Influential Factors of Building Footprint Location and Prediction of Office Shape in City Blocks in Tokyo's Commercial Zones

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Introduction

Recently there has been a policy shift in Japan from the development of new cities to the renovation of existing cities. Particularly, in central commercial zones in Tokyo, the importance of city block restructuring has been strongly emphasized. Three reasons can be identified. First, in a small city block, large buildings cannot be constructed because of urban planning regulations, which may fail to motivate developers to renovate. Second, large offices cannot be located in a small city block. Therefore, the city may lose the opportunity to attract investment from global industries. Third, the existence of roads that are too narrow is an obstacle to disaster preparedness. For all these reasons, city block restructuring has become necessary.

In Japan certain areas have been classified as "urgent urban renewal areas" based on the Urban Renewal Act. Urgent renovation is required in this context. Local governments can relax urban planning regulations such as the floor area ratio (FAR) and motivate developers to renovate. The Ministry of Land, Infrastructure, Transport and Tourism (MLIT) has prepared guidelines for city block restructuring. These show effective examples of city block restructuring and prompt local governments to renovate city blocks. Developers are motivated to renovate city blocks, which can create an attractive city in terms of business, tourism and lifestyle. However, the building shape and location after restructuring are not evident. Spatial images of the city cannot be estimated before renovation.

Our previous study (Taima et al. 2016) classified city blocks by the difference in influential factors of building footprint location (building location of the first floor) and examined whether the city blocks in each class showed predictability of building footprint location. "Predictability" means that the building locations of

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each city block are estimated accurately. As a result, a city block comprised entirely of office buildings was shown to be one such class.

Office development is one of the major reasons for restructuring city blocks in Tokyo's commercial zones. Policies and legal systems support the initiative. In the future many offices will be developed in Tokyo's commercial zones.

However, the office shape and location after restructuring are not evident. If the building shape and location could be predicted, and reflected in the restructuring plans, the process would be considerably improved. In addition, environmental influences, such as energy consumption and wind direction, can be estimated. Therefore, the predictability of building development in city blocks is crucial for planning city centers.

In this study, a city block with office buildings only is the focus, and the probability of building coverage for each point on every floor level is visualized to produce a spatial image.

City Planning Regulations in Japan

In this section the major city planning regulations are explained (Ministry of Land, Infrastructure and Transport 2003).

Land Use Zones

In Japan land use zones can generally be categorized into residential, commercial and industrial uses. Twelve categories of land use zones are defined and provide a pattern for land use zoning in each type of urban area. Each land use zone is governed by specifications concerning the use of buildings that can be constructed in the zone.

This study focuses on the category of the commercial zone. Banks, cinemas, restaurants and department stores are constructed in this zone. Residential buildings and small factory buildings are also permitted.

FAR and Building Coverage Ratio

In each land use zone category, maximum floor area ratios (%) and maximum building coverage ratios (%) are defined, and they are shown in Fig. 1. In the commercial zone, the maximum floor area ratio (%) is between 200 and 1300%. The maximum building coverage ratio (%) is 80% in all the areas of the commercial zone (see Table 1).

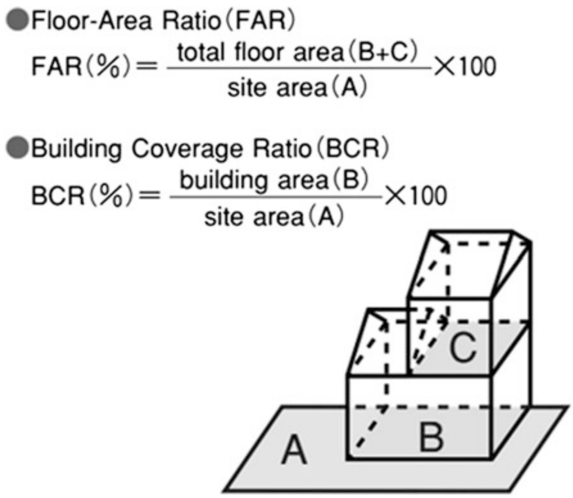

Fig. 1 Floor area ratio and building coverage ratio (Ministry of Land, Infrastructure and Transport 2003)

Table 1 Floor area ratio and building coverage ratio regulations in land use zones (Ministry of Land, Infrastructure and Transport 2003)

Category of land use zone	Maximum floor-area ratios (%)	Maximum building coverage ratios (%}
Category 1 exclusively low-rise residential zone	50 60 80 100 150 200	30 40 50 60
Category II exclusively low-rise residential zone	50 60 80 100 150 200	30 40 50 60
Category 1 mid/high-rise oriented residential zone	100 150 200 300 400 500	30 40 50 60
Category II mid/high-rise oriented residential zone	100 150 200 300 400 500	30 40 50 60
Category 1 residential zone	100 150 200 300 400 500	50 60 80
Category II residential zone	100 150 200 300 400 500	50 60 80
Quasi-residential zone	100 150 200 300 400 500	50 60 80
Neighborhood commercial zone	100 150 200 300 400 500	60 80
Commercial zone	200 300 400 500 600 700 600 900 1000 1100 1200 1300	80
Quasi-industrial zone	100 150 200 300 400 500	50 60 80
Industrial zone	100 150 200 300 400	50 60
Exclusively industrial zone	100 150 200 300 400	30 40 50 60

Restrictions on Building Shape in the Commercial Zone

The restrictions on building shape are different in each zone. In the commercial zone, slant plane restrictions are the major restriction on building shape (Fig. 2). The restrictions limit the building heights based on the distance from the other side of the boundaries of the roads that they face or from the adjacent site boundaries. This ensures adequate space for light and ventilation between buildings or on roads.

Literature Review

Office Shape

Several factors are related to office shape. In office design terms, offices require a high rentable ratio (the rentable area divided by the area available for use in a building) and an efficient working environment. According to Kooijman (2000), office design has changed because of globalization and the needs of the local environment. The office layout is said to be associated with work practices.

Various studies have focused on the analysis of office shape. Chau et al. (2007) analyzed the optimal office shape under building height regulatory restrictions. Shpuza and Peponis (2008) measured the floorplate shape in two different ways and analyzed its influence on office layout. Some studies have proposed models to

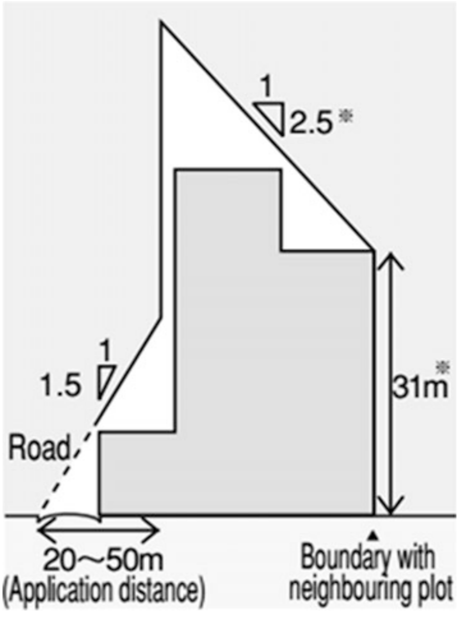

Fig. 2 Slant plane restrictions in commercial zone (Ministry of Land, Infrastructure and Transport 2003)

simulate the optimal office building shape using a genetic algorithm (Grierson and Khajehpour 2002; Ouarghi 2006; Wang et al. 2006).

These studies focused on the office building shape but did not consider the city block shape. The office building shape is influenced by the city block shape, because the city block shape determines almost all the city planning regulations in the block. In this study the office building shape is analyzed from the perspective of the city block shape.

Urban Renewal

Changes in building shape through urban renewal have been analyzed. Some studies have concluded that the initial city block shape affects the building form or city block form after urban renewal. Siksna (1998) examined the influence of the initial city block shape on the building form after development. Ryan (2006, 2008) suggested that new residential patterns are established after the transformation of city blocks.

Processes of urban renewal have also been studied. Lin and Lin (2014) adopted game theory to analyze urban renewal processes based on the characteristics of landowners. In addition, some studies have focused on the process of change in city blocks in the center of Tokyo (Matsukura and Miyawaki 2006), the development process of traditional rectangular city blocks in Kyoto (Hayami 2009) and the development process of city blocks used for office buildings in Marunouchi (Nomura 2014).

These researchers studied the changing building shape and process of urban renewal, but the building shapes of the future could not be estimated. To estimate these, we must develop a model.

Building Location

Malcata-Rebelo and Pinho (2010) found that land use and office location were the relevant variables to the mechanisms of office supply, office demand and market equilibrium. They concluded that these results support municipal decisions concerning office location and management. However, it is not obvious where buildings are located in the new shape of a city block after city block restructuring.

There are many studies about the land use of city blocks. Makio et al. (2006) analyzed apartment house location on the city block scale after a change of building use to apartments. Targeting a provincial city, Saito and Kato (2013) researched changing land use and the current status of each city block. Nam et al. (2007, 2008) analyzed parking based on the relation between green space conservation and business balance. Nagatomi et al. (2007) examined land use in city blocks adjacent to a highway. Nakao and Ito (2012) analyzed urban conditions in terms of building density and building coverage ratio in a city block. Kawaguchi et al. (2015) conducted a quantitative study about the relation between scale and fluctuation of open space and scale and fluctuation of green space. Matsumiya et al. (2014) calculated the distribution of the open space ratio among buildings in a city. These studies analyzed the use of space in city blocks, but further analysis is required to estimate future uses.

Estimation

In this study building location and floor area are estimated. Some estimation methods for urban physical status have been developed in previous research.

Asami amd Ohtaki (2000) developed a model to estimate detached house location. Orford (2010) developed a methodology for estimating the floor area of individual properties from digital infrastructure data, which were, however, deficient in detail. Shiravi et al. (2015) assessed the utility of some models for estimating floor area using three data sources: a geographic vector building footprint layer, a LiDAR data set and field survey data for the south side of the city of Fredericton, Canada. They discussed the reliability and accuracy of each model. In other research Brunner et al. (2009) extended a methodology for building height estimation and tried to improve its accuracy. Schmidt et al. (2010) presented an approach to the estimation of building density on the city block scale.

Many researchers have focused on the estimation of land use: for example, building block use (Spyratos et al. 2016), urban land change (Güneralp et al. 2012) and future urbanization (Debnath and Amin 2016).

Energy and Urban Physical Condition

Estimations of building shape can be applied in many fields. Energy is one such field. Some researchers have analyzed the relation between energy and urban physical condition. Ourghi et al. (2007) developed a method for predicting the impact of the shape of an office building on its annual cooling and total energy. The analysis indicated the strong correlation between the shape of a commercial building and its energy consumption. The result also showed a direct correlation between relative compactness and total building energy use as well as the cooling energy requirement. Rode et al. (2014) examined the theoretical heat energy demand of different types of urban form. They concluded that compact and tall building types had the greatest heat energy efficiency on the neighborhood scale and detached housing had the lowest. Mortimer et al. (2000) studied various aspects of the patterns of energy use in non-domestic buildings derived from the statistical analysis of data.

On the urban scale, Ko and Radke (2014) provided an empirical evaluation of the association between urban form and residential energy use, particularly residential electricity use, for space cooling. The study revealed that urban forms have a statistically significant impact in terms of saving energy for cooling. O'Brien et al. (2010) examined the relation between net energy use and three housing forms: low-density detached homes, medium-density townhouses and high-density high-rise apartments in Toronto. The results show that high-density development uses one-third less energy than low-density development. Only when the personal vehicle fleet or solar collectors are made to be extremely efficient does the trend reverse; low-density development results in lower net energy. These results showed a paradoxical relationship between the density of solar housing and net household energy use.

The other benefit of building shape estimation is that planners can understand the building shapes and locations of the future and use the result for planning. In addition, citizens can easily understand the future image in the city block. They can judge whether the urban renewal plan is better.

Study Area and Data Source

In this study an urban planning GIS data set of Tokyo (March 2013) is used. This data set contains building types, the number of floors, land use zones, the FAR and the building coverage ratio.

City blocks in urgent urban renewal areas are chosen for analysis, because the areas are designated for urgent city block restructuring. The urgent urban renewal area is shown in Fig. 3. The Government finances and promotes the development.

Regarding building location analysis, the difference in the FAR may influence the building location. Therefore, the FAR of blocks is set to be equal to 600%, as this is found to be the mode value of all the blocks in the urgent urban renewal area. As a result, 205 city blocks are chosen, which are used as reference blocks.

Method

Model

A building location estimation (BLE) model was developed to estimate building locations from a city block shape. A similar model has been used to estimate a detached house location (Asami and Ohtaki 2000).

If two city blocks are similar in shape and other spatial features, we can expect that the building locations in the city blocks will tend to be similar. This naive but simple assumption enables us to estimate the building location. Accordingly, a

Fig. 3 Urgent urban renewal area in Tokyo (*black area*)

model was developed to estimate the probability of each point on every floor level covered by a building.

More specifically, the locations of buildings on reference blocks were overlaid so that the gravity center of the reference blocks matched that of a given block. A probability was assigned to each overlaid layer depending on the similarity of the block shape. The Lee-Sallee measure (Lee and Sallee 1970) judges the similarity between two city blocks by the quotient value, the intersection area divided by the union area of the two blocks.

An index expressing the similarity between two city blocks, the similarity index, s, is defined below.

Generally, a city block can be treated as a compact set on a two-dimensional plane. Let x. a point on the plane. Let $x(\in X)$ be a point in the city block X and let $g(X)$ be a vector of the gravity center of the city block X. $A(X)$ is the area of the city block X. The similarity index, s, is calculated as the value, that is, the intersection area divided by the union area of the two blocks, by matching the gravity center of the two blocks. Let $G(X)$ be the set that is given by moving in parallel the city block X, so that the gravity center of the block coincides with the origin. Set $G(X)$ is defined as follows:

$$G(X) = \{z : z = x - g(X), x \in X\} \tag{1}$$

Based on the Lee–Sallee measure, the temporal similarity index, s^*, between city block X and city block Y is defined as follows:

$$s^*(X, Y) = \frac{A(G(X)\ \cap G(Y))}{A(G(X)\ \cup G(Y))} \tag{2}$$

Building location greatly depends on the direction of any adjacent road. The direction of the road is different in each city block. The influence of the adjacent road on the building location in city blocks is not particularly different when a city block revolves around a gravity center within angle $\pm\pi/4$. Allowing for such revolving, the final similarity index, s, is defined as follows. Let $R(X, \theta)$ be the revolving city block θ around the gravity center of the city block X. The similarity index, s, is defined as follows:

$$s(X, Y) = \max_{-\pi/4 \le \theta \le \pi/4} \frac{A(G(X) \cap R(G(Y), \theta))}{A(G(X)\ \cup R(G(Y), \theta))} \tag{3}$$

Reference blocks are used to calculate the probability of building location. Let I be a set of reference blocks. If two city blocks are similar in shape and other spatial features, we can expect that the building locations in the city blocks will tend to be similar. Therefore, if the building location in city block X is estimated, it is appropriate to use the city block that has a high similarity index, s. It is possible to use the similarity index, s, as a weight that determines the priority of the reference city block. However, if this is the case, then all the reference blocks must be used for the BLE model. A better model can be developed by rejecting city blocks with an apparently different shape. To exclude differently shaped city blocks, it is necessary to designate the weight as zero. To do so, we define the weight function, $f(s)$, based on the similarity index, s, as follows:

$$f(s) = \begin{cases} \frac{s-t}{1-t} & s > t \\ 0 & s \le t \end{cases} \tag{4}$$

where t is a parameter and its range is zero to one $(t \in [0, 1])$. When the similarity index, s, is less than parameter t, the weight function, $f(s)$, is zero (Fig. 4). The similarity index, s, and weight function, $f(s)$, between city block X and city block Y are expressed as $s(X, Y)$ and $f(s(X, Y))$.

The way to estimate building location can be described as follows. Let $G(i)$ be the reference city block by moving city block $i(\in I)$ in parallel so that its gravity center coincides with the origin, and let B_i be a building location set on the reference city block $G(i)$. In the case in which a point z. $G(i)$ is $z \in B_i$, the building covers point z..hus, the more building location set B_i covers point z.,he more likely point $x(\in X)$ is to be covered. The building existing probability $p(x, X, I)$ (the probability that point x. covered by buildings) is defined by the weight function,

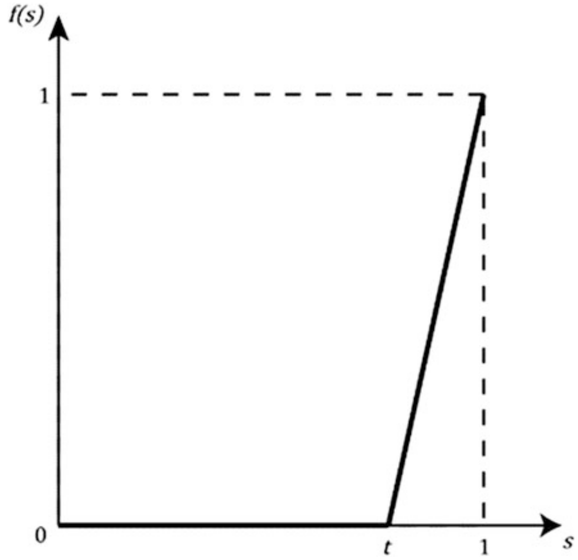

Fig. 4 Weight function, $f(s)$

$f(s)$. First, the indicator function expressing that point x. covered by building location set B_i is defined as follows:

$$\chi(x, B_i) = \begin{cases} 1 & x \in B_i \\ 0 & x \notin B_i \end{cases} \tag{5}$$

Then, the building existing probability $p(x, X, I)$ at point $x(\in X)$ in city block X is defined as follows:

$$p(x, X, I) = \frac{\sum_{i \in I} f(s(X, i))\chi(z, B_i)}{\sum_{i \in I} f(s(X, i))}, \mathrm{x}(\in X) \tag{6}$$

Parameter t is decided so that the accuracy of the building location estimation is maximal. To this end, an arbitrary city block, i, is chosen from the reference city block set, I, and the building location on the city block, i, by using reference city blocks except for city block i (let I_{-i} be the reference city block set except for city block i). We calculate the highest ρ, which is the estimation accuracy index, by trying all of the reference blocks, $i(\in I)$, where the estimation accuracy index, ρ, is defined as follows:

$$\rho = \sum_{i \in I} \int\limits_{x \in B_i} [p(x, i, I_{-i})\chi(x, B_i) - p(x, i, I_{-i})(1 - \chi(x, B_i))]dx \tag{7}$$

The estimation accuracy index, ρ, expresses the summation of both the integral value of the building existing probability at the points covered by buildings and the integral value of the building existing probability at the points not covered by buildings. The value of parameter t is used for the BLE model in the highest estimation accuracy index, ρ.

Influential Factor of Building Location in a City Block

In the future many office buildings will be built in Tokyo, but their location and shape are not evident. One hypothesis is that the locations of each floor of buildings will be estimated accurately (predictable) after the city blocks comprised entirely of office buildings are chosen from all the city blocks. "Predictability" means that the building location of each city block can be estimated accurately by the BLE model.

To determine whether an office building is predictable, the BLE model error is used. The error of the model is calculated as follows. The building existing probability at point $x(\in i)$ in reference city block $i(\in I)$ is expressed as $p(x, i, I_{-i})$. $\chi(x, B_i)$ is an indicator function equal to one when point x. included in B_i and zero otherwise. The error ratio is calculated as the integral value of the absolute value of the difference between $p(x, i, I_{-i})$ and $\chi(x, B_i)$ divided by area $A(i)$ of the reference city block, i. The error ratio is calculated by all the reference city blocks and summed. The error ratio of the estimation of the reference city block set, I, is calculated as the sum divided by the number of reference city blocks, N_I. The error ratio, E, is defined as follows:

$$E = \frac{\sum_{i \in I} \frac{\int_{x \in i} |p(x, i, I_{-i}) - \chi(x, B_i)| dx}{A(i)}}{N_I} \tag{8}$$

The error ratio, E, is used as an index of the model's accuracy. It is used to judge whether the building location of a city block comprised entirely of office buildings can be estimated accurately. If the error ratio, E, of the classified blocks is smaller than that of the unclassified ones, it means that the extracted city blocks have better predictability of the building locations. In the classified city blocks, the building locations can be estimated accurately by the BLE model and the building locations have predictability. Therefore, the class is a factor that influences building locations (influential factor). On the other hand, if the error ratio, E, of the classified blocks is larger than that of the unclassified ones, the building locations in the city blocks are scattered in the classification. The method described above can ascertain whether the building locations of a city block comprised entirely of office buildings can be estimated accurately.

Visualization

The probability of building coverage for each point on every floor level can be used to predict the potential urban environment before the development. In particular, it is important to know office building shapes, because many offices will be in Tokyo's central zones. Therefore, the estimation of the probability of building coverage for each point on each floor level needs to be visualized to obtain the spatial image.

The building existing probability $p(x, X, I)$ is visualized as follows. First, hypothetical blocks are set, and the building existing probability of the points on the block is visualized. Points are set every 1 m in a north-south direction and an east–west direction. Then, reference blocks are overlaid on a hypothetical block. Second, the building existing probability of each point is calculated by summing the building existing probability of the point overlaid by reference city blocks, which is calculated based on the similarity between the reference city blocks and the hypothetical block. The probability is expressed by brightness. In the black area, the probability is high. Conversely, in the white area, the probability is low.

Hypothetical blocks are set by changing their size, and the probability of building coverage for each point on every floor level is calculated. Hypothetical blocks are rectangular and set based on the size 35 m*35 m block. The reasons for the size are based on the mean area and mean perimeter of the reference city blocks. The mean area of all the city blocks is 1285.54 m^2, and the mean perimeter of all the city blocks is 147.41 m. If the city blocks are rectangles, the average shape is calculated as 35 m*35 m from the average area and the perimeter. In all the rectangular blocks, each edge of hypothetical rectangular blocks varies from 20 m to 60 m every 5 m. Almost all the reference city blocks are included in this range. The size of each city block is shown in Tables 2 and 3. In Table 2 the east–west side of the city block varies from 20 m to 60 m, while the north–south side is fixed as 35 m. On the other hand, in Table 3, the north–south side of the city block varies from 20 m to 60 m, while the east–west side is fixed as 35 m. The building existing probability of each hypothetical block is also visualized.

In addition to the visualization of building existing probability, the "estimated area" (the building area considering the probability) and the estimated building area ratio (the ratio of the estimated area in the city block area) are calculated. The estimated area is calculated as the block area multiplied by the average building existing probability of the block, and the estimated building area ratio is calculated as the estimated area divided by the block area.

The index known as the volume sufficiency ratio can measure how far the buildings occupy the maximum volume of the city block. The volume sufficiency ratio is defined as the whole building floor area divided by the maximum volume of the city block. The maximum volume of the city block is calculated as the city block area multiplied by the FAR (600%).

Table 2 Size of each city block (city block ns35*es20–ns35*ew60)

City block	ns35*ew20	ns35*ew25	n&35*ew30	ns35*ew35	ns35*ew40	ns35*ew45	ns35*ew50	n&35*ew55	ns35*ew60
North–South direction side (m)	35	35	35	35	35	35	35	35	35
East–West direction side (m)	20	25	30	35	40	45	50	55	60

Table 3 Size of each city block (city block ns35*es20–ns35*ew60)

City block	ns20*ew35	ns25*ew35	ns30*ew35	ns35*ew35	ns40*e*v35	ns45*ew35	ns50*ew35	ns55*ew35	ns60*ew35
North–South direction side (m)	20	25	30	35	40	45	50	55	60
East–West direction side (m)	35	35	35	35	35	35	35	35	35

Table 4 Error ratio, E

Class	Sample number	Error ratio E	Difference
All city blocks	205	0.330	–
City blocks comprised entirely of office buildings	34	0.319	−0.011

Results

Error Ratio, E

According to the result of Table 4, the error ratio, E, of the class with city blocks composed of office buildings is smaller than that of unclassified ones (class: all city blocks). In this case the classification of city blocks comprised entirely of office buildings means that the extracted city blocks have better predictability of the building location. In this classification the building locations can be estimated accurately by the BLE model. Therefore, all the office buildings in a city block can be seen as the influential factor of the building footprint location.

Visualization of Building Existing Probability

The building existing probability is visualized in Figs. 5 and 6. The similarity between the reference city block and the hypothetical block is not over the similarity index, t, and the building location cannot be estimated by the BLE model. In this case the symbol "–" is marked.

Estimated Area and Estimated Building Area Ratio

The estimated area and the estimated building area ratio of each city block are calculated in Tables 5 and 6. Figures 7 and 8 show the estimated building area ratio.

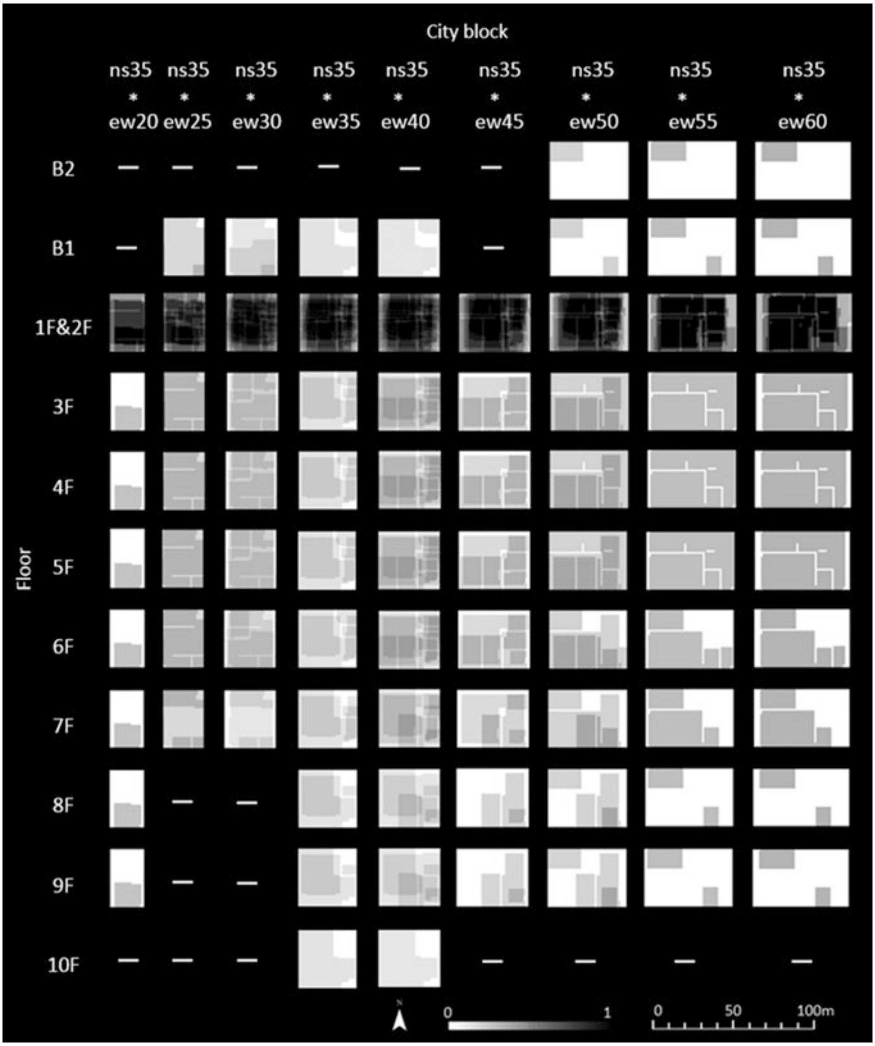

Fig. 5 Visualization of the building existing probability (city block ns35*es20–ns35*ew60)

Volume Sufficiency Ratio

The volume sufficiency ratio is calculated as shown in Tables 7 and 8. The results are also shown in Figs. 9 and 10.

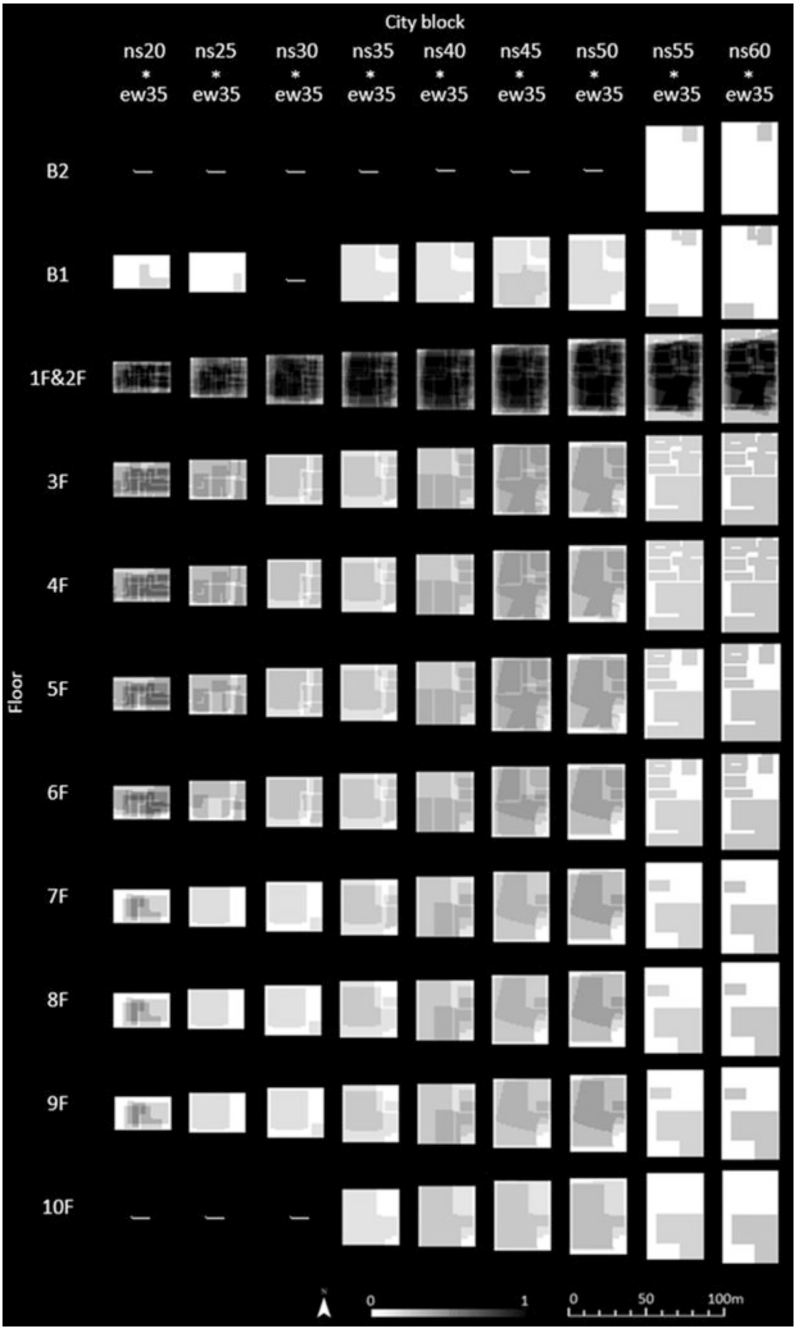

Fig. 6 Visualization of the building existing probability (city block ns20*es35–ns60*ew35)

Table 5 Estimated area and estimated building area ratio (city block ns35*es20–ne6035*ew60)

City block			ns35*ew20	ns35*ew25	ns35*ew30	ns35*ew35	ns35*ew40	ns35*ew45	ns35*ew50	ns35*ew55	ns35*ew60
Area (m^2)			700	875	1050	1225	1400	1575	1750	1925	2100
Floor	B2	Estimated area (m^2)	–	–	–	–	–	–	40.71	62.14	72.42
		Estimated building area ratio	–	–	–	–	–	–	0.02	0.03	0.03
	Bl	Estimated area (m^2)	–	125.2	130.16	107.75	97.86	–	59.03	88.87	103.58
		Estimated building area ratio	–	0.14	0.12	0.09	0.07	–	0.03	0.05	0.05
	1F&2F	Estimated area (m^2)	490.89	637.58	787.31	936.77	984.81	1122.55	1174.5	1377.18	1480.95
		Estimated building area ratio	0.7	0.73	0.75	0.76	0.7	0.71	0.67	0.72	0.71
	3F	Estimated area (m^2)	52.21	232.77	232.53	187.03	342.39	269.89	407.51	410.69	478.67
		Estimated building area ratio	0.07	0.27	022	0.15	0.24	0.17	0.23	0.21	0.23
	4F	Estimated area (m^2)	52.21	232.77	232.53	185.36	340.87	269.89	407.51	410.69	478.67
		Estimated building area ratio	0.07	0.27	0.22	0.15	0.24	0.17	0.23	0.21	0.23
	5F	Estimated area (m^2)	52.21	232.77	232.53	185.36	340.87	269.89	407.51	410.69	478.67
		Estimated building area ratio	0.07	0.27	0.22	0.15	0.24	0.17	0.23	0.21	0.23
	6F	Estimated area (m^2)	52.21	232.77	219.71	185.36	338.25	266.15	328.81	284.93	332.1
		Estimated building area ratio	0.07	0.27	0.21	0.15	0.24	0.17	0.19	0.15	0.16
	7F	Estimated area (m^2)	52.21	170.91	111.65	174.55	294.98	207.21	275.37	263.15	306.71
		Estimated building area ratio	0.07	0.2	0.11	0.14	0.21	0.13	0.16	0.14	0 15
	8F	Estimated area (m^2)	52.21	–	–	157.38	207.49	104.12	159.19	88.87	103.58
		Estimated building area ratio	0.07	–	–	0.13	0.15	0.07	0.09	0.05	0.05
	9F	Estimated area (m^2)	52.21	–	–	157.38	207.49	104.12	159.19	88.87	103.58
		Estimated building area ratio	0.07	–	–	0.13	0.15	0.07	0.09	0.05	0.05
	10F	Estimated area (m^2)	–	–	–	96 94	88.04	–	–		
		Estimated building area ratio	–	–	–	0.08	0.06	–	–	–	–

Table 6 Estimated area and estimated building area ratio (city block ns20*es35 ~ ne60*ew35)

City block			ns20*ew35	ns25*ew35	ns30*ew35	ns35*ew35	ns40*ew35	ns45*ew35	ns50*ew35	ns55*ew35	ns60*ew35
Area (m^2)			700	875	1050	1225	1400	1575	1750	1925	2100
Floor	B2	Estimated area (m^2)	–	–	–	–	–	_		14.91	22.58
		Estimated building area ratio	–	–	–	–	_	_		0.01	0.01
	B1	Estimated area (m^2)	23.82	6.79	–	107.75	118.31	178.61	143.21	45.05	72 07
		Estimated building area ratio	0.03	0.01	–	0.09	0.08	0.11	0.08	0.02	0.03
	1F&2F	Estimated area (m^2)	475.07	567.79	736.87	936.77	1013.97	1058.02	1141.62	1204.37	1279.42
		Estimated building area ratio	0.68	0.65	0.7	0.76	0.72	0.67	0.65	0.63	0.61
	3F	Estimated area (m^2)	298.26	234.51	184.68	187.03	307.48	447.4	434.52	242.47	343
		Estimated building area ratio	0.43	0.27	0.18	0.15	0.22	0.28	0.25	0.13	0.16
	4F	Estimated area (m^2)	287.66	234.51	184.68	185.36	304.89	443.78	430.17	242.47	343
		Estimated building area ratio	0.41	0.27	0.18	0.15	0.22	0.28	0.25	0.13	0.16
	5F	Estimated area (m^2)	269.4	219.86	184.68	185.36	304.89	443.78	430.17	196.43	280.48
		Estimated building area ratio	0.38	0.25	0.18	0.15	0.22	0.28	0.25	0.1	0.13
	6F	Estimated area (m^2)	242.98	174.38	181.61	185.36	304.89	406.68	404.69	196 43	280.48
		Estimated building area ratio	0.35	0.2	0.17	0.15	0.22	0.26	0.23	0.1	0.13
	7F	Estimated area (m^2)	155.5	121.85	168.11	174.55	272.59	310.94	388.92	170.26	237.06
		Estimated building area ratio	0.22	0.14	0.16	0.14	0.19	0.2	0.22	0.09	0.11
	8F	Estimated area (m^2)	102.68	63.65	69.85	157.38	272.59	310.94	388.92	121.73	165.64
		Estimated building area ratio	0.15	0.07	0.07	0.13	0.19	0.2	0.22	0.06	0.08
	9F	Estimated area (m^2)	102.68	63.65	69.85	157.38	272.59	310.94	388.92	121.73	165.64
		Estimated building area ratio	0.15	0.07	0.07	0.13	0.19	0.2	0.22	0.06	0.08
	10F	Estimated area (m^2)	–	–	–	96.94	209.63	227.23	274.78	106.66	145.88
		Estimated building area ratio	–	–	–	0.08	0.15	0.14	0.16	0.06	0.07

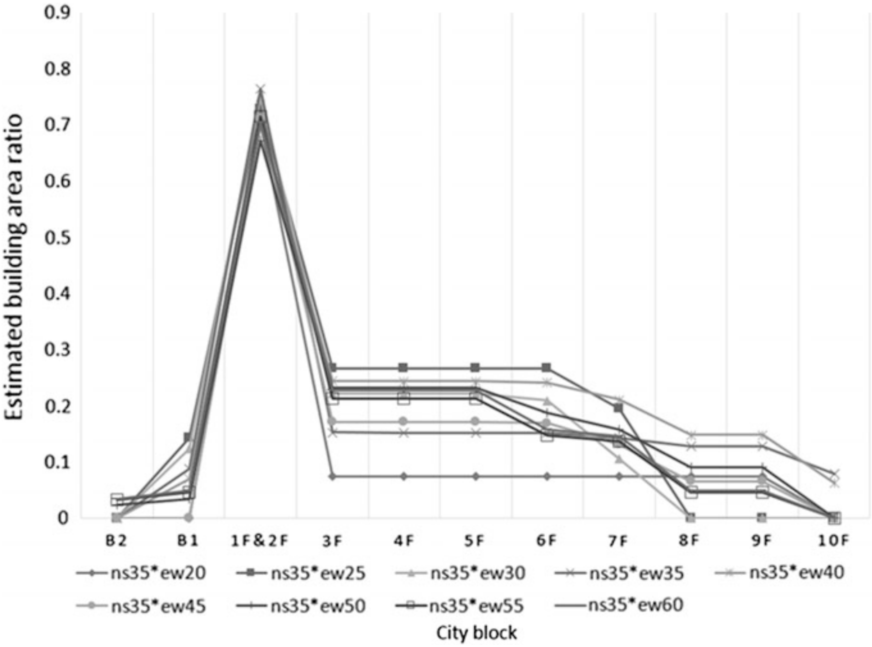

Fig. 7 Estimated building area ratio (city block ns35*es20–ns35*ew60)

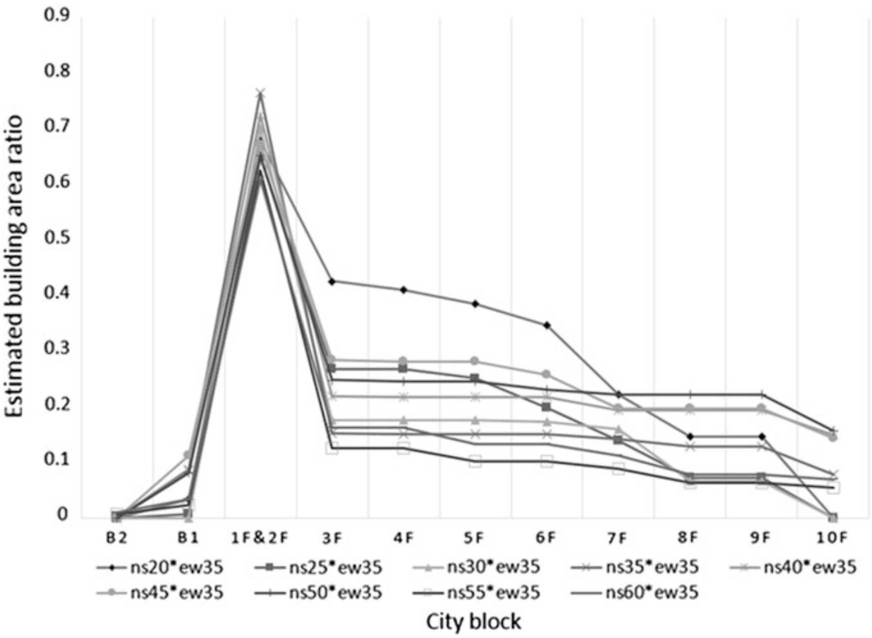

Fig. 8 Estimated building area ratio (city block ns20*es35–ns60*ew35)

Table 7 Volume sufficiency ratio (city block ns35*es20 ~ ns35*ew60)

City block	ns35*ew20	ns35*ew25	ns35*ew30	ns35*ew35	ns35*ew40	ns35*ew45	ns35*ew50	ns35*ew55	ns35*ew60
Volume sufficiency ratio	0.20	0.36	0.31	0.32	0.39	0.28	0.33	0.30	0.31

Table 8 Volume sufficiency ratio (city block ns20*es35–ns60*ew35)

City block	ns20*ew35	ns25*ew35	ns30*ew35	ns35*ew35	ns40*ev*35	ns45*ew35	ns50*ew35	ns55*ew35	ns60*ew35
Volume sufficiency ratio	0.47	0.32	0.28	0.32	0.40	0.44	0.42	0.23	0.26

Discussion

According to Table 4, the error ratio, *E*, of the city blocks comprised entirely of office buildings is smaller than that of unclassified ones (class: all city blocks). Therefore, blocks comprised entirely of office buildings can be seen as an influential factor and provide a steady building location of a city block. Offices require a high rentable ratio (the rentable area divided by the area available for use in a building) and an efficient working environment. These requirements are reflected in the design and may result in predictability of building location in a city block.

According to Figs. 5 and 6, high buildings tend to be developed in large city blocks. In Fig. 5 buildings with more than 8 floors exist in all the city blocks larger than city block ns35*ew35 (including city block ns35*ew35). On the other hand, buildings with more than 8 floors exist in only 1 city block smaller than city block ns35*ew35 (not including city block ns35*ew35). In Fig. 6 buildings with more than 10 floors exist in all the city blocks larger than city block ns35*ew35 (including city block ns35*ew35). On the other hand, buildings with more than 10 floors do not exist in city blocks smaller than city block ns35*ew35 (not including city block ns35*ew35). These results suggest that higher buildings tend to be built in larger city blocks. City planning regulations on the set back and FAR in small blocks cause the buildings to be small. City block ns35*ew35 is the threshold of high buildings.

In addition, buildings with an underground basement tend to be built in large-scale city blocks. In Fig. 5 buildings with a second basement exist in city blocks larger than city block ns35*ew50. In Fig. 6 buildings with a second basement exist in city blocks larger than city block ns55*ew35. The basement is developed to strengthen the foundations of a large city block. Therefore, larger city blocks may promote underground development.

According to Figs. 7 and 8, on the upper floors, the estimated building area ratio is higher in large city blocks. On the other hand, on the lower floors, the estimated building area ratio is higher in small city blocks. In Fig. 7 the estimated building area ratio is high for the third floor (lower floor) in small city blocks like city block ns35*ew25 and city block ns35*ew30, but for the eighth floor (higher floor), city block ns35*ew40, city block ns35*ew35 and city block ns35*ew50 have a high estimated building area ratio. The estimated building area ratio of small city blocks decreases rapidly on higher floors. In Fig. 8 the estimated building area ratio is high for the third floor in small city blocks like city block ns20*ew35 and city block ns25*ew35, but for the eighth floor, larger city blocks like city block ns50*ew35 and city block ns45*ew35 have a high estimated building area ratio. Similar to Fig. 7, the estimated building area ratio of small city blocks decreases rapidly on higher floors. The slant plane restriction is one reason for the results. To promote sufficient space use on higher floors, the city block size should be larger.

According to Fig. 6, the building location may be centered on too small a block. In city block ns35*ew20, the buildings are located at the center of the city block, compared with other city blocks. This is possibly because the regulation of slant

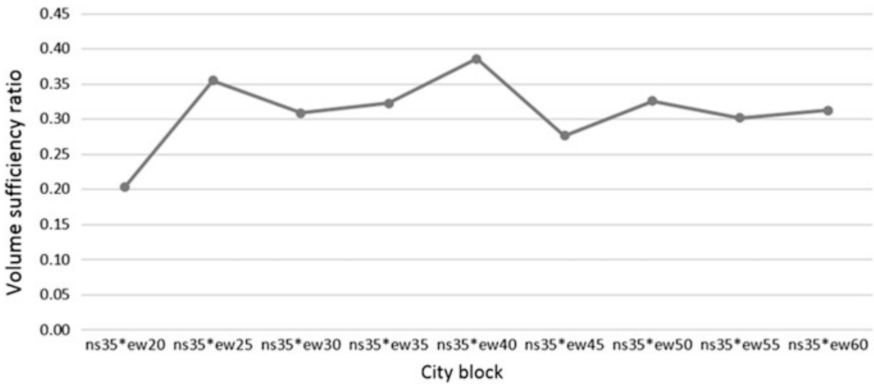

Fig. 9 Volume sufficiency ratio (city block ns35*es20–ns35*ew60)

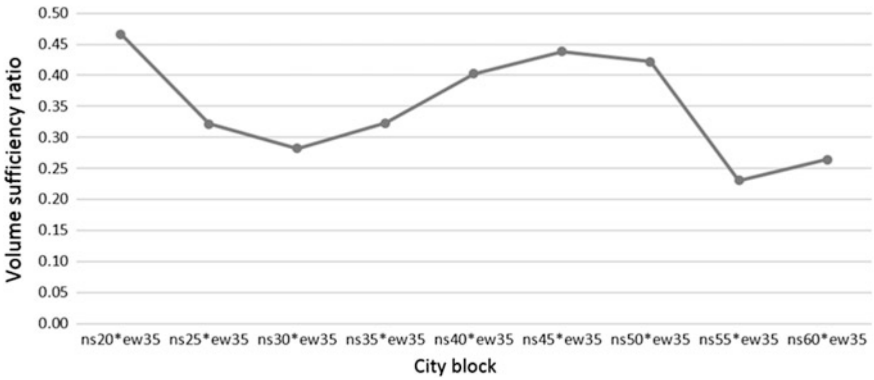

Fig. 10 Volume sufficiency ratio (city block ns20*es35–ns60*ew35)

plane restrictions is strict with regard to small city blocks. Therefore, buildings, particularly high-rise buildings, tend to be located at the center of the city block. In Fig. 5, however, the trends of the building locations cannot be found because of the few reference city blocks of city block ns20*ew35.

Figures 9 and 10 did not show significant results regarding the volume sufficiency ratio. However, this will be discussed below. The volume sufficiency ratio is high around city block ns35*ew40 and city block ns45*ew35, and the volume sufficiency ratio decreases in blocks larger or smaller than city block ns35*ew40 and city block ns45*ew35, except for city block ns20*ew35. It is possible that the buildings do not need to occupy the maximum limited volume in city blocks larger than city block ns35*ew40 and city block ns45*ew35. However, in city block ns20*ew35, the volume sufficiency ratio is high. The buildings occupy much of the volume of the city block. However, city block ns20*ew35 is a small city block. It cannot constitute efficient land use because high buildings cannot be built in a block of this size. Therefore, the city block size should be larger than the size of city block ns35*ew40 or ns45*ew35 to satisfy the needs of the development.

In the future office buildings will be developed and city blocks renovated steadily. The building locations in Figs. 5 and 6 show a visual image of the future of the city blocks. If city blocks of a similar size are developed in the future, the building locations will be similar to the city blocks in Figs. 5 and 6. These results can be used for renovation planning. Previous studies have examined whether energy use is related to building density and floor area and found that energy use can be estimated from the estimation of building locations and the floor area. In addition, the townscape and wind direction can be predicted from the estimation of building locations. In conclusion, the estimation of building locations in city blocks can be applied in various fields.

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