International Journal of the Malay World and Civilisation (Iman) 4(Special Issue 2), 2016: 5 - 12
(http://dx.doi.org/10.17576/IMAN-2016-04SI2-01)

Quantitative Description of Urban Landscape by Analyzing Topography in "Openness" Index A Case Study in Tokyo Yamanote Region

Penerangan Kuantitatif Berkaitan Landskap Bandar dengan Menganalisis Topografi Index "Keterbukaan" Satu Kajian Kes di Rantau Yamanote Tokyo

Yusaku Takano & Yoh Sasaki

ABSTRACT

Although land use in megacity is changing rapidly, topography condition is relatively stable. To understand the characteristics of topography and its effect to the formation of urban landscape, it is important to discuss not only about natural environment sustainability, but also socio-cultural identity in the area. The topography of Tokyo is generally clarified as two zones, the west side called "Yamanote" which is the highland eroded by small rivers and valleys, and the east side called "Shitamachi" which is the alluvial land. There are some differences in urban landscape and socio-economical phenomena between these two areas which are influenced by topographical characteristics. Especially Yamanote area, labyrinthine street networks are formed by narrow and curved valleys, green spaces are preserved in steep land, while each place has unique landscape. Usually, these characteristics are discussed in fuzzy and qualitative sense, but in this paper, we present these characteristics by quantitative methods and indexes. We specifically analyzed such topographical characteristics in Tokyo Yamanote area by "Openness" index where slope can be described in broader scale. Furthermore, we described two characteristics of built environment by Space Syntax theory for street network pattern and GIS data for land use property included green area. By layering these three characteristics, the uniquely of areas could be identified. This method might be important to be applied in actual planning.

Keywords: Topography analysis; openness; space syntax; Tokyo

ABSTRAK

Walaupun guna tanah di bandar raya berubah dengan sangat cepat, keadaan topografi dalam keadaan stabil. Untuk memahami karektaristik dan kesan pembentukan landskap bandar, adalah sangat penting untuk membincangkan identiti sosiobudaya di kawasan itu serta kelestarian alam semula jadi. Topografi di Tokyo secara umum terbahagi kepada dua zon. Bahagian barat dinamakan "Yamanote" yang mana tanah tinggi yang terhakis oleh sungai-sungai kecil dan lembah, dan sebelah timur dipanggil "Shitamachi" yang merupakan tanah lanar. Terdapat beberapa perbezaan dalam landskap bandar dan fenomena sosioekonomi antara kedua-dua kawasan yang dipengaruhi oleh ciri-ciri topografi. Terutama kawasan Yamanote, rangkaian jalan labirin terbentuk oleh lembah sempit dan melengkung, kawasan hijau dipelihara di tanah curam, manakala setiap tempat mempunyai landskap yang unik. Biasanya, ciri-ciri ini akan dibincangkan dalam erti kabur dan kualitatif, tetapi dalam kertas kerja ini, kami membentangkan ciri-ciri ini dengan kaedah kuantitatif dan indeks. Kami secara khusus menganalisis ciri-ciri topografi seperti di kawasan Tokyo Yamanote oleh "Keterbukaan" indeks di mana cerun boleh digambarkan dalam skala yang lebih luas. Tambahan pula, kami diterangkan dua ciri-ciri persekitaran yang dibina oleh teori Space Syntax untuk corak dan GIS data rangkaian jalan untuk kegunaan tanah harta termasuk kawasan hijau. Oleh itu lapisan ketiga-tiga ciri-ciri yang unik kawasan dapat dikenal pasti. Kaedah ini mungkin penting untuk diaplikasikan dalam perancangan sebenar.

Kata kunci: Analisis topografi; keterbukaan; space syntax; Tokyo

INTRODUCTION

TOPOGRAPHY IN TOKYO

It is well known that Tokyo is one of the largest Megacities in the world. Its urban area has evolved in relation to the surrounding topographic conditions, since the foundation of Edo (the former name of Tokyo) in the 17th century. Figure 1 shows the topography of Tokyo[1], where blue indicates the lower elevations, brown and yellow indicate the higher elevations. The territory of Edo in the pre-modern age can be seen in Figure 1 (the limits are denoted within the red colored line).

The topography of Tokyo is generally classified into two zones; the west side known as "Yamanote" (composed highland eroded by small rivers and valleys), and the east side known as "Shitamachi" (alluvial land), and some differences in the urban configuration exist between the two zones. For example, most of the street patterns in Shitamachi are shaped as regular grid blocks, which have been enabled because of the flat landform, whereas the main street pattern in Yamanote is irregular, complicated, and organic, because of the steep and concavo-convex landform. This difference has thus influenced the land use within each area, and the socio-economic and cultural identity of each part of the city has evolved.

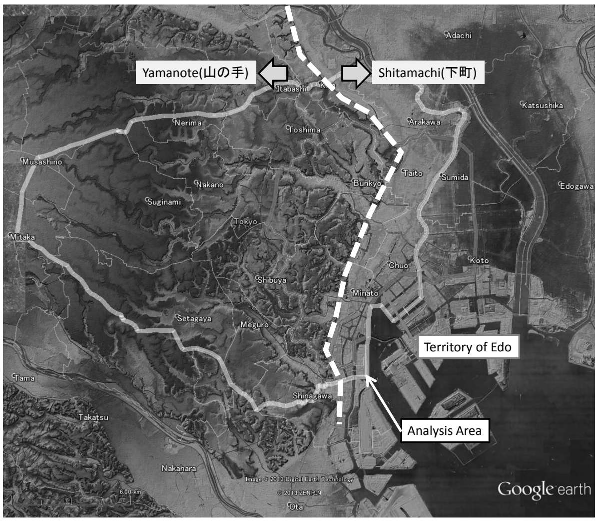

FIGURE 1. Topography in the center of Tokyo

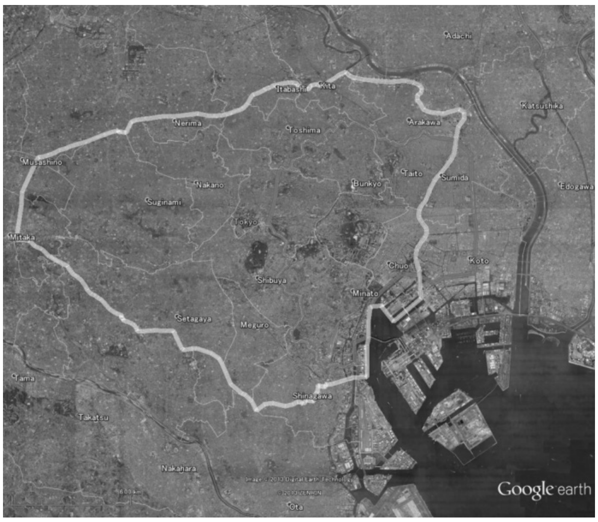

FIGURE 2. Satellite Image of Tokyo

STUDY AIMS

Much research has referred to topographical characteristics and street patterns in a qualitative way. As a representative example, Humihiko Maki et al. [2] studied the characteristics of topography, street patterns and buildings, focusing particularly on the originality of Edo and Tokyo, and pointed out that the street pattern of Tokyo lacks centrality within its system, which is a common future of Japanese castle towns. In place of centrality, the study relates that Japanese towns have the characteristic of "Oku"; which means "depth" in Japanese.

Such ideas, and those of other studies, are highly suggestive, but they use qualitative means to describe their findings. Therefore, the development of methods and indices for the analysis of such phenomena is considered necessary. Because of the result of the recent progress in remote sensing technology techniques and the disclosure of precise geographical information data, the use of GIS enables a broad and detailed analysis of topography. In addition, certain methods have been designed to analyze the spatial configuration of urban space, and Space Syntax theory is an example of such a method. The purpose of this study is to present a way of describing these characteristics using quantitative methods and indices.

LAND USE IN TOKYO

The fundamental structure of Tokyo's urban area was formed in the 17th Century, and has been gradually extended during the pre-modern age. Following the industrialization and modernization of the late 19th century, the urban area was subsequently rapidly extended and densely developed.

Unfortunately, the Great Kanto Earthquake of 1923, and the air attacks of the 2nd World War in the mid 1940's had completely burned and destroyed Tokyo. However, the rehabilitation projects implemented after these two disasters ensured that the fundamental structure of Tokyo was not drastically changed, and certain reasons exist for this adherence to the original structure. The major reasons are, of course, financial and political; the country was not financially able to construct an entirely new infrastructure. However, another dominant reason was that the basic condition of the topography strongly constrained the urban configuration.

Figure 2 shows a current satellite image of the same area shown in Figure 1. The land is seen to be predominantly covered with buildings, with the exception of a few large green areas, which are associated with places such as the Imperial Palace and Meiji-Jingu Shrine.

Figure 3 shows the current land use area ratio for each ward inside the analysis zone of 2006. The major land use type appears to be residential and the second most common land use type is commercial, (with the exception of streets). However, some wards cannot be categorized using such a generalization. The land use of Chuo, Chiyoda, and Minato Wards is dominated by the existence of offices, and Arakawa Ward is relatively dominated by factories (the classic characteristic of Shitamachi).

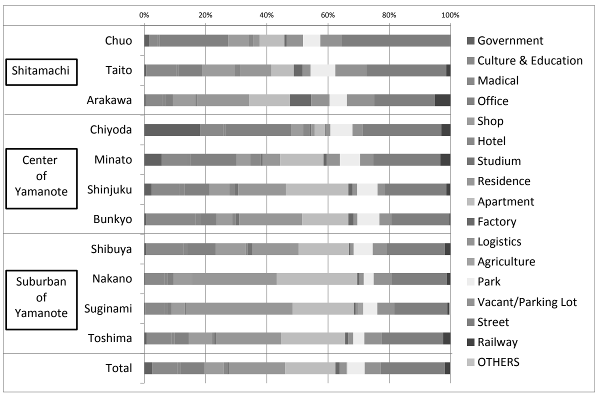

FIGURE 3. The current land use area ratio

METHODOLOGY

OPENNESS INDEX

The Openness Index was developed by Yokoyama et al. in 1999 to analyze topographical conditions of mountainous areas, with a particular focus on the risk of landslides[3]. The study developed two types of indices; over-ground openness which is the characteristic to describe sky extent over the point; and under-ground openness which is the characteristic to describe underground extent. Figure 4 shows images of the indices.

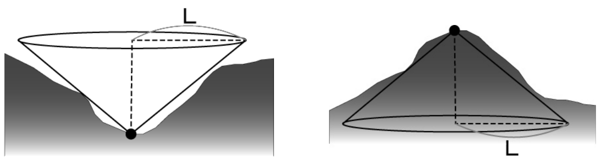

FIGURE 4. Image of openness (Left; over-ground, Right; under-ground)

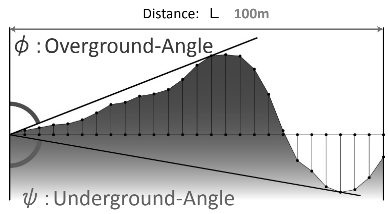

FIGURE 5. Image of over/under-ground angle

The process of calculating the indices of openness are summarized as follows:

1. To calculate the over-ground angle φ, or the under-ground angle ψ, in the optional searching distance range L; a distance of 100m was set in this study. Figure 5 shows an image of the over-ground angle and the under-ground angle.
2. Openness is calculated by the average of ground angles of eight directions in each point.
   Dimension of the openness is in degrees. If the landform of a point is convex, the reading of over-ground openness is higher, and if the landform of a point is concave, the over-ground openness is lower. In this study, we firstly apply over-ground openness to analyze the characteristics of valleys and steep lands and then examine the difference between openness and slope index. Figure 6 shows two maps of the same part of Tokyo: the left hand map shows the characteristics of slope; the right hand map shows the characteristics of openness. The characteristics of gradient on a local scale can be described using the slope index, because the slope index is calculated by the relationship between continuous points. However, by doing so, we can understand the characteristics of topography on a broader scale and identify the shape of each valley or steep land as a region, but it is not possible to avoid noise from the microscopic irregularity of landform.

FIGURE 6. Slope map and openness map

SPACE SYNTAX THEORY AND AXIAL ANALYSIS

Space Syntax theory was devised by Prof. Bill Hillier and Prof. Julienne Hanson in 1970's, and was then developed by their colleagues at The Bartlett, University College London[4]. According to the Website of "Space Syntax Network"[5], the Space Syntax theory is explained as follow; *Space syntax is a science-based, human-focused approach that investigates relationships between spatial layout and a range of social, economic and environmental phenomena*.

Originally, the uniqueness of Space Syntax used the basic components of analysis; convex space and axial line, which are based on visibility and accessibility. The open space of analysis is divided into segments by these components, and the relation between components is then measured in topological distance. In other words, the Euclidean distance is ignored in Space Syntax. In recent studies, however, various methods and indices are developed for much more precise and detail analysis.

Usually, axial analysis is applied for the analysis of broad scale urban space; particularly for street network patterns (see Figure 7 for a representative process of axial analysis).

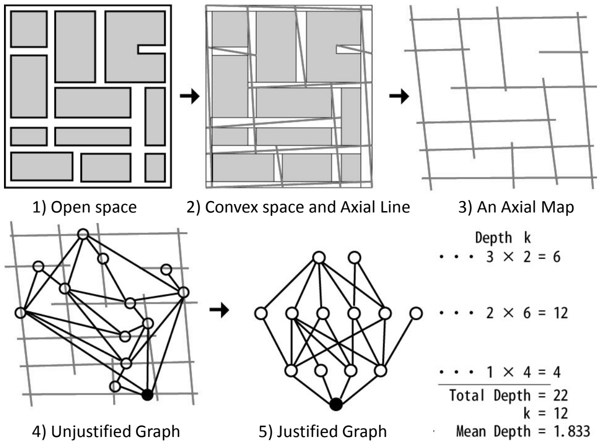

FIGURE 7. The process of making an axial map

The steps shown in Figure 7 for making an Axial Map are denoted as follows:

1. Open space is identified from the original map.
2. Open space is divided into convex spaces. Axial lines are then drawn along the convex spaces until all convex spaces are stringed by the least set of the longest axial lines.
3. An axial map is produced.
4. Axial lines are replaced to the nodes of a graph, and the connections between contiguous lines are replaced to the paths. This figure is called an "unjustified graph".
5. Nodes of the unjustified graph are ordered by the depth from each node. The justified graph is made using every node in the graph. The relationship between axial lines is calculated in topological distance and is known as "depth". The depth between two lines is the minimum number of axial lines passing through one line to others.
6. The Mean Depth (MD) is calculated by the average of all the values of depth.

In this study, we apply Integration Value, which is calculated from Mean Depth using the following equations:

$$\mathrm{RA} = \frac{2(MD-1)}{k-2} \tag{1}$$

$$\mathrm{Dk} = \frac{2\left(k\left(\log_Z \frac{(k+z)}{s}\right)+1\right)}{(k-1)(k-2)} \tag{2}$$

$$\mathrm{RRA} = \frac{RA}{Dk} \tag{3}$$

$$\text{Integration Value} = \frac{1}{RRA} \qquad (4)$$

where

MD is Mean Depth and

k is the number of axial lines

Relative Asymmetry (RA) is calculated by dividing the number of axial lines by MD. Real Relative Asymmetry (RRA) is calculated by dividing Dk by RA. Dk is the coefficient to reduce the system size effect. The Integration Value is then calculated using the inverse of RRA.

Integration Value indicates the potential of natural movement. The line has higher accessibility when the Integration Value of the axial line is higher. The Integration Value is then calculated using two types of radii; the Global Integration Value, which is calculated within the whole system, and the Local Integration Value, which is calculated within an optional radius.

According to existing research[6], the Local Integration Value calculated in Radius = 3 has the best correlation with pedestrian density, and the Global Integration Value (or the Local Integration Value calculated using the higher Radii) has better correlation with the movement of car. In this study, we apply the Local Integration Value in Radius = 3 to describe spatial configuration on a pedestrian movement scale.

ZONING BY VALUES

As previously discussed, when quantitative indices are given it is possible to draw a thematic map using these values. However, the way of identifying a specific point tends to be qualitative and arbitrary. To solve this problem, we attempt to identify the "zone" by the value of indices.

Concretely speaking, we drew the contour line of the value by using the function of ArcGIS. By setting an optional threshold for the value, we can identify specific zones as polygons. By then layering polygons with different characteristics (openness and the integration value in this study) the relationship between two characteristics can be clarified.

ABOUT ORIGINAL DATA SOURCES

The original data sources used for analysis are as follows:

1. Digital Elevation Model Data published by the Geospatial Information Authority of Japan (2003) Used for the analysis of Openness. The mesh size is 5m, and the degree of accuracy is 0.1m.
2. 1:2500 Scale Digital Topographic Map published by Tokyo Digital Map Co. (2004). The shape of the street polygon was obtained from this data, which was then used for making the axial map.

OVERVIEW OF RESULTS

OPENNESS

Figure 8 shows a thematic map indicating openness, using a grayscale color gradient. Lighter color indicates a higher value, and darker color indicates a lower value. Using this scale, major steep zones are seen to be continuously distributed along the rivers.

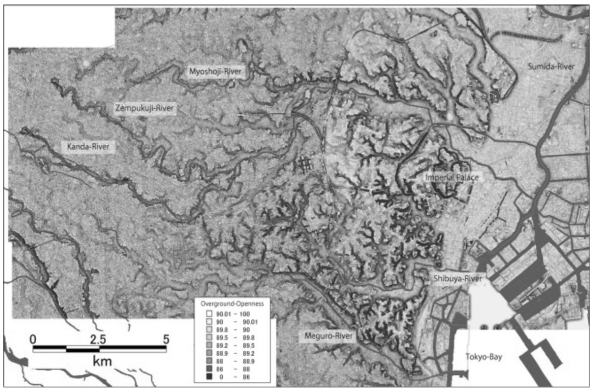

FIGURE 8. Thematic map of over-ground openness

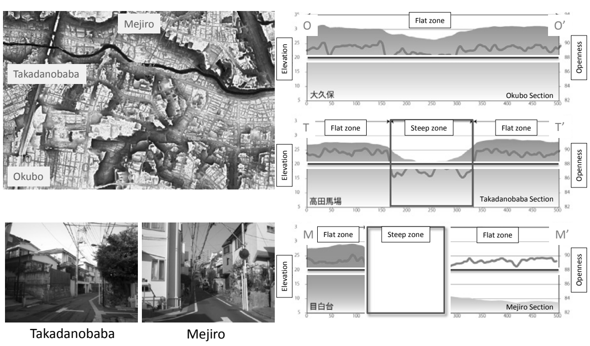

FIGURE 9. Openness threshold study

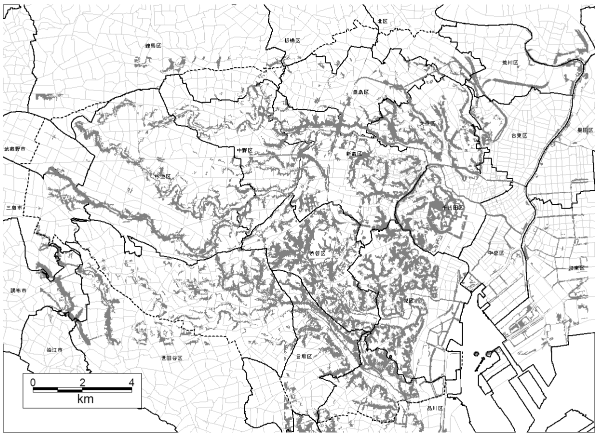

FIGURE 10. Distribution of steep zones

In order to identify steep zones by the value of openness, we examined the threshold of certain sections, and elevation and openness were measured in three sections (as samples) (Figure 9). When the threshold was set as 88 degrees, it was possible to identify a valley in the Takadanobaba Section, and a slope in the Mejiro Section as a steep zone. There is a shallow concave area in the middle of the Okubo section, measuring approximately 2 m in height and 100 m in width but this is not identified as a steep zone in this study. Figure 10 shows the steep zones and flat zones in the analysis area. The shape of steep zones traces the line of the river and valley, and this can be seen particularly in Minato Ward and Shibuya Ward in the southern part of Yamanote.

SPACE SYNTAX (INTEGRATION VALUE)

Figure 11 shows an axial map indicating integration values (Radius = 3). The red color indicates a higher integration value and the blue color indicates a lower integration value. The characteristics of street patterns are summarized as follows;

1. In general, integration value of a grid shaped street pattern tends to be higher, because the grid pattern is an efficient street pattern in the viewpoint of accessibility. Thus, in this analysis, Shitamachi to the east and Suginami area to the west have higher integration values because they are towns designed with a dominant grid pattern.
2. Because the line shape of lines in the main streets tends to be linear, the axial lines on main streets tend to be longer and connect with more other lines. Thus, the integration value of main streets tends to be higher. In this analysis, almost all the designated main streets are identified as having high integration value.
3. However, the inner core of the block that is surrounded by main streets has a lower integration value, particularly in the Yamanote area.

To identify significant zones using the value of the integration value, we set two thresholds: the Integration Value >=3.0 for identifying the higher integration zone and the integration value < 2.0 for identifying the lower integration zone. Figure 12 shows the distribution of the higher and lower integration zones. It is evident that the areas representing the lower integration zones are relatively smaller than those of the higher integration zone.

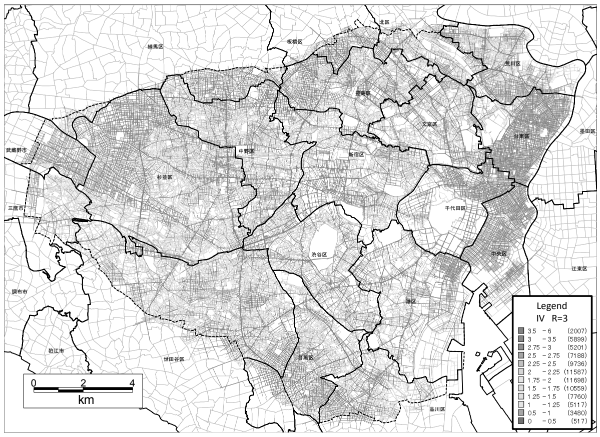

FIGURE 11. Axial map (integration value radius=3)

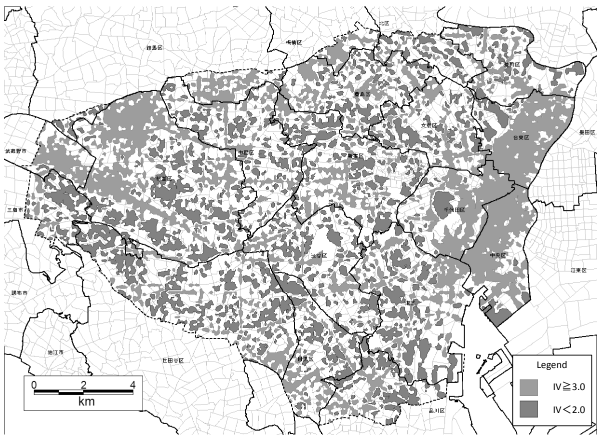

FIGURE 12. Integration value polygons

CASE STUDY

RELATION BETWEEN OPENNESS AND INTEGRATION VALUE

Using a regular shape grid to build streets within straight lines and blocks is generally easier if the landform of the city is plain. Thus, zones with higher integration value zones tend also to be distributed on flat zones. In other words, the points where these two zones layer each other have the potential of being remarkable places within a city.

Figure 13 and Figure 14 show maps layering the two zones: the higher/lower integration value zone and the steep zone. The red-colored polygons show the higher integration value zone, the blue ones show the lower, and the gray ones show the steep zones. The star on the map indicates the location of a railway station; the thick dotted lines indicate the railway line.

Figure 13 shows a map of Shibuya city (one of the most famous entertainment and commercial districts of Tokyo), with its unique topography. Shibuya station is located in the bottom of the valley and the shops, theaters and offices (the pedestrian destinations) are located along the hill. Because some main streets intersect one another near the station, a higher integration value zone is identified around the station. This higher integration value zone also intersects with some steep zones near the station. In addition, some lower integration value zones are distributed around the station, and almost the entire area of each zone intersects with steep zones.

Figure 14 shows a map of the area around Shinjuku city, where the Tokyo Metropolitan government building is located. Shinjuku is also the central business and entertainment district. Due to land adjustment projects and re-development projects, the street pattern around Shinjuku Station has been relatively improved to that of a regular shape. Thus, the integration value around the station is high, and some areas of large higher integration value zones are identified. However, these do not tend to intersect with the steep zone, and areas of the lower integration value zones with steep zones are located at relatively large distance from Shinjuku Station.

These structural differences in the topography and the street pattern may, therefore, influence the characteristics of the landscape. Both Shibuya and Shinjuku are the representative commercial, business and entertainment districts of Tokyo, but the characteristics of the landscape and the image of town are quite different from each other. It is evident that single elements such as a building, sign, or street is unique, and is a primary factor defining the image of the city, whereas the characteristics of topography and street pattern identified in this study are not as predominantly visible. However, it is clear that these characteristics too are important factors, because they are based on the shape of ground, and therefore influence the fundamental image of the city.

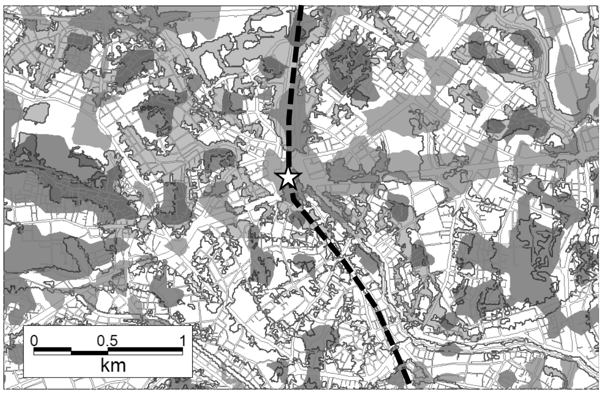

FIGURE 13. Layering map in Shibuya

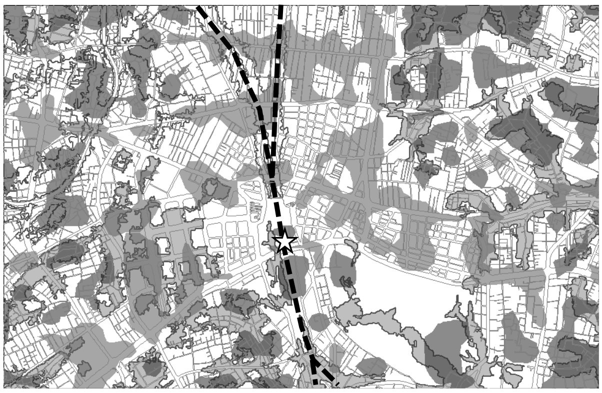

FIGURE 14. Layering map in Shinjuku

CONCLUSION

In this study we applied two quantitative methods, the Openness index for analysis of topographical characteristics, and the Space Syntax Theory for street patterns, and presented the way of identifying specific zones according to values, as calculated by previous methods.

As a result of conducting a case study, we described the different characteristics of spatial configuration between two districts: Shibuya and Shinjuku. Furthermore, the characteristics of landscape and an image of the district can be clarified. It is considered that this method could be applied to other indices of various characteristics and a quantitative understanding of urban space may be achieved for application in actual urban planning by using layering in many different kinds of maps.

ACKNOWLEDGEMENT

I would like to show my greatest appreciation to Mr. Takanori Tsunogai. Important parts of this paper are based on his master thesis. Without his idea and great contribution, this paper would not have been passible. This work was supported by JSPS KAKENHI Grant Number 23-7004.

Yusaku Takano
Department of Civil and Environmental Engineering
Waseda University
*Corresponding Author.
Tel: +81-3-5286-3989
Fax: +81-3-5286-3989
E-mail: ysk.takano@aoni.waseda.jp

Received: 12 July 2015
Accepted: 08 January 2016

REFERENCES

Google Earth. 2012. Tokyo Terrain for Google Earth. http://www.gridscape.net/. Access on: 12 February 2012.

Hillier, B. 2003. A Theory of the City as Object. *Proceedings of 4th International Space Syntax Symposium*.

Hillier, B., Hanson, J. 2009. *The Social Logic of Space*, Cambridge University Press.

Maki, H., Wakatsuki, Y., Ono, H., Takatani, T. 1980. Miegakure-suru-Toshi,Kajima-Publishing.

Space Syntax Network. http://www.spacesyntax.net/. Access on: 12 February 2012.

Yokoyama, R., Sirakawa, M., Kikuchi, Y. 1984. Representation of topographical features by openness. *Journal of the Japan Society of Photogrammetry and Remote Sensing* 38(4): 26-33.