Incorporating the Built Environment Interactions into Spatial Pattern Models to Understand Urban Metabolism in Tokyo's Residential Area

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Abstract: In Tokyo, as residential areas exist in the urban areas and are composed of areas owned by individual land owners, basically spatial changes are brought by redevelopments of each sites conducted by individual circumstances and motivations. Continuous redevelopments and spatial changes can be found dispersedly in areas. Once the spatial change in a certain site occurred in an area as a building, it will be contained in the built environment of the residential area which is defined by residents, planners and designers who will take part in the following spatial changes. In Tokyo, public transportation facilities are well developed, and residents' daily life involves activities such as a slow walking and bicycle, etc. around the place of residence near the public transportation hubs, each living territories are formed in this kind of manner. Considering the maintenance of spatial value in residential areas while understanding transformation of visual local environment in residential areas which focuses on appearance of each spatial change in an area of street will be of significant importance. In this paper, the authors try to describe interactions of spatial changes in existing urban residential areas focusing on utility of players who might take part in the following spatial changes and the method of discrete choice model.

Key words: Existing urban residential areas in Tokyo, redevelopment of housing, site modification, interaction, discrete choice model.

1. Introduction

In Tokyo City, residential areas exist in the urban context located on the periphery of central Tokyo and are composed of areas owned by individual land-owners. Such a characteristic result from the government policy called "one's own house policy" [1]. At the point of view of land tenure, the number of land-owners especially in large city area in Japan increased remarkably after World War II. In Japan, the right of freedom to construct buildings in each site is presumed to be included in land ownership. As municipalities have limited authority, market mechanisms are supposed to have strong influence to

outcome of utilizing each land [2].

Though, there are general restriction in usages and formation of buildings, spatial changes in the urban areas are basically brought by redevelopments of each sites and premise conducted by individual circumstances and motivations. Thus, in existing urban residential areas, continuous redevelopments and spatial changes which are supposed to meet the needs of land-owners or the market can be found dispersedly in areas. Such repeated modifications to space mean that components of visual local environment are modified continuously. Once the spatial change in a certain site occurred in an area as a building, it will be defined in built environment by residents, planners and designers who might take part in the following spatial changes. Considering market efficiency, utilization on potential of site can be

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assumed, the authors can point out that there are interactions among individual spatial changes and transformation of visual local environment. These interactions of spatial changes in modification process can be observed as metabolism in existing urban areas.

For a long time, “one’s own house policy” to promote individuals to acquire a detached house was a main trend in Japan. It was assumed as the terminal goal in life course as family consisted of married couple and children. Due to the high economic growth till the mid-1960s, Tokyo experienced explosive increase of young population, lack of housings and deterioration of environment in residential areas. Government encouraged the policy to supply housings developing suburban areas. For these reasons, continuing growth in peripheral areas expanded however and caused rapid decline in the populations of 23 wards of Tokyo after 1970s [3]. Housing diffusion to the suburb has been taken into reconsideration now again from the viewpoint of continued management to declining birthrate, a growing proportion of elderly people and a huge existing stock of housing. In recent years, this peripheral expansion has slowed in contrast with growth in both supply of housing and population in 23 ward of Tokyo, the tendency of people to return to the city central is found. In aspect of residents in Tokyo, the second generation will become main residents in the near future. They have residential sense and manner of living in density populated city compared to the first generation that came from the provinces of Japan and settled down in suburban residential area of Tokyo [4]. As they select residential locations more freely and make much more different choices compared with the former generation, the changes in residence behavior patterns on the axis of time in the life cycle is assumed to occur. In these post-period of the high growth of the economy, they have an idea to secure their choices with flexibility and various options in realistic manners considering their lifestyles,

condition of household members and their preference for housing and environment. In this context, the importance of often observed “built environment” is increasingly recognized by both residents and players such as developers, planners, constructor and designers who supply housing.

There are rich and abundant literature on built environment and neighborhood changes in residential context which target North American and Western European cities. As a notion that to understand patterns of social and spatial differentiation within cities is commonly accepted, there are multiple related research which argue differences among localities, while generalized focus on the housing context in the built environment and neighborhood regeneration is also explored [5]. In the aspect of neighborhood changes, gentrification is a focus of many studies, relating to the rehabilitation of housing including the timing, cost and the type of renovation, from the point of view on regeneration through residential which contribute to sustainability [6-8], and so on. But few research are found to focus on the physical situation of residential areas, such as spatial changes, modification of sites and premises and appearance in visual local environment. As an example, the microscopic study focusing on changes in existing residential areas [9] is found in which relations between site modification and appearance in an area of street are not considered.

With regard to the housing life cycle, it seems that it is very short in cities in Japan compared to North American and Western Europe cities. Basically, spatial changes in each site and premises are brought by individual circumstances and motivations, sometimes accompanied modifications of sites. In others words, the cycle of modification in built-up areas is short, which can be characteristic of existing urban residential areas in Tokyo.

On the other hand, Tokyo can be assumed as one of the best cities where the transportation facilities are

developed in aspect of wide covered area and high and fulfilling density in railway system. Dependence on railroad system in traffic is high [10]. Thus, residents' daily life involves activities such as a slow walking and bicycling, etc. around the place of residence near the public transportation hubs. Each living territories are formed in this manner. Until recently, these spaces have been viewed mainly as community spaces for neighbors to associate with each other, children playgrounds, etc.. Caused by diversification of lifestyle and household composition, individual activities and changes in working structure, a living area-based association of people and the space use for that purpose are thought of being gradually lost in these days. Even if so, areas regarded as favorable residential areas maintain quality of street space and comfortable environment of living territories, in which repeated modifications to space and spatial changes dispersedly in areas can be observed. Those redevelopments are supposed to meet the needs of the market, inflow of new residents is caused by redevelopments. Thus, sustainability of regional value such as maintaining population balances can be observed.

Taking general review of the available literature on individual redevelopment in existing urban residential areas in Japan, there are some research from perspective of tendency in detached houses and land subdivision. For instance, there are research focusing on land subdivision and residents in aspect of where they moved from Ref. [11], on elements in street-scape [12], and on modification of open space on street brought by redevelopment of apartment building [13]. But few research are found to consider the appearance of an area on street related to built environment and its transformation. Some research modification of site and land with formalization of models are found in Ref. [14, 15], but those focus on sites exclusively so that appearance of an area on street are not taken into account.

In existing urban residential areas, marketing value

of areas seems to be tied to dispersed and continuous metabolic changes of spaces such as exclusion of old buildings, new developments and renovations of existing housings. These values are brought by both immigrations as people change their housings and rolling population who opt to reside in areas continuously. In this paper, the authors intend to describe interactions of the built environment in housing redevelopment and modification of sites analyzing the existing residential quarters in which redevelopments and spatial changes by individual circumstances in each site and premises are conducted for market efficiency. Assuming the concept of utility of players such as land-owners, planners and designers who might take part in the following spatial changes, the method of discrete choice model was incorporated. As the authors intend to describe interactions between each spatial changes and the quality of street spaces that people can share as the living territories, the authors introduced some indexes as explanatory variables of the model focusing on appearance in an area of street in cases of spatial changes.

2. Research Outline

In this study, a survey of spatial change in the residential areas of "eight cho-chome and Meguro-ku Tokyo" was conducted. Selection was based on two stages analysis in aspect of diversity of people's lifestyle and liveability in each area. The authors tried to obtain market trend from interviews with the entrepreneurs who develop housing business in Tokyo who expected positive behavior in residential selection. From the analysis of their project locations, south and west areas in Tokyo City were specified. In the aspect of liveability in residential area, the authors placed importance on the population balance, diversity of residents and households, metabolic changes of spaces such as new development and reuse of existing housings and positive growth cycle on land and building value in an area. Meguro-ku (Fig. 1) was

selected for further analysis and comparative studies in this point of view.

Then the authors sort all city blocks in Meguro-ku according to the condition of existing residential stocks focusing on the owned-housing rate and detached houses rate. As a result, four types characterizing each area were classified: mainly owned apartment housing area, mainly owned detached housing area, mainly and rented housing area. Rented apartment housing area, and mixed in owned from the urban viewpoint, population trend in the entire Meguro-ku changed from declining to increase in 1995. From all these screenings, eight cho-chome (city blocks) were selected for the survey as follows:

(1) Mainly Rented Apartment Housing area:

- A-1 population increasing area/Shimomeguro 2chome;
- A-2 population declining area/Nakameguro 1chome;
- (2) Mainly Owned Apartment Housing area:
 - B-1 population increasing area/Megurohoncho 2chome;
 - B-2 population declining area/Meguro 3chome;
- (3) Mainly Owned Detached Housing area:
 - C-1 population increasing area/Yakumo 2chome;
 - C-2 population declining area/Midorigaoka 1chome;
- (4) Mixed in Owned and Rented Housing area:
 - D-1 population increasing area/Tairamachi 1chome;
 - D-2 population declining area/Senzoku 1chome.

Fig. 1 Location of survey area (eight city blocks in Meguro-ku, Tokyo).

3. Basic Analysis

3.1 Basic Analysis on Surveyed Cases of Spatial Changes

As an outcome of the survey on spatial changes in existing residential areas of selected eight cho-chome Meguro-ku Tokyo, spatial changes brought by redevelopments of each sites and premise were listed on each case with information for instance on site area, period of the spatial change, residential type, with of each site abutting on street, and so on. Those data were acquired by comparing each city block with housing maps of Meguro-ku, published by Zenrin, versions of 1995, 2000, 2005 and 2010. The authors made a basic analysis on these data of the survey as follows.

In order to compare trends in spatial changes in eight city blocks where land area is not exactly the same, the authors defined ratio of spatial changes with land area for residential use in each city blocks as “spatial change rate” and use it as a standard for comparison. The authors found significant difference

in quantity of spatial changes between the population increasing area and the decreasing area, especially in cases of spatial change occurred with site continuity and integration (Fig. 2).

To compare condition in spatial dispersion in population increasing area and the decreasing area, land area in each blocks surrounded by streets with spatial changes were aggregated and ratio of spatial changed area in each blocks were calculated. Fig. 3 shows cumulative frequency distribution with the ratio in each block. In population decreasing areas, ratio of spatial changes are zero or little in the most street blocks, while in the population increasing area, the authors found ratios of spatial changes are evenly distributed.

This analysis indicates that, in the population increasing areas redevelopments are observed not to occur in a confined, limited area, but dispersed in a larger area.

Then the authors made some basic analysis taking general view in amount of spatial changes focusing on site modification. In the cases of spatial change occurred

Fig. 2 Ratio of spatial changes with land area for residential use in each city block (spatial change rate) contrasting residential increasing and decreasing areas.

Fig. 3 Cumulative frequency distribution with ratio of spatial changes with land area in each block surrounded by street.

by subdivision of site, the authors could not find much difference in amount between the population increasing areas and the decreasing area. The authors found difference in amount in the cases of site subdivision of integrated premises. In the cases of spatial change occurred with site continuity, small difference was found in pattern of modification into detached houses, large difference in apartment housings. In the cases of spatial change occurred accompanied by site integration, large amount of cases were found in population increasing areas especially in spatial modification from premises of detached house, or premises which was in formerly commercially used area. Accordingly, the authors can understand that each city blocks are differentiated in the amount of spatial changes and inclination in patterns of redevelopment.

3.2 Typical Spatial Changes and the Street-Scape in Residential Areas

The above mentioned basic analysis indicates that visual local environment in the residential areas are

differentiated by trend of patterns in spatial changes and in appearance of an area on street in process of redevelopment. Appearance of area on street-scape in each spatial change seems to be differentiated not only by the building types of housing but also the modification patterns of each site such as spatial division, continuity, maintenance and integration of premises. Intending to clarify these differences, the authors studied on classification with qualitative appearance of area on street in microscopic view. In existing residential areas in Japan, detached houses frequently made up with subdivision of sites. Usually land is sold in lots on the occasion of inheritance to pay off succession tax. For construction purposes, each site has a side that purchase and in most cases divided site abutting on the street in inheritance to pay off succession tax. For construction purposes, each site has a side that purchase and in most cases divided site abutting on the street in minimum 6 m otherwise just about 3 m on the street as the path and definite land at a bottom (Fig. 4). In this case of detached houses in subdivision of sites,

Fig. 4 Typification of land subdivision in redevelopment providing detached houses (upper); General subdivision with each site abutting on the street (below); Land subdivision case with conducting clu-de-sac.

frontage on the street tends to be occupied by a parking lot and a small entrance for the residents (Fig. 5). Otherwise sites are surrounded by fence to protect residents' privacy. As another pattern in dividing the land for sale in lot, subdivision creating clu-de-sac as a private road on which each lot is abutted is introduced (Fig. 4).

As for the apartment buildings, housings for single household are in large demand, the authors can find large quantity of such buildings. Usually those are rented housing in small site simple structure, thus contribution of these spatial changes pattern to the built environment in effect of introducing planting areas and open spaces along the street is limited. Generally small apartment buildings for single household consist of very small room under 20 m². In the case of the apartment type housing for sale, land size are comparatively large, the building and the

landscape are designed well that planners are aware of the value of space which they can add to the selling prices. Those buildings provide areas planting trees and shrubberies along the streets, and open spaces as pedestrian buffer spaces between sidewalks and buildings which is utilized as approach and entrance space for the building. Considering people's perception of built environment of an area, spatial changes into those apartment buildings bring enhancement of these area which people feel openness and enjoy quality of spaces and share them as their territories for living.

Some difference can be found in appearance on an area of street in middle-to-low height buildings and high rise residential building. As middle-to-low height residential buildings are built in areas regulated as low-rise residential area, residential spaces are placed on ground floor for better utilization of the sites. In

Fig. 5 Typical design of detached house abutting on street in about 5 m width.

to protect residents' privacy, buildings tend to be surrounded by fences which are composed by greening and hedgerows which brings sense of high quality along the street. Assumed typical site plan in this pattern is indicated in Fig. 6.

In Japan, regulation in greening on road side is laid down in many municipalities, Meguro-ku (city) has this kind of rules. Greening on street side has to be planned on occasion of building construction on the site above 200 m² in definite ratio with the width that the premise abut on the street.

As mentioned above, classifications of the spatial changes in each site in the appearance on the streets are conducted as follows:

- A: detached house on site area of less than 200 m²;
- B: small apartment housing mainly for single households;
- C: detached house on site area of more than 200 m² which provides greening space on the street based on regulation in greening on road;
- D: detached house along clu-de-sac;

E: apartment building on mid-sized site (site specification 600-2,000 m², mainly rented);

F: apartment building on large-sized site (site specification of more than 2,000 m², mainly owned).

These patterns can be found wherever in the existing residential area which the authors selected for the survey. In Fig. 7, figures and six photos that exemplify each distinctive feature in the appearance in those patterns are shown.

3.3 Analysis of Site Area with Spatial Changes

Further analysis was conducted in the aspect of site area of each spatial change. As the scale of site is assumed to be related with what kind of spaces will be created along the street, composition of site areas in the cases of spatial change occurred in each city blocks has influence in creation of the spaces which contribute to the quality of the spaces along the street. There is difference in accumulation of each pattern among eight city blocks, which indicate disparity in formation of local visual environment in residential

area. Fig. 8 illustrates the ratio of site area in which spatial changes occurred in the total land area of the city block excluding the street and road area, by

distinction of land size.

The authors can find some difference among areas for instance in cases of which site areas are above 200 m²

Fig. 6 Typical design of apartment building in low-rise residential area with residential spaces on ground floor.

Fig. 7 Figures and photos that exemplify each distinctive features in the appearance in six patterns.

Fig. 8 Ratio of site area on which spatial changes occurred beyond total land area of each city block in distinction of each land size.

which is lower bound of the regulation of greening along street and in cases of site areas above 600 m². These differences can be pointed out as particular tendency of redevelopment of existing residential areas in population increasing areas and in population decreasing areas.

4. Model Estimation

The authors made a model estimation to describe the mechanism and process of housing redevelopments and spatial changes revealing factors which form visual local environment in the residential quarters. Estimation was conducted in the method of maximum likelihood using function for generalized optimization of free software R. In aspect of processes of planning, each redevelopment conducted by individual circumstances and motivations seems to be made the most of the potential of the site and the built environment. For instance, if the permitted floor area ratio is high, it will be profitable especially to the apartment housings, quality of street-scape with greening and openness that people can share them as their territories for living is assumed to be favorable for owned housings for both detached houses and apartment buildings. Concept of payoff in game theory can be found in the choice of housing type,

appearance on the street, and so on. Thus spatial changes patterns can be presumed as alternatives of the utility function. Multinomial logit model which is a popular modeling approach based on the discrete choice formulation pioneered by McFadden [16] is adopted for the description of the surveyed spatial changes.

The probability that a spatial change pattern i is chosen by the decision maker n in each site is defined as $P_n(i)$, where U_{in} is the utility that decision maker n obtain from the physical attributes of the site and neighborhood.

$$U_{in} = V_{in} + \varepsilon_{in} = \sum \beta_k x_{kin} + \varepsilon_{in} \quad (1)$$

$$P_n(i) = \frac{\exp(V_{in})}{\sum_{j=1}^J \exp(V_{in})} \quad (2)$$

In the above equation, x_{kin} is the a vector of observed attributes for the alternative i of the decision maker n , β is a vector of the model parameters to be estimated ε is the error term which represent unobserved effects assumed to be independently, identically distributed as gumbel distribution with extreme value. For explanatory variables, the authors can assume that attribution of each site and premises which has effect on feasible planning for spatial changes such as site area for the project, permitted floor area ratio, ratio of width/depth of the site, width of the abutting on the street, and so on. Furthermore, to incorporate chronological aspect that elements of built environment which past redevelopment provided as the street-scape affect proceeding redevelopments, the authors tried to set up these matters as variables. For each spatial change, the redevelopment cases within 100 m in former five years were scored. The case of which site area above 200 m² means that the regulation of greening along street is applied, and the case of apartment building and detached houses with clu-de-sac that provides small open space along the street. Definition of the model is described in the following, while the estimated results are indicated in Table 1.

Table 1 Estimation results of the Multinomial Logit Model on patterns in spatial change focusing residential type and appearance on the street.

Pattern of spatial changes	Variables	Parameter	t-stat	
Detached house site area under 200 m ²	Constant	6.354	7.33	**
	Width of the abutting on the street	4.492	5.03	**
Small apartment building for single household	Constant	2.064	2.52	*
	Permitted floor area ratio/100	0.793	0.85	
	Site area for the project/100	1.621	2.02	*
Detached house site area above 200 m ²	Constant	-0.133	-5.35	**
	Score of spatial changes with greening on the road in former five years within 100 m	-1.223	-5.50	**
Detached house along the clu-de-sac	Constant	1.275	4.52	**
	Ratio of width/depth of the site	0.836	3.44	**
	Score of spatial changes with greening on the road in former five years within 100 m	-0.066	-3.19	**
Apartment building site area 600-2,000 m ²	Constant	1.103	3.72	**
	Permitted floor area ratio/100	0.096	1.89	
	Width of the abutting on the street	0.920	2.71	**
	Width of the street on which the site abutting	0.150	2.72	**
	Score of spatial changes of Detached Houses with clu-de sac and apartment building which provide small open spaces along the street in former five years within 100 m	0.498	1.98	*
Apartment building site area above 2,000 m ²	Permitted floor area ratio/100	0.477	1.81	
	Width of the street on which the site abutting	0.219	1.42	
Number of observations		2,097		
Initial log-likelihood		-435.40		
Final log-likelihood		-301.26		
Rho-squared		0.308		
Rho-bar-squared		0.269		

** Significant at $\alpha = 0.01$; * Significant at $\alpha = 0.05$.

Formularization of spatial changes pattern model:

$$\begin{aligned}
 V_{i=1} &= \beta_6 a_i + \beta_1 (\text{Constant}) \\
 V_{i=2} &= \beta_7 v_i + \beta_8 a_i + \beta_2 (\text{Constant}) \\
 V_{i=3} &= \beta_{15} g_i + \beta_3 (\text{Constant}) \\
 V_{i=4} &= \beta_9 h_i + \beta_{16} g_i + \beta_4 (\text{Constant}) \\
 V_{i=5} &= \beta_{10} v_i + \beta_{11} z_i + \beta_{12} w_i + \beta_{17} o_i + \beta_5 (\text{Constant}) \\
 V_{i=6} &= \beta_{13} v_i + \beta_{14} w_i \quad (3)
 \end{aligned}$$

where,

i : patterns in spatial change focusing residential type and appearance on the street;

- 1: detached house with site area under 200 m²;
- 2: small apartment building for single household;
- 3: detached house with site area above 200 m²;
- 4: detached houses along the clu-de-sac;
- 5: apartment building, site area 600-2,000 m²;
- 6: apartment building site area 2,000 m²;

β : parameter;

v_i : permitted floor area ratio/100;

a_i : site area for the project/100;

h_i : ratio of width/depth of the site;

z_i : width of the abutting on the street;

w_i : width of the street on which the site abutting;

g_i : score of spatial changes with greening on the road in former five years within 100 m;

o_i : score of spatial changes of detached houses with clu-de-sac and apartment building which provide open spaces along the street in former five years within 100 m.

The result shows that the score of spatial changes with greening on the road was significant as a variable to the alternatives for the detached house with site area above 200 m² which can be classified as relatively

Fig. 9 Conceptual drawing of metabolism with spatial changes in existing urban residential area illustrating interaction in modification process of housing redevelopment even though there is no concrete urban planning and scheme.

large housings and the detached houses along the clu-de-sac which provide small open space along the street. The score of spatial changes of the spatial change pattern that provide small open spaces along the street was significant to the alternative of apartment building with site area 600-2,000 m² which can be assumed that it is also providing greening space and open spaces along the street. Here the authors can assume that the effect of the former spatial changes which contribute to improvement of quality of street-scape such as greening and openness on the road in the choice of certain spatial change pattern that itself has good influence with providing greening space or open space.

5. Conclusions

Transformation on visual local environment of existing urban residential area conducted by redevelopment in each site by individual circumstances and motivations due to the tenure of lands can be considered as a distinguished feature in Tokyo compared with situations in western European cities. In each area, redevelopment with certain

planning and design are conducted independently, once it appeared in an area as a building, it is contained in the built environment of residential area which is defined by planners and designers of following spatial changes. This interaction in modification process can be observed as metabolism of spatial changes in existing urban area. Above-mentioned analysis and model estimation suggest the positive growth cycle with continuous spatial changes of areas, immigration of new residents who would increase marketing value of inherent and new spaces and increment or maintenance in marketing value of area, quality of built environment, vigor and liveability can be found (Fig. 9). Individual site in residential area is like a cell which composes the living quarters. When the change occurs in cells, they are affected by other cells and surrounded environment. Needless to say, powerful authorities possibly can set certain transformation into the existing urban area. The phenomena in existing urban residential area in Tokyo suggests the possibilities that quality of built environment can be improved by interactions of spatial changes and built environment and decision of designers and developers who perceive and utilize the value of built environment. In this study, the authors suggested model estimation incorporating concept of utility in the choice of pattern in spatial changes for describing interactions among built environment, redevelopment and modification of housings in existing residential areas with simple method. The authors recognized that further investigation in this kind of cooperative game model on redevelopment in existing residential areas is needed.

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