Decomposition of density into their components: Analysis for the case of Japan

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Abstract

The concept of density has been changing through the time; originally, it has the simple definition of the total population divided by the area of analysis. However, the division of cities into residential and commercial areas, the increasing in the number of tall buildings, and the necessity of creating public spaces inside cities created the necessity of refine the original concept of density. This paper decomposes the concept of density into six indicators across the Japanese municipalities in order to explore the real characteristics of them under a more detailed analysis. We showed that, for example, some cities have high density but not due to be a crowded city; instead those cities have reduced residential areas or the average height of buildings are not as tall as other areas.

Keywords: Population density, Urban planning, Japan

JEL classification: J10, C80

1 Introduction

The data for Japan shows that the population density, defined as the total population divided by total area in squared kilometres, was around 258 inhabitants per squared kilometre in 1961. This value increased by

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34.5% until 2018 to the value of 347 inhabitants per squared kilometre. This fact suggests that the population density grew up at the annual average growth rate of 0.62%, this low rate seems to be a consequence of the low population growth rate that Japan has been exhibiting on the last decades. In more detail, until 2001, the annual average population density growth rate for Japan was 0.39% and from 2002 to 2018, the growth rate change to be negative to the annual rate of -0.31%.

From all the prefectures, Saitama exhibits the highest average growth rate for population density, 0.98% per year; and, on the other hand, Akita is the prefecture with the lowest average growth rate of population density, -0.53% per year. These two prefectures followed a very dissimilar growth path, Akita started to have negative growth rates since 1982 (-0.08%) until reach the rate of -1.51% in 2018; while Saitama had positive values for every year with its lowest rate in 2012 of 0.10%.

As we pointed out above, these population densities are the consequence of the demographic changes that the Japan has exhibiting on the last decades. Nevertheless, since the concept of population density is a rough measure of how the people living in a certain area are distributed; there is no a clear picture of what is changing in the demographic distribution among the country besides the low population growth rate. This problem is important it might affect the new lifestyles of modern cities and their future plans of development. For example: nowadays we have higher buildings, i.e. people are not living any more in houses of one or two floors, now we have buildings with more than ten floors that are able to host more than 100 households in it. Also, the city distribution may also affect the real space where people can actually live. Cities are building special public spaces where inhabitant can visit to reduce their living stress or share time together; those public spaces can be libraries, museums, governance buildings. Finally, cities are roughly divided into commercial and residential areas; in the first ones, people are not able to live because companies and factories use that space to their economic activities. Consequently, all these factors affect the real space that people can actually live, and it is not fully observable with the population density indicator.

Regarding this refining of the concept of urban density, in 2012, the OECD noticed that developed countries are pursuing the promotion of compact urban areas, and even developing countries are working to move toward the same direction of urban planing. The new literature is incorporating the idea that density population is an old fashion indicator that does not accurately measure the real density. Baumont et al. (2004) and Anderson and Klugmann (2014) studied and understood the new trend for density that might have an effect over other economic variables. However, not all researchers are in favour of this compacting process of cities, Neuman (2005) criticises the process and highlights the possible negative effects in housing affordability that compacting cities might have.

Probably one of the most revolutionary investigations about density is Angel and Lamson-Hall (forthcoming) which presents a methodology that measures the "urban density" (total population over the area) and decomposes that factor into pieces that we are able to identify and analyse separately. They highlight the idea that "urban density" is mainly composed of three factors: crowding, building height, and residential coverage. Each of these three factors influences the density we observe, but they are independent itself. In simple words, to truly understand the concept of density, we must consider whether the area of analysis is crowed by many inhabitants, or the buildings height is not as tall as other areas, or the area available to live in a city is big or small.

In this sense, this paper applies this new methodology to analyse in detail the municipalities in Japan by decomposing the gross concept of density into their factors and each factor into their sub-factors to be able to look into the most basic and primitive concepts of density. This new analysis with this pioneering methodology will lead us to develop new tools for urban planning policymakers to look in detail and propose more sophisticated and efficient policies in favour of Japanese municipalities' inhabitants.

This paper is organised as follows. Section 2 presents the main methodology of decomposition we use in our analysis. This section is also divided into three sub-sections, where we explain and decompose in detail each urban density's factor. Section 3 presents the main results and analysis of our data. This section is divided into five subsections: data, decomposition of urban density, further decomposition of crowding, further decomposition of residential coverage, and a summary of the empirical results. Finally, Section 4 presents the main conclusion of this paper.

2 Methodology of decomposition

This section is based in the methodology for refining the concept of urban density proposed by Angel and Lamson-Hall (forthcoming). This section has two subsection where initially we define the three factors that compose urban density, and in the second sub-section we refine these three components into their pieces.

2.1 Three factors

By following Angel and Lamson-Hall (forthcoming), the concept of urban density can be calculated as the multiplication of its three main factors, Crowding, Building height, and Residential coverage:

$$\begin{aligned} \text{Urban Density} &= f(\text{Crowding, Building Height, Residential Coverage}) \\ &= (\text{Crowding}) \times (\text{Building Height}) \times (\text{Residential Coverage}). \end{aligned} \tag{1}$$

The relationship between *urban density* and its components are:

$$f'(\text{Crowding}) > 0; \qquad f'(\text{Building Height}) > 0; \qquad f'(\text{Residential Coverage}) > 0.$$

Therefore, when there are more people living in the same area, i.e. more crowded areas, *ceteris-paribus* the remaining variables, the density of the analysed area will be higher. Similarly, *ceteris-paribus* the rest of the variables, the higher the number of floors of the buildings, the higher the density of the analysed area. And, finally, for the third factor, *ceteris-paribus* the rest of the variables, the higher the share of the residential area occupied by residential buildings, the higher the density of the analysed area. It is important to notice that the causality goes from the factors toward the urban density indicator and not viceversa. In other words, when we observed that crowding indicator increases, *ceteris-paribus*, then the urban density will increase; however, if the urban density increases, it does not imply that the crowding indicator is increasing.

To measure the constituting factors of *urban density*, we need to decomposed them properly into their basic factors; in this sense, the factors of *crowding*, *building height*, and *residential coverage* are measured in the following way.

$$\text{Crowding} = \frac{\text{Population}}{\text{Floor Area}}, \tag{2}$$

where this ratio measures the average number of people occupying a residential floor area in a specific area of analysis. Then, for a given floor area, when the population increases the crowding in the city increases. Consequently, higher population implies higher crowding areas and this one provokes higher *urban density*; however, the reversal inference is not possible because the *urban density* depends on the other two factors.

$$\text{Building Height} = \frac{\text{Floor Area}}{\text{Building Footprints}}. \tag{3}$$

The second factor that constitutes *urban density* is *building height*, which measures the number of floors per residential building footprints in the area of analysis. In other words, it is the average building height in the city. Similarly to the case of *crowding* factor, higher the *building height*, higher the *urban density.* Nevertheless, the reverse case it is not necessarily true.

$$\text{Residential Coverage} = \frac{\text{Building Footprints}}{\text{Urban Extent}}. \tag{4}$$

Finally, the third factor of the *urban density*, is the *residential coverage*, which measures the total area of the urban areas covered by the residential building footprints. Again, higher the *residential coverage*, higher the density. However, higher values of *urban density* does not imply higher *residential coverage* areas.

After we properly define the main components of the three main factors, we can introduce them into the *urban density* function to obtain a clearer panorama of the density concept:

$$\begin{aligned}\text{Urban Density} &= (\text{Crowding}) \times (\text{Building Height}) \times (\text{Residential Coverage}) \\ &= \frac{(\text{Population})}{(\text{Floor Area})} \times \frac{(\text{Floor Area})}{(\text{Building Footprints})} \times \frac{(\text{Building Footprints})}{(\text{Urban Extent})}.\end{aligned} \tag{5}$$

2.2 Decomposition of three factors

Regardless the decomposition we introduced in the previous section about the main three factors that constitute the concept of *urban density*, those factors are composed by sub-factors or primitive factors that, after interacting each other, will help us to compose the three main factors and, finally, obtain the indicator of *urban density*. In this sub-section, we explain in detail the primitive factors that constitute the three main factors we previously explained.

2.2.1 Crowding

The factor *crowding* help us to measure the density of people within dwellings in a specific area. Intuitively, this indicator has high values when a two-room house is occupied by a large number of members, and it has low values when a five-member dwelling occupies a big mansion. Nevertheless, this factor is actually constituted by three primitive factors that need to be analysed in detail.

$$\text{Crowding} = (\text{Living Area Density}) \times (\text{Occupancy Rate}) \times (\text{Floor Plan Efficiency}), \tag{6}$$

where:

$$\text{Living Area Density} = \frac{\text{Population}}{\text{Occupied Living Area}}. \tag{7}$$

This first sub-factor measures the average number of people that occupy a unit of residential living area in the city. Furthermore, this ratio is an accurate measure of overcrowding since it considers the actual people living in a specific area. Therefore, when the household size (number of people sharing a dwelling unit) increases, the *living area density* increases. In this sense, when a household is located in a smaller dwelling unit area, the *living area density* increases, and consequently, the *urban density* indicator. The equation (8) explains the proper derivation for the *living area density* sub-factor.

$$\begin{aligned} \text{Living Area Density} &= \frac{\text{Household Size}}{\text{Dwelling Unit Area}} \\ &= \frac{\text{Population / Dwelling Units}}{\text{Occupied Living Area / Dwelling Units}} \\ &= \frac{\text{Population}}{\text{Occupied Living Area}}. \end{aligned} \tag{8}$$

The second sub-factor that we must pay attention when we construct the concept of *crowding* is the *occupation rate*. This concept tells us the real portion of areas that is truly occupied respect to the total *living area*. It is defined as:

$$\text{Occupancy Rate} = \frac{\text{Occupied Living Area}}{\text{Living Area}}, \tag{9}$$

however, this concept traditionally is measured as the *occupied dwelling units* share respect to the *dwelling units* in a specific area. Scholmo et al. (2019) assume, to obtain equation (9), that the area share by dwelling units are the same for occupied and unoccupied ones. Finally, the third sub-factor, the *floor plan efficiency*, let us to measure the truly area where dwellings live. In certain buildings, households are living in smaller areas than the area of the building due to that some parts of the building are used for common spaces, stairs, elevators, inside green areas, electricity support structures, and so on. Those kind of small constructions inside buildings, houses, or shared houses, reduce the area that households effectively use for living. Therefore, the concept of *floor plan efficiency* can be defined as:

$$\text{Floor Plan Efficiency} = \frac{\text{Living Area}}{\text{Floor Area}}. \tag{10}$$

Given the detailed definition for the three sub-factors that compose the concept of *crowding*, we can combine them to obtain the final equation of this factor.

$$\begin{aligned} \text{Crowding} &= (\text{Living Area Density}) \times (\text{Occupancy Rate}) \times (\text{Floor Plan Efficiency}) \\ &= \frac{\text{Population}}{\text{Occupied Living Area}} \times \frac{\text{Occupied Living Area}}{\text{Living Area}} \times \frac{\text{Living Area}}{\text{Floor Area}} \\ &= \frac{\text{Population}}{\text{Floor Area}}. \end{aligned} \tag{11}$$

2.2.2 Building Height

Another factor we must understand in order to analyse the concept of *urban density* properly, it is the *building height*. This factor lets us include modern concepts into the traditional measure of density since now we include the idea that cities with higher buildings tend to have more population that are living in those buildings. Therefore, cities with taller buildings are denser, but the other way around it is not necessarily true. Therefore, to measure the *building height* we use the total floor area divided by the footprints of the buildings, like it is detailed in the following equation:

$$\text{Building Height} = \frac{\text{Floor Area}}{\text{Building Footprints}} \tag{12}$$

2.2.3 Residential Coverage

In this sub-section we analyse the concept of *residential coverage* that measures the extension of residential building footprints respect to the entire urban extension. Consequently, this concept does not include commercial, public, or green usage areas. The equation is defined as:

$$\text{Residential Coverage} = (\text{Plot Coverage}) \times (\text{Residential Share}), \tag{13}$$

where:

$$\text{Plot Coverage} = \frac{\text{Building Footprints}}{\text{Residential Area}}, \tag{14}$$

this sub-factor of *plot coverage* measures the area effectively used for living purpose respect to the total extension of the residential areas. This concept help us to clean-up the total area used for living purpose respect to other non-living areas such as green areas, common spaces, roads, and so on within the residential area.

$$\text{Residential Share} = \frac{\text{Residential Area}}{\text{Urban Extent}}. \tag{15}$$

For the second sub-factor, *residential share*, it is explained as the area occupied by the residential area respect to the urban extension. In other words, in this ratio, we measure the area that is only used for living purpose respect to the total area that the city occupied. The problem with only consider the urban area is that it includes industrial, public, transportation, office, and other areas not used for living purpose. Finally, after define properly the concepts of *plot coverage* and *residential share*, we can replace it into the equation of *residential coverage* and obtain its final definition.

$$\begin{aligned}\text{Residential Coverage} &= (\text{Plot Coverage}) \times (\text{Residential Share}) \\ &= \frac{\text{Building Footprints}}{\text{Residential Area}} \times \frac{\text{Residential Area}}{\text{Urban Extent}} \\ &= \frac{\text{Building Footprints}}{\text{Urban Extent}}.\end{aligned} \tag{16}$$

2.3 Interaction of the three factors

The definition of *urban density* as the ratio of *people* over the urban extension, which is the traditional measure of density that might be interpreted as the number or people living in a certain extension of area, can be divided into its factors and this factors into their sub-factors in order to analyse and obtain the interaction among them. Therefore, we have:

$$\begin{aligned}
\text{Urban Density} &= \frac{\text{Population}}{\text{Urban Extent}} \\
&= [\text{Crowding}][\text{Building Height}][\text{Residential Coverage}] \\
&= \left[\frac{\text{Population}}{\text{Floor Area}}\right] \times \left[\frac{\text{Floor Area}}{\text{Building Footprints}}\right] \times \left[\frac{\text{Building Footprints}}{\text{Urban Extent}}\right] \\
&= \left[\left(\frac{\text{Population}}{\text{Occupied Living Area}}\right)\left(\frac{\text{Occupied Living Area}}{\text{Living Area}}\right)\left(\frac{\text{Living Area}}{\text{Floor Area}}\right)\right] \\
&\quad \times \left[\frac{\text{Floor Area}}{\text{Building Footprints}}\right] \times \left[\left(\frac{\text{Building Footprints}}{\text{Residential Area}}\right)\left(\frac{\text{Residential Area}}{\text{Urban Extent}}\right)\right]
\end{aligned} \tag{17}$$

This interaction lead us know that the concept of urban density is actually a composition of other factors that we must take into consideration when we analyse population densities. Those other factors are difficult to observe due to the calculation dynamic they have once we combine them, but this equation lead us to observe them clearly.

3 Empirical result of decomposition

In this section, we decompose the urban density described in the previous sections using data for Japan. Specifically, we first discuss how to obtain data related to urban density in Japan and then how to construct a dataset to decompose the urban density using the data. We then use that dataset to decompose the urban density obtained into three factors and further decompose those factors into more detailed six factors.

3.1 Data

To decompose the urban density in this section, it is first necessary to select representative data. In this paper, the representative data are selected using the Japanese regional classification. The regional classification of Japan differs greatly from one statistical data to another[1]. Therefore, in this paper, we use urban density, which is data closely related to housing by using the classification of 'Building Start' provided by the Ministry of Land, Infrastructure, Transport and Tourism, Japan. According to this regional classification, Japan is

[1] `https://www.soumu.go.jp/main_content/000514009.pdf`, last visited on 2020-04-29.

divided into ten regions: Hokkaido, Tohoku, Kanto, Hokuriku, Chubu, Kinki, Chugoku, Shikoku, Kyushu, and Okinawa. Table 1 shows the prefectures (`pref`) that make up the region (`region`). In this study, the largest urban density in each region is selected as a representative city for the purpose of discussing the decomposition results of the population concentration and the characteristics of each region.

Table 1: Region classification of the prefectures of Japan, Building Start

region	pref	region	pref	region	pref	region	pref
Hokkaido	Hokkaido	Kanto	Tokyo	Kinki	Shiga	Shikoku	Kagawa
Tohoku	Aomori	Kanto	Kanagawa	Kinki	Kyoto	Shikoku	Ehime
Tohoku	Iwate	Kanto	Yamanashi	Kinki	Osaka	Shikoku	Kochi
Tohoku	Miyagi	Kanto	Nagano	Kinki	Hyogo	Kyushu	Fukuoka
Tohoku	Akita	Hokuriku	Niigata	Kinki	Nara	Kyushu	Saga
Tohoku	Yamagata	Hokuriku	Toyama	Kinki	Wakayama	Kyushu	Nagasaki
Tohoku	Fukushima	Hokuriku	Ishikawa	Chugoku	Tottori	Kyushu	Kumamoto
Kanto	Ibaraki	Hokuriku	Fukui	Chugoku	Shimane	Kyushu	Oita
Kanto	Tochigi	Chubu	Gifu	Chugoku	Okayama	Kyushu	Miyazaki
Kanto	Gunma	Chubu	Shizuoka	Chugoku	Hiroshima	Kyushu	Kagoshima
Kanto	Saitama	Chubu	Aichi	Chugoku	Yamaguchi	Okinawa	Okinawa
Kanto	Chiba	Chubu	Mie	Shikoku	Tokushima		

- `population`: retrieved from 'the population of residents in Japan based on the resident registration' of Statistics Bureau of Japan, Ministry of Internal Affairs and Communications, Japan, 2018.

- `urban_extent`: retrieved from 'Statistical Observations of Municipalities' of Statistics Bureau of Japan, Ministry of Internal Affairs and Communications, Japan, 2018. What we use here as `urban_extent` is the area of the habitable zone in this data, which is the total area minus the area of forests and major lakes.

- `total_residential_area`: retrieved from 'Land Use Planning' of Ministry of Land, Infrastructure, Transport and Tourism, Japan, 2018. This data is GIS data that shows how the land is used according to the legal system of the City Planning System in Japan. In this study, the following categories of control area regulation in this data are treated as residential areas: Category I exclusively low-rise residential zone, Category II exclusively low-rise residential zone, Category I mid/high-rise oriented residential zone, Category II mid/high-rise oriented residential zone, Category I residential zone, Category II residential zone, and quasi-residential zone. The area of polygons in the GIS data categorized by these categories, calculated for each municipality, is used as the `total_residential_area`.

- `total_living_area`: calculated by `number_of_dwelling` times floor area per living dwelling, where `number_of_dwelling` and floor are per living dwelling are retrieved from 'Housing and Land Survey' of Statistics Bureau of Japan, Ministry of Internal Affairs and Communications, Japan, 2018.

- `occupied_living_area`: calculated by `number_of_occupied_dwelling` times floor area per living dwelling, where `number_of_occupied_dwelling` and floor are per living dwelling are retrieved from 'Housing and Land Survey' of Statistics Bureau of Japan, Ministry of Internal Affairs and Communications, Japan, 2018.

- `average_household_size`: calculated by total household size divided by the number of households, where total household size and the number of households are retrieved from 'Housing and Land Survey' of Statistics Bureau of Japan, Ministry of Internal Affairs and Communications, Japan, 2018.

- `building_height_living`: Although data on the number of floors of houses are included in 'Housing and Land Survey', the number of houses is divided into categories according to the number of floors. This is coarse data in which the distribution within the categories is unclear and more than a certain number of stories are stacked into a single category, i.e., censored data. Therefore, in this study, the average number of stories of residential buildings in residential land was calculated based on the data included in 'Publication of Land Price Data', which is retrieved from the Ministry of Land, Infrastructure, Transport and Tourism, Japan, 2018. It should be noted that some of the data may be unreliable due to the variation in sample size for each municipality in the calculation of the average building height calculated by this data.

- `building_height_regulation`: In general, residential buildings have spaces that are not used for dwellings, such as corridors and entrances. Here, we use GIS data that shows how the land is used according to the legal system of the City Planning System in order to derive the space that is not used for the housing. The data is retrieved from 'Land Use Planning' of Ministry of Land, Infrastructure, Transport and Tourism, Japan, 2018. Specifically, we define the average floor space area based on this regulation, divided by the average building footprint, as the average number of floors that takes into account housing and unused space.

- `total_building_footprint`: It is defined as the total footprint of all residential buildings. Therefore, we define and calculate the indicator `total_building_footprint` as `total_living_area` divided by `building_height_living`.

- `gross_residential_floor_area`: It is defined as the sum of the residential floor space in all dwellings and space not used for dwellings. Therefore, the gross residential floor area is defined as the area of the building footprint used for residential use multiplied by the average number of floors, taking into account the space used or not for residential use. In other words, we calculate `gross_residential_floor_area` as the `total_buiilding_footprint` multiplied by `building_height_regulation`.

The municipality and basic statistics, which are representative of the regional blocks described above, are presented in Table 2. The highest per capita income is about 4.1 million Japanese Yen (approximately 40,000 US$ in 2020) in the representative municipality (Toshima-ku) of Kanto area, and the lowest is about 2.7 million Japanese Yen (approximately 25,000 US$ in 2020) in the representative municipality (Shiogama-shi) of Tohoku area. The largest population among the representative municipalities is Osaka-shi in the Kinki region, with about 2.7 million people, which is categorized as a government ordinance-designed major city. The largest urban extent is about 44,000 hectares[2] in Sapporo-shi (Hokkaido) and the lowest is about 600 hectares in Fuchu-cho (Chugoku). Calculated from dividing these populations by the urban extent, which is the criterion for selection of representatives in a regional block, the maximum is about 220.7 people per hectare in Toshima-ku in the Kanto area. This is one of the 23 wards designated as a special ward of Tokyo. On the other hand, the lowest urban extent is Kanazawa-shi in the Hokuriku area, with about 23.6 people per hectare.

Table 2: Basic data on the ten representative municipalities of Japan

region	pref	municipality	income_per_capita	population	urban_extent	urban_density
Hokkaido	Hokkaido	Sapporo-shi	3 034 902	1 952 348	43 898	44.475
Tohoku	Miyagi	Shiogama-shi	2 679 270	54 873	1 472	37.278
Kanto	Tokyo-to	Toshima-ku	4 124 163	287 111	1 301	220.685
Hokuriku	Ishikawa	Kanazawa-shi	3 201 714	454 416	19 224	23.638
Chubu	Aichi	Nagoya-shi	3 758 634	2 288 240	31 625	72.355
Kinki	Osaka-fu	Osaka-shi	3 228 708	2 702 432	22 521	119.996
Chugoku	Hiroshima	Fuchu-cho	3 316 205	52 081	593	87.826
Shikoku	Tokushima	Kitajima-machi	3 077 187	23 152	874	26.490
Kyushu	Fukuoka	Kasuga-shi	3 218 696	113 040	1 352	83.609
Okinawa	Okinawa	Naha-shi	2 944 250	323 290	3 966	81.515

Notes: The units of `income_per_capita`, `population`, `urban_extent` and `urban_density` are Japanese Yen per person, the number of people, ha, and the number of person per ha, respectively. `income_per_capita` is retrieved from 'Information on the status of municipal taxation' of Ministry of Internal Affairs and Communications, Japan, 2018.

In addition, the data related to density, which will be used in the empirical analysis, are shown in Table 3. Firstly, `total_residential_area` (the area within the urban extent that is defined for people to live in) is about 19,000 hectares in Sapporo-shi in Hokkaido, the largest, and about 275 hectares in Kitajima-machi in Shikoku, the smallest. Among them, `total_building_footprint`, which indicates the site area of residential buildings, is about 3,500 hectares at Nagoya-shi in Chubu, the largest, and 47 hectares at Kitajima-machi in Shikoku, the smallest. `gross_residential_floor_area`, floor area that takes into account both residential and non-residential space, is about 11,000 hectares at Nagoya-shi in Chubu, the largest, and 154 hectares at Kitajima-cho in Shikoku, the smallest. The maximum `total_living_area` (residential space in the gross residential floor area) is about 8,231 hectares in Osaka-shi, Kinki, and the minimum is about 94 hectares in

[2]One hectare is equal to 10,000 square meters.

Kitajima-machi, Shikoku. Furthermore, with regard to occupied_living_area (not vacant residential space within the total living area, i.e., occupied residential area), the largest is about 6,869 hectares in Nagoya-shi, Chubu, and the smallest is about 81 hectares in Kitajima-machi, Shikoku. In terms of the number of dwellings, the largest is Osaka-shi in Kinki, and the smallest is Kitajima-machi in Shikoku, both in terms of total and occupied. As mentioned above, the smallest number in those non-average data are all Kitajima-machi in Shikoku, which may be due to the fact that there are no government ordinance-designated cities in the Shikoku area and a relatively small municipality was selected as the representative of the regional block. As for the average number of people in a household, average_household_size, the largest is 2.52 members in Shiogama-shi, Tohoku, and the smallest is 1.67 members in Toshima-ku, Kanto. In the Tokyo metropolitan area, the number of households is decreasing, which may be an indication of a more advanced nuclear family. building_height_living, which is the average number of floors considering only the residential space of a residential building, is three floors in Toshima-ku, Kanto at the maximum and 1.81 floors in Kasuga-shi, Kyushu at the minimum. This is thought to be due to Fukuoka City's own regulations on the number of floors of buildings, which take into account the proximity of the airport to the city centre. This tendency can be seen in building_height_regulation, which is the average number of stories in a residential building that takes into account both residential and non-residential space by regulation.

Table 3: Density-related data on the ten representative municipalities of Japan

region	prefecture	municipality	total_residential_area	total_building_footprint	gross_residential_floor_area	total_living_area
Hokkaido	Hokkaido	Sapporo-shi	18795.48	3161.43	8910.93	7275.48
Tohoku	Miyagi	Shiogama-shi	844.82	106.93	335.90	213.87
Kanto	Tokyo-to	Toshima-ku	809.70	300.74	1316.25	902.21
Hokuriku	Ishikawa	Kanazawa-shi	5654.41	1013.35	3077.13	1992.35
Chubu	Aichi	Nagoya-shi	18375.99	3539.32	11051.84	8074.06
Kinki	Osaka-fu	Osaka-shi	9447.18	3080.78	8589.77	8230.98
Chugoku	Hiroshima	Fuchu-cho	458.75	90.05	278.95	180.10
Shikoku	Tokushima	Kitajima-machi	275.13	47.17	153.87	94.34
Kyushu	Fukuoka	Kasuga-shi	1128.85	204.50	530.62	370.66
Okinawa	Okinawa	Naha-shi	2480.22	358.71	1161.34	896.78

region	prefecture	municipality	occupied_living_area	total_dwellings	occupied_dwellings	average_household_size
Hokkaido	Hokkaido	Sapporo-shi	6275.54	912 400	787 000	2.04
Tohoku	Miyagi	Shiogama-shi	186.14	19 980	17 390	2.52
Kanto	Tokyo-to	Toshima-ku	761.52	175 390	148 040	1.67
Hokuriku	Ishikawa	Kanazawa-shi	1651.64	197 360	163 610	2.22
Chubu	Aichi	Nagoya-shi	6868.60	1 050 900	894 000	2.12
Kinki	Osaka-fu	Osaka-shi	6489.20	1 352 000	1 065 900	1.94
Chugoku	Hiroshima	Fuchu-cho	160.23	21 390	19 030	2.36
Shikoku	Tokushima	Kitajima-machi	81.35	9 080	7 830	2.47
Kyushu	Fukuoka	Kasuga-shi	323.92	43 540	38 050	2.44
Okinawa	Okinawa	Naha-shi	792.02	137 480	121 420	2.26

region	prefecture	municipality	building_height_living	building_height_regulation
Hokkaido	Hokkaido	Sapporo-shi	2.30	2.82
Tohoku	Miyagi	Shiogama-shi	2.00	3.14
Kanto	Tokyo-to	Toshima-ku	3.00	4.38
Hokuriku	Ishikawa	Kanazawa-shi	1.97	3.04
Chubu	Aichi	Nagoya-shi	2.28	3.12
Kinki	Osaka-fu	Osaka-shi	2.67	2.79
Chugoku	Hiroshima	Fuchu-cho	2.00	3.10
Shikoku	Tokushima	Kitajima-machi	2.00	3.26
Kyushu	Fukuoka	Kasuga-shi	1.81	2.59
Okinawa	Okinawa	Naha-shi	2.50	3.24

Notes: The unit of total_residential_area, total_building_footprint, gross_residential_floor_area, total_living_area, occupied_living_area is hectare, the unit of average_household_size is the number of people per household, and the unit of building_height_living and building_height_regulation is the number of stories per building.

3.2 Decompotion of urban density into three factors

In this section, we consider the results of decomposing the concept of `urban_density` into three actual primitive factors, `crowding`, `building_height` and `residential_coverage`. As mentioned in the previous section, the data used for the decomposition were collected from Japan in 2018 with the largest `urban_density` in the regions as a representative of the municipalities. `urban_density` and three other primitive factors are shown in Figure 1. This study discusses the details of the decomposition elements by looking at this Figure and tables, which express the values for each primitive factor.

3.2.1 Crowding

In Figure 1 and Table 4, the region classification to which the representative municipality belongs is shown on the y-axis, and in the case of `urban_density`, the urban density of the representative municipality is shown in terms of population per hectare, and in the case of `crowding`, the population per hectare is shown as an indicator of density considering floor area. The `crowding` is calculated by dividing the `population` by the `gross_residential_floor_area` among the data presented in Section 3.1. Looking at one of these three primitive factors, there are some interesting facts.

First, `crowding` is more than twice as large, from 148 people per hectare in the smallest Hokuriku to about 315 people per hectare in the largest, Osaka-shi, Kinki. This indicates a smaller municipality gap of `crowding` than the `urban_density`. Secondly, based on the perspective of urban density, which considers only two-dimensional factor, Toshima-ku in Kanto is more than two times denser than Osaka-shi in Kinki, which is the second denser, while Osaka-shi in Kinki is the largest based on the perspective of crowding, which considers a three-dimensional factor, floor space.

Table 4: Crowding for ten municipalities

region	Hokkaido	Tohoku	Kanto	Hokuriku	Chubu	Kinki	Chugoku	Shikoku	Kyushu	Okinawa
`urban_density`	44.475	37.278	220.685	23.638	72.355	119.996	87.826	26.490	83.609	81.515
`crowding`	219.096	163.361	218.128	147.675	207.046	314.610	186.700	150.466	213.035	278.377

Notes: The unit of `urban_density` and `crowding` is the number of population per hectare.

3.2.2 Building height

In Figure 1 and Table 5, in the case of `building_height`, the average number of floors per building is shown as an indicator of average height of buildings. If the total floor area of a city is evenly distributed throughout the city, it is an indicator of how many stories of buildings are stacked in all residential areas in the city. For the `building_height`, we use the average number of floors that takes into account housing and unused space in the `building_height_regulation` of the data presented in Section 3.1. Looking at one of these

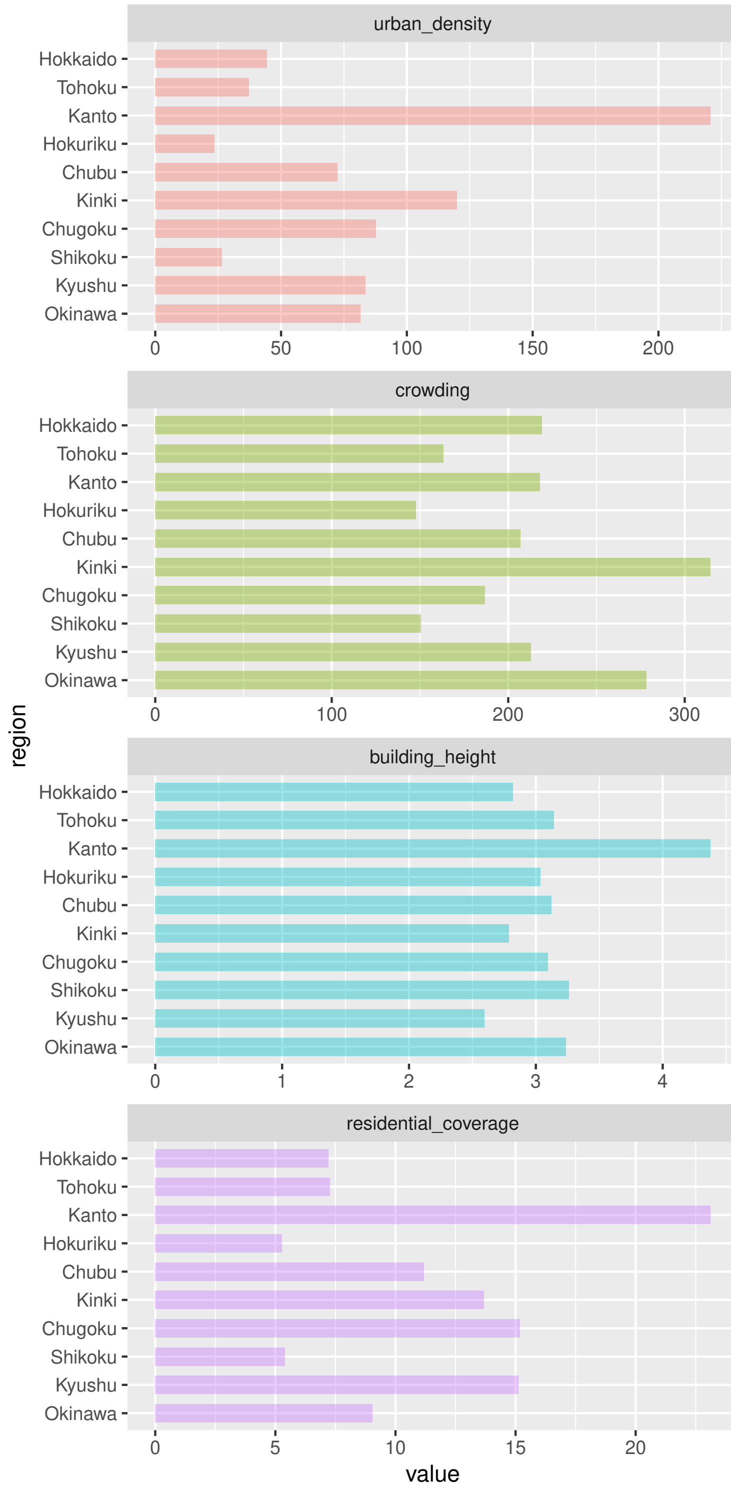

Figure 1: Three factors composing `urban_density` for ten municipalities
Notes: The unit of `urban_density` and `crowding` is the number of people per hectare, and the unit of `building_height` and `residential_coverage` are the number of floors and the percentage, respectively.

three primitive factors, there are some interesting facts.

Firstly, the difference in average building height between the lowest building height of Kasuga-shi, Kyushu (about 2.6 stories) and the largest building height of Kanto, Toshima-ku (about 4.3 stories), it is slightly less than two times. As discussed in Section 3.1, this minimum value can be read as the result of the legal system regulating higher buildings due to the special circumstances of the proximity of the airport in Fukuoka City, which are not found in other municipality. Second, Osaka-shi, Kinki, which had the largest value of `crowding`, was the second-lowest in building height. This means that, *ceteris-paribus*, the higher residential buildings in cities, the higher its density, but the reverse of this claim is not true. Under this case the data would clarify the result of the influence of two of the other primitive factors.

Table 5: Building height for ten municipalities

region	Hokkaido	Tohoku	Kanto	Hokuriku	Chubu	Kinki	Chugoku	Shikoku	Kyushu	Okinawa
`urban_density`	44.475	37.278	220.685	23.638	72.355	119.996	87.826	26.490	83.609	81.515
`building_height`	2.819	3.141	4.377	3.037	3.123	2.788	3.098	3.262	2.595	3.238

Notes: The unit of `urban_density` is the number of population per hectare, and the unit of `building_height` is the number of floors per building.

3.2.3 Residential coverage

In Figure 1 and Table 6, in the case of `residential_coverage`, percentage is shown as an indicator of residential share of urban extent. It is an indicator of the percentage of residential buildings within a given urban extent, and is therefore expressed as a percentage distributed between 0 and 1. The `residential_coverage` is calculated by dividing `total_building_footprint` by `urban_extent` among the data presented in Section 3.1. Looking at one of these three primitive factors, there are some interesting facts.

First, the difference in residential coverage is about four times as large as the difference from about 5.2% in the lowest, Kanazawa-shi, Hokuriku, to about 23% in the largest, Kanto, Toshima-ku. Second, in addition to the fact that maximum and minimum values of municipalities are common, `urban_density` and `residential_coverage` appear to be correlated to some extent. Thirdly, it can be expected that the high `residential_coverage` and `building_height` results in high `urban_density`, especially in Toshima-ku, Kanto.

Table 6: Residential coverage for ten municipalities

region	Hokkaido	Tohoku	Kanto	Hokuriku	Chubu	Kinki	Chugoku	Shikoku	Kyushu	Okinawa
`urban_density`	44.475	37.278	220.685	23.638	72.355	119.996	87.826	26.490	83.609	81.515
`residential_coverage`	7.202	7.264	23.116	5.271	11.192	13.680	15.186	5.397	15.126	9.045

Notes: The unit of `urban_density` is the number of population per hectare, and `residential_coverage` is percentage.

3.3 Further decomposition of crowding

Two of the three primitive factors, `crowding` and `residential_coverage` that make up the concept of `urban_density` discussed in the previous section can be decomposed into further sub-factors, as described in Section 2. In this subsection, we present the results of the decomposition of `crowding` of the regional classification of Japanese municipalities, representing the largest `urban_density` in the regional classification.

To describe a further decomposition of two of the three elements more specifically, we can decompose `crowding` into `living_area_density`, `occupancy_rate` and `floor_plan_efficiency`. In the following sections, we discuss the empirical results of these further decompositions using the Japanese data, based on Figure 2.

3.3.1 Living area density

In the next three sections, we will discuss the three sub-factors that make up `crowding`. As mentioned in the previous section, `crowding` represents the density of people in urban housing, which, unlike `urban_density`, incorporates a three-dimensional factor. That this is a composite measure of several independent attributes of the city together can be shown by the following decomposition.

To begin with, we describe one of the three components of `crowding`, `living_area_density`, where Figure 2 and Table 7 show the values of living area density in 10 representative municipality. In this table, the region classification to which the representative municipality belongs is shown on the y-axis, the urban density in the representative municipality is shown in terms of population per hectare in the case of urban density, and the population per hectare in the case of living area density as an indicator of density considering the floor area and the fact that the house is not actually vacant. The `living_area_density` is calculated by dividing `population` by `occupied_living_area` among the data presented in Section 3.1. Looking at one of the three factors that make up this `crowding`, there are some interesting facts.

First, the difference in living area density is only 1.5 times as large as the difference from about 275 people per hectare in the smallest Kanazawa-shi and Hokuriku to about 416 people per hectare in the largest Osaka-shi, Kinki. It can be seen that `living_area_density` shows a smaller municipality gap than `urban_density`. Secondly, with regard to urban density, which is simply the ratio of population to an urban extent, Toshima-ku in Kanto is more than twice as dense as Osaka-shi in Kinki, while Osaka-shi in Kinki has the highest density based on living area density, which is an indicator that takes into account the floor area and the fact that the house is not actually vacant. Third, one exception is that Naha-shi, Okinawa, which was the fifth-lowest for `urban_density`, was the second closest to the maximum for `living_area_density`. Third, the numerical trends of `living_area_density` and `urban_density` are very similar to those of `crowding`,

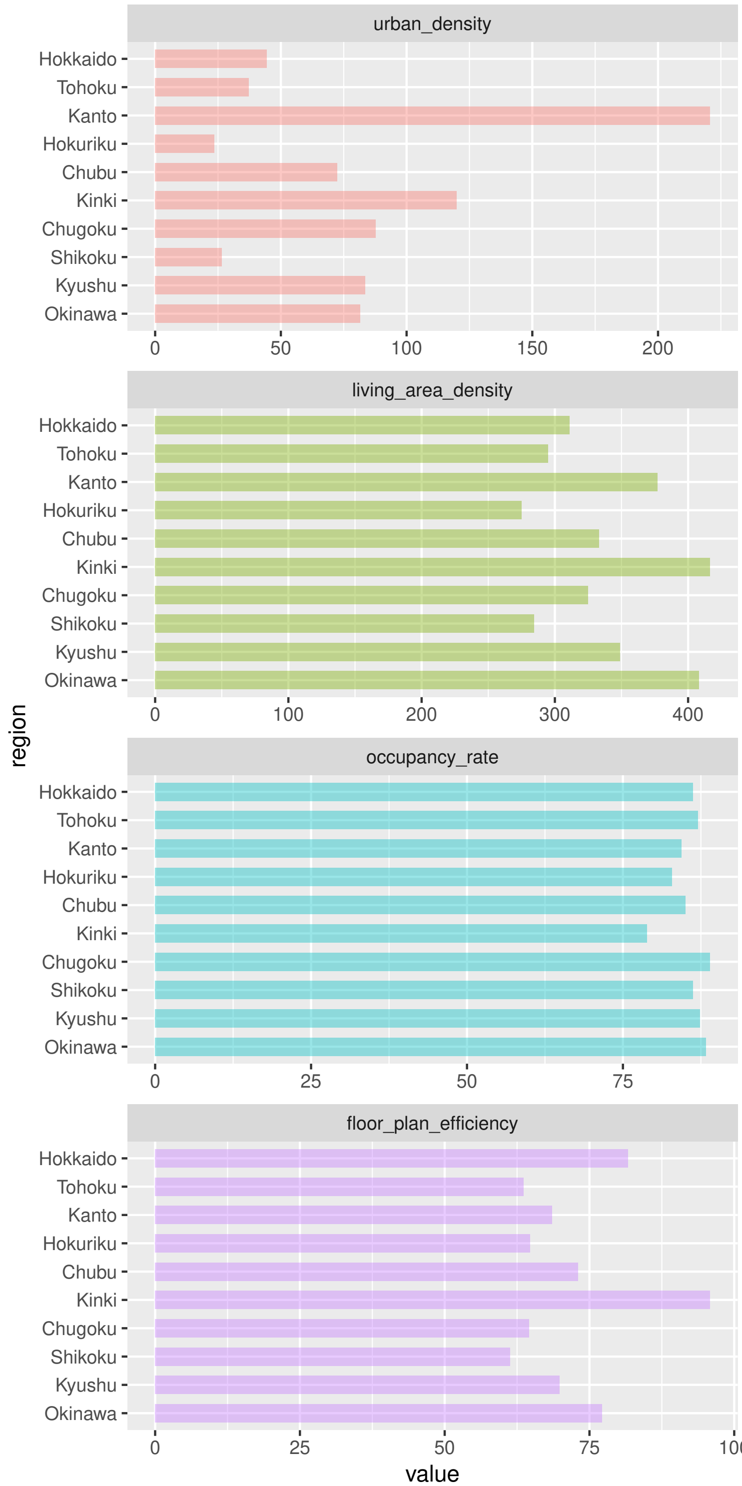

Figure 2: Three factors composing `crowding` for ten municipalities

Notes: The unit of `urban_density` and `living_area_density` is the number of people per hectare, and the unit of `occupancy_rate` and `floor_plan_efficiency` is the percentage.

with the exception of Naha-shi, Okinawa.

Table 7: Living area density for ten municipalities

region	Hokkaido	Tohoku	Kanto	Hokuriku	Chubu	Kinki	Chugoku	Shikoku	Kyushu	Okinawa
urban_density	44.475	37.278	220.685	23.638	72.355	119.996	87.826	26.490	83.609	81.515
living_area_density	311.104	294.790	377.025	275.130	333.145	416.451	325.034	284.584	348.975	408.183

Notes: The unit of urban_density and living_area_density is the number of population per hectare.

3.3.2 Occupancy rate

Next, we discuss occupancy_rate, one of the three components of crowding, where Table 8 shows the values of the occupancy rates for the ten representative municipality. In this table, the occupancy rate is shown as a percentage as an indicator of the percentage of the floor area, which takes into account that the house is not actually vacant, and the floor area, which includes the house that is vacant. The occupancy_rate is calculated by dividing occupied_living_area by total_living_area among the data presented in Section 3.1. Looking at one of the three factors that make up this crowding, there are some interesting facts.

First, the occupancy rate is not much different from the smallest Osaka-shi, Kinki (about 79%) to the largest Fuchu-cho, Chugoku (about 89%). Second, Osaka-shi, Kinki show the lowest number for occupancy_rate, which is a component of crowding, but the largest number for crowding. As is shown by the decomposition, it can be interpreted that the data show that if occupancy_rate, which indicates the occupancy rate of a dwelling, is high, then crowding will be high, but the reverse is not true.

Table 8: Occupancy rate for ten municipalities

region	Hokkaido	Tohoku	Kanto	Hokuriku	Chubu	Kinki	Chugoku	Shikoku	Kyushu	Okinawa
urban_density	44.475	37.278	220.685	23.638	72.355	119.996	87.826	26.490	83.609	81.515
occupancy_rate	86.256	87.037	84.406	82.899	85.070	78.839	88.967	86.233	87.391	88.318

Notes: The unit of urban_density is the number of population per hectare, and occupancy_rate is percentage.

3.3.3 Floor plan efficiency

Next, we discuss floor_plan_efficiency, the last one of the three components of crowding, where Table 9 shows the values of floor plan efficiency in ten representative municipality. In this table, floor plan efficiency is shown as a percentage as an indicator of the ratio of the floor area that includes both vacant and unoccupied residences to the floor area used as a residence and the floor area not used as a residence. The floor_plan_efficiency is calculated by dividing total_living_area by gross_residential_floor_area among the data presented in Section 3.1. Looking at one of the three factors that make up this crowding, there are some interesting facts.

First, the floor plan efficiency does not differ much from about 61% in the smallest Kitajima-machi, Shikoku to about 95% in the largest Osaka-shi, Kinki. Second, the factor floor_plan_efficiency for crowding, as well as living_area_density, shows the largest value for Osaka-shi and Kinki. On the other hand, as mentioned above, Osaka-shi showed the smallest occupancy_rate, which means that it shows the largest crowding by offsetting the smallest occupancy_rate by floor_plan_efficiency and floor_plan_efficiency, which shows the largest occupancy_rate among these other representative municipalities.

Table 9: Floor plan efficiency for ten municipalities

region	Hokkaido	Tohoku	Kanto	Hokuriku	Chubu	Kinki	Chugoku	Shikoku	Kyushu	Okinawa
urban_density	44.475	37.278	220.685	23.638	72.355	119.996	87.826	26.490	83.609	81.515
floor_plan_efficiency	81.647	63.670	68.544	64.747	73.056	95.823	64.564	61.313	69.854	77.220

Notes: The unit of urban_density is the number of population per hectare, and floor_plan_efficiency is percentage.

3.4 Further decomposition of residential coverage

In this subsection, we present the results of the decomposition of residential_coverage of the regional classification of Japanese municipalities, representing the largest urban_density in the regional classification.

To describe a further decomposition of two of the three elements more specifically, we can decompose residential_coverage into plot_coverage and residential_share. In the following sections, we discuss the empirical results of these further decompositions using the Japanese data, based on Figure 3.

3.4.1 Plot coverage

In the next two sections, we will discuss the two elements that make up residential_coverage. As mentioned in the previous section, residential coverage indicates the extent to which a city's residential areas cover the entire city. That this is a composite measure of several independent attributes of the city, similar to coverage, can be shown by the following decomposition.

To begin with, we describe one of the two components of residential_coverage, plot_coverage, where Figure 3 and Table 10 show the values of plot coverage in ten representative municipalities, where the region classification to which the representative municipality belongs is shown on the y-axis, the urban density is shown in terms of population per hectare in the case of urban density on the x-axis, and the share of residential buildings is shown as a percentage of residential land in the case of plot coverage. The plot_coverage is calculated by dividing total_building_footprint by total_residential_area among the data presented in Section 3.1. Looking at one of the two factors that make up this residential_coverage, there are some interesting facts.

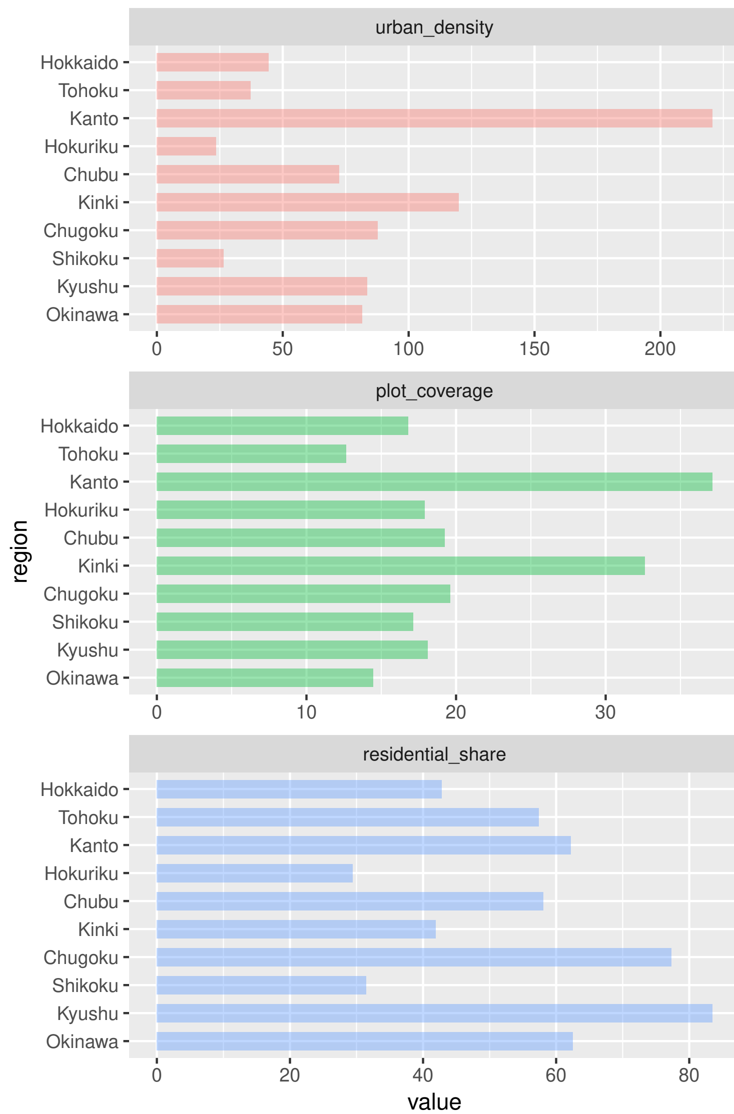

Figure 3: Three factors composing `residential_coverage` for ten municipalities
Notes: The unit of `urban_density` is the number of population per hectare, and the unit of `plot_coverage` and `residential_share` is percentage.

First, the difference in plot coverage is about three times as large as the difference from about 12.7% in Shiogama-shi, Tohoku, the smallest, to about 37.1% in Toshima-ku, Kanto, the largest. It can be seen that plot_coverage shows a smaller municipality disparity than urban_density. Second, in relation to the first point, plot coverage appears to be correlated to some extent with urban density, but their deviations are not as large as urban density.

Table 10: Plot coverage for ten municipalities

region	Hokkaido	Tohoku	Kanto	Hokuriku	Chubu	Kinki	Chugoku	Shikoku	Kyushu	Okinawa
urban_density	44.475	37.278	220.685	23.638	72.355	119.996	87.826	26.490	83.609	81.515
plot_coverage	16.820	12.657	37.141	17.921	19.261	32.611	19.630	17.145	18.116	14.463

Notes: The unit of urban_density is the number of population per hectare, and plot_coverage is percentage.

3.4.2 Residential share

Next, we discuss residential_share, the last of the two sub-factors that make up residential_coverage. Table 11 shows the value of the residential share in the ten representative municipalities. In this table, for residential share, the ratio of the residential land designated by the urban planning law to the area of habitable land, i.e., the total area of municipality minus the area of forest and major lakes, is shown. This residential_share is calculated by dividing total_residential_area by urban_extent among the data presented in Section 3.1. Looking at one of the two factors that make up this residential_coverage, there are some interesting facts.

Firstly, the residential share is not much different from 29.4% in the smallest city (Kanazawa-shi, Hokuriku) to 83.5% in the largest city (Kasuga-shi, Kyushu). Second, the element residential_coverage, residential_share, shows various numbers, which do not appear to be correlated with residential_share. Thirdly, the reason why Kasuga-shi, Kyushu has the largest residential share may be that the residential land is widely reserved for low-rise housing. As mentioned above, Fukuoka City's unique proximity to the airport makes it impossible to erect buildings with high floors by law. Fourth, as with the previous point, residential_share shows a variety of numbers, and they do not appear to show a similar pattern to urban_density. Of course, it is possible that an increase in residential share would increase residential coverage, as well as urban density. However, it is clear from this data analysis that for residential shares, the disparity is not so great that it does not contribute much to the increase in elements of larger categories than those.

3.5 Summary of empirical result of decomposition

In this section, urban density is decomposed into three primitive factors, coverage, building height and residential coverage, with the largest urban density in Japanese municipalities as a representative. In addition,

Table 11: Residential share for ten municipalities

region	Hokkaido	Tohoku	Kanto	Hokuriku	Chubu	Kinki	Chugoku	Shikoku	Kyushu	Okinawa
`urban_density`	44.475	37.278	220.685	23.638	72.355	119.996	87.826	26.490	83.609	81.515
`residential_share`	42.816	57.393	62.237	29.413	58.106	41.948	77.361	31.480	83.494	62.537

Notes: The unit of `urban_density` is the number of population per hectare, and `residential_share` is percentage.

we decompose two of these three elements into their primitive factors by using similar data for two of them: coverage for living area density, occupancy rate and floor plan efficiency, and residential coverage for plot coverage and residential share.

In order to visually summarize the results of the empirical analysis, this study shows how the components of urban density, crowding, and residential coverage are different for each municipality compared to the situation in urban density. Figures 4, 5 and 6 show the extent to which the disparities in urban density, crowding, and residential coverage differ from the disparities in urban density for the three components of urban density, crowding, and residential coverage for the two components of urban density, respectively. In those figures, in order to make the comparison understandable, we standardise each indicator k for municipality p, r_{kp}. This is calculated by the following formula:

$$r_{kp} = \frac{s_{kp} - \min_p (s_{kp})}{s_{k,p^*} - \min_p (s_{kp})}, \tag{18}$$

where $p \in$ {Hokkaido, Tohoku, Kanto, Hokuriku, Chubu, Kinki, Chugoku, Shikoku, Kyushu, Okinawa} $:= \mathcal{P}$ is representative municipality of regional classification $k \in \{\text{Urban Density}, \text{Crowding}, \text{Building Height}, \text{Residential Coverage}, \text{Living Area Density}, \text{Occupancy Rate}, \text{Floor Plan Efficiency}, \text{Plot Coverage}, \text{Residential Share}\}$ is indicator, s_{kp} is value of kth indicator of municipality belongs to regional classification p, and $p^* \in \mathcal{P}$ is a reference municipality. For p^*, we chose the municipality of Kanto with the largest `urban_density` in the figures. Thus, Equation (18) is performing a simple min-max normalization with the number falling to the closed interval $[0, 1]$ in the case of $k =$ Urban Density, since the reference municipality, Toshima-ku (Kanto) shows the largest value in the set $\mathcal{P}$ for $s_{\text{Urban Density},p}$. This value can be used to show the relative distance between the values indicated by the representative municipality with respect to the minimum and the value for p^* with respect to the minimum.

From these figures, we can see that these indicators can be divided into two groups: those with similar trends in `urban_density` in terms of its disparity, and those without. Specifically, the first group with similar distribution to that of `urban_density` is composed of `building_height`, `residential_coverage` and `plot_coverage`. Then, the groups with dissimilar distribution to that of `urban_density` are composed of crowding, living_area_density, occupancy_rate, floor_plan_efficiency, and residential_share. We can also see that among the components of each group, there is a mix of those that have large disparities and those that do not make when compared to the disparity with urban_density. For example, it has been shown that crowding has a large disparity among the representative municipality, while occupancy_rate has a lesser disparity among them. These are things that have been mentioned in the above analysis as well.

The overall result that has been observed throughout the analysis in this section is that, even within a country that can be expected to have some homogeneous urban planning, the trends shown by the urban density and those of the primitive factors that have been decomposed are not all that similar, although some are similar. In particular, the crowding was about 1.5 times higher in Osaka-shi (Kinki) than in Toshima-ku (Kanto), while the disparity in urban_density was about half of that in Osaka-shi (Kinki) than in Toshima-ku (Kanto). This indicates that there is a lack of information in urban_density, which is a simple population divided by the area in two dimensions, and crowding, which incorporates the concept of three dimensions by floor area, gives us a new perspective to analyze how well-populated an area is. This phenomenon can be attributed to the fact that the numerical variation of the primitive factors can be said to play a part in the numerical variation of the urban density of which they are composed, but not the other way around, that is, the numerical variation of the urban density cannot be said to play a part in the numerical variation of the primitive factors of which they are composed.

In Angel and Lamson-Hall (forthcoming), they select one representative city from each of the different major world regions and two from East Asia, where the exceptions are cities with different political regimes. Therefore, the urban_density calculated in Angel and Lamson-Hall (forthcoming) ranges widely from a minimum of 10 people per hectare (Minneapolis, United States) to a maximum of 372 people per hectare (Dhaka, Bangladesh), and thus significant differences were found in the decomposed factors. On the other hand, our analysis covers municipalities within one country and Japan where homogeneous urban planning is considered to exist, and therefore urban_density is distributed over a smaller range. Nevertheless, one major contribution of this study is that it shows a disparity in factors resulting from decomposition, which cannot be explained only by the urban_density gap.

In this way, we believe that it will be possible to formulate urban planning policies more in line with reality by using a group of factors that include more detailed information, such as density measures that include not only urban density but also other three-dimensional factors that can be obtained by decomposing them, and density measures that take into account places that are not actually vacant.

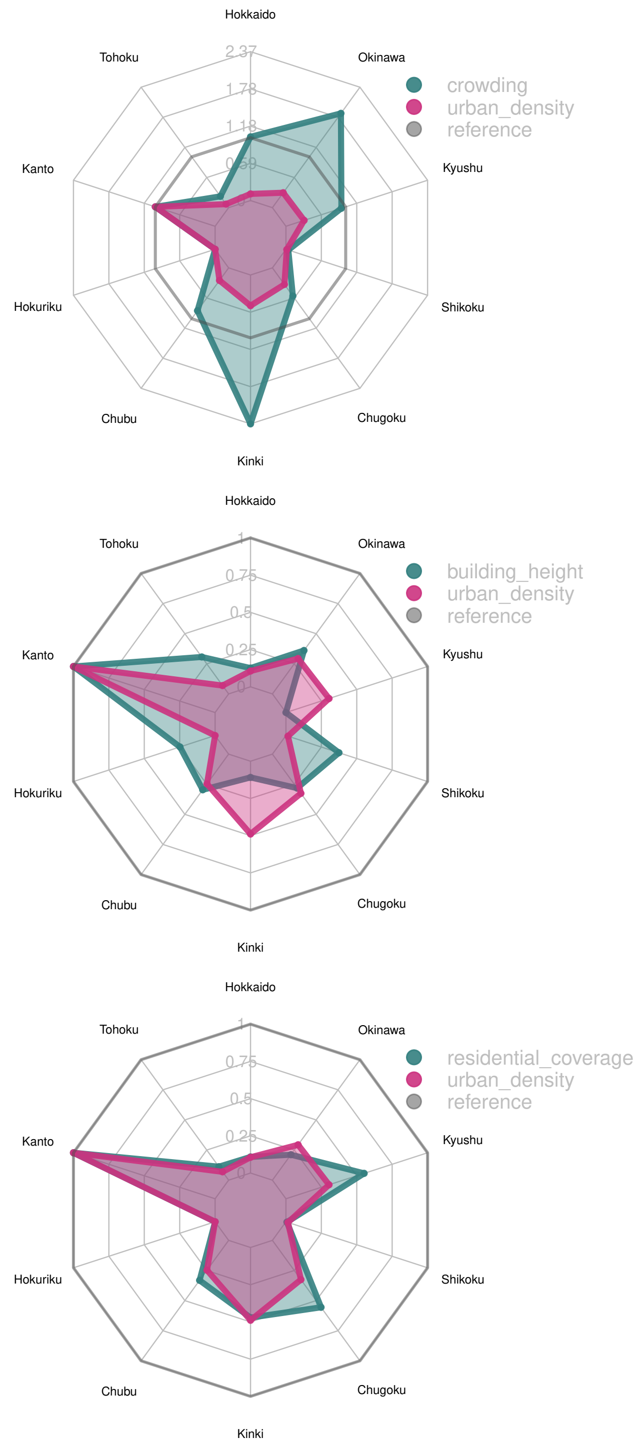

Figure 4: Three factors composing `urban_density` for ten representative municipalities: radar-chart
Notes: All the values are relative distances from the minimum value of each indicator, with 1 being the reference value of Kanto, Toshima-ku, which has the maximum value for `urban_density`. The top panel is for `crowding`, the middle panel is for `building_height`, and `residential_coverage` is in the bottom panel, showing the extent to which the three measures that make up `urban_density` and its `urban_density` in a representative municipality differ.

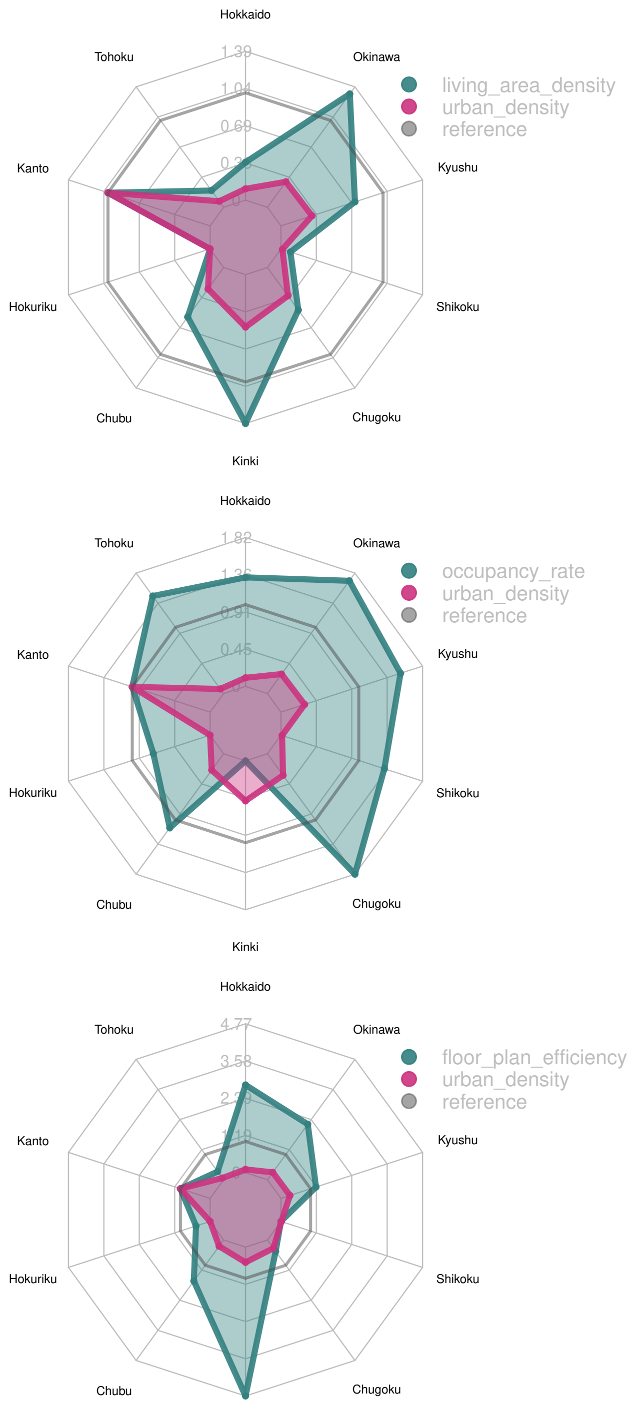

Figure 5: Three factors composing `crowding` for ten representative municipalities: radar-chart

Notes: All the values are relative distances from the minimum value of each indicator, with 1 being the reference value of Kanto, Toshima-ku, which has the maximum value for `urban_density`. The top panel is for `living_area_density`, the middle panel is for `occupancy_rate`, and the bottom panel is for `floor_plan_efficiency`, showing the extent to which the three measures that make up `crowding` and its `urban_density` in a representative municipality differ.

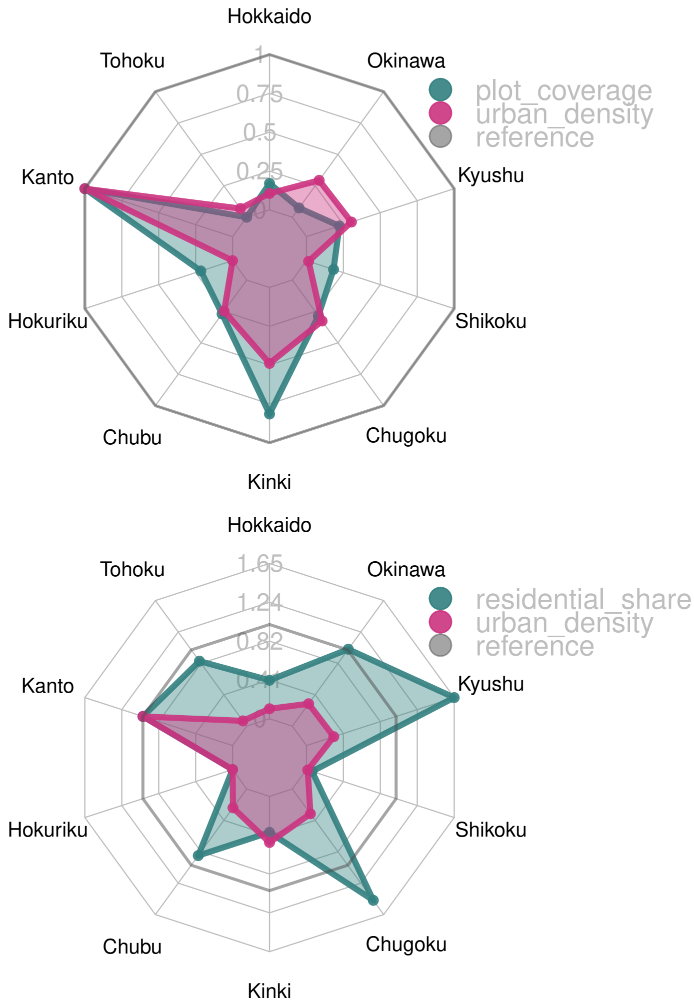

Figure 6: Two factors composing `residential_coverage` for ten representative municipalities: radar-chart
Notes: All the values are relative distances from the minimum value of each indicator, with 1 being the reference value of Kanto, Toshima-ku, which has the maximum value for `urban_density`. The top panel is for `plot_coverage`, and the bottom panel is for `residential_share`, showing the extent to which the three measures that make up `residential_coverage` and its `urban_density` in a representative municipality differ.

4 Conclusion

The aim of this paper is the application of a pioneering methodology to decompose the urban density into their main components. Furthermore, this paper innovates in the application of the methodology to analyse the Japanese municipalities.

Firstly, urban density analysis shows heterogeneity across municipalities. To make our analysis more understandable, we compare the municipalities with the highest urban density in each region, where each region might be composed by many prefectures. Nevertheless, even among the municipalities with the highest urban densities, there is evidence of big differences across them. The municipality with the highest urban density is Toshima-ku with 220.7 persons per hectare located in Tokyo prefecture on the region Kanto; on the other hand, Kanazawa-shi exhibits the lowest urban density with 23.7 people per hectare at Ishikawa prefecture in Hokuriku region.

Secondly, the results of the urban density are not completely correlated with the values of its components. It means, the indicator of urban density hides important heterogeneity that we must consider when we analyse density. For example, Even Toshima-ku (Tokyo, Kanto) is the municipality with the highest urban density, Osaka-shi (Osaka, Kinki) and Naha-shi (Okinawa, Okinawa) are more crowded areas than Toshima-ku (Tokyo, Kanto). In the case of the residential share, a sub-factor of residential coverage, Kasuga-shi (Fukuoka, Kyushu) and Fuchu-cho (Hiroshima, Chugoku) have higher levels of the residential share; in other words, in those areas, the urban extent is more covered by residential areas than Toshima-ku (Tokyo, Kanto).

Thirdly, these results open the possibilities to new research areas where we can decompose the concept of density to obtain refined results and propose better policies of urban planning. For example, transportation development plans and housing policies require different treatment and tools in cities where crowding are the main reason why those cities are highly dense; or when building height or residential coverage are the main drivers of urban density. In this regard, it is important to remember that the causality direction is clearly defined, i.e. the three factors (crowding, building height, and residential coverage) affects urban density and no vice-versa.

Fourthly, it remains as research agenda, the analysis of the impact of these components of urban density into other variables that depends on population densities such as land price, and school supplies (to understand in more detail the causes of closing schools in Japan).

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