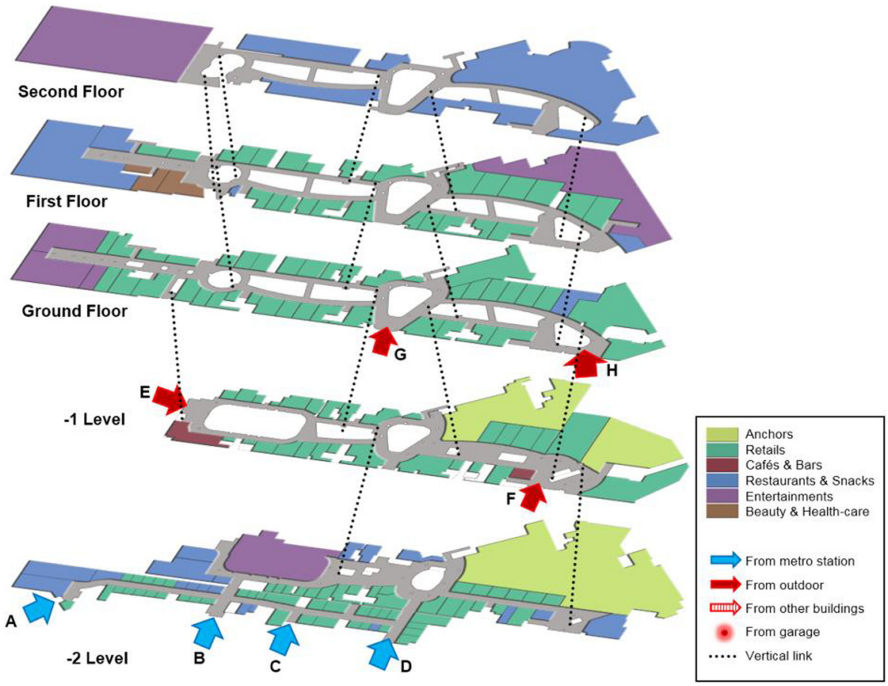


Figure 1-3. Layout of the Yitian Holiday Plaza, with vertical links and entrances.

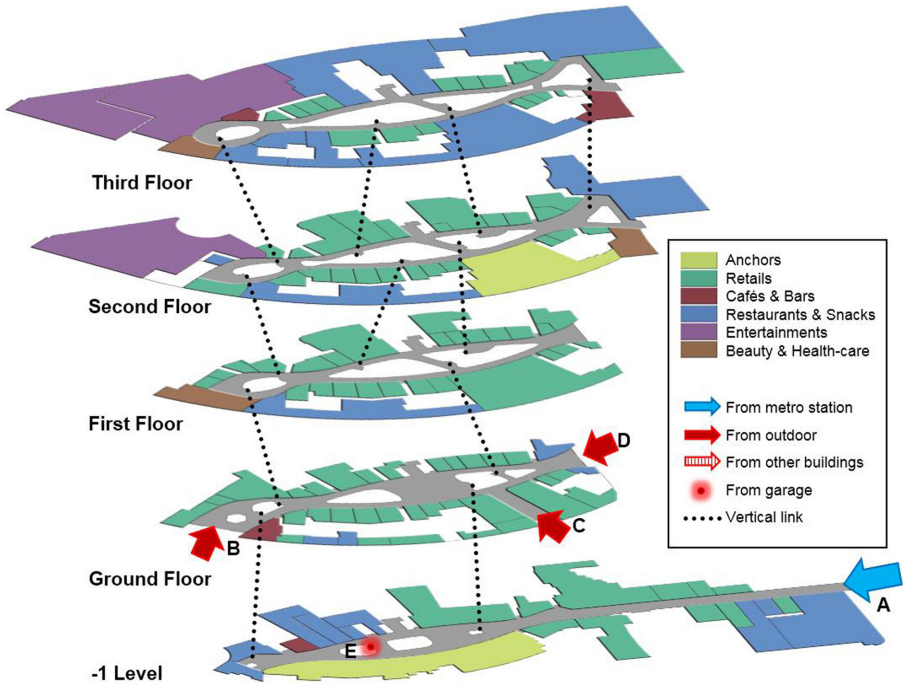


Figure 1-4. Layout of the KK Mall, with vertical links and entrances.

the whole spatial system. These two elements also dominate the density of pedestrians at a given point (pedestrians per unit area) (3). In the technology of Visibility Graph Analysis (VGA) of Space Syntax, there are two analysis parameters corresponding to these two elements: visual step depth, which can describe the relationship of visual depth of two spaces; and integration, which can explain the position of a unit of space within the whole system (2).

This research aims to determine the issues caused by negligence of entrances and exits in current analysis technology, through practical case studies, exploring resolutions and ways to improve the methodology, and to prom-

	A	B	C	D	E	F	G	H
In	7964	3252	2372	1176	2050	1338	2100	960
Out	6960	1198	2358	1918	2106	1326	1744	438
Total	14924	4450	4730	3094	4156	2664	3844	1398
%	30.17%	9.00%	9.56%	6.25%	8.40%	5.39%	7.77%	2.83%
	I	J	K	L	M	N	O	
In	156	144	168	60	1158	1133	1764	
Out	78	216	108	72	2544	912	1692	
Total	234	360	276	132	3702	2045	3456	
%	0.47%	0.73%	0.56%	0.27%	7.48%	4.13%	6.99	

Figure 3-1. In-Out Entrance Traffic Statistics of MIXC (6 Hours in Total).

	A	B	C	D	E	F	G	H
In	2022	1902	2454	2232	1050	984	282	1524
Out	2082	2748	294	2382	1140	1002	894	2250
Total	4104	4650	2748	4614	2190	1986	1176	3774
%	16.3%	18.4%	10.9%	18.3%	8.7%	7.7%	4.65%	14.9%

Figure 3-2. In-Out Entrance Traffic Statistics of YHP (6 Hours in Total).

	A	B	C	D	E
In	6583	4596	1593	1722	456
Out	7823	4755	1560	1506	396
Total	14406	9351	3153	3228	852
%	46.5%	30.2%	10.2%	10.4%	2.7%

Figure 3-3. In-Out Entrance Traffic Statistics of KK Mall (6 Hours in Total).

ote the capability of Space Syntax in explaining pedestrian distribution in large public building spaces, as represented by commercial complexes, in order to develop a more accurate analysis and prediction technology for pedestrian distribution based on Space Syntax.

2. CASE Selection

In this paper, three shopping centers situated in the central district of Shenzhen are chosen as the objects to be studied: MIXC, Yitian Holiday Plaza (YHP) and KK Mall. All of these are close to Shennan Avenue, the main road of central Shenzhen, and are also located at the junction of two subway lines. The underground commercial floors in each case are directly connected to the nearby subway stations.

3. Data Collection and Traditional Methods Analysis

For the sake of refraining from being influenced by special commercial activities on the flow of people and eliminating the difficulty of data collection triggered by overcrowded Shenzhen shopping centers during holidays, the human traffic in the three shopping centers above have been measured during working days. Restricted by available human resources, the three cases could not be observed simultaneously. So in the selection of date for measurement, it was ensured that the three shopping centers were observed in clear weather with closely-matched temperatures, and that there were no outsize impacts from large commercial events. From this, the researchers developed two core datasets, including in-out entrance flow statistics as well as snapshot mapd of people flow.

In-out entrance flow statistics: All in-and-out passageways in each shopping center (inlets and outlets connected to the outdoors, subways and garages, as well as access to other buildings are included) are observed for 10 minutes per hour from 13:30 and 16:30 on two working days. The human traffic of these inlets and outlets across 6 hours are then estimated (by extrapolating the human traffic observed during 10 minutes per hour and multiplying this figure times 6) (4).

Snapshot map: In the same period, a real-time snapshot map on all levels of the shopping center is captured by scheduling multi-point synchronized snapshots every hour. These dot-like maps are superimposed to obtain a 6-hour overall snapshot map for the three shopping centers on working days.

Pedestrian density map: For better comparison of the measured data with the analysis results, the eventual human-flow punctuation map is translated into the VGA-

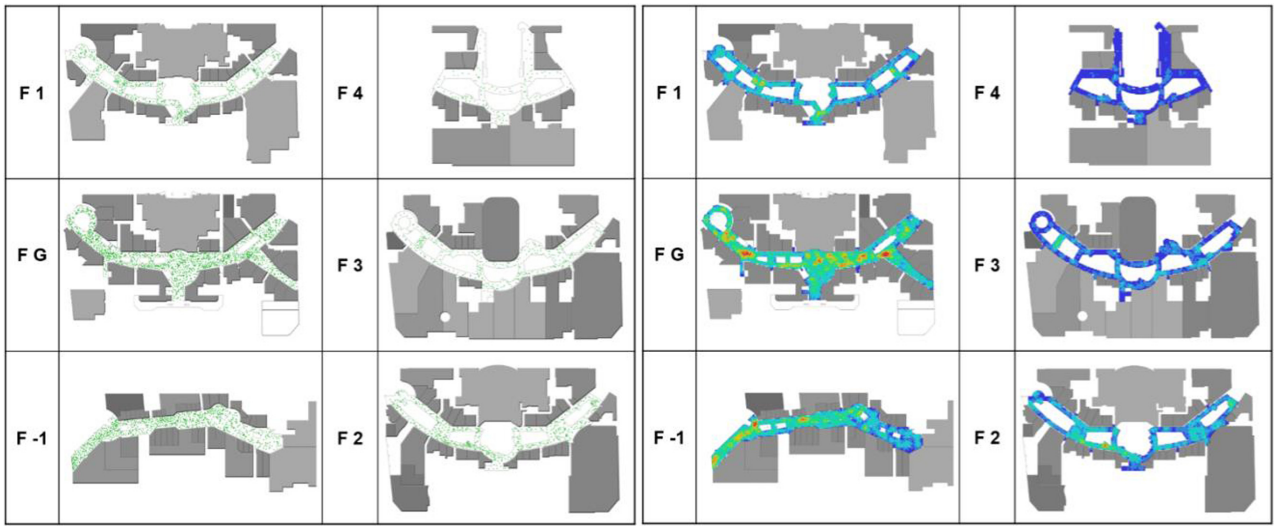


Figure 3-4. Snapshot Map (Left) and Pedestrian Density Map (Right) of MIXC Mall.

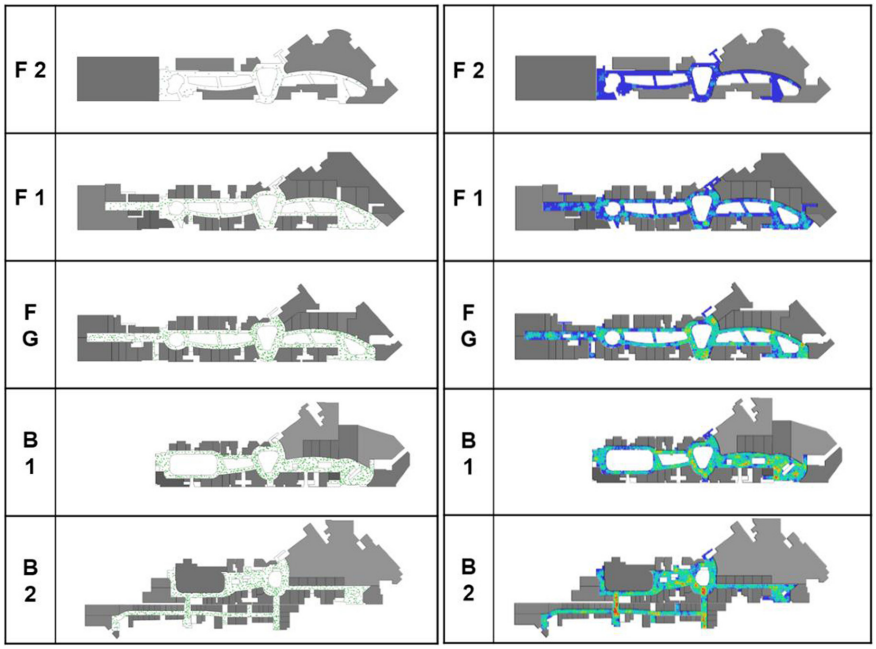


Figure 3-5. Snapshot Map (Left) and Pedestrian Density Map (Right) of YHP.

grid-based flow density map in this pape. (The density index of each grid point is equal to the number of people in a circular region with a radius of 2.5 meters (5) (6)). In this regard, by comparing the correlation coefficient between the analytical prediction values on each grid point and the actual flow density value, the accuracy of different analysis methods for the prediction of human traffic can be tested (4).

By analyzing the public circulation space within the three shopping centers via the traditional VGA analysis technology, the analysis results are shown in Figs. 3-7, 3-8, and 3-9.

From the comparison between the analyzed results and previous measured pedestrian density map, common problems can be found in the three analyses. First of all, the accessibility prediction result of the underground commercial floor is obviously low. In particular, the analysis result of the space adjacent to the subway connection is far lower than the actual situation. Secondly, the accessibility prediction result of the ground floor is higher as a whole, but that near the inlet and outlet is relatively lower, which is also unreasonable.

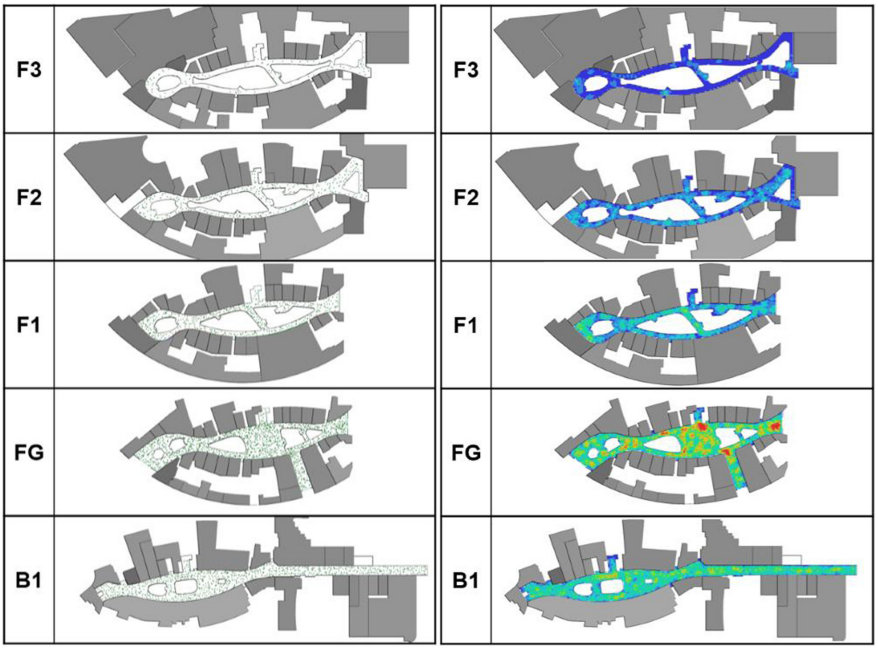


Figure 3-6. Snapshot Map (Left) and Pedestrian Density Map (Right) of KK Mall.

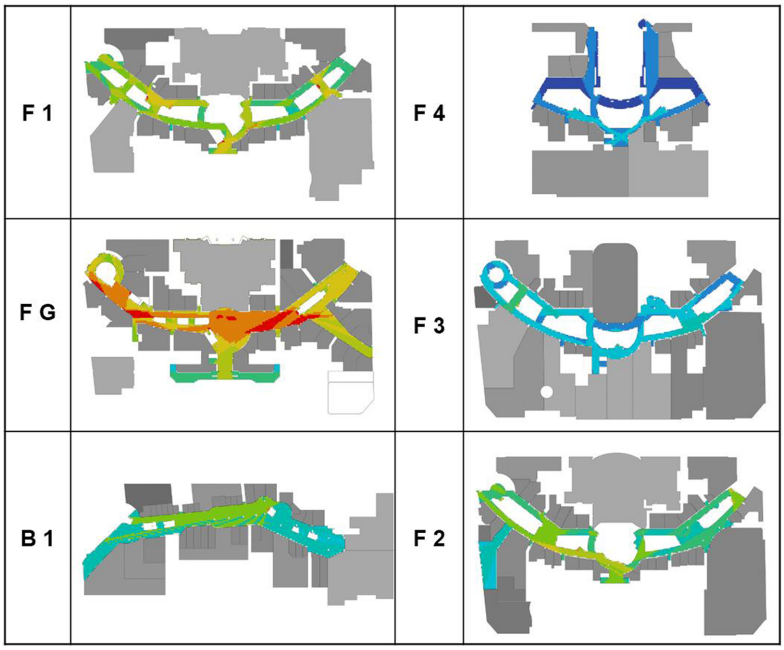


Figure 3-7. Visual integration at knee-level of the circulation spaces in MIXC Mall.

4. Problems in Traditional Analytical Methods

As can be seen in the scatter diagram built with spatial integration and pedestrian density value on the left, the correlation coefficients of R^2 for MIXC, YHP and KK Mall are separately 0.459, 0.177 and 0.515. It is indicated that sometimes (as in the case of YHP), the analysis results are lower than the interpretation of human traffic (like in the case of YHP). Generally speaking, the prediction can be deemed to be successful until R^2 meets with 0.5. In this context, the application value of Spatial Syntax VGA technology in large public buildings such as the shopping centers has been severely affected.

To further analyze the specific problems, it proposed to investigate the space with the largest difference between

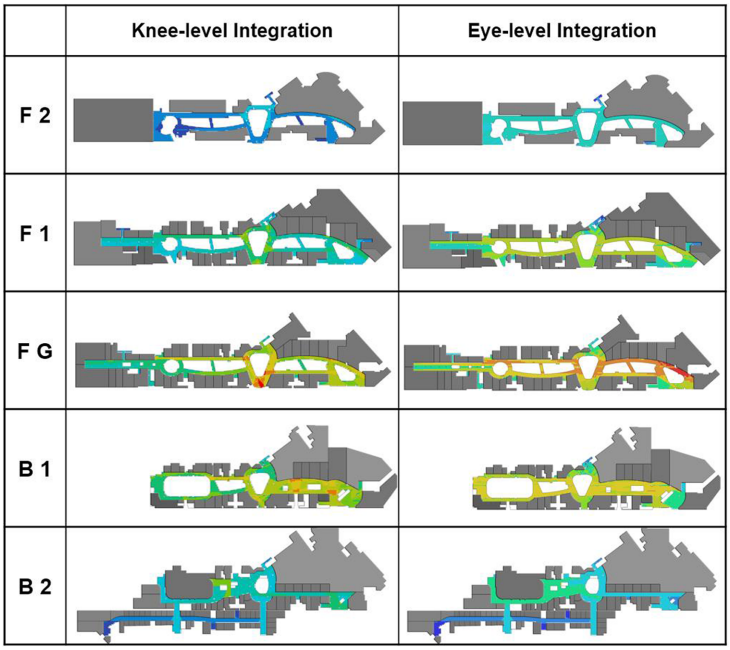


Figure 3-8. Visual integration of the circulation spaces in Yitian Holiday Plaza.

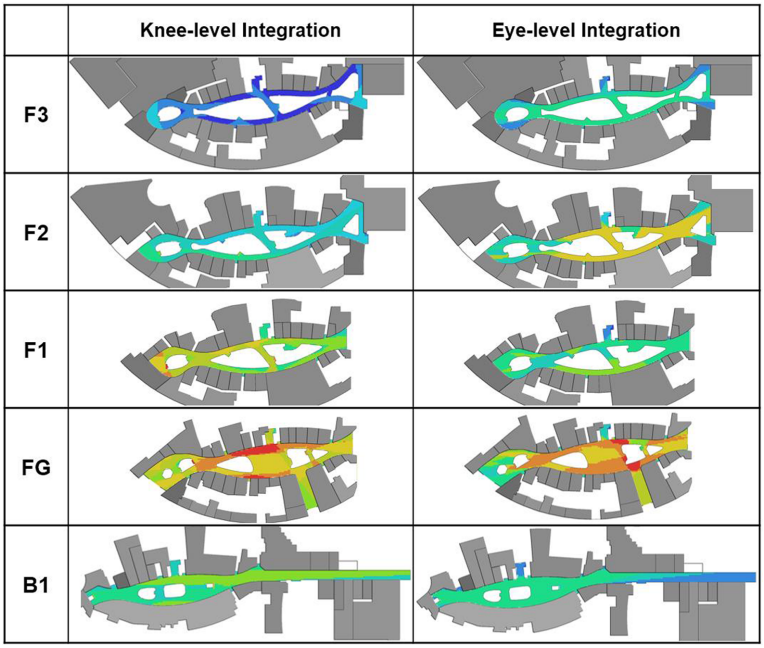


Figure 3-9. Visual integration of the circulation spaces in KK Mall.

the predicted results and the measured data, thus setting the goal for the improvement of analysis technology.

Attributed to the corresponding index function of the scatter diagram and plane in DepthMap, it can be seen where the points most significantly deviated from the tropic in the scatter diagram (red in the scatter chart) with respect to the plane figure (faint yellow in the figure).

As can be seen from the above three figures, after comparing the measured pedestrian density with the predicted results, the outliers are almost all located at entrances close to the first floor and the basement of the shopping centers. Logically, this is triggered by the neglected factor of inlets and outlets in the traditional analysis.

The parts with too-high pedestrian density are generally scattered at the edge of some dynamic line junctions in the space system. To some extent, it may be attributed to the

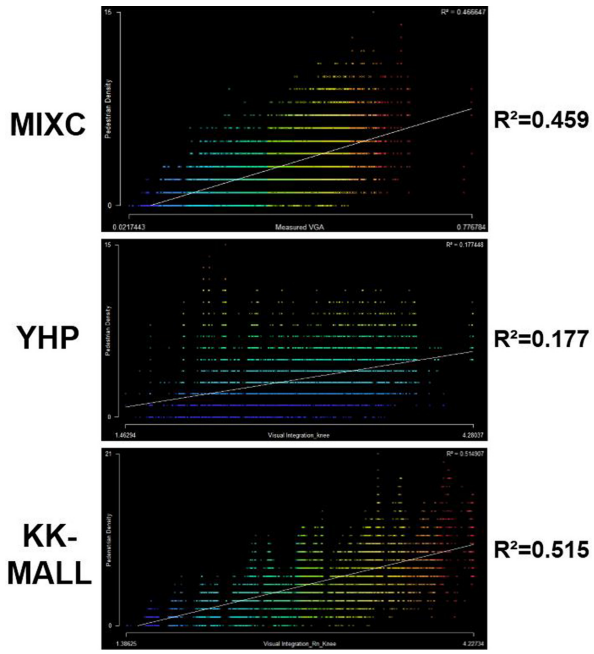


Figure 4-1. Coefficient of determination between pedestrian density and knee-level visual integration.

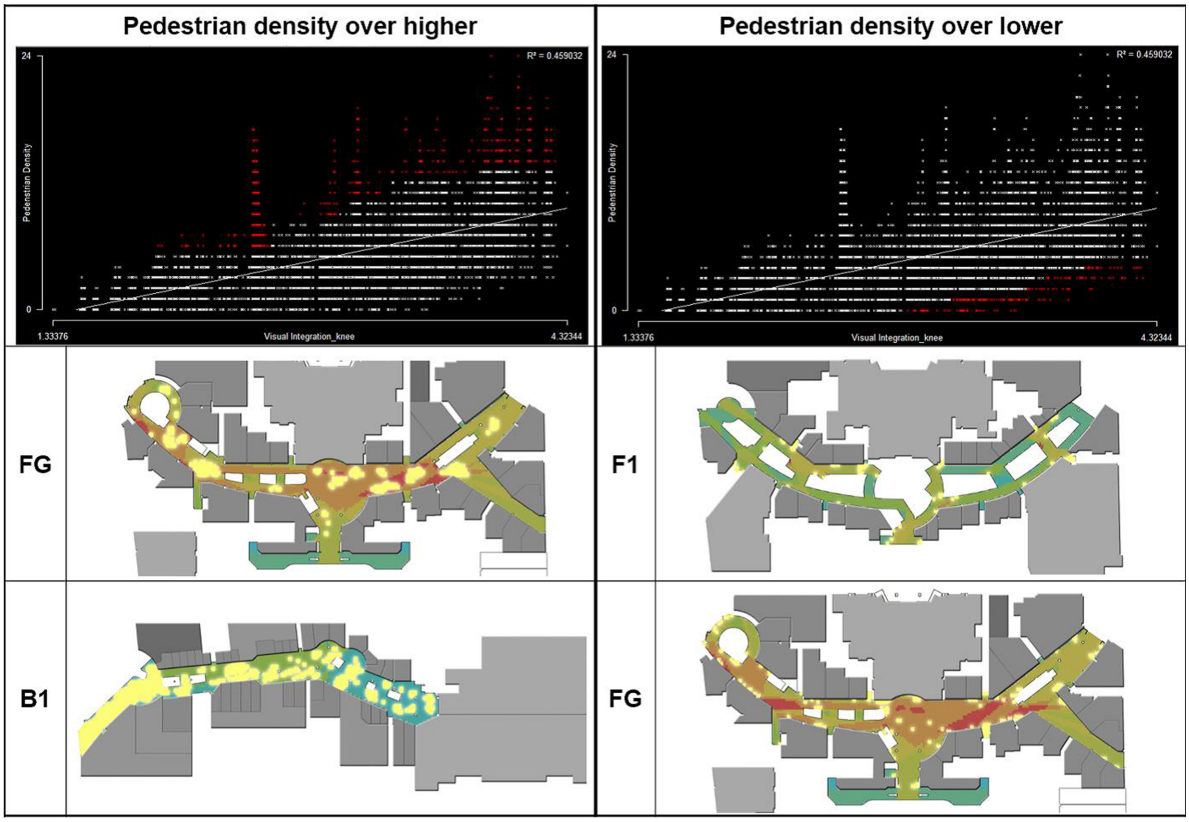


Figure 4-2. The Spaces with the Worst "Correlation" at MIXC Mall.

neglected entrance and exit and higher computational integration surrounding the dynamic intersection point in the traditional analysis.

Consequently, the problems existing in the traditional VGA technology can be obtained: The negligence of the impact of the inlet and outlet on the flow has resulted in

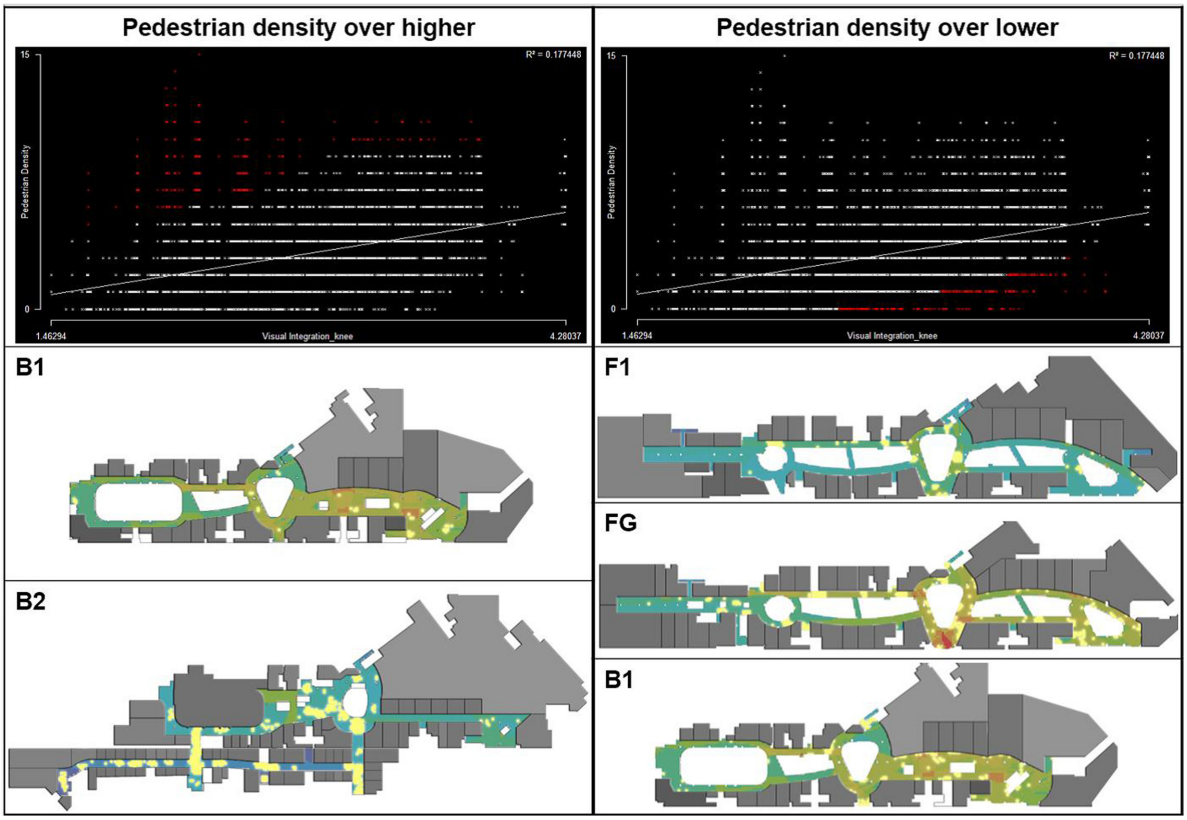


Figure 4-3. The Spaces with the Worst "Correlation" at YHP.

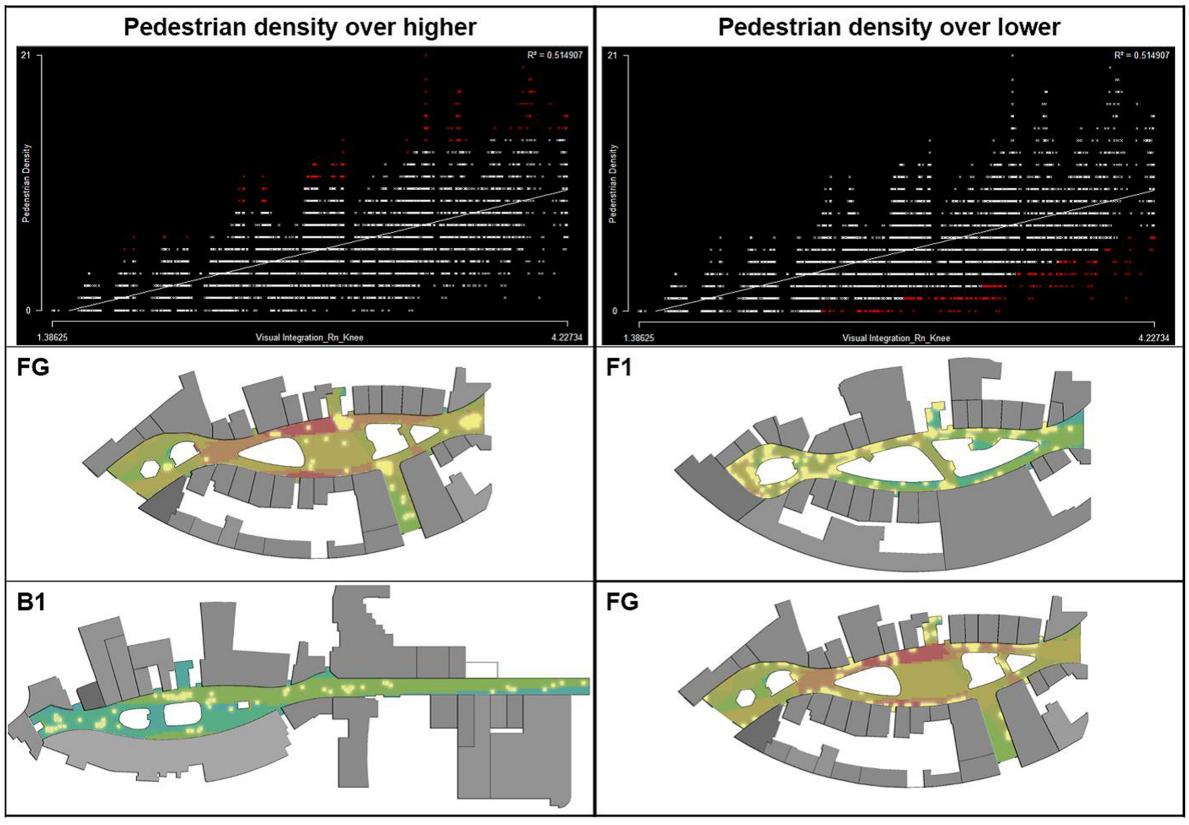


Figure 4-4. The Spaces with the Worst "Correlation" at KK Mall.

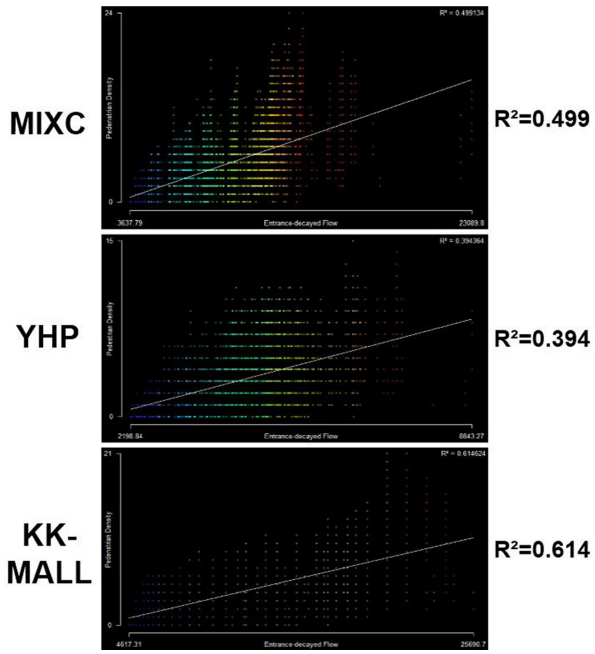


Figure 5-1. The scatter plot between the Entrance-Decayed Flow and the pedestrian density.

the difference between the predicted results and the actual pedestrian density.

In this regard, questions for improving analytical technology are proposed:

How to establish a new analytical method based on the theoretical framework of spatial syntax, while still weighing in on the entrance factor?

How to combine the element of entrance with the traditional VGA technology to improve the accuracy of human traffic prediction?

5. Exploration of New Methods

5.1. Step 1: Algorithm of "Entrance-Decayed Flow"

To address the problems of the ignored entrance flow revealed by the traditional analysis results above, the influence on the pedestrian density in a space unit of a system mainly depends on two elements. They are respectively the distance between the visual step depth of each entrance as well as the people flow in each entrance. On this basis, the authors have introduced a new analysis parameter, namely Entrance-Decayed Flow, and it is calculated (4):

$$F_{ed} = \Sigma \frac{F_n}{D_n + 1}.$$

Of these,

F_{ed}: The value of "Entrance-Decayed Flow" in a VGA grid point;

F_n: The volume of gate count for each entrance.

D_n: The visual step depth from an isovist point to each entrance.

A new analytical value can be calculated by using this formula. The following outcomes can be obtained via the scatter point analysis with this set of results and the measured pedestrian density:

As shown in Fig. 5-1, the correlation coefficient R^2 of "Entrance-Decayed Flow" and pedestrian density is higher than the spatial integration in the cases of three shopping centers. At YHP in particular, R^2 has been lifted to 0.394 from 0.177.

5.2. Step 2: Algorithm of "Weighted Accessibility Index" - Combination between Spatial Integration with Entrance-Decayed Flow

Despite that, the algorithm of "Entrance-Decayed Flow" proposed in this article can predict the pedestrian density more accurately than the traditional spatial integration, the influence of spatial integration on human traffic cannot be ignored based on the theory of spatial syntax and extensive practical research experience.

After separately normalizing the two parameters including integration and entrance-decayed flow, a new algorithm of "weighted accessibility index" for new parameters has been obtained in the form of the weighted calculation (Fig. 5-2):

$$V_m = 7 \cdot NF_{ed} + 3 \cdot \sqrt{NK_{int_k} \cdot NV_{int_e}}$$

With the research results of "weighted accessibility index", the VGA analysis of circulation spaces of the three shopping centers is eventually acquired:

5.3. Analysis & Comparison

After summing up and comparing the correlation coeffi-

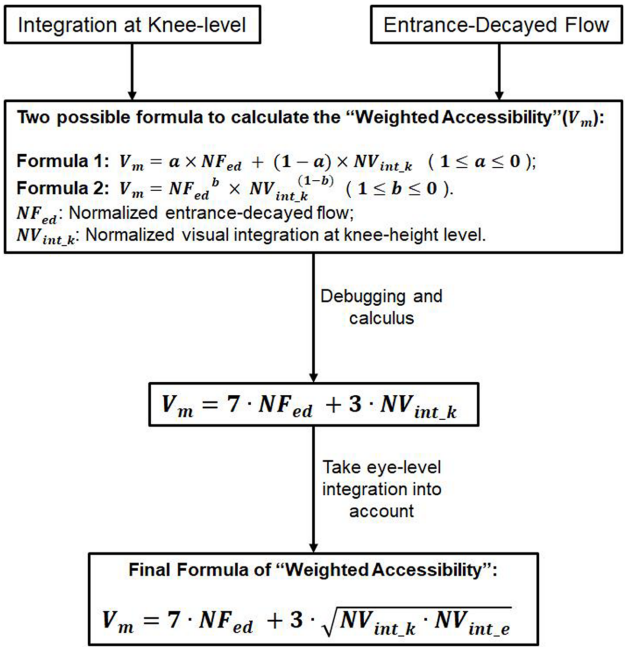


Figure 5-2. Evolution of "Weighted Accessibility" Algorithm.

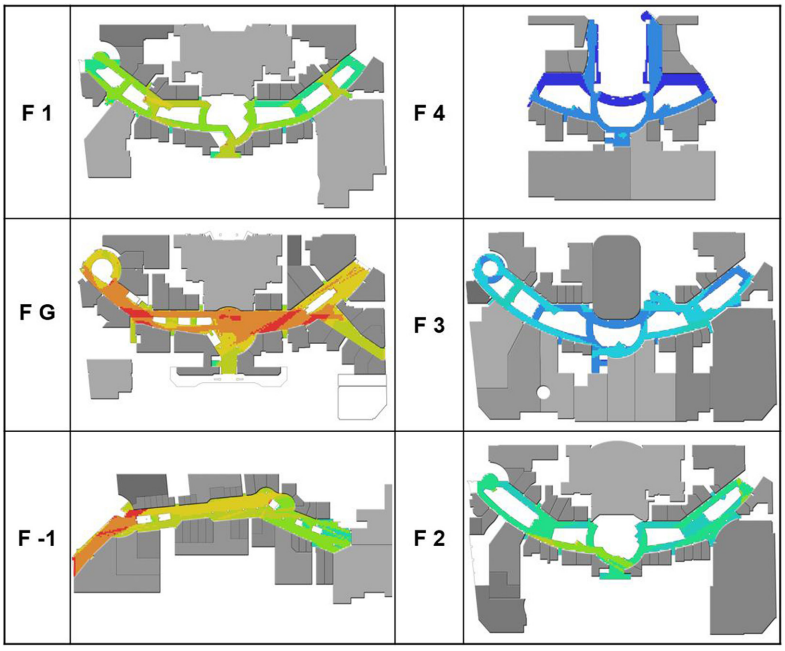


Figure 5-3. "Weighted Accessibility" of the Circulation Spaces of MIXC.

cients of all analytical methods and measured-flow density distribution diagrams mentioned in this paper, the following table is obtained:

As shown in Fig. 5-6, the improved "weighted accessibility index" method has a much higher coincidence between the analysis results and the actual pedestrian density in the three cases than is seen in that of various traditional analysis methods. In either case, the ratio of increase is more than 20%. The correlation coefficient R^2 of MIXC, YHP and KK Mall has lifted from 0.46 to 0.55, from 0.18 to 0.47, and from 0.51 to 0.64 in each respective location.

Nevertheless, on the surface of the final test, the introduction of accessibility at the sight level into the formula fails to obviously improve the correlation coefficient, which may be attributed to two factors. For one thing, the influence of sight accessibility on human traffic is much

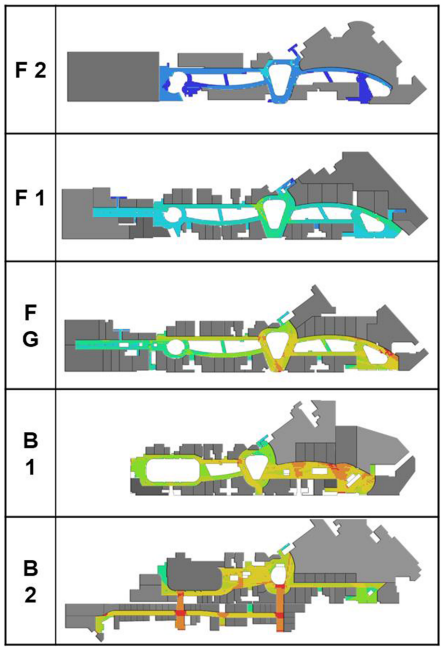


Figure 5-4. "Weighted Accessibility" of the Circulation Spaces of YHP.

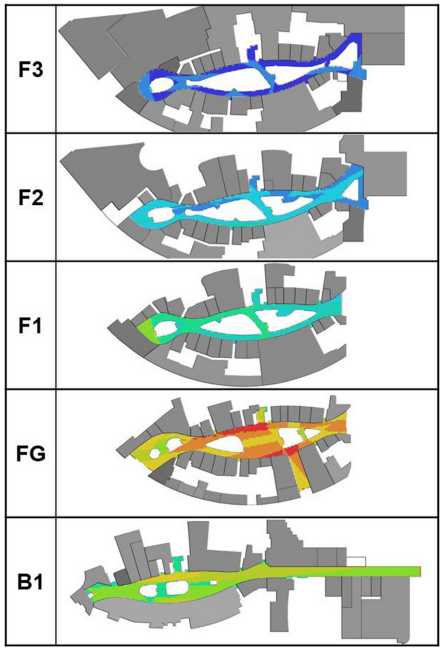


Figure 5-5. "Weighted Accessibility" of the Circulation Spaces of KK Mall.

The R^2 with pedestrian density	MIXC	YHP	KKMALL
Visual integration (at eye-level)	0.0220795	0.0244973	0.145707
Visual integration (at knee-level)	0.459031	0.177448	0.514907
Visual step depth (all entrances)	0.293559	0.38786	0.523235
Entrance-decayed flow	0.499134	0.394364	0.614624
$V_m = 7 \cdot NF_{ed} + 3 \cdot NV_{int_k}$	0.545255	0.46044	0.631013
$V_m = 7 \cdot NF_{ed} + 3 \cdot \sqrt{NV_{int_k} \cdot NV_{int_e}}$	0.550766	0.466647	0.64035

Figure 5-6. Comparison of All Analytical Methods.

less than that of other factors; for example it does not account for the purposeful attraction of some space or function, nor for the impact of business form and scale (reflected by specifically using store area and active frontage length as parameters) on the distribution of flow. The other factor is that there are technical barriers existing in the current analysis, and it may be wrong to add sight accessibility into the formula in this way.

6. Conclusion

Through the comparative study of traditional VGA technology in Space Syntax and results from on-site testing, this dissertation discovers the key defect of current technology, and promotes the correlation between analysis results and the pedestrian patterns by bringing the collection of pedestrian statistics at entrances, specifically, into the spatial analysis of commercial complex.

The new methodology is applicable for the management and operation of shopping centers as well as the secondary design of spatial layout: such as predicting and analyzing the pedestrian patterns in public space so as to estimate the commercial values of stores, and to provide evidence for business plans. Meanwhile, this set of results can also inform the interior design after the shopping centers are completed. For example, it allows researchers to seek out the design deficiency of factors such as landscape or the effectiveness of temporary retailing stores and venues for short-term campaigns in public space, in order to improve the distribution of pedestrians by arranging anchor tenants and public service facilities in a way that would be more attractive to customers.

With the advancement of analysis technology, analysis and research of building space is playing an increasingly important role in assisting management of commercial complex in cities with high population densities. With a

relatively accurate measure of pedestrian density, the businesses can be better distributed in advance, which not only improves commercial efficiency, but also benefits the customers by maximizing the utilization of space. These are inevitable trends for commercial building space in high-density cities.

However, the new methodology promoted by this research still has its limitations and leaves room for improvement:

Firstly, the case study focuses on one type. All the three cases are located in high-density areas of Shenzhen, and they are all shopping centers with similar circulation designs. Changing the object into other architectures or shopping centers of other types or with different background, the formula of this dissertation needs more in-depth research and many more cases to prove its accuracy.

Secondly, the pedestrian statistics used in the research are testing data of actual flows in built projects. The new methodology won't work without such statistics. For management departments, these statistics are easily accessible, which allows the methodology to estimate the value of commercial space. Burt for those projects that are still under construction, designers and developers might need the analysis technology of Space Syntax to predict the pedestrian movement of surrounding cities. Although this technology has been proved to be a mature application, the question is, how to connect it with the new methodology presented by this dissertation? This is still a subject awaiting future research and exploration.

Last but not least, the improvement of this methodology is based on the technology of two-dimensional VGA. The biggest limitation of VGA in Space Syntax is that it still reslies on the planar pattern of two dimensions. However, for multistoried building space, this issue can only be temporarily solved by connecting the vertical circulations on each floor. In this case, the outcome is inevitably lack of precision, which is also the highest technical barrier of Space Syntax. The Space Syntax Laboratory of UCL has been developing VGA under three-dimensional pattern (7, 8). Whether the improvement methodology of this dissertation can facilitate the development of 3D-VGA is still a subject open to arguments and communications of researchers at home and abroad.

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