AN EVALUATION METHOD FOR SMART URBAN QUARTERS IN TERMS OF QOL AND CO_2 EFFICIENCY

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ABSTRACT

Various types of low carbon technologies proposed in transport field, such as low carbon vehicles, pedestrian- & cycle-oriented development, car-sharing system. However, it is not revealed that how individual technologies should be integrated each other and implemented into real urban space. Therefore, this study focuses on "Urban Quarters" on a spatial scale between city and each building, and constructs a model system which can evaluate low-carbon performance level. We examine how to reconstruct urban quarters given boundary conditions such as residential population, working population, CO_2 emission target and so on, which are set based on an examination of macro-level urban structure.

Keywords: low carbon city, district planning, Quality of Life, eco-efficiency, reconstruction

1. INTRODUCTION

Environment oriented urban planning is one of a key issue, and also its concept have been implemented in real city practically, which is called Environmental-Model-City, Eco-Police, Eco-City, or Low-Carbon-City. Moreover, these cities have been compared with each other in various past studies. However, because of macro perspective which is far from the real implementation process of element technologies, most of these studies are remained as superficial surveys.

On the other hand, a plenty of detailed technical researches have been only focusing on subsystems or element technologies itself. Various types of low carbon technologies also proposed in transport field, such as low carbon vehicles, pedestrian- & cycle-oriented development, car-sharing system. But, it is not revealed that how individual technologies should be integrated each other and implemented into real urban space.

Therefore, this study focuses on "Urban Quarter" on a spatial resolution level. Urban quarter is defined as a group of building blocks, and it is ranked between city and each building. In urban quarter resolution level, we can examine the best suitable integration system of individual element technologies for actual urban space with taking real building and infrastructure arrangement into consideration. Moreover, examination scope will be more spread and the vista or community design of urban quarters also can be examined.

Based on the above background, this study aims to develop a model system to evaluate the amount of CO_2 emissions from each activity and also to evaluate residents' quality of life by the urban quarter. In addition, a case study is implemented in the Nagoya metropolitan area(mainly focusing on commercial urban quarter in city center), and changes in each indicator for each urban quarter are analyzed from 2005 to 2050. Then, a direction for measures required to improve the sustainability in each urban quarter of the city/region is considered.

2. POSITIONING THIS STUDY IN TERMS OF PAST RESEARCH

Previous research aimed at evaluating urban spatial structures from the perspective of sustainability (for example [1],[2]) have been conducted, but most such efforts were carried out from a single perspective (such as environment or financial issues), and there has been insufficient verification of sustainability from an integrated perspective. [3]set out indicators from the TBL perspective, but their research uses macrodata for each city and it does not provide a method for analyzing urban spatial structures in detail.

Additionally, even if it has been confirmed that a particular urban spatial structure, such as the "compact city" concept, is efficient in terms of urban maintenance expenditure requirements and has low CO_2 emissions, the disposal of inefficient existing buildings and the construction of new buildings/infrastructure associated with the urban restructuring required to achieve that particular urban spatial structure entails considerable expenditure requirements, and CO_2 generation during the process must also be taken into consideration.

Unlike those in developing countries, it is not possible to plan new urban spaces in developed country such as Japanese cities from a zero base. Therefore, incremental renewal while using existing urban areas is required. Additionally, numerous local governments are being squeezed financially, which makes it difficult to encourage population movements by providing land compensation. Consequently, in order to effectively promote the conversion of urban spatial structures, it is necessary to ascertain the metabolic patterns of a city in terms of housing/infrastructure renewal and household movements, and then analyze how, specifically, each urban quarter within an urban area changes from the eco efficiency perspective.

Therefore, the authors of this article have developed a model system called "Smart Urban area Relocation model for sustainable QUAlity Stock" (SURQUAS), which enables the examination of sustainable urban spatial structures from macro perspective. As quantitative indicators of each element of environment, economy, and society, the system can estimate CO_2 emissions, urban maintenance expenditure requirements, and QOL in 500 m meshes.

In this research, while working to improve this system, urban quarter units (which are considered socially and geographically uniform) are used as evaluation units for examining sustainability.

There are several representative methods to evaluate low-carbon performance in urban quarter scale, such as CASBEE-urban development[4] of Japan, LEED for neighborhood development[5] of the USA and BREEAM[6] of the UK. However, as these methods, which were developed for planning or designing stages, are suitable for finding out indices of output such as introduction of individual technologies or consideration of designs, they are unsuitable for grasping the outcome of the development.

If the scope is limited in energy system, some previous study shows ideal integrated energy system image which is based on combination of variety of energy source such as electricity heat and biomass energy (for example[7]). There are also practical energy system planning support tools, and these tools are review is papers[8, 9]. In article [8], 37 type of evaluation tools are put in order based on questionnaire survey to each tool developers. And these tools are classifies 7 major types(simulation, scenario, equilibrium, top-down, bottom-up, operation-optimisation and investigation-optimization). On the other hand, in article [9], how identifying suitable energy system is discussed, which is based on a survey about design method of distribution type of energy system. But the concrete process is not revealed. And, aspects of co-operating urban stock metabolism process is not considered sufficiently.

Accordingly, we need a model system enabling us to evaluate the performance of total urban quarter which is metabolically changing. In addition, chronological changes should be analyzed in re-modeling in the existing urban area. This study aims to develop a model system enabling us to dynamically predict future requirements for building reconstruction, to present a renewal plan accordingly and to evaluate the plan in order to study steps for introducing policies or technologies chronologically according to step-by-step reconstruction of buildings.

In this research, evaluations that integrate each indicator using, for example, monetary value, is not carried out. One reason for this is that, when evaluating the QOL/CO_2 from a long-term/broad perspective, the number of uncertain factors impacting in the scope of the evaluation inevitably increases. Thus, even if future market prices are predicted, and CO_2 and QOL are converted into monetary values, this uncertainty will increase. Accordingly, it was considered better to provide each indicator side-by-side, and to leave the evaluation of the indicators to the relevant decision maker.

3. MODEL SYSTEM

Even though main target of this research is to reveal general method how the urban quarters should be reconstructed in the future, each urban quarters have to match in actual urban context. Therefore, we consider two different scale models, macro(urban scale) model which can evaluate balance of whole urban area and micro(urban quarter scale) model which can evaluate low-carbon-performance of an urban quarter itself. Figure-1 shows relationship between macro(urban scale) model and micro(urban quarter scale) model.

Macro(urban scale) model simulates spatial population distribution and transportation patters, and, population and transportation balance which can decrease CO_2 emissions are identified.

And, and boundary condition for planning of urban quarters(population and offices, etc.) are identified.

On the other hands, micro(urban quarter scale) model evaluate detail design under boundary condition which is given by macro(urban scale) model. Moreover, this model can evaluate amount of CO_2 emissions from infrastructure, building and equipment in life cycle perspective. However, it is difficult to evaluate all urban quarters, so we have to picked up representative urban quarters from classified group based on their respective characteristics.

And, we construct QOL indicator evaluation model which can evaluate production and city life level given by the urban quarters. Finally, we construct Eco-efficiency (QOL/CO_2) index which can evaluate urban quarters. And, this model can examine factor value which is proportion of eco-efficiency changed by renewal of urban quarters.

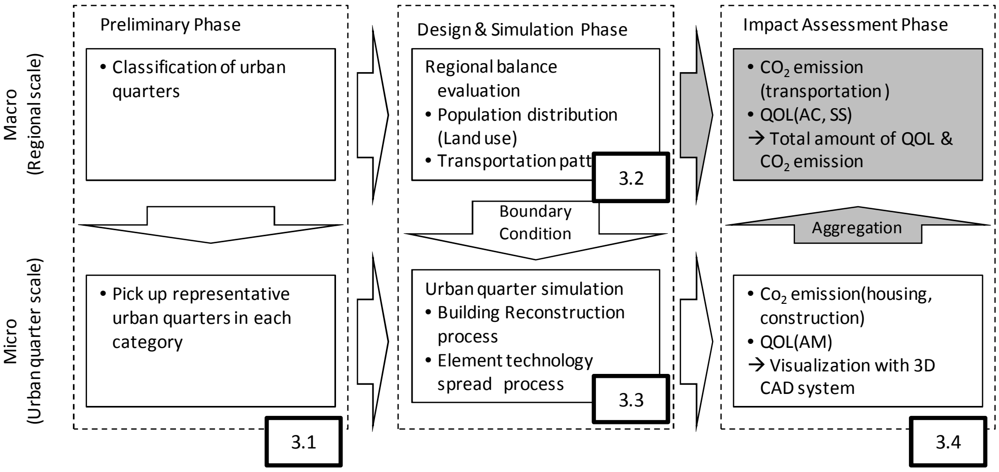

Figure-1 Relationship between urban and quarters

3.1 Classification of urban quarters

In order to pick up representative urban quarter for reducing calculation loads, urban quarters are classified based on their respective characteristics.

General factors considered when classifying districts include distance zone from city center, population density, use, function, etc. In addition, urban restructuring plans can involve large-scale renewal of infrastructure and housing. A particular feature of urban areas in Japan is the existence of many districts that were renovated all at once during the period of rapid economic growth. While the constituent elements of such districts all reach the renewal stage at the same time, there are also districts that undergo renewal in an incremental manner, so it is also necessary to consider development history when classifying districts.

In regard to these categories, a high correlation was found between population density/distance zone and use/function in the preliminary investigation, Accordingly, we attempt to classify the urban quarters districts by grouping them according to two categories: “use/function” and “development period/renewal pattern”.

3.2 Urban balance evaluation system

(1) Population cohort model

For each urban quarters, future population by five-year age groups is predicted over time using the cohort model. All populations predicted in this model indicate nighttime populations. Figure 2 shows an overview of the cohort model.

With regard to natural increases and decreases, assumed values for survival rates and birth-rates published by the National Institute of Population and Social Security Research are used.

Out-migration populations are calculated by multiplying the out-migration ratio by the population in each age group in each period. Furthermore, the values used for the out-migration ratio are the actual values obtained from the National Censuses of 2000 and 2005. However, in estimations for each small district, value instability resulting from, e.g., individual development projects, led to the adoption of an average value per district type based on age group population composition ratios, which will be discussed later. This is because districts that currently have similar population compositions are considered to have followed similar in- and out-migration patterns up to the current time.

Next, the calculated out-migration populations by five-year age groups are adjusted for the population migrating in or out of the target region established in the scenario, and the result was taken as the population movement for each period.

The in-migration population was found by distributing the population movement according to the in-migration potential of each urban quarters. The in-migration potential is the ratio of in-migration population by age group in each urban quarters to the entire target region, and was obtained from the results of the 2000 and 2005 National Censuses.

In addition, the number of households in each urban quarters was estimated using the headship rate method based on the obtained population broken down by age group. The headship rate method makes use of the fact that the number of households is equivalent to the number of householders. Thus, to find the number of households multiply the population by the headship rate. The assumed values were based on the 2005 estimates the National Institute of Population and Social Security Research. However, while those estimate only extend up to 2030, in this research, an estimation up until 2050 was carried out by presuming that the values assumed for 2030 will remain constant until 2050. Additionally, this research adopts the same five basic household family used by the institute. They are: “one-person household”, “couple-only household”, “couple-and-children household”, “one-parent-and-children household”, and “other general households”.

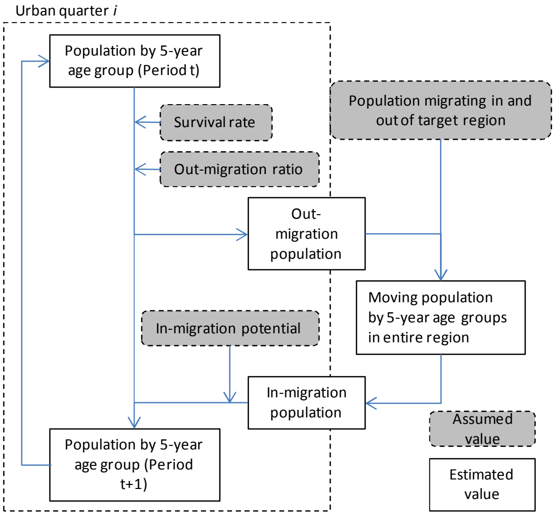

Figure-2 Flow diagram of population cohort model

(2) Transportation model

We constructed a travel behavior model for calculating the car and public transport traffic volumes that are necessary for calculating CO_2 emissions and accessibility (AC), which is one factor for evaluating QOL. The model has a two-stage structure comprising a destination choice (Equation(1)) and a mode choice (Equation (2)). The parameters are estimated with an aggregate logit model using data from the Chukyo Urban Area Person Trip Survey (2001). The accessibility indicator of each zone is derived using the logsum variable.

$$p_j^{i,m} = \frac{\left(At_j\right)^{\alpha^m} \exp\left(-\theta_1^m t_{ij}^m\right)}{\sum_j \left(\left(At_j\right)^{\alpha^m} \exp\left(-\theta_1^m t_{ij}^m\right)\right)} \quad (1)$$

$$p_m^i = \frac{\exp \theta_2 \left(AC_i^m + V_i^m\right)}{\exp \theta_2 \left(AC_i^C + V_i^C\right) + \exp \theta_2 \left(AC_i^P + V_i^P\right)} \quad (2)$$

Here, At_j: Attractiveness of Zone j, t_{ij}^m: Time required to move between Zones i and j using Mode m, AC_i^m: Accessibility of Mode m in Zone i, V: Explanatory factor for modal split other than accessibility for each zone (population density and bus stop density are used in this research), α, θ: Parameters.

3.3 Urban quarter simulation model

(1) Prediction of reconstruction of existing buildings

Predicting the exact timing of reconstruction of existing individual buildings is so difficult that we applied the Monte Carlo Method to design a model instead. Specifically, using a function of residual ratio, R_c, proposed by Komatsu et al.[10] for calculating residual ratio for a building construction 'C' with an elapsed years of 'a' , as an explanatory variable, we calculated residual probability of a building 'i' in the year of 't' as $P_{i,c}$ using Formula (3), and based on the results, we constructed a model for predicting the timing of reconstruction of buildings in a specified area by repeating the simulation year-by-year.

$$P_{i,c}\left(t+1,a+1\right)=R_c\left(t,a\right)\times P_{i,c}\left(t,a\right) \quad (3)$$

(2) Implementation assumptions of low-carbon technologies along to reconstruction

In this study, future performance of low carbon technologies is classified according to the existing plan made by the government and others[11-13], and we assumed that the latest technologies in performance are to be introduced when a new building is constructed.

3.4 Impact assessment system

QOL and CO_2 efficiency evaluation system to evaluate the low carbon performance of the urban quarters individually. On the assumption that the services provided by the urban quarters derived from the above systems are considered to represent the quality of life (QOL) of the residents, eco-efficiency is defined as Formulas(4).

$$EF=QOL/E \qquad (4)$$

Here, QOL: QOL value in the year of t, E: CO_2 emission per head in the year of t.

(1) Estimation method for QOL indicators

In order to quantitatively evaluate the QOL of inhabitants, a model created in prior research[14]) is employed. In this model, the QOL value is comprised of three classifications: accessibility (AC), indicating ease of access to social capital and public/private facilities; amenity (AM), indicating habitability and favourability of scenery; and safety and security (SS), indicating safety from disasters and accidents/crimes. The QOL value is defined by the sum of products of physical quantities influencing the neighbourhood environments, LPs (Table 1), and weightings (w) representing the subjective perceptions of the inhabitants living there, and is formulated as in Equation (5). By establishing weightings (w) representing perceptions in each habitation and age group area, differences in perceptions of QOL based on attributes are included in the estimation.

$$QOL = \sum_i w_i \left(LPs_i - LPs_{0i} \right) \qquad (5)$$

LPs_{0i} represents the reference value for LPs. This means that the QOL value in areas where all LPs_i correspond to LPs_{0i} is 0. Quality Adjusted Life Year (QALY) values, used in fields of medical/environmental risk, are used as a measure of QOL. A QALY value is the number of years of life adjusted for QOL, and the units used are "years" or "days".

(2) Estimation method for CO_2 emissions

CO_2 emissions generated from housing and passenger transportation are taken as evaluation targets for environmental loads arising from urban activities. Equation (6) shows the estimation equation.

$$E = E_h + E_l + E_t \qquad (6)$$

Here, E: Total CO_2 emissions from each area, E_h: CO_2 emissions originating in housing, E_h: CO_2 emissions originating in consumer sector (home)[15], E_t: CO_2 emissions originating in passenger transportation.

CO_2 emissions originating in infrastructure were also examined, but preliminary investigations determined that their impacts were very small, so they are excluded from the estimates of this research.

Table-1 Components of QOL

Category	Evaluation component	Indicator
Accessibility (AC)	Employment	AC to place of work
	Education and culture	AC to schools
	Health and medical	AC to hospitals
	Shopping and services	AC to large-scale retailers
Safety & security (SS)	Earthquake risk	Risk of death caused by earthquake
	Flood risk	Expected depth of flooding
	Crime risk	Number of street crimes/break-ins
	Traffic accident risk	No. of traffic accidents causing injury or death
Amenity (AM)	Usability of Living Space	Total dwelling floor area per capita
	Harmony of townscape	Variation in building height
	Surrounding natural environment	Area of green space per capita
	Local environmental load	Level of traffic noise

4. CASE STUDY

4.1 Overview of case study area

As shown in Figure 3, the case study was conducted covering the municipalities included roughly within a 20 km radius centered on Nagoya Station (31 municipalities as of February 2012). According to the 2005 National Census, the total population is 4.64 million, of which, the percentage of working-age people (15-64 years old) is 67% and the percentage of elderly people is 18%. Additionally, 74% of the working-age population is employed and, of this, the percentage of people employed in agriculture, forestry, and fisheries industries is 1.3%. Spatial structure features of the target region include a flood hazard zone extending throughout the western part of the metropolitan area (at elevation 0 m and below), and large-scale new towns such as Tokadai and Kozoji located in the northeast. Table 2 also shows basic information on the urban quarters (which are defined by the elementary school districts) in the target region, which are the basic analysis units in this research.

Figure-3 Case Study Area

Table-2 Overview of urban quarters

No. of school districts	571
Average area	2.4 [km^2]
Average population	8,100 [people]
Average population density	5,612 [people/km^2]

4.2 Classification of urban quarters

(1) Classification according to function/use

In urban quarters, several uses normally coexist. Here, land use composition was calculated for each use in urban quarters using 10 × 10 m mesh land use data (Detailed Digital Information (1997)), and a cluster analysis was conducted based on this. This made it possible to divide the districts into five types.

(2) Classification according to development period/renewal pattern

In order to ascertain the development period of each urban quarters, the populations for each five-year age group obtained from the 2005 National Census is used. This is because the data is easily obtainable and biases according to generation are considered to represent district characteristics such as development history. However, because population distribution by age group is considered to be the result of residential choice in household units, population cohorts by five-year age groups are used in a factor analysis. Information is grouped into five factors, and based on the obtained factor scores, the target region is classified using a cluster analysis. Accordingly, each factor can be interpreted as reflecting household structure, which is a factor governing population composition. From these characteristics, districts can be

Table-3 Features of each category

Urban quarter category	Location in metropolitan area	No. of Urban quarters	Overview
1) Commercial	Central area inside Nagoya City	20	Although there is inflow of people in their 20s, there is a serious outflow of people in their 30s. There is a mixture of medium- and high-rise housing with commercial and industrial districts.
2) City Center Residential	Peripheral area inside Nagoya City	70	Inflow of people aged 15–24 is striking. There is population inflow from other regions for reasons such as universities being situated nearby.
3) Inner Suburban Residential I (declining trend)	Peripheral area of Nagoya City and central areas of core cities	40	There is no population inflow. There is a trend for population outflow centered on people in their early 20s.
4) Inner Suburban Residential II (recent development)	Areas along railroads situated outside city center residential district	95	Inflow of family households appears to have been occurring in 2005.
5) Outer Suburban Residential I (junior baby boomer)	Entire outer suburbs	56	The proportion accounted for by the junior baby boomer generation is large, and this type of district is considered to have become residential as a result of home buying by this generation.
6) Outer Suburban Residential II (baby boomer)	Entire outer suburbs	82	The proportion accounted for by the baby boomer generation is large, and this type of district is considered to have become residential as a result of home buying by this generation.
7) Agricultural	Entire outer suburbs centered on western side of metropolitan area	69	There is no population inflow. There is a trend for population outflow centered on people in their early 20s.
8) Mountain Forest	Far edge of eastern side of metropolitan area	54	This type of district exists in hilly and mountainous areas. Many districts were opened up as residential areas for the baby boomer generation, but there are also districts that have been developed in recent years.
9) Other	Northern and southern edges inside Nagoya City	59	District where large-scale public facilities, etc. are situated.
10) Industrial	Primarily close to the harbor	26	District where large-scale factories are situated.

broadly grouped into two types: districts for which the development period is clear, and districts for which the development period is unclear.

(3) Classification results

Furthermore, as a result of consolidating each subtype (each element of the matrix) from a geographic perspective. With regard to the type called “Other”, districts in which industry/industrial parks are located are separated into “Industrial”. The spatial distribution of the urban quarter classifications is shown in Figure 4, and an overview of each type is given in Table 3.

4.3 Urban balance evaluation

(1) Future population forecasts

Reflecting the trend towards Japan’s population decline as a whole, the in-migration population from outside the target region in 2050 is assumed to have fallen to half that of the actual value of 2005. The interim period is linearly interpolated. Additionally, assuming that the current in- and out- migration trends in the region are maintained, the out-migration ratio and the in-migration potential are assumed to retain the same values as in 2005.

The population of the entire target region will decrease from 4.62 million people in 2005 to 4.01 million people in 2050. Furthermore, the percentage of aged residents will increase from 14% in 2005 to 37% in 2050. In particular, the population of residents aged 75 years and over will increase significantly.

The spatial distribution of rate of population change for 2050 compared to 2005 is shown in Figure 5. In central districts, the population maintains the status quo or shows a slight upward trend, while in the inner suburban districts, an upward trend is observed. In contrast, the population in outer suburban districts is seen decreasing significantly, and halves in some districts. The average age of the population is advancing in all districts, and reaches a higher value in outer suburban districts that also experience a severe population decline.

(2) Transportation simulation result

Modal split of public transportation and average trip length, which is output result of transportation model, are shown in figure-6 and figure-7 respectively. As figure-6 shown, modal split of public transportation is high in central city (Nagoya) where have rich public transportation network. On the other hand, the value is low in outer ring city. But, the value is relatively high along rail load even in suburban area. And we also pointed out that car trip share is more than 20% even in central city urban quarters such as 1)Commercial and 2)City center residential. On the other hand, as shown in figure-7, the more distant from city center location of urban quarter is, the longer average trip length is. The disparity between central city and outer ring city is 3 times.

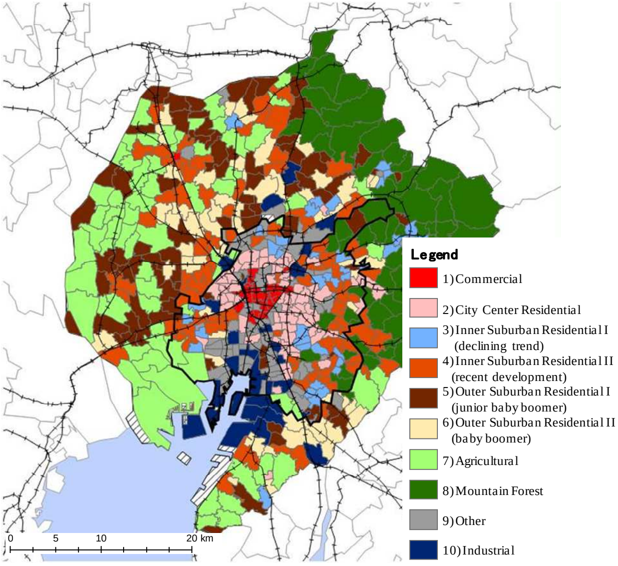

Figure-4 Urban quarter classification results

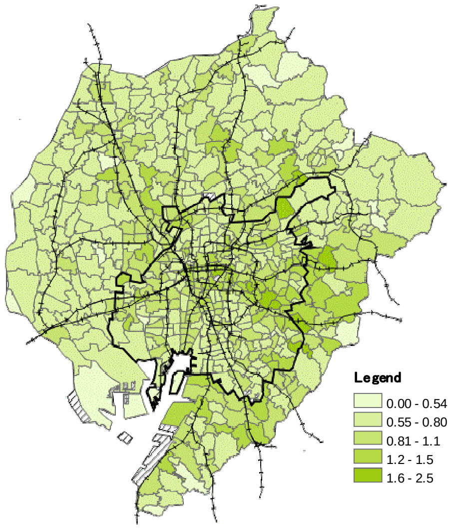

Figure-5 Rate of population change (2050/2005)

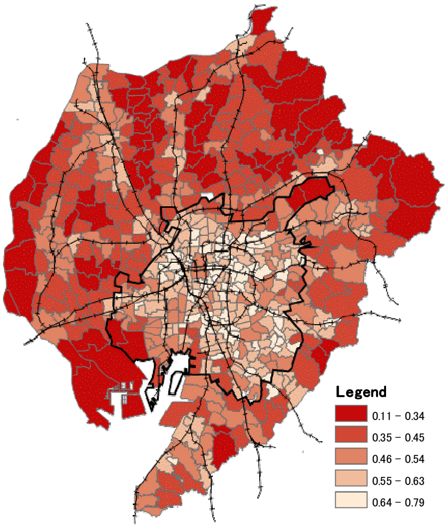

Figure-6 Modal split (2005)

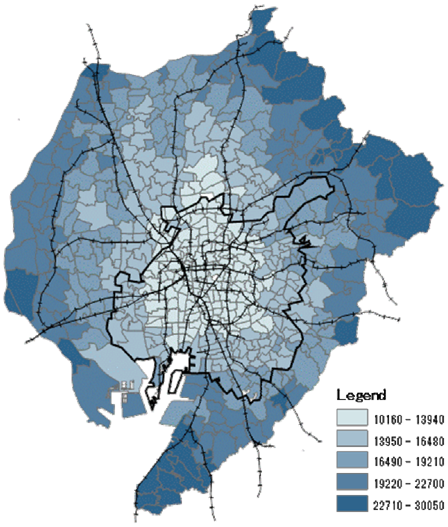

Figure-7 Average trip Length (2005)

4.4 Urban quarter simulation

In this study we focus on a commercial urban quarter, in which the shares of parking spaces and roads are high and where housing spaces and greens are not secured effectively, as indicated in Figure-8. (The concrete position of case study urban quarter is pointed out in figure-4.) Through improving these points, it will become possible to combine the aggregation of population and the maintenance and upgrading of QOL.

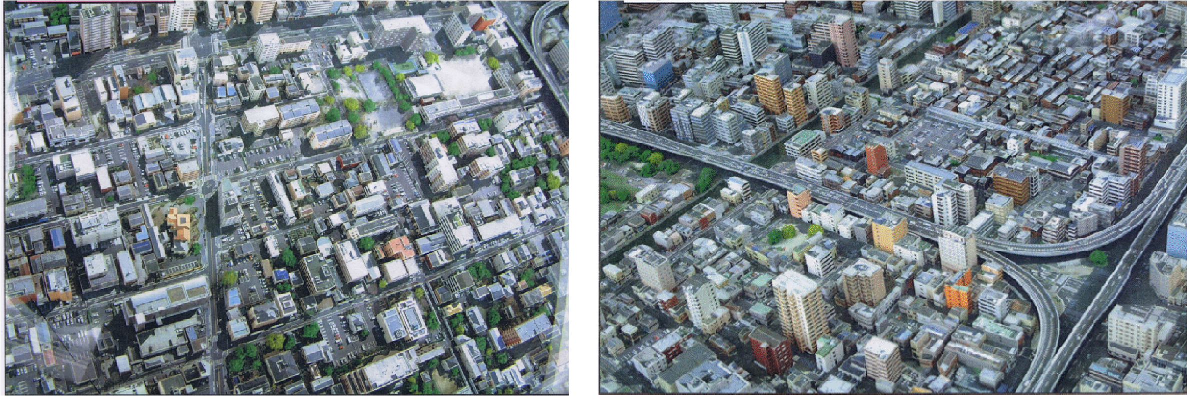

Figure-8 Present State of City Center

(1) Constructing an analysis scenario

For analyzing, two scenarios are constructed: (1) "Business as usual (BAU) scenario, which means that the existing buildings will be freely reconstructed until 2050, and (2) "Collaborative reconstruction (CR) scenario", which means that buildings built in similar years will be collected to form a group for collaborative reconstruction in the city blocks and the reconstruction of the city blocks will be carried out under a fixed plan. The number of households and workers of 2050 will be estimated to increase to 1.8 times and 1.4 times of 2010 respectively, based on a target for macro urban balance model.

(2) Results of reconstruction simulation

Examples of forecast for reconstruction with intervals of ten years by each scenario are shown in Figure-9. In the "BAU scenario", reconstruction will be continued for forty years on a step-by-step basis as buildings are reconstructed in the same place as before. Further, in the event of reconstruction, as wider floor space is generally needed in the same limited area where the prior building stood, the possibility of more uneven spatial structure in the city blocks may occur due to the volume of reconstructed buildings may vary in widely.

On the other hand, in the "Collaborative reconstruction scenario", as it may take a certain period to secure sizable land, it is forecast that demolishing old buildings will precede for the first ten years from 2020 and reconstruction of buildings will be concentrated in the next ten years.

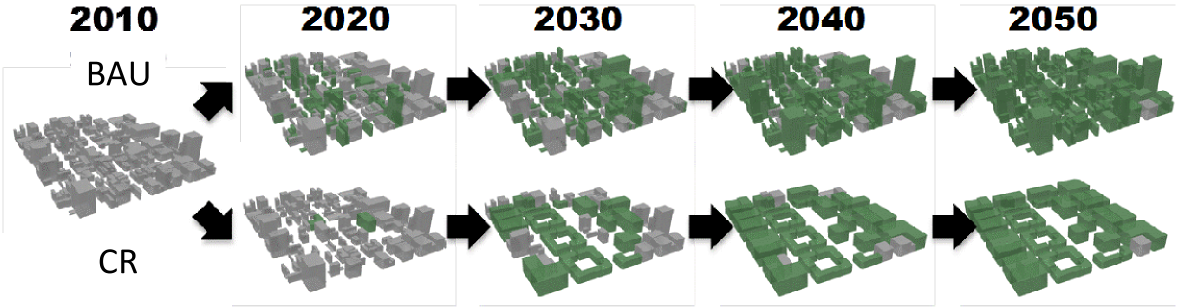

Figure-9 Results of reconstruction simulation (Decade by decade)

4.5 Impact assessment of low-carbon performance

(1) Results of calculation of CO_2 emission

Calculated results of CO_2 emission per head (excluding service and construction sectors) in both scenarios is shown in Figure-10. From the calculation, it is expected as a whole that CO_2 will be reduced by 60% in the "BAU scenario," and 65 % in the "Collaborative reconstruction scenario" respectively from 2010. In addition, in the "BAU scenario," CO_2 emission will be reduced gradually toward 2050, and in the "Collaborative reconstruction scenario," CO_2 emission will increase until 2020 according to the preceding demolishing of buildings, and then CO_2 emission will be decreased drastically. Accordingly, total emission of CO_2 for the forty years in the "BAU scenario" will be larger than that in the "Collaborative reconstruction scenario."

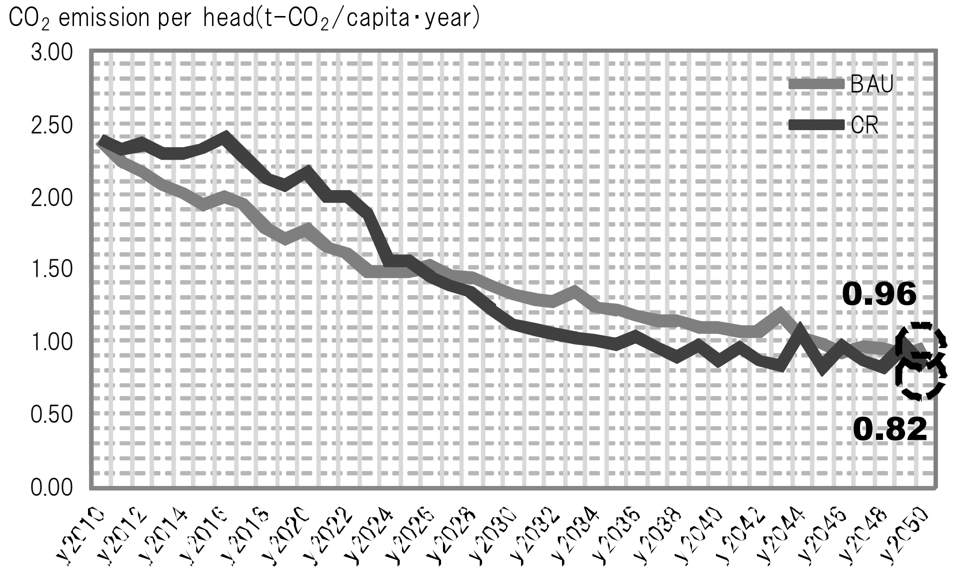

Figure-10 Calculated results of CO_2 emission per head

(2) Results of calculation of eco-efficiency

Results of the calculation of eco-efficiency are shown in Figure-11. The results show that eco-efficiency in the "BAU scenario" will be improved to 2.5 times of 2010 and that in the "Collaborative reconstruction scenario" to 3.8 times. This is caused by drastic reduction of CO_2 emission in the both scenario, however, the "Collaborative reconstruction scenario" will contribute further to improve QOL in addition to CO_2 reduction, which, it is considered, will enlarge the gap with "BAU scenario."

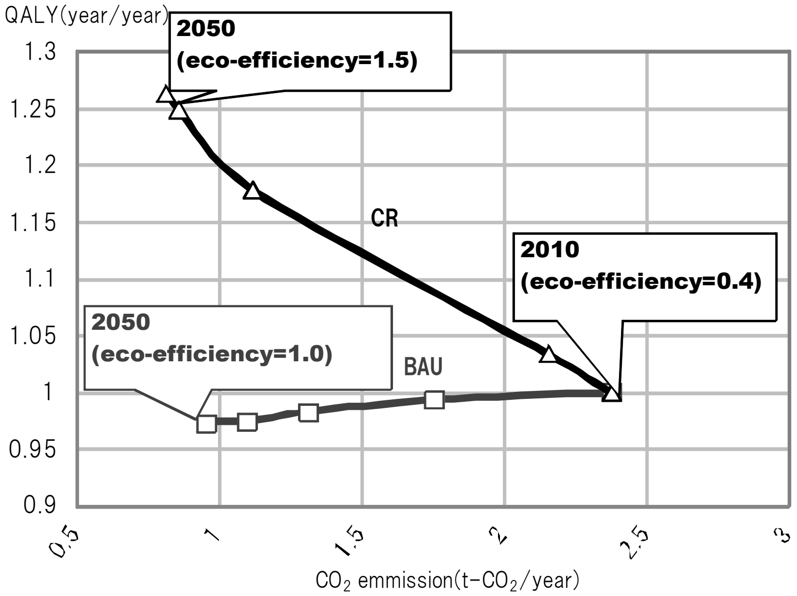

Figure-11 Results of the calculation of eco-efficiency

5 CONCLUSION

In this study, we constructed a model system to evaluate the existing urban quarters under boundary conditions which is given by macro level urban balance model. And, we can identify the optimal detail design by predicting the reconstruction schedule of existing buildings yearly based on actual data such as constructed year. The study enables us to make a chronological design plan for changing the existing urban quarters to a low-carbon society according to a fixed plan.

In addition, this research analyzed the Nagoya metropolitan area by urban quarter units. The following points are revealed from the case-study.

- In the efficiently used area, reconstruction by the unit of a total urban quarter will contribute more to improving QOL of residents and to reduce CO_2 emission than reconstruction by individual buildings.
- In the case of collaborative reconstruction, as a temporary increase of unoccupied area or a concentration of reconstruction can be easily expected, planning of the reconstruction process for the whole urban quarter is considered important.

Hereafter, we will use the results of this research to examine the specific spatial structure design of each urban quarter and proceed to analyses of the relationship between sustainability of each urban quarter and the sustainability of the entire metropolitan area.

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