PAPER REF # 8094
Proceedings: Eighth International Space Syntax Symposium
Edited by M. Greene, J. Reyes and A. Castro. Santiago de Chile: PUC, 2012.

A STUDY ABOUT THE PEDESTRIAN DISTRIBUTION IN THE COMMERCIAL BUILDINGS BY THE LOCATION OF STORES AND THE STRUCTURE OF THE WALKING SPACE

AUTHOR: **Masaya FUJITANI**
Graduate school of Science and Technology, Keio University, Japan
e-mail: m.fujitani1771@gmail.com

Tatsuya KISHIMOTO
Department of System Design Engineering, Keio University, Japan
e-mail: kishimoto@sd.keio.ac.jp

KEYWORDS: *Visibility Graph Analysis, Commercial Building, Store Floor Areas, Multiple Regression Analysis, Models*

THEME: Methodological Development and Modeling

ABSTRACT

Most buildings are designed by the architects with subjective judgment. It is safe to say that the configuration of the space gives people big influence. Therefore, in addition to a subjective judgment, the quantitative technique of evaluation is also necessary. In this study, we made calculable models to the amount of the people in the commercial buildings where configuration of the space is related to the sales. And we estimated the distribution of the people quantitatively. This model will be useful to evaluate space with numerical value.

To make accurate models we classified the commercial buildings into two types of building forms. One is the commercial buildings extending to the vertical direction, and the other is the commercial building extending to the horizontal direction. We made models taking the two different into account. For making the models, first of all we did a multiple regression analysis with numerical values of the space syntax using visibility graph analysis and the distribution of the people we observed in the commercial buildings. As numerical values of the space syntax, we used Connectivity, Clustering Coefficient, VSD from entrance, and Integration Value. Next, the index that combined store floor areas with VSD using the way of thinking of the gravity model was made. And the indexes of existence of atriums, elevators, and benches were also made. Then, multiple regression analysis with them was performed. Then we found out that these indexes are very important because it was a more accurate result. Next, we integrated the explanatory variables of the models to reducing the influence of multicollinearity. Finally, we made the models.

From these models, the differences were found out in the distribution of the people. And, from the result of the multiple regression analysis, it seems that the connections from the entrance give the people's behavior big influence in the commercial buildings extending to the vertical direction. In the commercial buildings extending to the horizontal direction, it seems that the store floor areas give the people's behavior big influence. The feature of the people's behavior was become clear in the commercial buildings by making the models separately by the types of building forms.

1. INTRODUCTION

In recent years, commercial buildings have advanced to the suburbs and they have become a big scale. Moreover, there are many commercial buildings that have charm and individuality. By placing the squares and the pedestrian spaces, such commercial buildings are often used as a place where people can relax. Those spaces are aimed to gain more profits by making people migrate in the commercial buildings. It is safe to say that the configuration of the space gives people big influence on their behavior. Therefore, in addition to a designer's subjective planning, the quantitative technique of evaluation of spatial configuration is also necessary.

In this study, we made calculable models to the amount of the people in the commercial buildings where configuration of the space is related to the sales. And we estimated the distribution of the people quantitatively. This model will be useful to evaluate the buildings' space with numerical value.

To make accurate models we classified the commercial buildings into two types of building forms. One is the commercial buildings extending to the vertical direction, and the other is the commercial building extending to the horizontal direction.

From the results of the models, we considered the characteristics of pedestrian behavior in the commercial buildings. And I compared to behavioral differences in two types of building forms.

The past researches related to this study are below.

Parvin, A et al (2007) analyzed relations of pedestrian flow and visual accessibility in a public area and its circumstances in a complex facility by applying space syntax theory (henceforth, SS theory). They focused on Telford Gardens /Plazas in Hong Kong, which includes one railroad station, a residential section, and commercial land. The number of pedestrian flow was analyzed mainly by the index of Visual and Spatial Integration Value. As a result, it came to be clear that "visibility" in a multi-layer space has an important on the pedestrian flow.As research in the commercial; An et al (2003) examined the relationship between sales and seeking behavior. In this study, as an element of spatial planning and evaluation of large-scale commercial buildings, the concept of seeking behavior is applicable.

However, it is still very few that the research which was focused on the differences in the types of building forms and considering the influences of shops.

Then this study has two features. First, it investigates correlations between pedestrian distributions in two types of commercial building forms and various indexes of space syntax theory. Second, it considered the floor size of shops as influences of shops.

2. METHOD

2.1. Study area

In selecting the two types of commercial buildings, two commercial buildings were selected in each of the typical commercial buildings in Kanagawa Prefecture.

Commercial building A (extending to the horizontal direction)

Commercial building A has five-story. 2F is connected directly to the station.

And it consists of a large floor area, it can be imaged that pedestrians mainly move to the horizontal direction.

Next, because the boundary between the station and commercial building is vagueness, the study area of Commercial building A come to be the shapes as seen in Figure 1.

Also, because the entrances are seems to be a major impact on pedestrians, mark the entrances of the Commercial building A in Figure 1. There are 19 entrances in Commercial building A.10 entrances were connected directly to the parking lot.

Commercial building B (extending to the vertical direction)

Commercial building B is a building which was built over a railroad station. It has eleven-story. And it is only accessible from near the ground.

As the features of the Commercial building B, the pedestrians often use elevators and escalators.

Next, like the Commercial building A, the study area of Commercial building B come to be the shapes as seen in Figure 1.

Because pedestrians cannot move freely, 8F, 9F, and a part of 6F were removed from the study area. There are 9 entrances in Commercial building B.

We compared the behavioral differences of pedestrians between the two types of building forms by researching Commercial building A and Commercial building B.

2.2. Summary of investigation and analysis method

The actual amount of pedestrian distribution in Commercial building A was investigated in September and October, 2010. The Commercial building B was investigated in July, 2010.

In analyzing by Depthmap, it becomes the result of only considering the connection in the plane. So the connections between the floor (elevators, escalators, and stairs) were connected in Depthmap. In addition, in the connections between the floors, considering the real connection, one step was added. And, Because Depthmap output is divided by a segment of 1m × 1m plan, to compare the output with the pedestrian investigation, common analysis area is needed.

Analysis area was determined by caring below.

• Take a large area as possible.
•Where the result of Depthmap was significant changing, analysis area was divided.

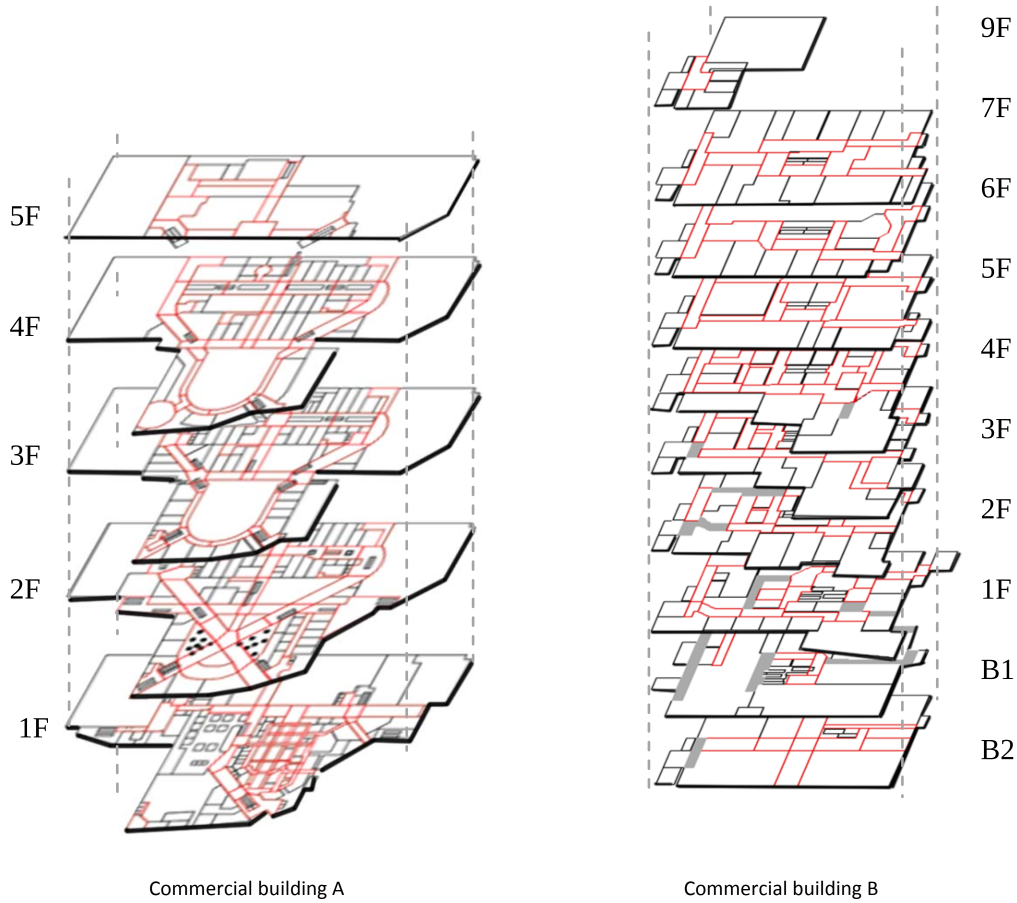


FIGURE 1: Study area of each commercial building

After that, the strength of each index explaining the pedestrian distribution can be evaluated with multiple regression analysis, and the behavioral differences of pedestrians between the two types of building forms are analyzed. In a multiple regression, the purpose variable is the population density per unit obtained by investigation, and the explaining variable is each index used by VGA.

3. ACTUAL PEDESTRIAN DISTRIBUTION

In order to measure the pedestrian distribution, investigations were conducted by each commercial building. In this study, so as not to nuisance, pedestrian distribution was plotted while walking on a certain route.

And to make it easy to plot the pedestrians, the whole area of each commercial building was divided. The commercial building A was divided into 152 zones. The commercial building B was divided into 115 zones. In each zone, actual pedestrian distribution at that time was plotted in the drawing.

The investigation was conducted three times in each commercial building.

In the commercial building A, investigation day and the weather are as follows.

2010/9/12(Fine), 9/19(Fine), 10/9(Cloud)

In the commercial building B, those are as follows.

2010/7/11(Cloud), 7/25(Fine), 7/25(Fine)

Figure 2 shows the population density per unit.

The population density per unit was high in 1~4F in commercial building A (see Figure 2). There are many shops there. Pedestrians were stopping and shopping at these shops. In addition, it is also possible to shop while moving the floors, because there are many escalators.

The other side, it is clear that the population density per unit is high in the center of the commercial building B (see Figure 2). In addition, the average of the population density per unit of the commercial building B is higher than commercial building A. It is considered that the distribution of pedestrians was concentrated. The reason is that the commercial building B has small floor areas.

And the pedestrians determine the route of shopping by using the escalator in the center of the plan. So the population density per unit is high in the center of the commercial building B.

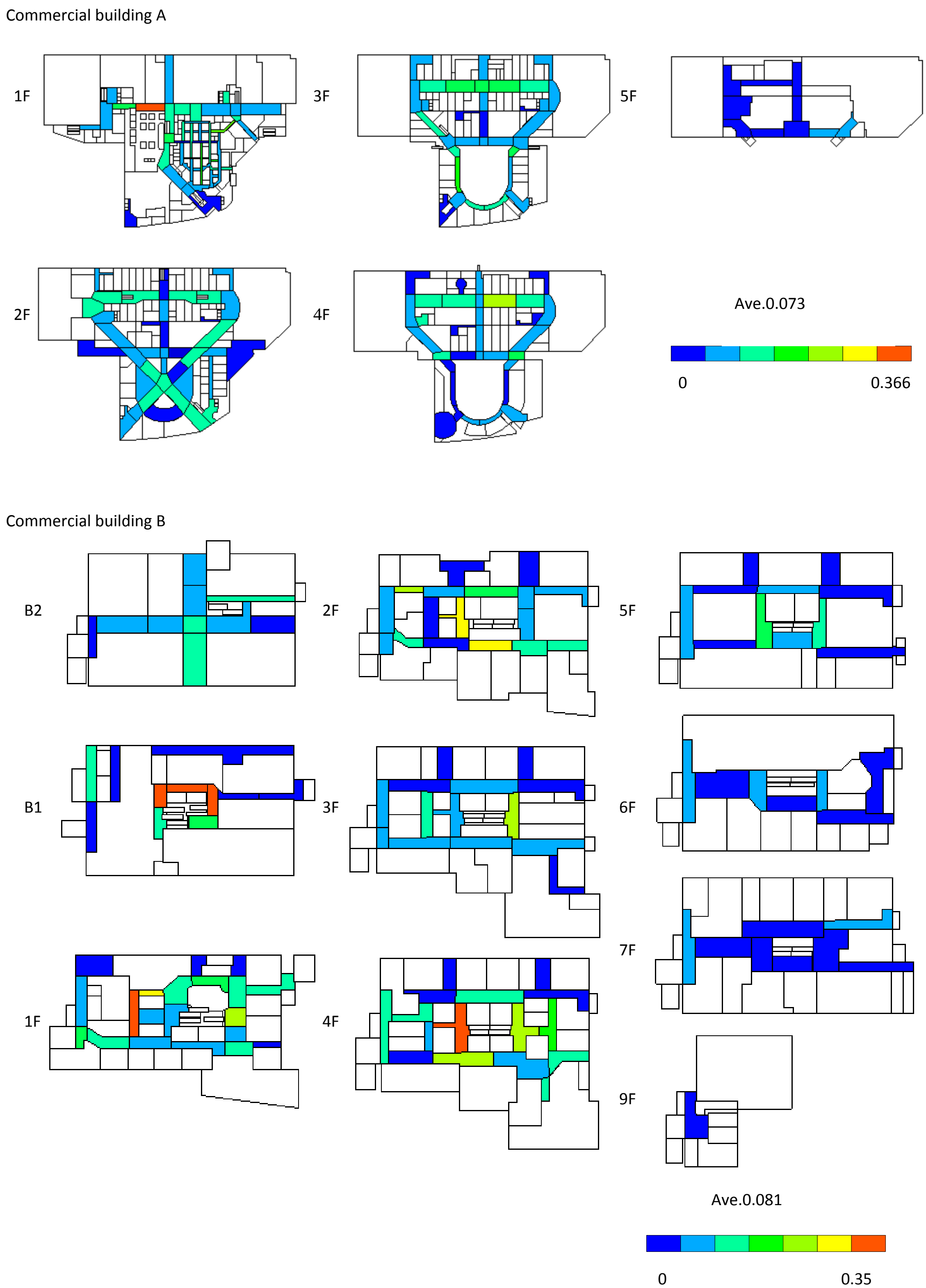


FIGURE 2: the population density per unit

4. SPATIAL ANALYSIS

Spatial configuration was analyzed by Visual Graph Analysis of Depthmap.

Connectivity, Clustering Coefficient, Integration, Visual Step Depth (VSD) were used as the indexes in this study. In addition, using a floor area of shops and VSD, determined the impact of the store because we considered that the stores have a significant impact on the behavior of pedestrians. In concrete terms, the store floor areas were used as the index of the impact of shops. The impact of the store at the place was calculated as this index by adding the sum of the floor areas of the shops where the pedestrians are able to go from the place in specific VSD. (see Figure3).

In this study, VSD = 1, VSD = 2 were taken as specific VSD.

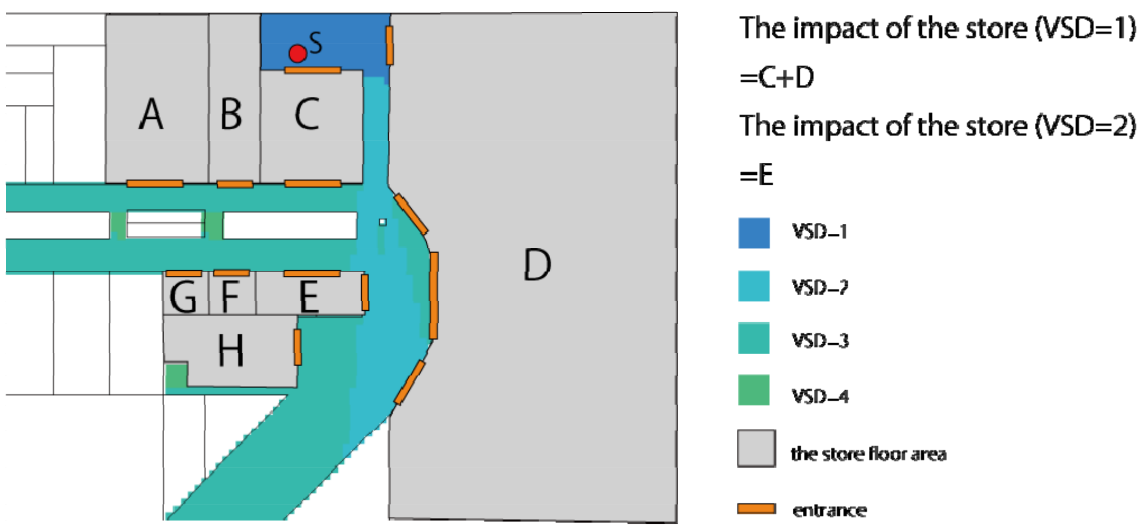


FIGURE 3: Calculation method of the impact of the store at S

The result of Connectivity, Clustering Coefficient, Integration, the store floor areas (VSD = 1), and the store floor areas (VSD = 2) were shown respectively.

Connectivity

When Connectivity is high in particular space, it means that the visible range from the space is wide, or multi directions are visible. In the commercial building A, the Connectivity value was high at the part of the square in 2F (see Figure 4). On the contrary, the spaces which have elevators and restrooms were relatively low values of connectivity. For this space, the signs are needed. Little distribution was investigated and actual users are also few in those spaces. It can be attributed to visible narrowness that has a negative impact on a pedestrian channel selection or staying. In the commercial building B, the average of Connectivity was lower than commercial building A (see Figure 4).As a point in common with commercial building A, the value of Connectivity was low near the elevators and the restrooms.

Clustering Coefficient

Where the space is high value of the Clustering Coefficient, the space is a convex shape. The space near the elevators and restrooms in the commercial buildings the value is high. On the contrary, the value at the square of 2F in the commercial building A was lower (see Figure 5).

Integration (Global)

If Visual Integration Value is higher, it means the zone is easier to reach from any networked spaces. And pedestrians choose a route where integration value is higher.

Figure 6 shows that the average of the Integration value in the commercial building A was higher than commercial building B. It means that the commercial building A has good access. The reason is that the commercial building A was extending to the horizontal direction and pedestrians can move easily. And there are many escalators, stairs and elevators. The commercial building A was high vertical ties.

In the commercial building B, the integration value was relatively high in the center of the plan. On the contrary, the integration value was low in 7F and 9F. There are specialist shops. Most of pedestrians come to these shops with purpose.

Store floor areas (VSD = 1)

If Store floor areas Value (VSD = 1) are higher, the pedestrians can shop at various shops in one step. In the commercial building A, the value of a main passage in 1F is high (see Figure 7). The reason is that the passage is wide and the field of view also wide. So it is safe to say that many pedestrians are attracted to the shops in the visible range. In the commercial building B, the value was relatively high in the wide passage in B1F.

Store floor areas (VSD = 2)

If Store floor areas Value (VSD = 2) are higher, many pedestrians are attracted to the shops. By being two steps, the pedestrians became to go to a lot of shops. Figure 8 shows that the value is higher than the results of VSD = 1. In particular, the value was increased on a large scale in 1~4F of the commercial building A. There are a lot of stores in 1~4F.

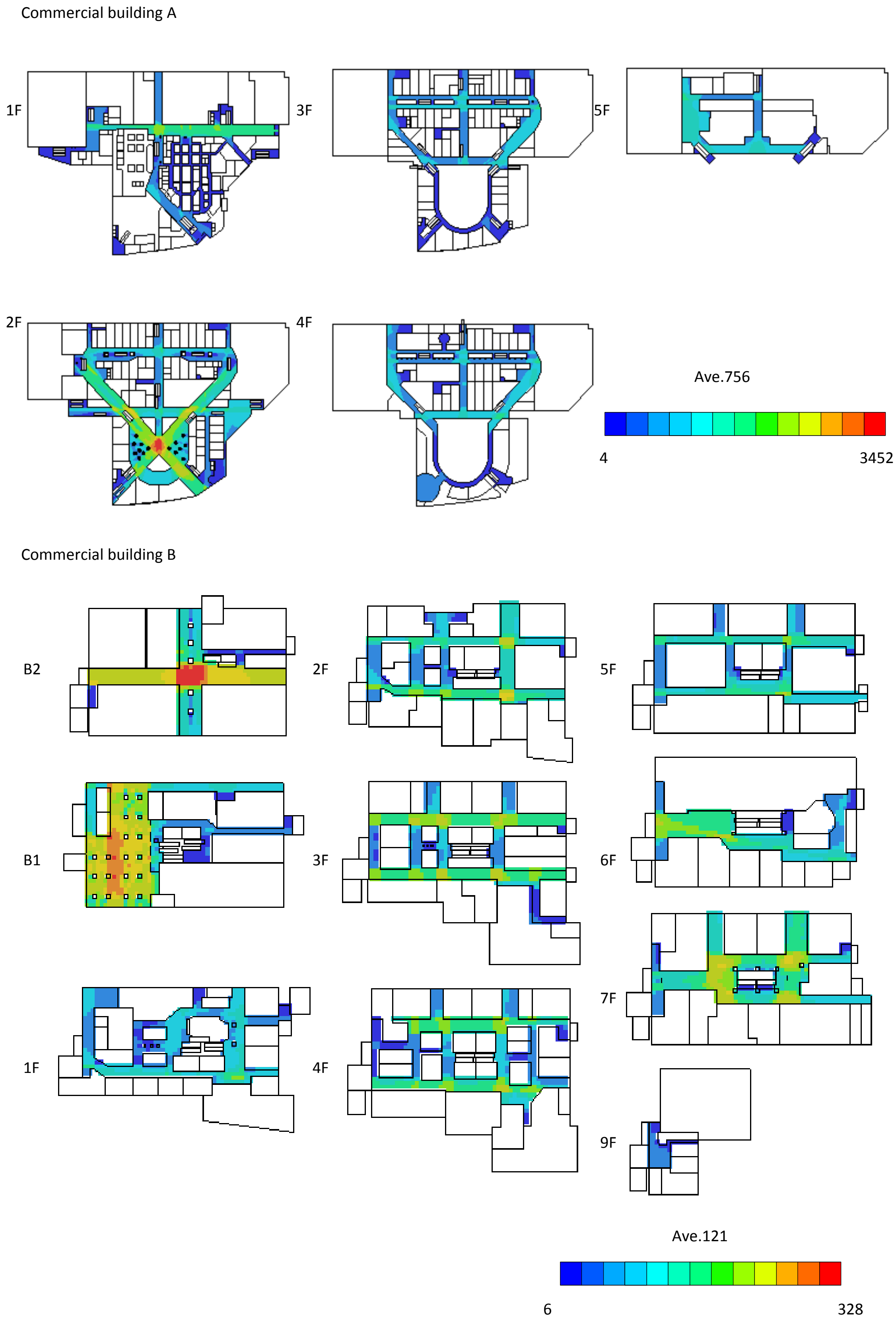
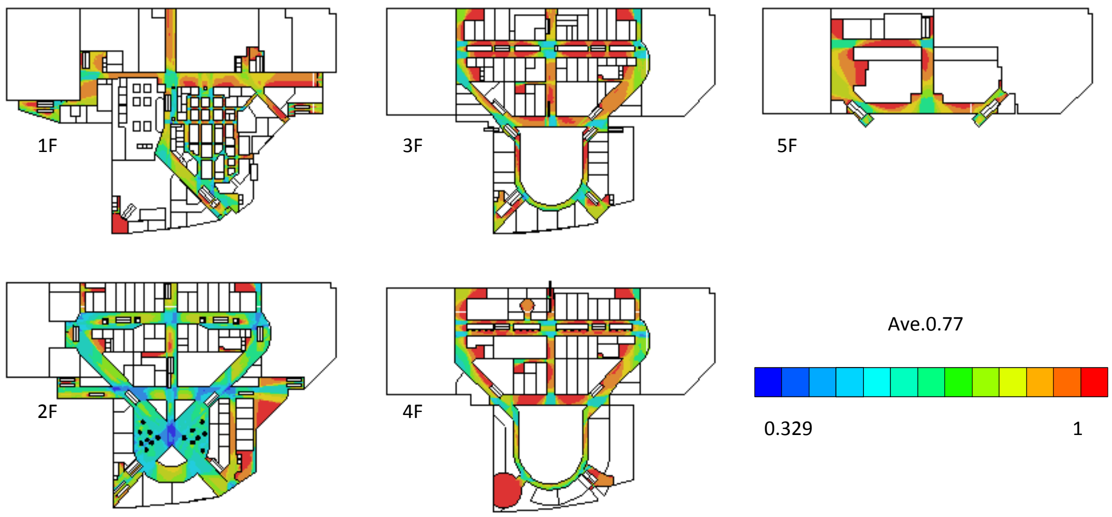


FIGURE 4: The result of Connectivity of Visibility Graph Analysis

Commercial building A



Commercial building B

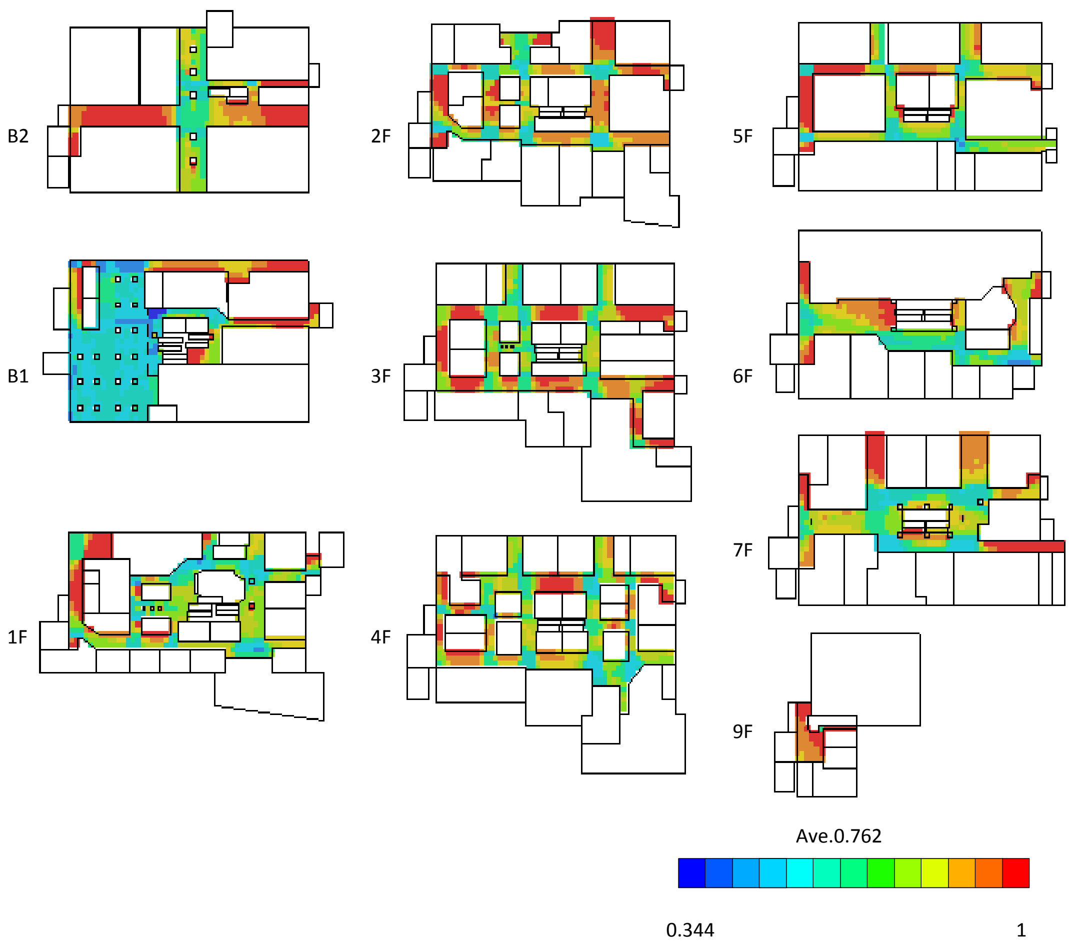


FIGURE 5: The result of Clustering Coefficient of Visibility Graph Analysis

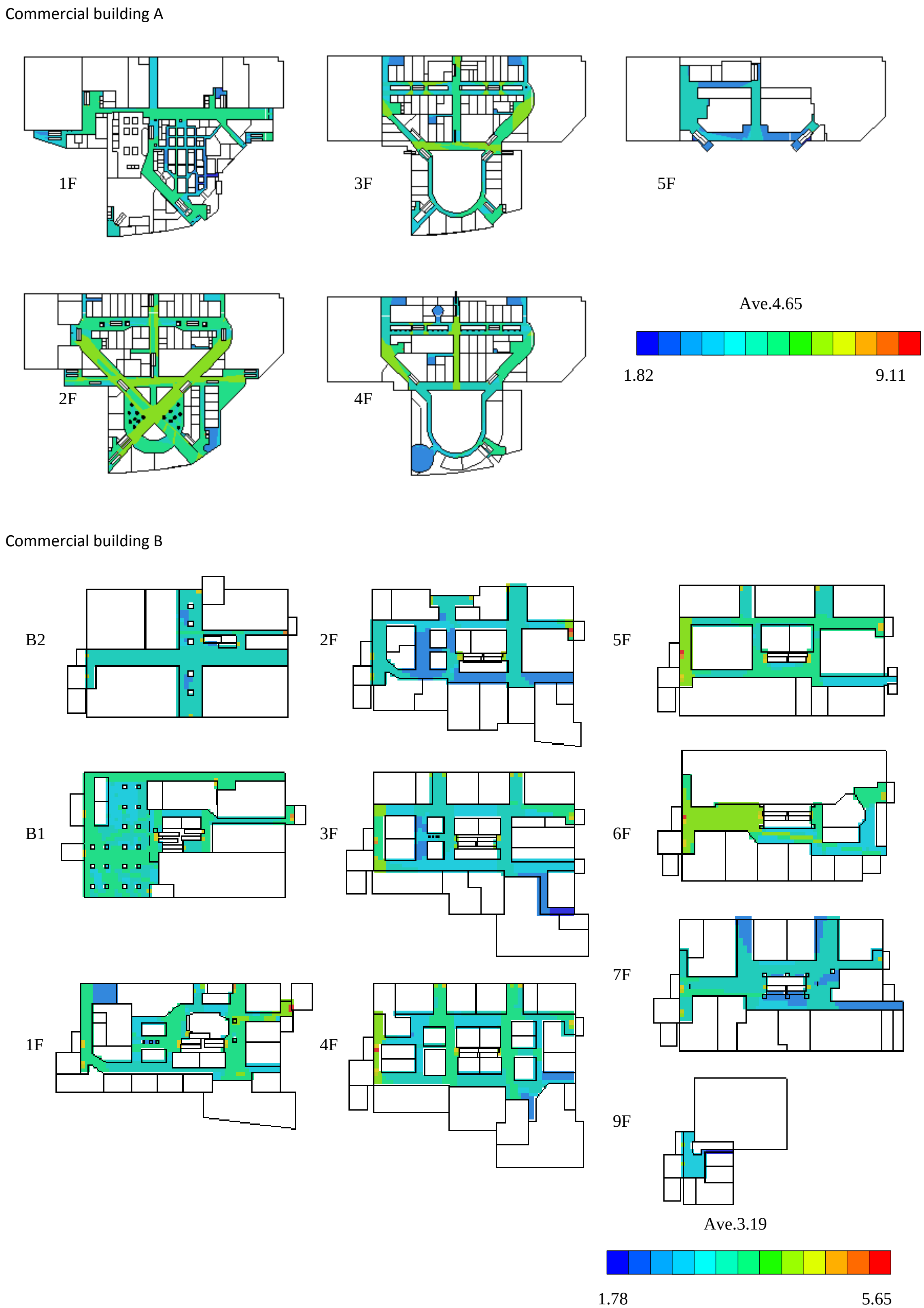


FIGURE 6: The result of Integration (Global) of Visibility Graph Analysis

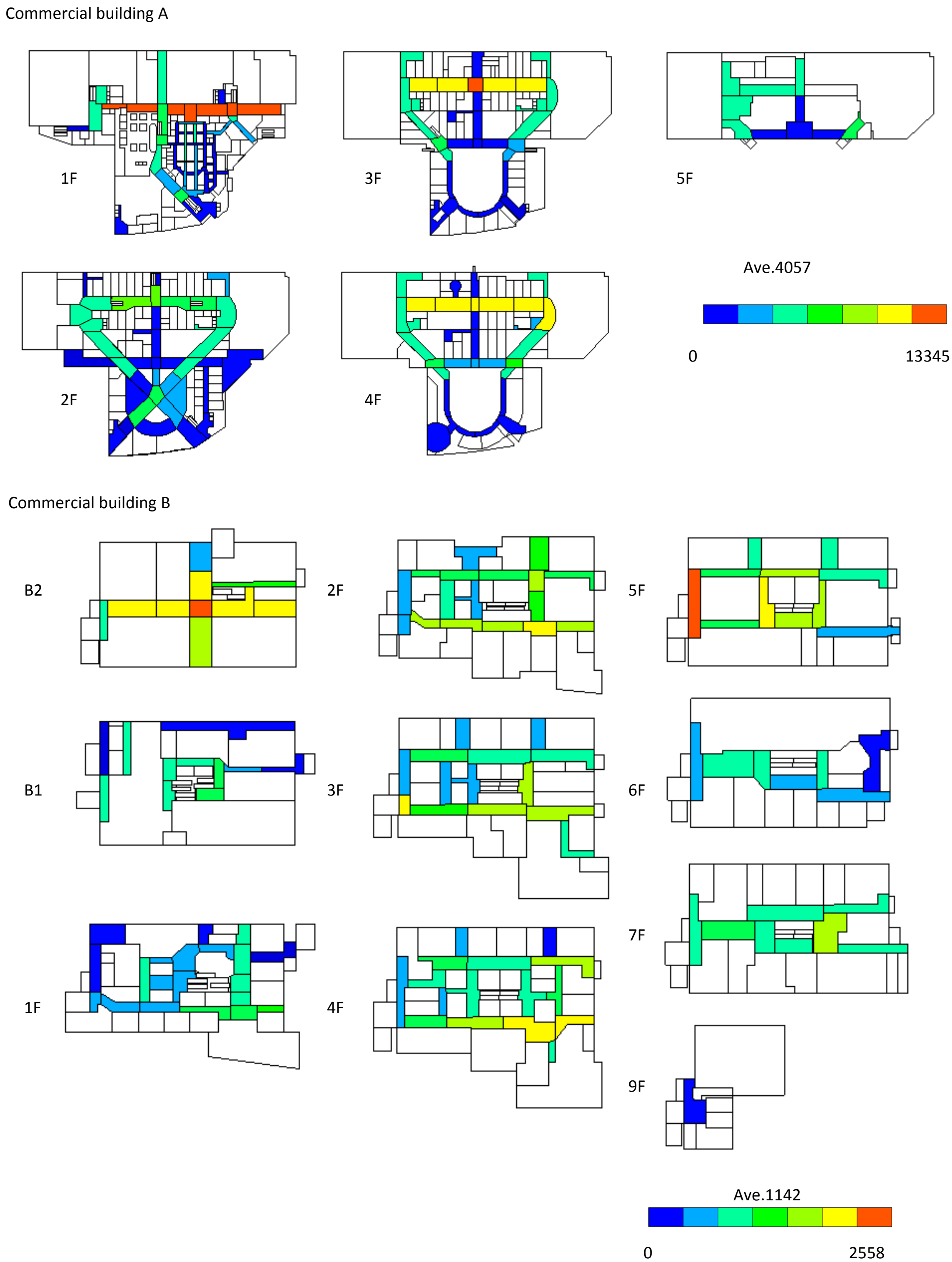
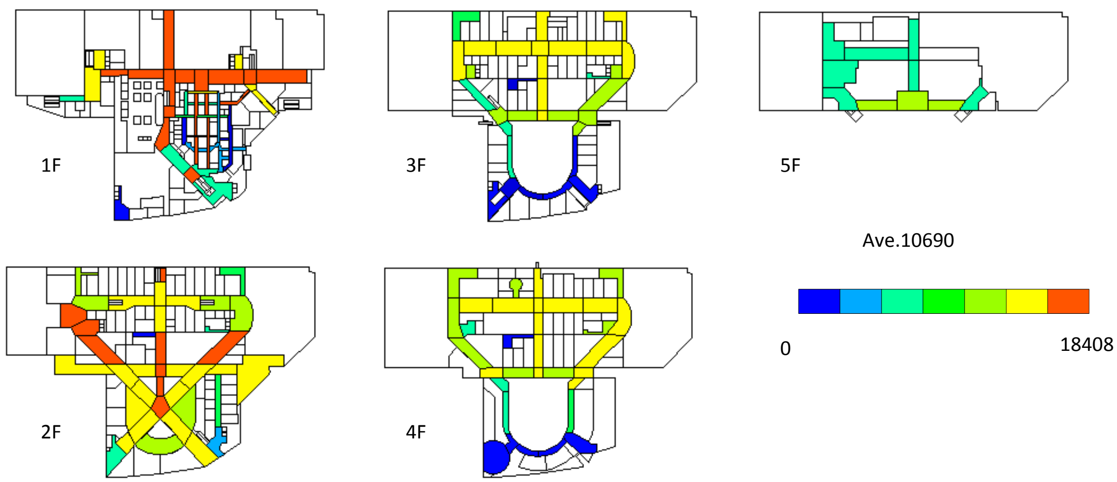


FIGURE 7: The result of Store floor areas (VSD = 1)

Commercial building A



Commercial building B

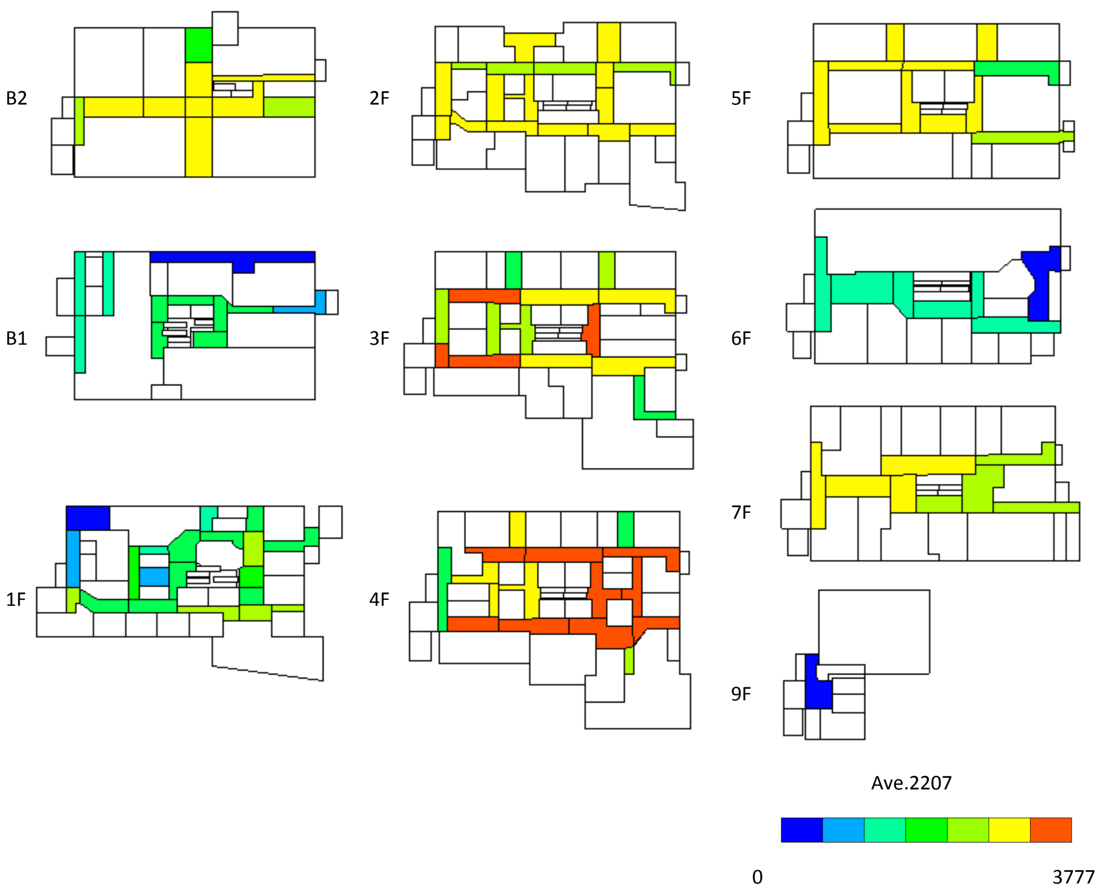


FIGURE 8: The result of Store floor areas (VSD = 2)

5. MULTIPLE REGRESSION ANALYSIS

The strength of each index explaining the pedestrian distribution can be evaluated with multiple regression analysis, and the behavioral differences of pedestrians between the two types of building forms are analyzed. In a multiple regression, the purpose variable is the population density per unit obtained by investigation, and the explaining variable is each index used by VGA.

First of all, minimum value and mean value from each entrance was added to VSD analyzed with VGA, min of minimum and mean of mean were applied to each initial, and they were assumed min. VSD, and mean VSD.

Second, the store floor areas (VSD = 1) was added to the quarter of the store floor areas (VSD = 2) as the impact of the store. It was based on Gravity model.

Then the square of min. VSD, mean VSD, and the difference from the main entrances were added as the explaining variable.

Furthermore, 3 dummy variables (atrium, elevator, and bench) were added to the explaining variable because it was thought that these also affect the pedestrian behavior.

After all, two models were made with such variables. One is the model of the commercial building A, and the other is the model of the commercial building B. SPSS was used to build the models, and forced entry method was adopted.

5.1. The result of multiple regression analysis

To making the models accurately, the areas less than 150 square meters in the commercial building A were excluded as the errors.

And the areas less than 60 square meters in the commercial building B were also excluded. Because it was thought that the error was generated by one pedestrian in the small area.

The multiple correlation coefficient and contribution rate of each model are shown in Table1. The results of analyzing the model of the commercial building A and the model of the commercial building B are shown in Table 2, Table 3.

The correlation coefficient of a model of the commercial building A was 0.833(see Table1). And the contribution rate of a model of the commercial building A was 0.694. There is a strong correlation between the actual data and the model.

The correlation coefficient of a model of the commercial building B was 0.662(see Table1). And the contribution rate of a model of the commercial building A was 0.438. There is some correlation. But there is multicolinearity among the explaining variables of these models. To solve this problem, perform the intensification of the explaining variables.

TABLE 1: The multiple correlation coefficient and contribution rate of each model

	R	R2	adjusted R^2
the commercial building A	0.833	0.694	0.638
the commercial building B	0.662	0.438	0.334

(R: Multiple correlation coefficient, R^2: Contribution rate)

TABLE 2: The result of analyzing the model of the commercial building A

	USC	SC	T-value	P-value
connectivity	-1.239×10^{-5}	-0.133	-0.959	0.342
clustering coefficient	-0.106	-0.321	-2.329	0.024
integration	-0.031	-0.488	-0.488	0.143
difference from the main entrances	-0.005	-0.353	-0.353	0.014
impact of the store	7.152×10^{-6}	0.586	5.562	0.009
min. VSD	0.003	0.274	1.358	0.18
mean VSD	-0.005	-0.518	-1.181	0.243
atrium	0.027	0.286	2.987	0.004
elevator	-0.006	-0.051	-0.525	0.602
bench	0.021	0.243	2.568	0.013

(USC: Unstandardized Coefficients, SC: Standardized Coefficients)

TABLE 3: The result of analyzing the model of the commercial building B

	USC	SC	T-value	P-value
connectivity	-0.001	-0.575	-4.462	0
clustering coefficient	-0.48	-0.112	-0.937	0.353
integration	0.034	0.269	1.372	0.176
difference from the main entrances	-0.001	-0.301	-2.324	0.024
impact of the store	2.635×10^{-5}	0.35	2.694	0.009
min. VSD	-0.003	-0.169	-0.917	0.363
mean VSD	0.002	0.182	0.775	0.441
atrium	-0.011	-0.101	-0.692	0.492
elevator	-0.027	-0.26	-1.855	0.069
bench	0.004	0.032	0.214	0.831

(USC: Unstandardized Coefficients, SC: Standardized Coefficients)

5.2. Intensification of the explaining variables

To perform the intensification of the explaining variables is not only to solve the problem of multicolinearity but also simplify the results of multiple regression analysis.

"Integration" which shows the connection with other points in space syntax and "elevator" represent the "integrity".

"clustering coefficient" which shows the potential of perceptual co-existence in space and "bench" represent the "retentivity ".

"connectivity" which shows visibility in space syntax and "atrium" represent "field of view".

"min VSD ", "meanVSD" and " difference from the main entrances " which indicate the "connection with the entrances".

After Intensification of the explaining variables, the explaining variables of the models were "integrity", "retentivity", "field of view", "connection with the entrances", and "impact of the store".

When to perform the intensification of the explaining variables, each value obtained from the linear sum of the partial regression coefficient (see Table2, Table 3).

After intensification of the explaining variables, the multiple correlation coefficient and contribution rate of each model are shown in Table4. The results of analyzing each model are shown in Table 5, Table 6.

The model formulas are below.The former is the model of the commercial building A and the latter is the model of the commercial building B.

P $= 7.68 \times 10^{-6}$ ×impact of the store－0.005×integrity－0.008×retentivity＋1.51×10^{-6} ×field of view－0.001×connection with the entrances＋0.039

P $= 2.484 \times 10^{-6}$ ×impact of the store－0.896 ×integrity－0.988 ×retentivity＋1.74 ×field of view－0.638 ×connection with the entrances＋0.019

(P = the population density per unit)

The correlation coefficient of a model of the commercial building A was 0.799(see Table4). And the contribution rate of a model of the commercial building A was 0.638. There is a strong correlation between the actual data and the model.

The correlation coefficient of a model of the commercial building B was 0.608(see Table4). And the contribution rate of a model of the commercial building A was 0.370.

In addition, the models were able to reduce the effects of multicollinearity.

TABLE 4: The multiple correlation coefficient and contribution rate of each model after intensification

	R	R2	adjusted R^2
the commercial building A	0.799	0.638	0.603
the commercial building B	0.608	0.37	0.308

(R: Multiple correlation coefficient, R^2: Contribution rate)

TABLE 5: The result of analyzing the model of the commercial building A after intensification.

	USC	SC	T-value	P-value
impact of the store	7.681×10^{-6}	0.694	6.657	0
integrity	-0.005	-0.14	-1.228	0.225
retentivity	-0.008	-0.27	-0.233	0.817
field of view	1.51×10^{-5}	0.198	1.765	0.083
connection with the entrances	-0.001	-0.171	-1.455	0.152

(USC: Unstandardized Coefficients, SC: Standardized Coefficients)

TABLE 6: The result of analyzing the model of the commercial building B after intensification.

	USC	SC	T-value	P-value
impact of the store	2.484×10^{-6}	0.043	0.338	0.737
integrity	0.896	0.335	2.66	0.01
retentivity	0.988	0.153	1.143	0.258
field of view	1.74	0.229	1.595	0.117
connection with the entrances	0.638	0.363	3.012	0.004

(USC: Unstandardized Coefficients, SC: Standardized Coefficients)

Moreover, the intensity of the impact of each explaining variables were as follows(see Table5, Table 6).

"impact of the store">"field of view">"connection with the entrances">"integrity">"retentivity"

This is the intensity of the impact of each explaining variables of the commercial building A.

The intensity of the impact of the store was big in the commercial building A. Because the commercial building A was extending to the horizontal direction, a big difference of the number of stores was born depends on the place.

"connection with the entrances">"integrity">"field of view">"retentivity">"impact of the store"

This is the intensity of the impact of each explaining variables of the commercial building B.

The result shows that the connection with the entrances affects the pedestrian behavior very much. Because the commercial building B was extending to the vertical direction, the entrances were limited to a ground floor. Then the connection with the entrances is important to the pedestrian behavior.

6. CONCLUSION

The purpose of this study is to investigate correlations between pedestrian distributions in two types of commercial building forms and various indexes of space syntax theory and making the models of two types of commercial building forms.

The model formulas are below. The former is the model of the commercial building A and the latter is the model of the commercial building B.

P $= 7.68 \times 10^{-6}$ ×impact of the store－0.005×integrity－0.008×retentivity＋1.51×10^{-6} ×field of view－0.001×connection with the entrances＋0.039

P $= 2.484 \times 10^{-6}$ ×impact of the store－0.896 ×integrity－0.988 ×retentivity＋1.74 ×field of view－0.638 ×connection with the entrances＋0.019

(P = the population density per unit)

In addition, as a result, it was shown that the impact of the store value was quantitatively accountable for pedestrian behavior in the commercial building extending to the horizontal direction. And the connection with the entrances value was quantitatively accountable for pedestrian behavior in the commercial building extending to the vertical direction.

REFERENCES

Alasdair Turner, Maria Doxa, David O'Sullivan, Alan Penn (2001) From isovists to visibility graphs: a methodology for the analysis of architectural space [Environment and Planning B: Planning and Design, volume 28, p103-121]

Afroza Parvin, Arlen Min Ye, Beisi Jia (2007) MULTILEVEL PEDESTIAN MOVEMENT: does visibility make any difference? [6th International Space Syntax Symposium, Istanbul,No.040 pp040.01-040.16.]

Kigawa, T., Furukawa, M., (2006), Study on a Vector in Kyoto's Modernization by Means of Space Syntax [Journal of the City Planning Institute of Japan, No. 40-3, pp.139-144.]

Kigawa, T., Furukawa, M., (2004), The Urban Entropy Coefficient: a measure describing urban conditions -A morphological analysis on evolutional process of Paris [Journal of the City Planning Institute of Japan, No.39-3, pp.823-828.]

Christoph Hölscher, Martin Brösamle, Georg Vrachliotis(2009) Challenges in multilevel wayfinding: a case study with the space syntax technique [Environment and Planning B: Planning and Design, advance online publication, doi:10.1068/b34050t]

An Eun-Hee,Lee Kyung-Hoon(2003) Importance of wayfinding performance as an evaluation criteria for the design of large-scale shopping center [Journal of the City Planning Institute of Japan, No. 564, pp. 173-177.]

Takayama,K.,Nakai,N.,Murai,M.,(2002) A Study on the depth of space in the commercial area : A case of Shimokitazawa [City planning review. Special issue, Papers on city planning, No. 37, pp. 79-84.]

Ueno,J.,Kishimoto,T., (2007) An analysis of pedestrian movement in multilevel complex by Space Syntax theory : In the case of Shibuya station [City planning review. Special issue, Papers on city planning 43(3), 49-54]