Study of structural changes after formative period at urban development areas in metropolitan suburbs - Case study of industrial estates in the eastern part of the Tokyo metropolitan area -

Junichi Tamura and Hideki Kobayashi

Division of Architecture and Urban Science, Chiba University Graduate School of Engineering, Chiba, Japan

ABSTRACT
This study seeks to obtain basic knowledge about structural changes in the period of urban maturation by understanding the changes in real structures at urban development areas in suburbs developed during the urban expansion period. In this study, existing inland industrial estates in a suburb were studied, with the main focus being the changes in spatial composition and the development processes of the changes. It is argued that changes in the areas induced recycled utilisation of sites, and consequently contributed to maintaining the sustainability of the area.

1. Introduction
1.1. Background

Major cities in Japan experienced rapid population inflows during the period of high economic growth after the end of the Second World War. The consequent deterioration of the urban environment led to social problems, prompting the urbanisation of the metropolitan suburbs. In 1956, the suburbs within a radius of approximately 50 km of the Tokyo Metropolitan Area, which were developed during this period of the urban expansion, were classified as suburban consolidation zones under the National Capital Region Development Act in an attempt to restrict the development of disorderly urban areas. At the same time, factories above a certain size were relocated to the suburbs in order to improve the urban environment, which had been degraded by the concentration of the population in the inner-city areas. From the late 1990s, there has been a vigorous debate concerning the reversal of urban expansion and a return to the urban centres, leading to the large-scale redevelopment of built-up areas and the construction of large blocks of multi-storey buildings.

Urban areas in the suburbs of the Tokyo Metropolitan Area that were developed during this period of urban expansion can be broadly categorised into unplanned urban areas, which were formed through urban sprawl, and urban development areas (UDA), which were systematically developed as part of the urban plan. The urban infrastructure for the newly developed urban areas at that time was developed mainly via methods such as Land Readjustment Projects (LRP) for inland areas and reclamation projects for coastal areas.

Upon entering the 21st century, Japan began encountering a shrinking population, and the concentric expansion towards the periphery all but ceased (Nakaigawa 2011). In the present day, which is increasingly witnessing a transition in value from quantity in the expansion period to quality in the contraction period in existing suburban cities, there is a move in urban planning away from new development and towards the revitalisation of urban areas. In such a context, UDAs formed in the period of urban expansion, which are sometimes criticised for being classic examples of uniformity and a lack of individuality, are now, in the period of urban maturity, gaining attention as model examples of the regeneration of urban stock.

In this context, this study aims to provide fundamental knowledge on the state of UDAs by delineating, through an examination of spatial and chronological changes, the post-formation changes, which occurred in suburban UDAs developed in the post-war period of urban expansion.

1.2. Purpose of the study

While UDAs, which were formed by way of the land readjustment method, have been credited with contributing to the creation of favourable urban environments, it has also been pointed out that the medium- and long-term assumptions employed in planning tend to have the problem of “diverging from” or “lagging” behind the actual state of the UDA formation process (Ishida and Hatano 1982). The question of how to address this issue is a major challenge for urban planning. Further, the issues of how UDAs, which have already been formed, change in the post-development period without the presence of
a primary planning organisation, and how existing urban areas can be restructured in the future are still at the trial and error stage.

There are eight methods of planning new UDAs, including land readjustment projects (LRP) and industrial estate development projects, but common to all of them is the difference between the preparation of the urban foundation through separate development and the urbanisation of land, including buildings. As such, despite the fact that preceding changes, such as those in lots and buildings, can be expected in post-formation urban change, there is a lack of follow-up studies on post-formation changes in any of the development planning types. For example, while changes to buildings may occur in residential UDAs, which comprise the majority of suburban UDAs, subdivisions or changes to roads have, at the present time, only been partially reported on.

In this context, this paper examines the case of inland industrial estates (IE) as a first-stage case study in the investigation of changes to UDAs that have already been formed. IEs are industrial areas that have been newly created by industrial estate development works and include both basic development, such as the creation of blocks and roads, and the establishment of urban facilities essential for industry. As they are fundamentally influenced by industrial structures, industrial estates are susceptible to change, meaning that it can be assumed that rapid changes, such as frequent building renewal, changes in land usage, and changes in ownership due to company entry and withdrawal will be observable (Watts 1987; Matsubara and Kamakura 2016). Accordingly, such estates were considered an appropriate subject for this study.

In the period of urban expansion, planning targets were first set, with new development occurring in line with such targets. Conversely, it is difficult to set planning targets when redevelopment of existing urban areas is the central concern. As such, this study seeks to delineate, in part, the post-formation changes in the structure of UDAs, with a focus on the composition of roads and landscapes.

1.3. Literature review

Existing literature relating to suburban district planning can be broadly categorised as that which primarily discusses the formation processes of new urban areas and that which focuses on post-formation UDAs. Research on the formation processes focus on the development of new urban areas in the suburbs via the LRP method during the urban expansion period. Representative studies in this area include detailed works by (Ishida and Hatano 1982) and (Dohi et al. 1997). Studies that focused on lot formation processes include those by (Hatano and Miyashita 1982) and (Murahashi and Nakagawa 1992). Higasa’s (1988) large-scale study of UDAs, during the period of urban expansion, delineated the urban development of the suburbs of the Tokyo Metropolitan Area in their entirety.

In the 21st century studies like Alba’s (2015) post-formation changes in UDAs that had not previously been observed began to emerge. Further, case studies of residential areas include Harada’s studies on multiple lot ownership that utilised unused land (Harada et al. 2006) and spongification (Ujihara, Abe, and Nonaka 2016). While studies that focus on changes to lot boundaries and block form in built-up areas do exist, (Min and Sato 2007) there are, to this author’s knowledge, no case studies on UDAs in the suburbs.

On the other hand, there are many studies that focus on industrial estates, which investigate phenomena such as the relocation of small town factories caused by the Factory Restriction Act and changes in land use, including mixtures of residential and industrial activity(Wada and Nakai 1994; Shimizu and Nakayama 2007). Further, there are only a few studies that investigate post-formation changes in suburban industrial estates from an urban planning perspective, for example, studies on coastal industrial estates (Nobra 2006) and IEs, (Shiroma et al. 2008) while there are no follow-up studies, to the author’s knowledge, focusing on changes at the lot level.

2. Subjects and methods

2.1. Method

Two-dimensional materials for each decade were prepared in order to trace changes or continuity in the basic components of the LRPs – namely roads, blocks, and lots. The materials were prepared as follows.

Geospatial data were analysed to determine the following elements: the demarcations and layouts of the sites, the plans of buildings, and the road configurations. The data consisted of residential maps from 1970 to 2018 (ZENRIN: Residential Maps of the Sakura City 1970–2018; ZENRIN: Residential Maps of the Noda City 1970–2018; ZENRIN: Residential Maps of the Matsudo City 1970–2018), as well as aerial imagery from 1958 to 2009 accessed from the Geospatial Information Authority of Japan’s website (https://mapps.gsi.go.jp/) and, for 2018, aerial imagery accessed from Google Earth. The geospatial data were collated with historical sources for each IE, historical sources concerning Chiba Prefecture’s industrial heritage, and informational literature about construction works. The public roads were differentiated from private roads by referring to a map of authorised roads obtained from the municipal office.

In addition to the above process, a survey was conducted at the Sakura Industrial Estates (SIEs; discussed later), which had permitted an on-site survey on the private land. The on-site survey focussed on elements such as building configurations, site boundaries, and intra-site roads. To determine the present condition of the buildings, multiple surveys were conducted on site
between 2016 and 2018. To determine changes in site ownership, a land registry was analysed. The registry data pertained to the site that best represented the changes.

### 2.2. Subjects of the study

-While 70% of the urban areas in the Tokyo Metropolitan Area suburbs that were developed during the period of urban expansion proliferated as a result of urban-sprawl-type growth, the remaining 30% were urban areas that were developed in a systematic fashion. The proportion of systematically developed UDAs in Chiba Prefecture, which was a focal point of post-war urban development is, however, particularly high at approximately 60%.9). In this context, the study focused on the Tokatsu–Hokuso suburban consolidation zone in Chiba Prefecture, where urban development was systematically aggregated as a destination specified in the 1959 Factory Restriction Law (Table 1) (Figure 1).

#### Table 1. List of IIEs in the northern Chiba Prefecture until the oil crisis in the 1970s. (LDPC = Land Development Public Corporation).  (Statistics Division of Chiba prefectural government 2007)

| Name of IE           | Address       | Business entity                     | Start of sale |
|----------------------|---------------|-------------------------------------|---------------|
| Minoridai IE         | Matsudo city  | LDPC of municipality                | 1961          |
| Matsushidai IE       | Matsudo city  | LDPC of municipality                | 1964          |
| Kita-matsudo IE      | Matsudo city  | Others                              | 1966          |
| Nedo IE              | Kashiwa city  | LDPC of municipality                | 1968          |
| Toyohuta IE          | Kashiwa city  | municipality                         | 1971          |
| Kashiwa kikaikinzoku IE | Kashiwa city  | Others                              | 1965          |
| Nodanakazato IE      | Noda city     | LDPC of Chiba Prefecture            | 1965          |
| Nodanabu IE          | Noda city     | LDPC of Chiba Prefecture            | 1963          |
| Sekiyado IE          | Noda city     | LDPC of Chiba Prefecture            | 1968          |
| Shirai first IE      | Shirai city   | LDPC of Chiba Prefecture            | 1968          |
| Shirai second IE     | Shirai city   | LDPC of Chiba Prefecture            | 1973          |
| Minami narashino IE  | Hunabashi city| LDPC of municipality                | 1974          |
| Sakura first IE      | Sakura city   | LDPC of Chiba Prefecture            | 1964          |
| Sakura second IE     | Sakura city   | LDPC of Chiba Prefecture            | 1972          |
| Kumanodou IE         | Sakura city   | LDPC of municipality                | 1977          |
| Yakou IE             | Sakae city    | Others                              | 1973          |
| Toyosumi IE          | Narita city   | Prefecture agency                   | 1975          |
| Nogedaira IE         | Narita city   | Prefecture agency                   | 1974          |
| Tomisato IE          | Tomisato city | LDPC of Chiba Prefecture            | 1977          |
| Kozaki IE            | Kozaki city   | Prefecture agency                   | 1973          |
| Omigawa first IE     | Katori city   | LDPC of Chiba Prefecture            | 1972          |

#### Figure 1. Locations of the IIEs in the northern Chiba Prefecture.
Of the above, the oldest group of IIEs, developed in the early 1960s, was chosen to be the subject of the study. Of these, (a) Matsuhidai Industrial Estate (MIE) located in Matsudo City, 20 km from Tokyo, (b) Nodananbu Industrial Estate (NIE), 30 km from Tokyo, and (c) the Sakura Industrial Estates (SiEs), comprising the three geographically close industrial estates of Sakura First Industrial Estate, Sakura Second Industrial
Estate, and Kumanodou Industrial Estate, 40 km from Tokyo, were selected as the samples for this study (Figure 2).

(a) MIE is located at the centre of Matsudo City, which borders the Tokyo Metropolitan Area, and is adjacent to a large cemetery. As it is on the site of the former Matsudo Airforce Base, it is topographically flat, and the blocks are grid-like in shape. At the time of development, the Matsudo City Development Association was in charge of the development of MIE, whose subdivision into saleable lots for industrial use began in 1964 (Figure 3).

As of 2018, 88 companies were operating in MIE. With regard to the distribution of industry by type, 54 companies were involved in manufacturing or processing which, including one company in the recycling industry, accounted for just over 60% of the companies on the estate. Other industries that were increasing in number included transportation and construction equipment lease companies, as well as religious facilities (due to the fact that the estate is adjacent to a cemetery) (Table 2).

(b) NIE is located in the south of Noda City, flanked by the Edo and Tone Rivers, and is adjacent to National Route 16, a main beltway that runs through the city roughly from north to south. At the time, the Land Development Public Corporation of Chiba was in charge of the development of NIE, whose subdivision into saleable lots primarily for industrial use began in 1963 (Figure 4).

As of 2018, 119 companies were operating in NIE. With regard to the distribution of industry by type, 72 companies were involved in manufacturing or processing which, with the inclusion of four companies in the recycling industry, accounted for just over 60% of all companies on the estate. The number of companies in the transport industry, in

Table 2. Number of industry types in the Matsuhidai IE (Company).

| Manufacturing & Processing Industries | Other Industries | MI: Manufacturing Industry |
|--------------------------------------|-----------------|---------------------------|
| 55                                   | 33              |                           |
| 52                                   | 2               | 1                         |
| MI                                   | Pl              | RI                        |
|                                      | LW              | LC                        |
|                                      | RL              | RS                        |
|                                      | OT              |                           |
|                                      |                 |                           |

|                           | RI | LW | LC | RL | RS | OT |
|--------------------------|----|----|----|----|----|----|
|                          | 9  | 3  | 5  | 2  | 14 |    |

R: Recycling Industry
LW: Logistics & Warehouse
LC: Leasing Company
RI: Research facility
RL: Religious facility
OT: Other

In 1991, Matsuhidai Station opened to the south of MIE, leading to an increase in residential lots that eventually surrounded the estate (Photo 1). In tandem with this development, MIE became increasingly convenient for residents; in 1997, for example, a post office opened in a corner of MIE.

As of 2018, 119 companies were operating in NIE. With regard to the distribution of industry by type, 72 companies were involved in manufacturing or processing which, with the inclusion of four companies in the recycling industry, accounted for just over 60% of all companies on the estate. The number of companies in the transport industry, in
particular, is increasing, with 16 companies, both large and small, currently located on the estate (Table 3).

Around the time the land started being sold as lots, National Route 16 was designated a ring road (Photo 2). Shortly thereafter, two facilities were located on the south side of National Route 16: One was a school affiliated with a private university; the other was the headquarters of a religious organisation. Before 1990, a section of NIE served as a university’s sport ground. In 1990, the section became a driving school. In 2000 and thereafter, the grounds of the religious organisation started expanding, eventually penetrating into NIE.

(c) The SIEs, located in Sakura City, are positioned between the Port of Chiba and Narita International Airport near the Higashi-Kanto Expressway. What was previously a topographically flat, elevated former agricultural area located to the south of a former castle town with Sakura Castle at its centre was developed into the SIEs. At the time, the Land Development Public Corporation of Chiba was in charge of the development of Sakura First Industrial Estate, a 51.9 ha site, whose subdivision into saleable lots

| Table 3. Number of industry types in the Nodananbu IE (Company). |
|---------------------------------------------------------------|
| Manufacturing & Processing Industries | Other Industries |
|--------------------------------------|-----------------|
| MI                                   | PL              |
| 69                                   | 3               |
| MI                                   | RI              |
| 76                                   | 4               |
| MI                                   | LW              |
| 16                                   | 16              |
| MI                                   | LC              |
| 3                                    | 1               |
| MI                                   | RL              |
| 2                                    | 2               |
| RI                                   | RS              |
| 21                                   | OT              |

Photo 1. Aerial views of MIE in 1970, 1996, 2013.

Photo 2. Aerial views of NIE in 1967, 1998, 2013.

Photo 3. Aerial views of SIEs in 1970, 1997, 2009.
primarily for industrial uses began in 1964. Subsequently, the same organisation planned and developed Sakura Second Industrial Estate in 1970. Construction from the south to the north of the current industrial estate began after the Sakura Interchange of the Higashikantou Expressway opened on the southern side of the current industrial estate. It was opened as an exclusive industrial zone with a total area of 41.6 ha in 1971. Kumanodou Industrial Estate was an undeveloped low-lying portion of land between the First and Second Sakura Industrial Estates, which was developed as an area for small-scale factories. The Sakura City Promotion Association developed the estate, with development starting in 1976, and the subdivision into saleable lots being completed in 1979 (Land Development Public Corporation of Chiba Prefecture: 25th Anniversary 1985; Land Development Public Corporation of Chiba Prefecture: 40th Anniversary 2000) (Figure 5).

As of 2018, 111 companies were operating in the SIEs. With regard to the distribution of industry by type, 65 companies were involved in manufacturing or processing which, with the inclusion of one company in the recycling industry, accounted for just under 60% of all companies on the estate. Transportation and construction machine lease companies are increasing, with nine from each industry currently located on the estate (Table 4).

After the Higashi-Kanto Expressway opened in 1971, the Sakura Interchange opened south of SIEs. From the mid-1980s, SIE’s environs became increasingly residential. However, being built on a plateau, the residential land remained segregated from the site (Photo 3).

These three industrial estates situated in the suburbs of the Tokyo Metropolitan Area were developed...
in the same period under the influence of factors, such as the Factory Restriction Law of the high economic growth period, and all three had a large block structure to facilitate the entry of factories of a certain scale and larger. Changes to industrial structures after the oil shock further increased activity to lure commercial industry to the area. The end of the bubble period saw the withdrawal of large-scale factories, and the 21st century saw the growth of companies from industries other than manufacturing, such as logistics and warehousing and leasing, which continues to the present day.

Terms and definitions

| Term                        | Definition                                                                 |
|-----------------------------|---------------------------------------------------------------------------|
| Urban Development Area (UDA)| A systematically developed new urban area created during the period of urban expansion in the post-war era of high economic growth. |
| Scheduled Urban Area (UDA)  | Land that has been established under the district plan but has not yet been urbanised. |
| Industrial Site             | Private land that excludes public land, such as roads and parks, which is used for purposes such as housing production facilities after the development of the industrial estate. |
| Rate of Urbanisation        | The ratio of sites with structures built on the urban foundations prepared by land readjustment. |
| District                    | A parcel of land that has been systematically zoned according to the separate development method. |
| Block                       | A parcel of land surrounded by an authorised public road                  |
| Lot                         | Division of land within a block                                            |
| Site                        | An aggregation of lots that are utilised by one company in a seamless fashion |
| Changes of site area        | A change in the amount of site area managed by one company                 |

3. Comparison of IIEs

3.1. Changes in urban area

In this study, the rates of urbanisation of the industrial sites since their development were calculated (Figure 6) in order to confirm the changes in the UDAs over time. Results showed that at a particular point in time, the growth pace of the rate of urbanisation suddenly slowed, a phenomenon this study defines as “saturation”. At the same time, due to the fact that industrial sites with sites that had changing boundaries were included, sites that experienced changes in area after development were also taken into account. This paper defines “sites with changed area” as land where the site area managed by one company has changed due to a change in ownership or change in production facilities.

3.2. Changes to sites

Next, industrial sites developed within SUAs were divided into those whose area changed and those whose area did not change, and then each of the industrial estates was examined (Figure 6, 7).

(a) In MIE, more than 90% of the SUA was industrial sites, taking approximately 15 years to reach saturation. The rate of urbanisation was particularly high compared to that of other industrial estates. Further, 40 years since development, it was found that sites that had experienced a change in area comprised only a very small portion of all the industrial sites.

(b) In NIE, more than 90% of the SUA was industrial sites, taking approximately 20 years to reach saturation. Further, the proportion of sites that had experienced a change in area since 1970

![Figure 6. Increases of industrial sites and changed sites.](image-url)
Figure 7. Industrial sites that have changed their site areas.

was in line with the rate of increase of industrial sites.
(c) In the SIEs, more than 90% of the SUA was industrial sites, taking approximately 25 years to reach saturation. It was found that approximately just under 70% of sites had experienced a change in area and that about 90% of the changed sites were located on topographically flat and elevated areas rather than in valleys.

A common result among the three estates was that changes in site area began even during the UDA formation process, with the area usable for industrial purposes increasing within the SUA. Conversely, it was found that when the rate of urbanisation of the industrial site exceeded approximately 90%, the SUA became saturated, and the speed of urbanisation tended to dramatically decrease. As such, this paper refers to the point when the rate of urbanisation exceeds 90% and the rate of increase of industrial sites plateaus as the “saturation point”, when the development of the urban area was completed. The period after the point of saturation is a particular focus of this study, as a post-formation period of change.

A common post-formation period change was the rapid increase in sites with changed area, which was driven by the large number of partitioned sites created after the exodus of large-scale factories. In particular, the fact that other types of industries, mainly religious facilities, began to enter the industrial estates from the year 2000 is likely to have had a restricting influence on the rate of increase of industrial sites.

At this point, sites that had seen a change in the site boundary after subdivisions began in the early 1960s and which are aggregations of lots utilised by one company were extracted in order to understand the rate of incidence of changes in site area. Results uncovered three broad types of site area changes:

(i) Site enlargement (Figure 8): This change is characterised by the enlargement of a company’s site by incorporating unused development land within the SUA or land left unused due to the withdrawal of another company. Site enlargement is generally carried out with respect to a neighbouring site within the same block. Other examples were, however, observed. These include the enclave landholding type, which spans blocks surrounded by roads or waterways, and the boundary adjustment type, where the site was slightly enlarged by clarifying a previously unclear boundary.
(ii) Site shrinkage (Figure 9): This refers to shrinkage in an existing site when the site is subdivided and sold off after a company withdraws. Common examples of site shrinkage are the demolition of existing buildings or change in their use following a company's withdrawal,

Figure 8. Transition of site enlargement in the site S in the SIEs.
Figure 9. Transition of site shrinkage of the site EE in the SIEs.

sale of the site after subdivision, and change in the use or total levelling of the site. Other types of shrinkage were also observed, such as the practice where a company rents out part of its site to another company without withdrawing, or where the boundaries are adjusted.

(iii) Unchanged site: This type indicates that there has been no change in the shape of the site boundary line since the start of the subdivision into lots, implying that changing times were managed by utilising the usable space within the site by building or demolishing buildings.

3.3. Changes to roads

Three types of roads were observed in IIEs: two-lane public roads (one lane each way), one-lane public roads (without a centre line), and private roads (without a centre line). Private roads connected to public roads can be roughly categorised into roads with a designated position, roads authorised in the city plan, and intra-site roads. Private roads are, fundamentally, private land, but roads with a designated position and roads authorised under the city plan are legally defined as roads. To determine the relationship between the city plan and road categories, the distributions of the road categories were analysed (Figure 10).

(a) As MIE was on a topographically flat site, public roads whose utility has changed from that of the previous roads have been laid out so as to form grid-shaped blocks. Two-lane public roads form the perimeter of the industrial estate, while one-lane public roads, whose use changed from that of the former agricultural roads, formed the back roads. There was only one road with a designated position in the north-western block where there was an aggregation of small-scale buildings, while all other roads were intra-site roads.

(b) NIE was on a topographically flat site, but the street composition was a deformed lattice shape due to the influence of the former agricultural roads. Two-lane public roads formed the majority of the perimeter and centre, while the single-lane roads, which were modified from the former agricultural roads, formed the blocks. The east side, home to mainly small- and medium-sized companies, had block shapes influenced by the slight topography of the land, which was based on the form of the valley floor. Apart from one road authorised in the city plan, which ran alongside the main belteway, and several roads in a block with a high density

Figure 10. Configuration of public and private roads.
of designated position roads and small-scale structures, all private roads were intra-site roads.

(c) The blocks of the SIEs took the form of the street composition, which had been influenced by the slight topography of the land. Two-lane ridge roads run vertically along the topographically flat-elevated areas with one-lane public roads that used to be agricultural roads running horizontally from them like branches. Apart from one road in a block with a high density of designated position roads and small-scale structures and one road authorised in the city plan, all private roads were intra-site roads.

Thus, the analysis revealed two broad road compositions among the city plans: grid and ridge. It also revealed a hierarchy in the road categories.

3.4. Relationship between changes in roads and sites

In light of these findings, the changes or continuity in each road category were examined by calculating the rate of increase in road length by road category.

(i) Two-lane public roads (Table 5): It was found that after being approved and built, all such roads in the IIEs have been maintained without any change until the present day.

(ii) One-lane public roads (Table 6): A number of cases were found where partial changes to such roads had occurred even after the development of the urban area. For example, despite the fact that the public roads on the western side of the SIEs were former agricultural roads, which were registered as authorised roads, they were considered unimproved roads, and their physical management was abandoned. Further, readjustment of the industrial estate boundaries due to LRP led to the modification of the authorised position of the public roads in the northern area and their subsequent relocation. Some public roads, however, were found to have been physically eliminated after being incorporated into neighbouring site enlargements without a change in the authorised position. The public roads in the northern area of the NIE were, despite being authorised, not in common use and not under management from the beginning.

(iii) Private roads (Table 7): Roads authorised as roads with a designated position and roads authorised under the city plan were part of the industrial estate and found not to have changed since the formation of the urban area. Most of all, other private roads were intra-site roads, which connect to public roads, and were found to have been added, eliminated, or changed as a result of additional construction or changes to site area after the creation of the urban area. In MIE, for example, the site enlargement, which occurred at the block situated in the southwestern area, was found to have led to the elimination of intra-site roads connecting to public roads in 2000. Further, in the SIEs, it was found that the management of private roads also changed with changes in site ownership and environmental changes, leading not only to new construction, but also to the abandonment of the management of intra-site roads in some cases.

Next, to determine the relationship between road changes and block formation, the decennial average in the surface area of blocks sections surrounded by public roads was sought for each of the three IIEs (Table 8).

(a) The average block area at MIE was found to be particularly low compared to the other industrial estates. Until 1975, construction works caused increases in the average block area. After the oil shock, however, blocks constructed specifically for small- and medium-sized companies caused the average block area to fall, with no further changes observed since 1985.

(b) The average block area at NIE was found to have continuously decreased from the time of construction to the present day. The reason for this was that the development, which started in the

| Table 5. Increasing rate of two-lane public roads. |
|---|---|---|---|---|---|---|
|     | 1965 | 1975 | 1985 | 1995 | 2005 | 2015 |
| Matsuhiida IE | 100% | 21% | 0% | 0% | 0% | 0% |
| Nodanabu IE | 100% | 46% | 12% | 0% | 3% | 0% |
| Sakura IEs | 100% | 206% | 13% | 0% | 0% | 5% |

| Table 6. Increasing rate of one-lane public roads. |
|---|---|---|---|---|---|---|
|     | 1965 | 1975 | 1985 | 1995 | 2005 | 2015 |
| Matsuhiida IE | 100% | -13% | 57% | 0% | 0% | 0% |
| Nodanabu IE | 100% | 32% | 12% | 0% | 10% | 0% |
| Sakura IEs | 100% | 76% | 13% | 4% | 0% | 0% |

| Table 7. Increasing rate of one-lane private roads. |
|---|---|---|---|---|---|---|
|     | 1965 | 1975 | 1985 | 1995 | 2005 | 2015 |
| Matsuhiida IE | 100% | -43% | 30% | 0% | -77% | 0% |
| Nodanabu IE | 0% | 100% | 4% | 3% | 0% | 0% |
| Sakura IEs | 100% | 110% | 0% | 25% | 0% | 39% |

| Table 8. Averages of block areas. |
|---|---|---|---|---|---|---|
|     | 1965 | 1975 | 1985 | 1995 | 2005 | 2015 |
| Matsuhiida IE | 4.4 ha | 4.9 ha | 3.6 ha | 3.6 ha | 3.6 ha | 3.6 ha |
| Nodanabu IE | 10.7 ha | 7.4 ha | 6.3 ha | 6.3 ha | 6.0 ha | 6.0 ha |
| Sakura IEs | 16.4 ha | 6.2 ha | 6.8 ha | 6.9 ha | 7.2 ha | 7.3 ha |
west, consisted of large-scale blocks, with the development of land for small and medium-sized companies progressing as development moved towards the east. This led to decreases in average block area.

(c) The average block area in the SIEs, after the end of the initial construction phase in 1975, was small but increased continuously over time.

One general observed pattern was that two-lane public roads would remain unchanged. Also observed were two constant road patterns within the IIEs: the presence of a trunk road and gridded streets. Of these, trunk roads are typical suburban features. Also of note, these two patterns differed from each other in terms of how their usage in the IIEs changed over time.

Specifically, regarding gridded streets, there were changes in how sites were segmented within blocks surrounded by road on all four sides. There were also examples of sites that extended across roads.

As for trunk roads, sites rarely extended across such roads. In some cases, however, a block with an ambiguous composition would extend inward into the SUA; such blocks were the result of a branch road diverging from the trunk road, leaving some space for development. The presence of such blocks explains why the average block area kept increasing, albeit modestly, over time.

On the other hand, one-lane, dead end public roads found in the SIEs were observed as an example of changes in site area affecting public roads (Figure 11). In the beginning, the road functioned both as a back road and a back entry/exit, but Company G’s site enlargement by encampment into the depths of the site resulted in the neighbouring site becoming detached from the back street. This resulted in the back street losing the back entry/exit and thus having no function, turning it into just a dead end road. Thus, the impact of site changes upon public roads primarily involved contextual changes.

3.5. Categorisation of sites with changes in area

To enable a more detailed analysis of sites with changes in area, such sites were categorised and their characteristics were analysed. First, area changes were broadly divided into enlargement or shrinkage, with area enlargements categorised as either “neighbouring enlargement” or “enclave enlargement”, and area shrinkages categorised as either “neighbouring subdivision” or “withdrawal” (Table 9). Further, sites where both increases and decreases in area were observed were defined as “repeated enlargement/shrinkage sites” and analysed separately.

(a) With a high proportion of sites that experienced area changes, MIE was found to have a comparatively high level of enclave enlargements. Due to the tendency of subdivided sites to be utilised as enclave landholdings, a large number of enclave landholdings were found to have emerged following the exodus of large companies, which started in the year 2000. Site enlargements through enclave landholdings were common in the metal assembly and processing industry.

(b) NIE was found to have a large number of subdivided sites, due to the withdrawal of large companies. For this reason, transportation companies tended to enter subdivided sites, which partly explains why the estate has more transportation companies than other industrial estates.

(c) The SIEs experienced a large number of changes in site area due to enlargements or shrinkages, which utilised neighbouring land. Additionally, a particular characteristic feature of this industrial estate was the large number of sites that experienced a repeated cycle of enlargement and shrinkage.

Results of the categorisation showed that there were many enclave enlargements in MIE and many withdrawals in NIE (Table 9). Further, the presence of site changes...

Figure 11. Influence of site enlargement of the site G in the SIEs.
enlargement/shrinkage, which utilised neighbouring sites, was striking in the SIEs, implying that there was a large number of enlargement/shrinkage sites, which experienced a repeated cycle of enlargement and shrinkage.

3.6. Detailed analysis of repeated enlargement/shrinkage sites

When considering the post-formation changes in urban areas (the aim of this investigation) from a long-term perspective, it is important to take a closer look at sites that have experienced a repeated cycle of enlargement and shrinkage. Based on the results of the categorisation, the SIEs, where a large number of repeated enlargement/shrinkage sites were observed, were selected as the subject of further analysis. First, of the SIEs sites, those whose areas had changed were selected for analysis (Figure 12). Next, residential maps were analysed in depth to trace the changes in tenancy among the 43 companies located in these sites (Figure 13). Site area was considered only for formed and urbanised sites, not for undeveloped land.

Organising the information along the time axis revealed that site area changes, which utilised existing sites, began in 1987 when Company A enlarged its site by incorporating a neighbouring site from where a company had withdrawn. On the other hand, it was found that subdivision of shrunk sites began with the entry of Company FF1 in 1979, after the withdrawal of Company FF. Ten of the above-mentioned 43 companies had repeated enlargement/shrinkage sites, with a particular tendency for this phenomenon to occur in older sites that had existed since the initial construction.

Next, to clarify the tenant-landlord relationship in the sites whose area had changed, the changes in land ownership were analysed using a certificate of registered company information that pertained to Company P. Company P was selected because its site (Site P) had been subject to the greatest number of land consolidations.

According to the results, there were no cases in which Site P was legally subdivided upon a change in landlord (Figure 14). There were, however, cases in which the land was physically subdivided upon a change in tenant. During the period in question, the landlord remained the same. A follow-up survey of Company EE’s site which had shrunk revealed a number of cases in which a physical subdivision was accompanied by a legal subdivision following a change in landlord.

Due to the fact that there is not normally much of a change in lot shape once it is formed, this type of change was considered a characteristic example for the area which was the focus of this study (Figure 15).

In Figure 16, the change-over-time in the surface area of legally subdivided plots has been plotted along
with that of industrial sites and sites whose area changed. Results showed that while the legal subdivision themselves had started before the formation of the urban area, full-fledged subdivisional changes started after the saturation point, i.e. from 1990. Further, approximately 70% of urban areas are made up of sites which experienced area changes, with approximately 40% of such changes in site area occurring in conjunction with the regal subdivision. In such cases, regal subdivisions were found in not only all of the shrunken sites but also in some of the sites that had experienced neighbouring enlargement. As such, this paper defines sites as mentioned above that experienced a change in area due to the property owner subdividing part or all of the site as "sites altered by regal subdivision".

In addition, site consolidations would occur when a new or existing company used an industrial site that had emerged in an urban area following the withdrawal of another company that was operating there. Accordingly, a further analysis was conducted focusing on change-over-time in such withdrawals in order to clarify the degree to which the sites were reused (Figure 17). Results showed that the entry and withdrawal of companies began to coalesce after 1990, with the number of entries and withdrawals being the same in 2015. From this, it can be surmised that when the SUA reached saturation point, there was increased pressure to acquire land in the industrial estate as a whole, accelerating moves to reuse sites that had been used by companies that had withdrawn. This shows that the period of the emergence of site changes due to regal subdivision and the period of the start of the coalescence of company entry and withdrawal closely overlap, confirming the relationship of the post-formation urban area change structures.

Figure 12. Location of changed sites.
4. Changes in buildings and intra-site roads: focusing on the SIEs

The cooperation of the Sakura Industrial Estates Liaison Council and others enabled the investigation of areas within private properties. Specifically, as the building density in 1990 was almost the same as now, a follow-up study focusing on the relationship between various aspects, such as changed sites, factory buildings, and intra-site roads, was conducted.

Figure 13. Transition of the changes in the areas of sites in the SIEs. Location of subdivided sites.

Figure 14. Repeated enlargement/shrinkage in the site P in the SIEs. Transition of the changes in the areas of sites in the SIEs.
4.1. The relationship between changes in buildings and sites

First of all, an examination of the factory building groupings in person and by use of aerial photographs revealed that many factories had added extensions to the existing structures (Figure 18). Forty-four of the 111 companies had building extensions, i.e., approximately one in three of the companies in the industrial estate had selected building extension as a way of production facility reorganisation.

On the other hand, there was an even distribution in the case of demolition across the entire industrial estate (Figure 19). In particular, there was a tendency for large-scale factory groupings to be demolished upon the withdrawal of a large company. Further, there were a few cases of building demolition, which may have been due to production facility reorganisation, even on sites where there was no history of company withdrawal. At this point, the ratio of buildings and sites by industry was calculated and analysed (Table 10, 11).

(i) Manufacturing and processing industry (65 Companies): The characteristic features of companies in the manufacturing and processing industries was that they were operating on almost all of the sites where building extensions had occurred. Specifically, of the 44 companies where building extensions were confirmed, 42 were involved in manufacturing, while the remaining two were automobile maintenance facilities. All of the enlarged sites were related to the manufacturing and processing industry, with other industries found to have no enlarged sites. On the other hand, demolition and change in use were found to be only slightly more common in the manufacturing industry.
(ii) Other industries (46 Companies): Compared to the manufacturing industry, other industries were found to have more shrunken sites, with examples of change in use from manufacturing to other industries after site subdivision. There was very little difference in the proportion of unchanged sites between manufacturing and other industries.

Next, to investigate the relationship between building changes and changes in site area, incidence rates were calculated and analysed (Table 12).

(i) Building extensions: Of the 43 sites that had experienced a change in area, 25 were found to have had building extensions, a rate of incidence of 58%. In comparison, of the 68 sites that did not experience a change in area, 17 were found to have had building extensions, a rate of incidence of 25%. An examination of individual incidence rates showed that 20 of the 21 enlarged sites had experienced building extensions, a particularly high rate of incidence of 95%.

(ii) Demolition: Of the 43 sites that had experienced a change in area, 32 were found to have undergone demolition, a rate of incidence of 74%. In comparison, of the 68 sites that did not experience a change in area, 23 were found to have experienced demolition, a rate of incidence of 34%. An examination of individual incidence rates showed that the incidence rate of demolition on enlarged sites was still high compared to shrunken sites.

(iii) Change in use: Of the 43 sites that had experienced a change in area, 26 were found to have had changes in use, a rate of incidence of 60%. In comparison, of the 68

Figure 18. Existing and extended buildings in the SIEs.
**Figure 19.** Existing and demolished buildings in the SIEs.

**Table 10.** Percentages of the types of industry with respect to changes of buildings in the SIEs (Company) (refer to Table 4).

|                   | Changed Buildings | Demolished | Diverted |
|-------------------|-------------------|------------|----------|
| MI, PI&RI        | Extended          | MI, PI&RI  | MI, PI&RI|
| 42/44 (95%)      | LW 0/2 (0%)       | LW 0/2 (26%)| LW 0/2 (26%)|
|                   | LC 0/2 (0%)       | LC 6/19 (32%)| LC 6/19 (32%)|
|                   | RL 0/2 (0%)       | RL 1/19 (5%)  | RL 1/19 (5%) |
|                   | OT 0/2 (100%)     | OT 6/19 (32%)| OT 6/19 (32%)|
| Others            | MI, PI&RI         | MI, PI&RI   | MI, PI&RI|
| 39/58 (67%)      | LW 5/19 (26%)     | LW 1/19 (5%)  | LW 6/15 (40%) |
|                   | LC 6/19 (32%)     | LC 1/19 (5%)  | LC 4/15 (27%) |
|                   | RL 1/19 (5%)      | RL 6/19 (32%)| RL 0/15 (0%) |
|                   | OT 6/19 (32%)     | OT 6/19 (32%)| OT 5/15 (33%)|

**Table 11.** Percentages of the types of industry with respect to changes of sites in the SIEs (Company) (refer to Table 4).

|                   | Changed Sites | Shrunken | Unchanged |
|-------------------|---------------|----------|-----------|
| MI, PI&RI        | MI, PI&RI     | MI, PI&RI| MI, PI&RI|
| 21/21 (100%)     | LW 2/12 (100%)| LW 5/12 (42%)| LW 4/34 (12%)|
|                   | LC 2/12 (100%)| LC 5/12 (42%)| LC 3/34 (12%)|
|                   | RL 0/0 (0%)   | RL 0/0 (0%)| RL 3/34 (10%)|
|                   | OT 0/0 (0%)   | OT 0/0 (0%)| OT 3/34 (10%)|
| Others            | MI, PI&RI     | MI, PI&RI| MI, PI&RI|
| 0/0 (0%)         | LW 0/0 (0%)  | LW 0/0 (0%)| LW 1/34 (3%) |
|                   | LC 0/0 (0%)  | LC 0/0 (0%)| LC 1/34 (3%) |
|                   | RL 0/0 (0%)  | RL 0/0 (0%)| RL 1/34 (3%) |
|                   | OT 0/0 (0%)  | OT 0/0 (0%)| OT 1/34 (3%) |
| 0/22 (55%)       | LW 5/12 (42%)| LW 5/12 (42%)| LW 6/19 (16%)|
|                   | LC 5/12 (42%)| LC 5/12 (42%)| LC 6/19 (16%)|
|                   | RL 0/12 (0%) | RL 0/12 (0%)| RL 6/19 (16%)|
|                   | OT 0/12 (0%) | OT 0/12 (0%)| OT 6/19 (16%)|
| 34/68 (50%)      | LW 4/34 (12%) | LW 4/34 (12%) | LW 4/34 (12%) |
|                   | LC 3/34 (10%) | LC 3/34 (10%) | LC 3/34 (10%) |
|                   | RL 1/34 (3%) | RL 1/34 (3%) | RL 1/34 (3%) |
|                   | OT 3/34 (10%) | OT 3/34 (10%) | OT 3/34 (10%) |
Table 12. Occurrence rates of changes of buildings with respect to the changes of the sites in the SIEs (Company).

| Changed Buildings | Extended | Demolished | Diverted |
|-------------------|----------|------------|----------|
| Unchanged sites   | Changed sites | Unchanged sites | Changed sites | Unchanged sites | Changed sites |
| 17/68 (25%)       | 25/43 (38%) | 23/68 (34%) | 32/43 (74%) | 14/68 (21%) | 26/43 (60%) |
| Enlarged          | Shrunken  | Enlarged    | Shrunken  | Enlarged    | Shrunken  |
| 20/21 (95%)       | 5/22 (23%) | 18/21 (85%) | 14/22 (64%) | 13/21 (62%) | 13/22 (59%) |

Figure 20. Building confirmation applications for new construction.

Figure 21. Building confirmation applications for buildings extension.

Table 13. Percentages of roads in the SIEs according to site types.

| Public Area | Public Roads | Private Roads |
|-------------|--------------|---------------|
|             | (Not in use, old farm roads) |             |
| 11.8 ha     | 0.3 ha       | 1.3 ha        |
| (100%)      | (3%)         | (10%)         |
| Public Roads|             |               |
| 12.0 ha     | 8.3 ha       | 3.7 ha        |
| (100%)      | (69%)        | (31%)         |
| Unchanged   | Channeled    | Changed       |

sites which did not experience a change in area, 14 were found to have changes in use, a rate of incidence of 21%. An examination of individual incidence rates showed that there were no particular differences in the predominance of changes (or not) in site area in the incidence rate of change of use.

The above results show that compared to unchanged sites, sites that had experienced a change in area had a higher rate of building extension, demolition, and change in use. In particular, the prevalence of a combination of building extension and site enlargement was strikingly high.

Building trends were further investigated through the examination of SIEs-related building certification applications that had been submitted to the Sakura City Government Office. Between 1963 and 2015, there had been a total of 76 new building applications (Figure 20) and 89 building extension applications (Figure 21). This confirms that there had been more building extension applications than new building applications. While new building applications rapidly declined at the conclusion of urban formation around 1990, submissions of building extension applications continue to the present day. This shows that building extensions have been the main form of post-formation activity.

4.2. The relationship between changes in intra-site roads and sites

Private roads within industrial estates include intra-site roads on private land that connect to public roads and intra-site roads that do not directly connect to public roads. It was observed that such intra-site roads are directly affected by changes to site area and company withdrawal, leading to repeated changes, such as change in use, change in shape, and elimination.

In the case of site enlargement, intra-site roads, which were developed when neighbouring sites were incorporated, tended to maintain their position on the plan, undergo a change in usage, and continue to be used. In the case of site shrinkage, however, site divisions due to company withdrawal tended to lead to major changes to intra-site roads, or their total elimination, with new layouts planned (Table 13).
5. Summary and discussion

Taking into account the above results, the following aspects can be underscored with respect to the structure of changes in the three suburban IIEs:

(1) When the rate of urbanisation in all three IIEs reached approximately 90%, the pace of urbanisation significantly slowed. This point of saturation can be positioned as the point of transition from the formative period to the change period.

(2) Even in the formative period, changes in site area can occur as a result of the entry and withdrawal of companies. In such cases, transformation of SUA into industrial sites due to changes in property ownership is the main type of change.

(3) The configuration of blocks surrounded by public roads generally remained stable; far more fluid was the segmenting of lots.

(4) Although based on rigid blocks, gridded street configurations reflected changes in that some sites would extend over block boundaries following enclave enlargement or withdrawal/shrinkage.

(5) When a side of a block was exposed to a trunk road, there would be an increase in neighbouring enlargement/shrinkage along the exposed side.

(6) There is currently no increase in unused land; industrial trends are reflected in the retention of existing industries or shifts to other industries.

As discussed above, for the industrial estates studied, changes in site usage due to landowner change had occurred even before the saturation point of urbanisation. This shows that, as initially assumed, a characteristic feature of industrial estates is that they are easily transformed by changes in industrial structure. Even in such industrial estates, however, block structures surrounded by public roads with a few exceptions hardly changed at all, and those surrounded by two-lane public roads did not change at all. On the other hand, changes to site boundaries were observable mainly through enlargement and shrinkage of sites within blocks. Stated differently, if urban metabolism consists, broadly, of changeable and static elements, then the public roads that provide the basic component of industrial estates, and the blocks these roads form, would represent static elements, while the lot boundaries and intra-site roads would be an example of changeable elements. Evidently, these changeable and static elements underlie the metabolic process of UDAs.

This metabolic dynamic does not in itself represent a novel finding. That said, this study has revealed that the way in which the changeable elements change depends on the block configuration (gridded streets/trunk road). For example, for MIE and NIE, both examples of a gridded configuration, due to the fact that the blocks were demarcated by public roads on all four sides, they were so stable and may have restricted changes in the site use. Conversely, in the SIEs, which represented the trunk road configuration, the estate peripheries were ambiguously defined, leaving some space for development; consequently, sites rarely extended across public roads. Thus, block configuration-specific restrictions may have determined the way in which the sites were used.

On the other hand, the transition from new use to existing reuse, which is driven by a high rate of urbanisation, is a post-formation change. This transition involves a flexible pattern of change in intra-block site use: Although the same companies generally continued to own the sites, there were cases where the sites were physically partitioned or underwent ownership change. Changes to site partitioning occurred not only when the landowner changed but they also occurred in cases where part of a site was leased. This practice enabled flexible metabolism. The introduction of new leaseholds in 1992 may have been a factor, a possibility that warrants further research.

Next, the following aspects relating to building changes were delineated:

(1) Almost all new building construction was concentrated in the formative period of the urban area, with a drastic decrease after the saturation point. On the other hand, building extensions that were prevalent in the period of initial construction continue to the present day.

(2) A large amount of building extension, demolition, and change in use, as well as site enlargement, was observed in the manufacturing industry. Conversely, the incidence of site shrinkages was slightly more common in other industries. No industry differences were found with regard to sites that did not change.

(3) Changes to buildings occurred, as a general rule, on sites that experienced changes in site area. In particular, almost all extensions and demolitions occurred on site enlargements. On the other hand, differences in the occurrence of changes in building use due to site change were not observed.

The above indicates that building extension, demolition, and change in use were more common in the manufacturing industry. In particular, there was a strong connection between building extension and site enlargement in the manufacturing industry. On the other hand, while very few building extensions and site enlargements were observed in non-
manufacturing industries, such as transportation and leasing, which had entered IIEs in large numbers since the beginning of the 21st century, a connection between change in building use and site shrinkage was observed for such industries. The following inferences concerning changes in UDA targets in the period of urban contraction can be drawn from the preceding discussion. The appearance of vacant lots due to decreased demand was not observed in the industrial estates in this study. The reason for this may be the increase in non-factory usage in the form of, for example, logistics and warehousing hubs and religious facilities, and the concurrent changes to site area and buildings that corresponded to industrial demand. This had the effect of preventing the creation of vacant lots. As such, it can be said that the size of the site divisions within the industrial estates and their receptivity to bothersome facilities had a positive effect in terms of the ease of corresponding to a diversity of uses. Through these aspects, this study has contributed to the understanding, in part, of post-formation changes in suburban UDAs.

6. Future research directions

In the context of such changes, the public roads and the block configurations they surround are aspects that do not change and form the skeletal structure of UDAs. However, it would be desirable to conduct a further investigation to determine what changes may occur if there is an increase in unused land.

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Disclosure statement

The authors have no conflict of interest to declare.

Notes on contributors

Junichi Tamura belongs to a graduate school of engineering in Chiba University in Japan. His research interests mainly include architecture and urbanism. He is a certified architect and currently runs own his architectural firm in Tokyo.

Hideki Kobayashi obtained his PhD in Engineering in 1985 from Tokyo university. He is currently an honorary professor in Chiba university, and his specialized fields are housing planning and design and urban planning. He was awarded the AU Prize in 2007 for his work “Research and Development of the New Leasehold System for Skeleton-Infill Housing”.

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