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Population and Morphological Change: A Study of Building Type Replacements in the Osaka-Kobe City-Region in Japan

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As cities adapt to new needs and challenges, their forms change in close relation to population dynamics. This article focuses on the link between population dynamics and the evolution of building hull types. The case study is the Osaka-Kobe city-region in Japan, a country globally witnessing an intense population decline. Morphometric indicators are coupled with a tree-like classificatory model in order to label buildings into consistent classes between two different periods (2003–2004 and 2013–2014). The building class distributions and their evolutions are studied in conjunction with population censuses. Urban adaptation processes are particularly accounted for through the study of the replacement of building types. Results show that, among other things, townhouses in traditional neighborhoods are gradually being replaced by small-size collective complexes. In far outlying areas, people are still eager to move and live in detached single-family homes despite a global context of population decline. Finally, central places are increasingly filled by narrow almost-adjointing towers. Relations between building types and population dynamics, detailed through maps and statistics, show that peoples are increasingly concentrating in central locations associated with specific building types, while some other peripheral locations are concerned by both a disappearance of specific building types and a population decline.

Introduction

Buildings within cities have their own life cycles that include construction, use, and sometimes demolition, reconstruction, or repurposing. In 1982, Van den Berg et al. (1982), classify the stages of evolution of urban agglomerations (named functional urban regions or FURs) into four categories: urbanization, suburbanization, deurbanization, and reurbanization. This classification, criticized for a cyclical nature that cannot be applied to most urban systems (Wolff et al. 2013), has yet the merit of discussing different stages of urban development, including degrowth,

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on a city-wide scale. However, it is important to note that this classification lacks a focus on morphological processes. Globally, the conceptual evolution seen in research focusing on growth and degrowth barely addresses morphological changes from a spatial point of view (Reis, Silva, and Pinho 2016). This is especially true for studies centered on shrinking cities or on the phenomenon of urban shrinkage, since such research often concentrates on gross population loss and on the underlying factors contributing to it (Buhnik 2010). The exception is to be found within the discipline that studies urban forms and their transformation over time: urban morphology. Morphological change from a spatial point of view resonates with the life cycle of a city. Cities, like organisms, go through natural phases of growth, decline, and renewal. From this perspective, adaptive cycles are a well-known subject studied by urban morphologists. The variation of building coverage at the plot level (the *burgage* cycle, Conzen 1960; Feliciotti 2018; Ünlü 2021) or the development cycles highlighted by Caniggia and Maffei (1979) at the settlement level, are good examples of studies on the evolution of urban landscapes in urban morphology. As cities adapt to new needs and challenges, their forms change. This evolution is not just about construction; it is a reflection of a city's character and resilience potential. From historical preservation to new constructions, each change tells a story. Morphological changes in this research thus refer to the formation and transformation of the spatial structure and characteristics of urban fabrics. In other words, it is the study of the identification and evolution of the components that make a city a city, such as buildings, streets, plots, public spaces, etc., and the analysis of their spatial patterns and dynamics over time. If we were to focus only on the possible morphological changes of the urban fabric, with no regard to triggers, they could be summarized by the following spatial processes: formation, transformation, adaptation, disappearance, and conservation.

First, urban *formation* refers to the fact that urban fabric appears where no built environment was previously standing. In the academic literature, urban formation is in line with patterns of edge-expansion (clustered urban sprawl), infilling, nonclustered leapfrog, and clustered leapfrog. In planning, urban formation could be described as a first attempt to give a response to the opportunities and challenges within undeveloped space (rural or natural) at a specific moment in time.

Second, urban *transformation* is related to the fact that urban fabric completely changes its properties from one period to another, including changes in the street layout. This process, well identified in urban morphology, overlaps with similar concepts in other disciplines (economics, planning, sociology), such as urban regeneration, renewal, consolidation, retrofitting and/or redevelopment. Indeed, these concepts do not always imply complete physical transformation of the urban form. Existing urban fabrics are fully removed to make way to new ones. In such cases, the essence of the previous state is lost, and a new fabric appears, corresponding to the transformative process of urban morphology. A well-known example would be West End Boston that was completely demolished and reconstructed with different street layouts and building models in the late 1950s (Jacobs 1961).

Third, urban *adaptation* refers to the addition and/or subtraction of new components constituting the essence of urban fabric, as well as the alteration of existing ones. In adaptive processes, most of the morphological infrastructure (i.e., the street layout) remains in place and changes concern primarily buildings, open space design and functions. In this respect, the essence of the previous state is not lost, but it rather evolves according to contemporary needs and/or constraints. Urban retrofitting and redevelopment (at least partial redevelopment), but also urban restoration, perforation (random generation), degeneration (clustered accumulation),

refurbishing, decay and requalification could all fall into this dynamic of adaptation. Concepts of urban renewal, regeneration and renovation seem more linked to morphological transformation, as well as urban redevelopment, at least as this is often meant in a North American context. Increasing densities associated with an increase in building coverage as well as the use of vacant lots for urban agriculture patterns with decreasing densities are both adaptation dynamics. Good examples of urban adaptation are the piecemeal urban intensification patterns coupling infill development and building substitutions, like the one studied by Ünlü (2021) in Mersin, Turkey, where whole districts of single-family houses on large plots became dense alignments of multistory buildings within the same street system.

Fourth, urban *disappearance* pertains to the complete removal of existing urban fabric without replacement. Edge-contraction (i.e., large-scale demolitions), urban perforation and degeneration (i.e., random generation and clustered accumulation), but also the demolition of full-fledged urban agglomerations and of non-clustered leapfrog patterns fall into this category. Slums and favelas removals are an example of disappearance dynamics (when they are not followed by new urban projects on the cleared sites).

Finally, urban *conservation* relates to the fact that urban fabric fully keeps its essence and properties. This is the case of the historic city centers or even of urban fragments of more recent periods illustrating a significant stage in human history, as recognized in UNESCO's definition of cultural heritage sites. In such cases, by-laws often safeguard the physical properties of the existing fabric, thus forbidding any variation. Urban conservation can be described as the frozen state of the last attempt that gave a response to former opportunities and challenges. Of course, much could be said of the contradiction between the absolute conservation of the physical form and the disappearance of the human usages and functions that previously characterized these sites. However, morphologically, conservation is a *sui generis* process, implying a total lack of change in the physical city.

The issue with growth and degrowth is that, from a morphological point of view, it can potentially occur within any of the aforementioned morphological processes. For example, a decline in the urban population can happen at the same time as an edge-expansion dynamic characterized by the sprawl of low-density neighborhoods (urban formation). A “towers in the park” model (buildings are placed in the middle of the blocks, surrounded by landscaped greenery instead of streets, etc.) could be fully replaced by a neighborhood of large-sized detached single-family houses (urban transformation), complemented by connecting infill buildings (urban adaptation), or destroyed without any new project (urban disappearance). Other urban landscapes could remain protected by local plans with no regard to population dynamics (urban conservation), like Venice, where the population in the old city passed from 174.000 in 1951 to 50.000 in 2022.

These considerations take on particular importance in Japan, where out-migration, slow-paced renewal of generations, and localized aging dynamics are strongly at work. As a result, anticipating and planning for a sustainable future that considers aging and accessibility (e.g., 15-min city) is a top priority for the Japanese government (Hara 2014; Usui and Perez 2020). However, the dearth of research on the link between morphological changes and population dynamics limits the effectiveness of any policy taken to spatially address shrinkage. Therefore, the aim of this article is to partially fill this void, by focusing on the link between population dynamics and the morphological evolutions of one of the finest components of urban fabrics: buildings. Urban adaptation processes will be particularly accounted for, through the study of the evolution and substitution of building types in the metropolitan area of Osaka-Kobe in the last decades. The article is organized as follows. Section [Population dynamics, planning](#)

and urban fabrics in Japan presents the specificities of Japanese cities in terms of urban fabrics, building types, and population dynamics. Section [Data and method](#) introduces the case study, the spatial data, and the methodology used to identify building types (morphometric indicators coupled with a tree-like classificatory model). Section [Building hull types: Validation and pseudo-correspondence to building types](#) presents the identified building types at different periods (2003–2004 and 2013–2014), the descriptive statistics and the validation of the procedure. Section [Building hull types and population locations](#) exposes the spatial arrangement of building types in the study area in relation to population distribution. Section [Building hull types and population evolutions](#) focuses on the spatial evolution of building types and population. A final section concludes the article with a discussion.

Population dynamics, planning, and urban fabrics in Japan

Japan is characterized by a high urbanization rate, coupled with a high life expectancy and a very low fertility rate. In 2020, 28.4% of the population was over 65 years old. If Japan maintains its current trajectory, its population should decrease by more than 13% by 2040 with a proportion of people aged over 65 above 35%. The urbanization rate, already at a very high level compared to other developed countries, continues to increase slightly: 91.8% in 2020; projected at 92.7% for 2030 (United Nations 2018). However, this increase, concomitant with a decline in population, is neither associated with a process of urban formation, nor with a process of disappearance (at least within the existing urban areas). National laws were passed to significantly limit urban sprawl largely before the end of the 20th century (*City Planning Act of 1919* and its numerous amendments, notably in 1968, Perez et al. 2019a). The increase in the rate of urbanization is thus linked to several factors, such as the out-migration of the young generations to urban areas, the relocation of isolated dwellings within existing urban areas (Akiyama and Akiyama 2019) and the decline of rural communities. The dying villages, which are much more affected by the nonrenewal of generations rather than by out-migration, bear a name: *Genkai shūraku* (限界集落).

Shrinkage in Japan is not purely seen as a demographic, economic, or social issue, but also as a planning challenge related to the anticipation of the locations experiencing the biggest loss in population. Yet, in Japan, zoning categories (residential, quasi-residential, commercial, industrial, quasi-industrial, and exclusively industrial) and subcategories are mostly indicative, and it is possible to build almost any kind of building anywhere (*City Planning Act, City Building Act*, and amendments; see Perez et al. 2019a). What matters most are two limitations, which vary according to the zoning categories: the building coverage ratio (BCR) and the floor-area ratio (FAR). The BCR is a ratio between the building footprint and the total surface area of its plot. The BCR allows laying foundations on between 30% and 80% of the surface of the plot, plus 10% when special circumstances occur (plot located in-between two roads, on a corner, building built with fireproof materials, etc.). The FAR is a ratio between the building total floor area and the total surface area of its plot, which can ultimately allow for an increase in the building total floor area by up to 500% in some residential subcategories, and 1300% in commercial areas. Yet, unlike the BCR, the FAR is also considering the local environment around the plot through a special rule that considers the width of the road the building is facing: the wider a street is, the more the number of allowed floors will be, with no regard to the zoning category. In addition, the lifespan of buildings in Japan, and especially the lifespan of single-family houses, is approximately 30 years (MLIT, 2007). This is in sharp contrast with most countries in Europe

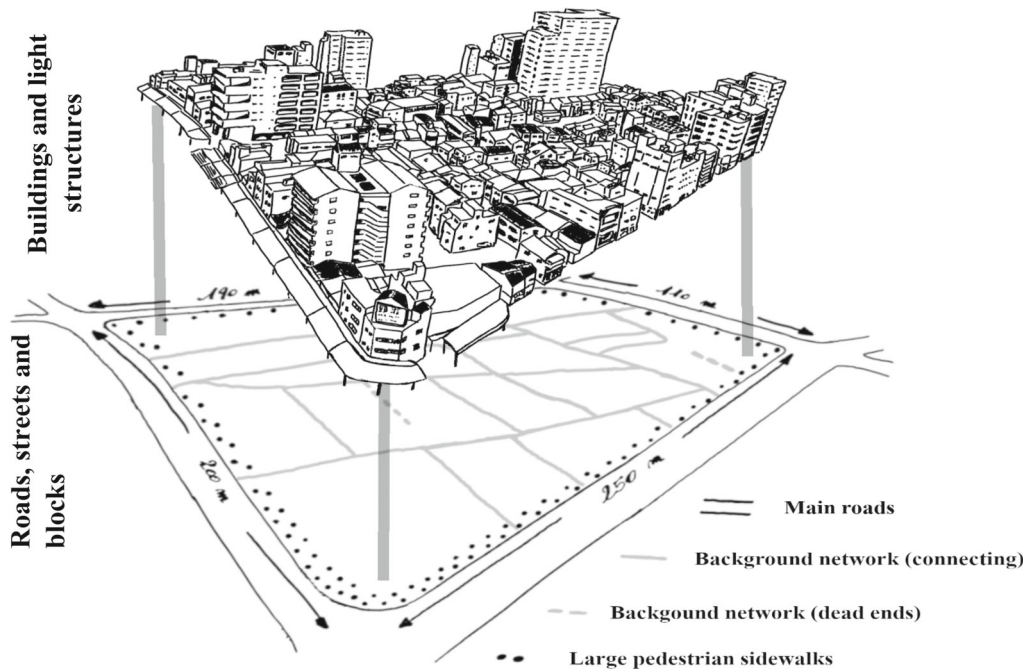


Figure 1. A typical neighborhood in dense urban areas in Japan (Asahi Machi, Suita-shi, Osaka province) with shops and services on the edges (*hard shell*) and residential blocks in the center (*soft yolk*).

in which the lifespan of buildings is two to three times higher. These limitations, coupled with the fast-self-organized processes of construction and deconstruction of buildings, contributed to the creation of quiet residential neighborhoods close to busy streets with tall buildings (referred to as *hard shell – soft yolk* by Popham, 1985). Such neighborhoods are perfectly in line with the urban concepts of hyper-proximity, 15-min city, etc., which promote walkable neighborhoods close to vibrant public spaces with shops and services (Speck 2013; Moreno 2020). Fig. 1 displays the different urban components of such a neighborhood in the Osaka-Kobe city-region. The spatial succession of these structures leads to distributed polycentrism, which is, once again, rather opposed to the dominant center-periphery model of most Western cities. Indeed, in such neighborhoods, shops and services are located on the edges of the residential area rather than within a close-by central place or hub.

Yet, it is increasingly difficult to find typical *hard shell – soft yolk* structures within the Japanese urban spaces at the beginning of the 21st century. There are a few reasons for this. Among them is the fact that the neighborhoods close to the main centers and subcenters have long been fully deregulated to become themselves a part of these central areas (top-down consolidation process through the *District Plans*, Akashi 2007; Perez et al. 2019a). Conversely, such structures have never emerged in the far outlying areas. This is due to the fact that before being limited, urban sprawl was mostly made of clusters of isolated housing complexes (see *Danchi* housings, Section [Building hull types: Validation and pseudo-correspondence to building types](#)), standardized single-family homes areas built by developers, or experiments, such as the working-class garden cities neighborhoods (*Den'en toshi – 田園都市*) and suburbs (*Den'en kōgai – 田園郊外*). The second reason is that the short lifespan of Japanese buildings

leads to a fast-piecemeal reorganization of urban spaces, a process leading to densification or de-densification of the built spaces within neighborhoods. In the case of densification, owners are selling their plots or parts of their plots to developers which are making the most of the FAR limitations to build small buildings (Osaragi 2014), while, in the case of de-densification, vacant plots are slowly accumulating. In a context of shrinkage, maintaining urban functions and services within every inch of urbanized spaces is costly. To cope with shrinkage, the government introduced a compact city policy (*Urban Renaissance Law and Act on Special Measures Concerning Urban Reconstruction* of 2002) that designates areas that need redevelopment, ease the city planning restrictions and guide funding. As discussed in Asami (2017), the 2014 amendment requires municipalities to constitute *proper location plans* to designate two types of development areas. First, the *urban function promotion area* aims at fostering the development of living facilities (commercial facilities, hospitals, etc.) around the main transportation hubs through a deregulation of planning restrictions and financial incentives to projects. Second, the *habitation promotion area* discourages developers from building large-scale housing development in areas not included in those plans (notification to municipality mandatory, “advice” from the municipality to scale down or give up, etc., Asami 2017). To summarize, the Japanese government nowadays prioritizes a reduced number of locations through an assumed *transit-oriented development* policy while trying, at the same time, to manage a gradual de-intensification of land use by letting vacant lots accumulate outside of designated areas (Yamagata and Maruyama 2016). Yet, those processes started to appear before the policies, with for example Kim, Onishi, and Suga (2007) noticing that in the last decades of the 20th century, disurbanization and reurbanization were increasing and co-occurring. The hypothesis is that *hard shell – soft yolk* neighborhoods, now mostly located in-between the central places and the far outlying areas, are slowly mutating. The study of the spatial evolution of building types that we propose in this article will provide new knowledge regarding the kinds of morphological changes these areas are witnessing.

Data and method

The case study is an area of 46 by 28 km in Southern Japan located within the core center of the Keihanshin (京阪神, “Kyoto–Osaka–Kobe”) metropolitan region. It contains central Osaka and Kobe, as well as their direct surroundings (Fig. 2). We decided to focus on the second biggest urban area in Japan since the metropolitan area of Tokyo carries out numerous specificities related to its status of capital. The Osaka-Kobe pair had a GDP of \$680,997 in 2015 (millions PPP\$ – rank 9th) and \$36,535 per capita (PPP\$ – rank 74th)¹. ZENRIN Residential Maps (Zmap TOWN II²), which are digital maps containing the building footprints throughout Japan, are extracted, and compiled into a single file (GeoPackage) for the extent of the test region in 2003/2004 and in 2013/2014. ZENRIN Residential Maps possess several attribute data from which two are of interest to this study: the height of the buildings, expressed in number of floors, and building specialization. Building specialization is a discrete attribute, encoded as follows: 1200 for official and religious buildings (schools, administrative buildings, temple, etc.), 1363 for collective housing, 1364 for single-family homes, 1365 for private offices and mixed-use buildings, 2190, 2191, and 2192 for light structures, such as buildings with no roof or walls (arbors, awnings, light-structure porches). In this article, we focus on residential buildings, both collective and individual housing (1,363 and 1,364), as well as on offices and mixed-use buildings (1,365). Using these three categories, all buildings that are likely to host residents are taken

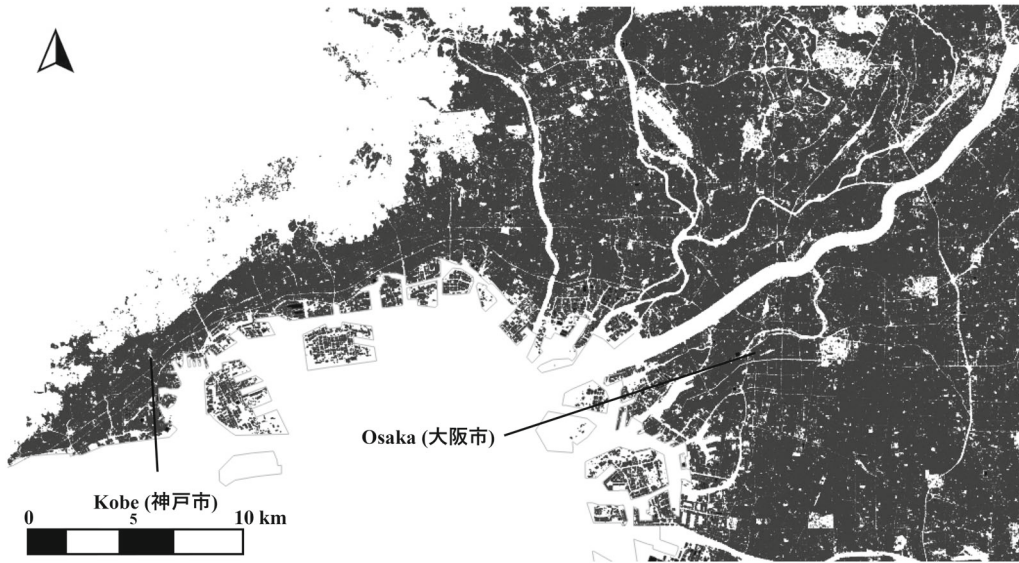


Figure 2. Study area and building footprints in 2013/2014.

into consideration. Together, they concern 1,497,258 buildings in 2003/2004 and 1,463,499 in 2013/2014, thus showing a decrease of -2.25% of buildings in 10 years.

The first step consists in computing a basic series made of morphometric indicators for each building: the building's footprint surface (area), the total amount of usable floor area, elongation, convexity, and the number of adjoining neighbors. They respectively provide a measure of how buildings are elongated compared to the most compact equivalent surface of a circle, if buildings have intricated or squared shapes, and finally, if buildings are free-standing detached structures or possess close-by neighbors (less than 1.5 m from building perimeters). The final set of indicators is made of the newly calculated morphometric indicators plus number of floors³ and specialization, taken from the attribute data. Elongation, convexity, and the number of adjoining neighbors are detailed in Perez et al. (2019b), in which we did our first tests on automated building clustering for different countries and on a fixed date.

Once the set of indicators is ready for 2003/2004 and 2013/2014, the next step is to perform a classification of building hull types. A classification of building types would require far more accurate indicators than the aforementioned ones, including, for example, variables related to the internal organization of buildings (distribution of units and rooms, bearing structure) and possibly style (material and design of façade and roof, colors). Yet, for some specific cases and cultural contexts, a given building hull can roughly correspond to a building type (section [Building hull types: Validation and pseudo-correspondence to building types](#)). For most cases, however, a building hull type covers several nonuniform units with close characteristics in terms of urban design and architecture. As the following sections will show, building hull types are enough to provide a broad picture of the link between population dynamics and perforation and regeneration of built space. To obtain hull class labels, expert knowledge is called upon regarding urban form and evolution in general, and for the specific case and history of Japan. Expert knowledge, derived from the literature, fieldwork observations and interviews with key actors (academics, inhabitants, developers, etc.) allows for defining conditional control statements that are applied on different quantitative descriptors of the data sets. The control statements successively split the

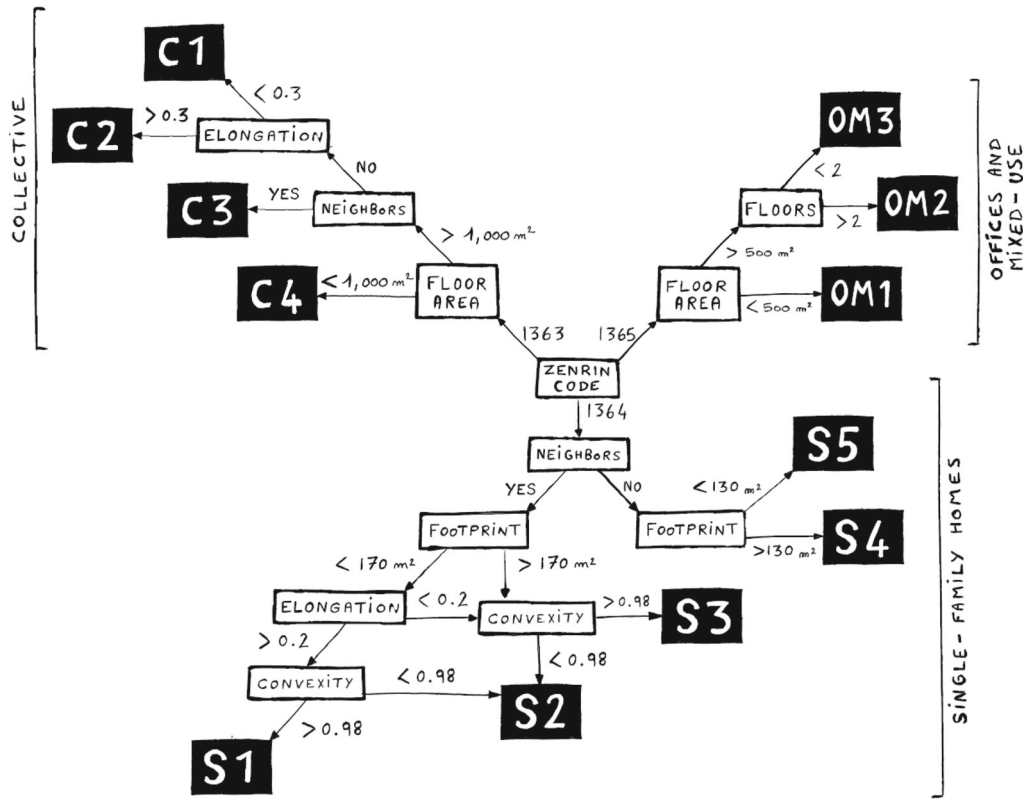


Figure 3. Conditional statements and thresholds used to create the class labels.

inputs into different subsets, ultimately leading to different class labels for building hull types, as shown in Fig. 3. From a technical point of view, a tree-like function like the one used in this article, with fewer class labels and a reduced test area (central Osaka only), has been compared to semi-supervised clustering and unsupervised clustering, and evaluated as being best suited for this research (Perez, Fusco, and Sadahiro 2022).

Fig. 3 tree-like classificatory model displays the thresholds implemented to obtain the final building hull types. First, the outputs are divided into three main categories: “collective,” “single-family,” and “office or mixed-use” following the official ZENRIN codes. For the collective buildings, the thresholds have been set to identify high-rise buildings with no neighbors (C1); elongated buildings also with no neighbors (C2), mid-to-large-size apartment complexes with neighbors (C3) and small-sized apartment complexes with or without neighbors (C4). The single-family category is made up of small-size and elongated houses with neighbors (S1), intricate houses with neighbors (S2), convex houses with neighbors (S3), large-size detached houses (S4), and small-size detached houses (S5). Office and mixed-use buildings have been divided into three categories: small to mid-size (OM1), mid to high-rise (OM2), and large and low-rise (OM3). The validity of the classified outputs is assessed by comparing the physical appearance of inputs drawn at random for each class label with the physical appearance (design, aesthetic, and spatial arrangement) expected by the experts who implemented the conditional statements and their related thresholds (section [Building hull types: Validation and pseudo-correspondence to building types](#)). When a solution is deemed robust for each building

hull type, the conditional control statements are used as benchmarks for both data sets (2003/2004 and 2013/2014). Percentage points for each class label and periods outline which hull types are most favorable to perforation, regeneration, or multiplication (statistics in Table 1). It is then possible to explore these dynamics from a spatial point of view ([Building hull types and population locations](#)) and in conjunction with other factors, such as population distribution and evolution (Section [Building hull types and population evolutions](#)). To achieve this, the Half Grid Square statistics,⁴ representing the finest granularity within the Japanese population censuses, are employed for the nearest periods corresponding to 2003/2004 and 2013/2014, specifically 2005 and 2015. The cells, which are square-area units of uniform size of about 66,100 m² ($\approx 230 \text{ m} \times 286 \text{ m}$), are superimposed over the extent of the test region. Cells that are not intersecting any building are filtered out of the grid. The total number of cells related to the study area accounts for 12,930 units. The total population related to the study area accounts for 7,249,243 inhabitants, with a positive increase of 111,107 inhabitants between 2005 and 2015. This very small increase is due to two factors. First, despite a global population shrinkage in Japan, the largest metropolitan areas in Japan are stagnating rather than declining thanks to interregional migrations. Second, we were not able to fully consider all the distant suburbs of Osaka, which are the places usually witnessing the biggest population decline (especially around the southern municipality of Sakai – 堺市). Indeed, beyond the study area, only the Grid Square statistics is available, which is too wide for a cross-analysis with building evolutions. Finally, the building hull types, grouped by labels, are counted for each cell and for both periods. Counts and differences between both periods are then mapped and analyzed. Correlation matrices ultimately allow exploring the spatial distribution and evolution of building types in conjunction with population distribution and evolution.

Building Hull types: Validation and pseudo-correspondence to building types

For each of the 12 identified class labels, a sample of 100 buildings is randomly drawn and localized using a geographic information system. Through fieldwork and the use of street-based urban imageries (such as Google Street View), inputs within the samples are analyzed to assess the accuracy of both the ZENRIN Residential Maps and the classification procedure. This quality check is operated using the class labels attributed to 2013/2014, and urban imageries as close as possible to this date are used. Labels attributed during the automated classification procedure are compared to what label would be given by an expert, provided the latter had access to each of every building part of the different samples. Inputs are evaluated as follows: “*correct*” if expert and tree function yield the same result, “*not correct*” if they do not, and “*n/a*” if the control is not possible (e.g., no visibility on street-based urban imageries, buildings destroyed with no archives, etc.) (Table 1). The 12 samples, associated with the set of indicators used to perform the classification are available as Data S1.

The automated classification demonstrates a high level of accuracy across all label classes. The lowest accuracy score, detained by S4, is as high as 85.56%. Most issues arise from a poor digitization and/or location of polygon shapes within the ZENRIN Residential Maps, creating a lack of neighbors when some should be present, and *vice versa*, the most recurring problem. Since the number of adjoining neighbors is calculated using a total distance of 1.5 m between buildings, the error margin is acceptable in the final protocol. Other classification tests, not discussed in this article, have shown that decreasing the distance used to detect the neighbors rapidly decreases

Table 1. Statistics and Validation of Identified Building Hull Types

Description	Statistics				Validation					
	Count 2013/2014	Share	Count evolution 2003/2004–2013/ 2014		Floor area total 2013/2014	Floor area evolution 2003/2004–2013/ 2014		Correct n/a	Not correct n/a	Accuracy (%)*
			2003/2004–2013/ 2014	2014		2003/2004–2013/ 2014	2014			
S1 Elongated townhouse	243,664	16,54%	-2.21%		19,686,417	1.09%	93	5	2	97.89
S2 Intricate townhouse	209,508	14,22%	-2.97%		31,196,743	-11.87%	84	5	11	88.42
S3 Compact townhouse	386,890	26,26%	-17.25%		40,722,774	-18.88%	88	2	10	89.79
S4 Large-sized detached house	27,789	1,89%	-17.99%		9,934,866	-21.72%	83	3	14	85.56
S5 Detached house	168,987	11,47%	21.18%		23,461,718	14.31%	80	14	6	93.02
C1 High-rise collective	10,610	0,72%	10.66%		38,927,182	24.31%	83	5	12	87.36
C2 Elongated collective	14,562	0,99%	12.87%		70,264,064	28.28%	97	2	1	98.97
C3 Narrow collective	23,787	1,61%	19.27%		105,945,799	29.7%	89	2	9	90.81
C4 Small-sized collective	102,434	6,95%	24.34%		40,287,225	21.08%	99	1	0	100
OM1 Small-mid-sized mixed-use	243,664	16,54%	5.47%		38,627,025	10.25%	77	21	2	97.47
OM2 Mid- to high-rise mixed-use	18,067	1,23%	0.72%		46,290,789	7.53%	96	3	1	98.97
OM3 Large- and low-rise mixed-use	23,113	1,57%	-13.14%		40,758,762	-12.6%	93	5	2	97.89
R† Removed	400,777	n/a	n/a		n/a	n/a	n/a	n/a	n/a	n/a

*Ratio between “correct” and “not correct” only.

† All other buildings than 1,363 (single-family homes), 1,364 (collective buildings), and 1,365 (offices and mixed-use).

the accuracy scores of most class labels. As discussed in the previous sections, each class label potentially contains a multitude of different building types. The validation procedure allowed obtaining an overview of the most common building types in terms of design, aesthetic, and spatial arrangement (within and in-between plots). Fig. 4 displays building archetypes for each class label that have been identified and sketched during the validation procedure.

S1, S2, and S3 are single-family homes characterized by the presence of neighbors and can thus all be considered as townhouses. Amongst them, S1 are small and elongated, and thus include traditional elongated building types, such as *Nagaya* (長屋) and *Uranagaya* (裏長屋), which are building types that appeared during the Kamakura (1185–1333) and Muromachi (1336–1573) periods (Bonnin, Nishida, and Inaga 2014). From this perspective, S1 a in Fig. 4 can be considered as a building type directly derived from the traditional back-alley tenements (*Uranagaya*). This archetype evolved by being rebuilt several times over, with the addition of rooms, a second floor, etc. Yūko (1995) provides a complete overview of the evolution of the shapes of *Nagaya* and *Uranagaya*, which includes, for example, the relocation of the kitchen within the dwelling at the beginning of the 20th century. S1 is never accompanied by frontages (strips of land between the street and the facade), and the main door thus always leads directly to a sidewalk or a road. This building type is also the only one prone to possess common walls or fully adjoining walls, a remnant characteristic of the fact that *Nagaya* were often constructed by a single landlord within a block, with units gathered under one long roof in order to accommodate the employees and/or servants working for the merchants/landlords and, further ahead in time, to accommodate factory workers and the poor working class in general (Yūko 1995). Contemporary elongated small houses have sometimes preserved the layout of the *Nagaya*, and as stated by Muminovic (2017), “the apartments are considered as individual, despite the fact that in many cases they are still sharing the walls.” In most occurrences though, S1 are small-sized and elongated individual townhouses following only the ground floor plan of an individual dwelling that were once part of a traditional *Nagaya*. S1 b is a good example of such a contemporary structure that even reaches three stories.

S2 are intricate townhouses of different sizes. Beyond some complex structures, such as small traditional-style Japanese houses caught up by densification, which are not a majority in this class label, most buildings are characterized by two blocks, one behind the other, with the house’s entrance within the first (S2 a) or the second block (S2 b). Houses have several floors and are usually accompanied by frontages, used as garages, parking lots or gardens. Buildings within the S2 category are either prefabricated houses (プレハブ建築) made of the assemblage of customized “components” (see mass customization of single-family homes in Noguchi 2003) or micro-homes, which, for the latter, could also be linked to the *Kyōshō Jūtaku* (狭小住宅) architectural movement. The *Kyōshō Jūtaku* movement focuses on designing and constructing houses on very small plots. It started appearing in the denser parts of Tokyo and Osaka during the 1960s and 1970s. The production of this movement became significant only around the 90s, when small houses were needed for those that wanted to remain in the denser parts of the cities, despite the increase in the market price of real estate property (see the Japanese asset price bubble) (Klastro 2019). Since *Kyōshō Jūtaku* houses are often designed by architects, they possess innovative shapes, and should thus be representative of the S2 category (however, *Kyōshō Jūtaku* houses can also be found within S1 and S3).

S3 are compact houses of different sizes. Most occurrences are either large two to three-story townhouses, such as the one displayed in S3 a, or micro-compact homes such as S3 b. Like S2, S3 houses possess direct neighbors, but no common walls. Except for *Nagaya*, rows of

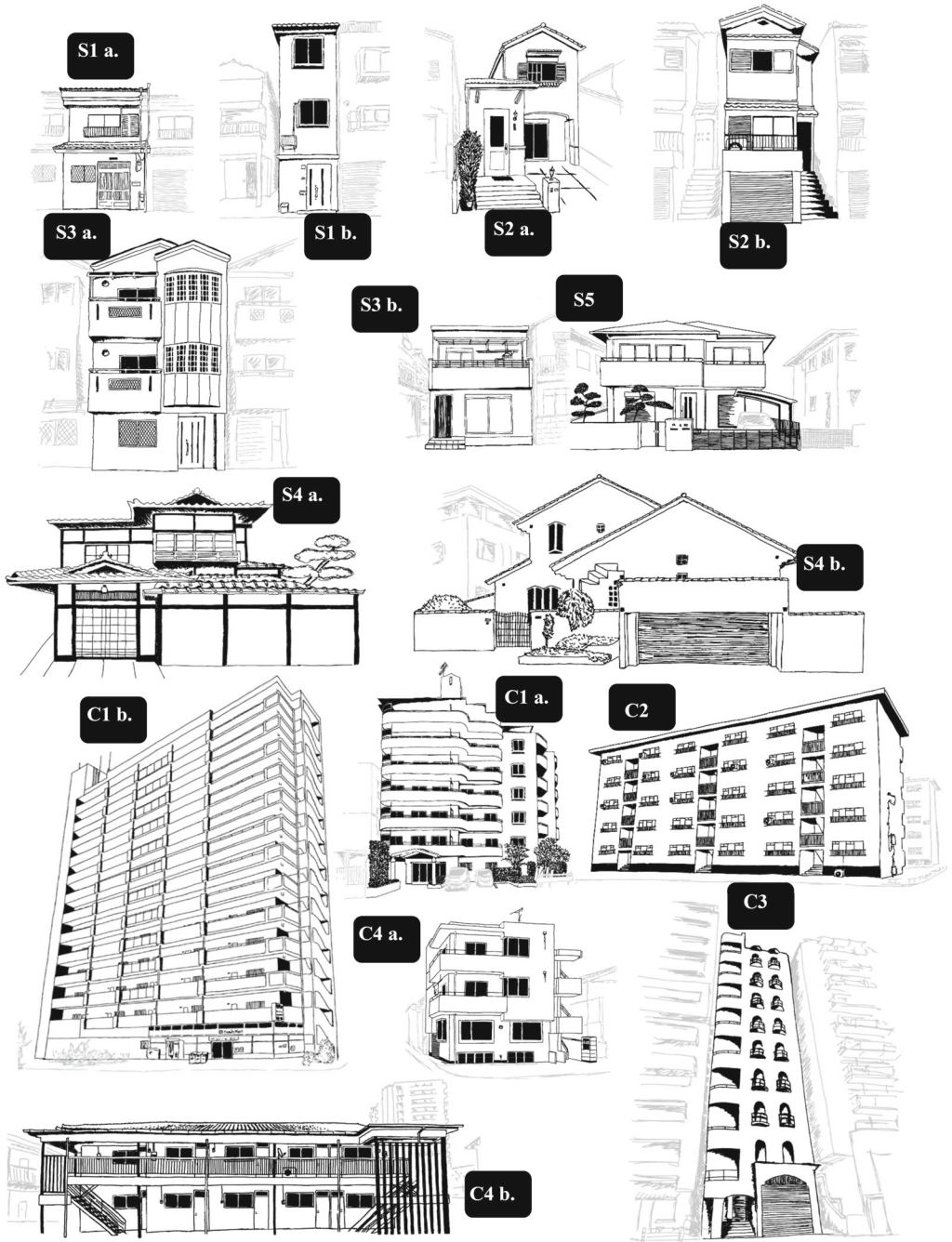


Figure 4. Correspondence of hull types to building types (identified and drafted within the Osaka-Kobe City-region).

attached dwellings in Japan do not possess common walls. Yet, neighboring outer walls are often only a few centimeters away, thus giving a false impression that dwellings within a row are physically attached. Large townhouses can possess a garage or a recess within the ground floor to park a car, while micro-compact home occurrences can have frontages, provided they have been built with a certain setback from the sidewalk. Since space is never wasted for S3, the micro-compact homes are either prefabricated houses or compact *Kyōshō Jūtaku* houses. The compact characteristics of the Japanese prefabricated houses, and especially the ones of the first generations, are well documented in the academic literature (Matsumura 2004; Matsumura et al. 2019). Finally, the traditional *Machiya* (町屋), which were wooden townhouses facing the main streets of the commercial districts, are also included in this category. The *Machiya* were both the houses and shops of merchants and craftsmen, with business premises on the first room of the ground floor. However, what is left of this traditional building type is rapidly disappearing from the urban landscape (Yano 2020), and there are too few *Machiya* remaining today for them to be representative of the buildings part of S3.

S4 are large-sized detached houses. Occurrences that are part of this category are made of conventional wooden houses following all or some features of the *Shoin-zukuri* (書院造) and *Sukiya-zukuri* (数寄屋造) architectural styles. By over-simplifying, the following traditional characteristics can be highlighted in a lot of occurrences: room partition with dividers, such as *shōji* (障子) and *fusuma* (襖), Japanese carpentry (woodworking), tatami-matted floors, porch running around the house (*engawa* – 縁側), and a yard fully surrounding the house. In Japan, conventional wooden houses are dominating the market share of newly built detached houses, but rare are the houses, newly built or not, that have all the traditional features displayed by S4 a in Fig. 3. Other conventional houses, not made of wood, such as spacious villas of different shapes and materials, are also part of this category (S4 b in Fig. 4).

S5 are small-to-midsize, detached houses. As for S4, what gives consistency to this class is the lack of neighbors and the size of the dwellings. Therefore, different possible shapes and architectural models are regrouped within this building type, such as prefabricated detached houses, conventional wooden houses also following some features of the *Shoin-zukuri* and *Sukiya-zukuri* architectural styles, architect's houses, etc. Since conventional and prefabricated detached houses are often built in clusters by promoters, whole neighborhoods of single-family houses with similar or close-by shapes shall emerge in the far outlying areas.

C1 to C4 categories are all collective buildings. C1 are mid-to-large-size complexes without neighbors. This category includes high-rise apartment buildings that could be facing the street, such as C1 b in Fig. 3, or high-rise apartment buildings following a “tower in the park” model. Multistory collective structures that are beyond five stories (C1 a in Fig. 4) spread around the 1970s and are commonly referred to as *Manshon* (マンション), while the ones above 20 stories (C1 b in Fig. 4) spread around the 1990s and are known as *Tower Manshon* (タワーマンション) (Bonnin, Nishida, and Inaga 2014). *Manshon* and *Tower Manshon* usually benefit from better location (shopping facilities, schools, train stations, etc.) than the collective elongated buildings (see the discussion below about C2).

C2 are mid-to-large-size elongated complexes without no direct neighbors. C2 mostly includes two types of multistory structures. The first one is made of standalone buildings that can be either located along wide roads or, once again, following a “tower in the park” model. The standalone buildings following a “tower in the park” model are a minority within C2, since isolated and large-size buildings located in the middle of the blocks in Japan are usually high-rise *Manshon* and *Tower Manshon*. The ones located along the roads are usually on the main axes

leading to the train stations, making best use of the FAR possibilities. Yet, standalone elongated buildings along the main roads are also a minority within C2, since, to make the most of the FAR, buildings are constructed vertically (see the discussion below about C3). The second type of building, which is the most representative of the C2 category, is a four-to-five story elongated building that covers a length of about 40–70 m (C2 in Fig. 4). This type of building bears the name of *Danchi* (団地). *Danchi* are clusters of uniform apartment buildings that have been, for the first generation, built in the 1950s and throughout the 1970s as an answer to the post-war housing shortage. There are three kinds of them that have been mass constructed all over Japan: public social housing, government housing, and company-owned housing (Bonnin, Nishida, and Inaga 2014). *Danchi* housing units are suffering from numerous issues that have been widely criticized in the literature (poor location, lack of services and accessibility, demographic aging, material decay, etc.; Sorensen 2002; Neitzel 2016).

C3 are mid-to-large-size complexes with neighbors. Large-size collective buildings that possess direct neighbors are almost exclusively elevated narrow buildings. As aforementioned, to make the most of the FAR, buildings are constructed vertically. In the denser locations, which are usually deregulated areas around the train stations or transportation hubs, this translates into successive narrow towers that have walls often a few centimeters away (C3 in Fig. 4). Narrow and collective buildings do not bear a specific name in Japan. According to the size of the building, they can even be referred to as *Manshon* and *Tower Manshon*, even if those terms are best used and understood for standalone high-rise condominiums. Narrow buildings are, in a sense, the collective and vertical counterpart of the *Kyōshō Jūtaku* architectural movement for single-family houses.

C4 are small-size complexes of apartments. Most occurrences within C4 can be divided into two categories. The first category is made of small square complexes of three-to-four stories (C4 a in Fig. 4). Such occurrences are usually modern constructions with direct neighbors. The second category is made of elongated two-story structures full of micro-apartments (C4 b in Fig. 4). Japanese micro-apartments are well-known since they have been widely documented in the media (sometimes referred to as “three-mat apartments”). What is lesser known is that those micro-apartments are always found in elongated two-story structures. Sorensen (2002) names these structures *Nagaya-style blocks* since they are following the pattern of the traditional *Uranagaya* (size, shape, a single roof for several units, etc.). In Japan, it is possible to build both collective buildings and detached houses within low-rise residential neighborhoods. As discussed in Section [Population dynamics, planning and urban fabrics in Japan](#), it leads to a model in which the owners of houses who live in residential neighborhoods with locational advantages are selling their plots or parts of their plots to developers; the latter will then construct collective buildings reaching the upper limit of the FAR. Within low-rise residential neighborhoods, and especially within typical 15-min walk neighborhoods (Fig. 1), those buildings are always classified as C4.

OM1, OM2, and OM3 are office and mixed-use buildings. In order to avoid having too many class labels, only the following three patterns have been sought for: small to mid-size (OM1), which is roughly corresponding to S1, S2, S3, S4, S5 and C4 buildings; mid to high-rise (OM2), which is corresponding to C1, C2 and C3 buildings; and large and low-rise (OM3), which is not corresponding to any of the aforementioned building hull types. OM1 often includes small shops that are inhabited on the second floor, such as convenience stores (*Konbini* - コンビニ). Adjoining low-rise inhabited shops and offices are sometimes forming *Shōtengai* (商店街), which are local and pedestrian commercial streets. OM2 are, in most cases, C1 and C3 buildings with shops or offices on the ground floor. In several instances of C3 (narrow buildings), shops and offices

are located within several floors and in basements. Finally, OM3 are large-size and low-rise complexes, which could be associated to mixed-use functions, such as for converted traditional Japanese warehouses (*Kura* – 蔵), or fully filled with shops and offices, such as for department stores (*Depāto* - デパート).

Building hull types and population locations

High-rise collective buildings (C1) show clustered patterns in the central part of Osaka (Fig. 5), and even more around the main subcenters, such as in and around the central part of Kobe (神戸市), Shin-Osaka station (新大阪駅), Esaka Station (江坂駅), and Senri-Chūō station (千里中央駅). Major communication routes within the Osaka-Kobe city-region also emerge, especially the eastern route from central Osaka towards Nara Prefecture (奈良県), the northern route towards Kyoto city (京都市) and the southern route towards Sakai city (堺市). These patterns confirm that *Manshon* and *Tower Manshon* are benefiting from better locations than elongated collective buildings (C2). As a matter of fact, elongated collective buildings show an opposite distribution, with spatial clusters that arise in between centers and subcenters, as well as in between major communication routes and in peripheral areas, thus once again confirming the *Danchi* location issues highlighted in the previous section. Narrow collective buildings (C3) nearly follow the very same distribution as high-rise collective buildings (C1), with the sole exception that they are even more present within the most densely populated and urbanized areas. Narrow collective is the building category that most typifies the central part of Osaka, thus highlighting that in the most attractive locations, planning has long been fully deregulated, and urbanization is now both extremely compact and vertical. Small-size collective buildings (C4) are far more present than all the collective buildings in most locations, although two exceptions remain. First, some clusters (but not all) of elongated collective buildings are devoid of small-size collective buildings. The difference is certainly found between *Danchi* housing units, which are poorly located, and more modern complexes that are closer to train stations and are thus blending themselves with other kinds of buildings. Second, the central part of Osaka remains slightly more occupied by narrow collective buildings (C3) than by small-size collective buildings (C4). The correlation matrix (Fig. 5) confirms these results and highlights a strong positive association between C1 and C3, and between C3 and C4. In other words, narrow buildings often cohabitate with either high-rise collective buildings, small-size collective buildings, or both. The association between high-rise and small-size collective buildings is weaker, but nonetheless exists. Among the collective categories, the small-size building is the category that accommodates the greatest population share (Fig. 5).

Elongated townhouses (S1) are strongly clustered in the outskirts close to the central part of Osaka, but overall, the densely populated and urbanized locations are devoid of this kind of buildings and the far outlying areas have less-elongated townhouses than most of the other types of single-family houses. The lack of association between elongated townhouses and narrow collective buildings (Fig. 5), which are the cornerstone of the central locations, confirms this fact. Intricate townhouses (S2) show an increasing gradient of presence from the central to the far outlying areas. Whole suburbs of intricate townhouses can indeed be found in the first peripheral belts. Even if the data does not allow drawing conclusions on when those buildings have been built, there is little doubt that we can link these spatial patterns with the development of the mass customization model of single-family homes, during and after the 1980s, as discussed in Noguchi (2003). Compact townhouses (S3) show a distribution like intricate townhouses, with

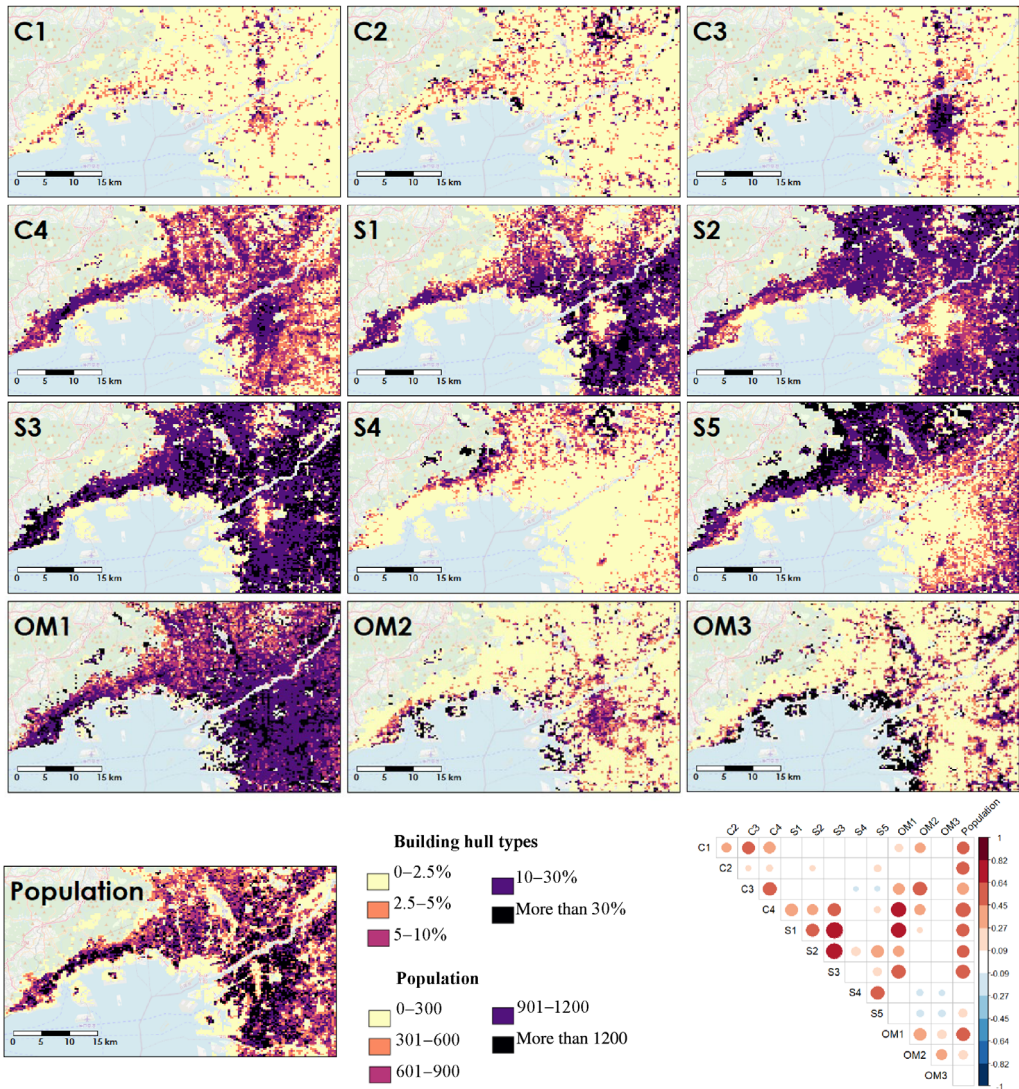


Figure 5. Share of building hull types within the Osaka-Kobe City-region (per half grid square), population and correlation matrix between building hull types and population in 2013–2014.

an even stronger presence around (but not within) the most central areas. Since the literature is pointing to the fact that micro-houses have been constructed for people to remain close to the central locations (despite the rise in real estate prices), it is thus possible that compact townhouses (S3) are more representative of the *Kyōshō Jūtaku* architectural movement than elongated (S1) and intricate townhouses (S2). Overall, even if the distribution of S1, S2, and S3 are slightly different based on the distance from the central places and the far outlying areas, S1, S2, and S3 are nonetheless often cohabitating, as highlighted by both the maps and the correlation coefficients within Fig. 5. Together, these three building types are the traditional residential cornerstone of the typical 15-min walk Japanese city, as highlighted by their location in between central places and far outlying areas. Large-size (S4) and normal-size detached houses (S5)

both show a distribution within the far outlying areas only. These two categories appear to be over-represented in the northern part of the study area, but this is probably a *bias* introduced by the fact that the study area does not fully consider the entire urbanized area, especially toward the north-east and the south. Amongst the single-family home categories, large-size (S4) and normal-size detached houses (S5) are accommodating much fewer people than other building types (Fig. 5).

Small-to-midsize offices and mixed-use buildings (OM1) are distributed throughout the entire study area, with a nonetheless weaker presence where detached houses stand in majority. As stated in the Section [Population dynamics, planning and urban fabrics in Japan](#), building types and functions are often blended in terms of land use. Yet, these results show that like other developed countries, Japan is also suffering from a lack of shops and services within low density areas made of detached houses. OM1 also appears to cluster near S1, S2, and S3, thus supporting the remaining presence of *Shōtengai* and low-rise shops and services within and around the 15-min walk neighborhoods. Mid to high-rise offices and mixed-use buildings (OM2) follow a distribution like C3, thus asserting that most of the buildings within OM2 are narrow buildings, with shops and/or offices on the first floors/underground levels, and dwellings atop of them. Unsurprisingly, large, and low-rise offices and mixed-use buildings (OM3) cluster within economic and logistical activity zones, in-between the main axes of communication in peripheral and outlying areas, and along the coastline, especially within the polders won over the ocean.

Building hull types and population evolutions

The 10-year evolution of building hull types and its relation to population dynamics (Fig. 6) is slightly more complex to interpret than the static distribution of building hull types in 2013–2014, but compared to the latter, it provides valuable knowledge on the spatial processes of morphological changes. High-rise (C1) and elongated (C2) collective buildings are very slowly growing (increase of 10.66% and 12.87% with small initial stocks; Table 1), with a very weak evolution within the center of Osaka and subcenters, as well as along the main axes of communication. C1 also shows a distribution of hot and cold spots, which is relevant to the fact that *Manshon* and *Tower Manshon* are large-scale initiatives that should be studied on a project-by-project basis. The evolution of C1 shows indeed no association whatsoever with the evolution of other building types, except for a weak negative correlation with mid to high-rise offices and mixed-use buildings (OM2). This negative correlation might be indicative of a functional specialization of high-rise buildings according to locations. C2, however, only displays an aggregation of cold spots since the areas with an increase of elongated collective buildings appear more spread out. This dynamic can be linked to the fact that *Danchi* have been no longer constructed since the 2000s. They are since considered as a valuable low-rent building stock that must be regenerated (Knoroz 2022). Cold spots of degrowth are probably clusters of *Danchi* housings that have been destroyed, while the areas of spread-out increase correspond to modern and single elongated buildings. Narrow and collective buildings (C3), as well as small-size and collective buildings (C4), are spectacularly increasing within the center and the subcenters of the study area. The negative correlation of these two collective building types with elongated (S1) and compact townhouses (S3), which are the two single-family home types the closest to the center and subcenters (Fig. 6), points at a gradual replacement of single-family home types with collective buildings in pericentral areas (decrease of -2.21% for S1 and -17.25% for S3 with large initial stocks; Table 1). The increase of small-sized collective buildings (C4)

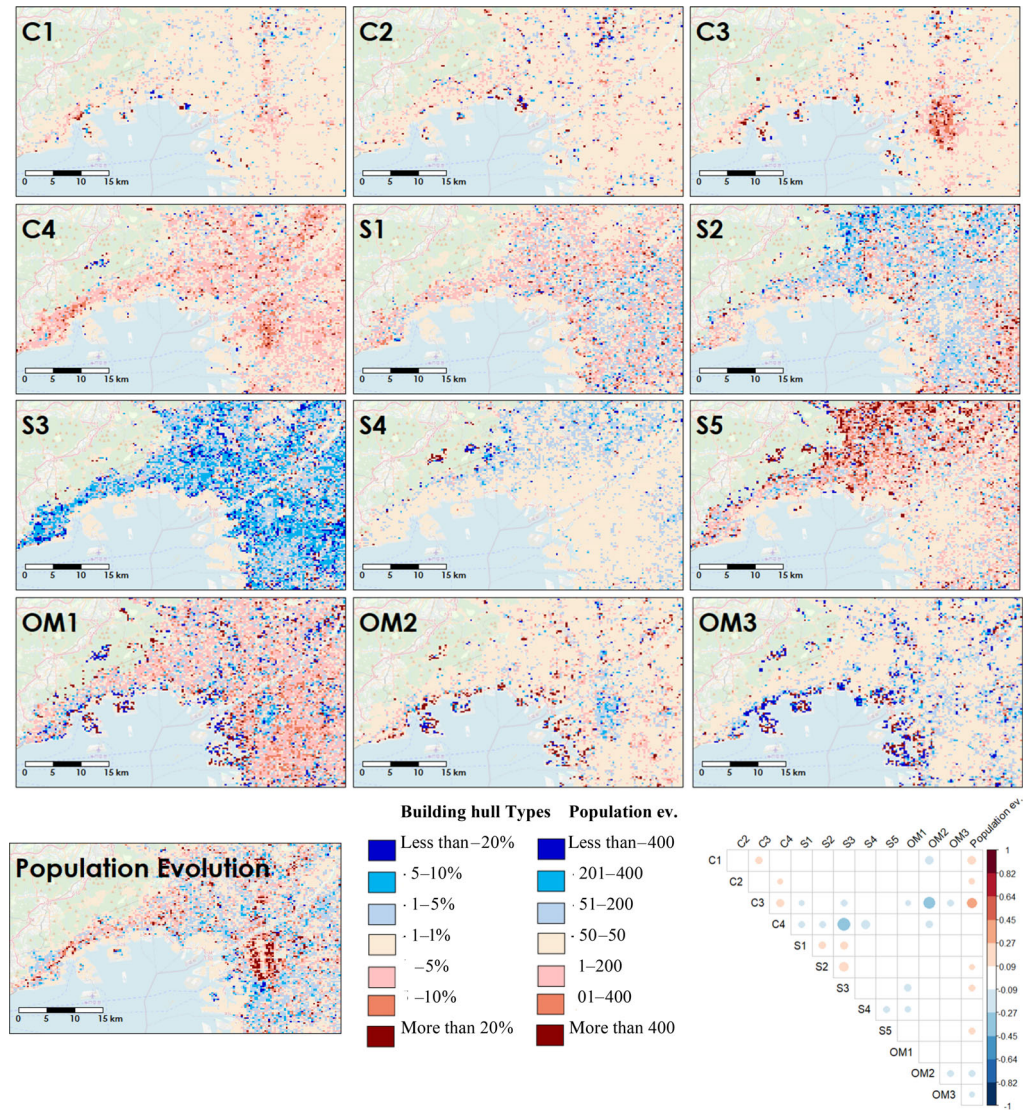


Figure 6. 10 years evolution of building hull types within the Osaka-Kobe City-region (per half grid square), population evolution and correlation matrix of evolution rates between 2003–2004 and 2013–2014.

is also present throughout the entire study area, with an additional negative association with intricate townhouses (S2) and large-sized detached houses (S4). Overall, a major pattern of urban adaptation stands out: single-family homes (except for detached houses S5) are getting replaced by small-size collective buildings. An interesting result is the absence of an association between the evolution of small-size collective buildings (C4) and the 10 years population evolution. Henceforth, this means that small-size collective buildings are not increasing the population density, as compared to narrow collective buildings (C3) which are strongly associated with population growth. Overall, the replacement of single-family houses with collective buildings

is a major but gradual process of urban adaptation linked more to changes in lifestyles and age-distribution than to population increase/decrease.

Together, S1, S2, and S3 represent more than half (57%; Table 1) of the buildings considered within this study, however, they are all losing ground in favor of other types of building types. There is also a positive association between these three building types so, no matter whether the dynamic is positive or negative, the townhouses are evolving all together in the same direction. Compact townhouses (S3) are decreasing in a spectacular manner throughout the whole study area, which is consistent with the literature pointing to a consumer rejection of standardized compact prefabricated houses (Noguchi 2003). Consumer rejection is, however, not solely responsible for this spectacular decrease. Indeed, beyond the fact that compact townhouses (S3) are not only characterized by standardized prefabricated houses (Section [Building hull types: Validation and pseudo-correspondence to building types](#)), the results also globally highlight an important shift from compact townhouses to small-size collective buildings (the strongest negative association is found between C4 and S3). Like S1, S2, and S3, large-size detached houses (S4) are also losing ground in favor of small-size collective buildings (C4) but compared to them, they are losing ground in favor of detached houses too (S5). As discussed in Section [Population dynamics, planning and urban fabrics in Japan](#), within the residential areas close to the subcenters, we are witnessing a subdivision of plots in favor of small residential complexes. The same dynamic with different building hull types seems to occur within the far outlying areas, with traditional houses and large villas either gradually subdividing their plots to build smaller detached houses (S5) or selling close-by plots to developers that subsequently build clusters of detached houses. Detached houses are the only single-family home type still witnessing a positive evolution (21.18%), the latter being mostly located in far outlying areas. S5 is also positively correlated with the 10-year population growth, which means that despite the global shrinkage of the Japanese population, people are still eager to move to the far periphery of metropolitan areas. However, since Japan has been quite successful at stabilizing the extent of the built-up areas during and since the 1970s (see the *City Planning Act and City Building Act*, Section [Population dynamics, planning and urban fabrics in Japan](#)), we are thus mostly in the presence of urban adaptation or transformation processes (subdivision or consolidation of former S4 plots). Yet, urban formation patterns can nonetheless still occur. We recall that the 2014 amendment of the *Act on Special Measures Concerning Urban Reconstruction* (Section [Population dynamics, planning and urban fabrics in Japan](#)) was directly aimed at discouraging developers from building large-scale housing in areas outside *habitation promotion areas*. It is thus very likely that clusters of S5 growth are exactly what the Japanese government is trying to inhibit. However, since the 2014 amendment corresponds to our second date of building distribution (2013–2014), we are not yet able to assess the success of this new policy in this article.

Small to mid-sized (OM1), mid to high-rise (OM2) and large and low-rise (OM3) dynamics of office and mixed-use buildings are easier to read. OM1 and OM2 are decreasing within the center and to subcenters (as well as within the logistic areas for OM1), to make way for narrow collective buildings (C3), thus in line with both a functional specialization of buildings and an increase of population density within these “hot” locations. Within the suburban areas, small to mid-size (OM1) are slightly increasing, thus accompanying the evolution of small-size collective buildings (C4). Large-size offices and mixed-use complexes are decreasing (OM3: – 13.14%), a dynamic leading to the fragmentation of former large-size blocks of logistic activities in favor of residential functions, as highlighted by the negative correlation between OM3 and the population evolution.

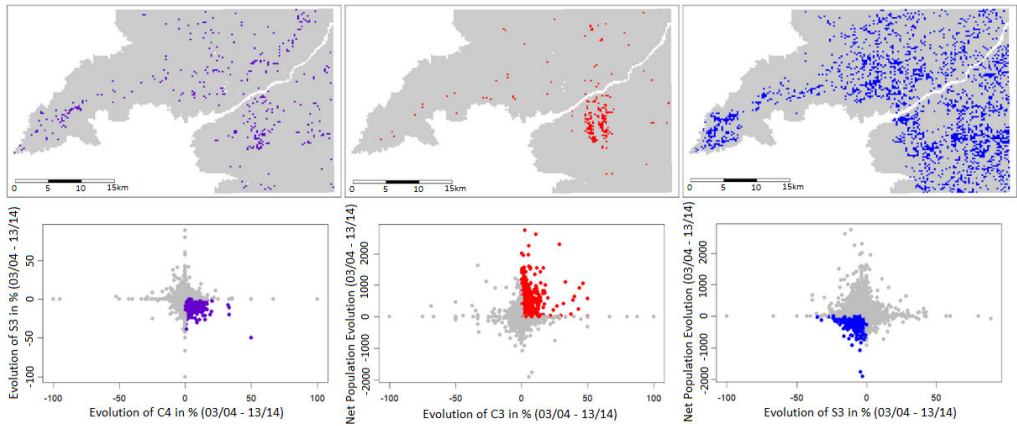


Figure 7. Substitution of S3 by C4 (left), increasing population density and occurrences of C3 (middle), decreasing population density and disappearance of S3 (right).

Fig. 7 assists in validating findings derived from the interpretation of both maps and correlation matrices. Compact townhouses (S3) are indeed getting replaced in locations close to the core center of Osaka, as well as in several subcenters and clusters located along the main axes of movement. The increase of narrow and collective buildings (C3) can be associated with a strong population increase in the core center and subcenters while compact townhouses (S3) reduction can be associated with population decrease in the peripheries.

Discussion

The aim of this article was to link population dynamics with spatial processes of morphological change. To do so, we extracted one of the finest components of urban fabric in the Osaka-Kobe City-region: the buildings, and identified different building type classes, from single-family homes (S1–S5), collective housings (C1–C4) to offices and mixed-use buildings (OM1–OM3). The class labels have been used as benchmarks for two different dates: 2003–2004 and 2013–2014 and aggregated at the *Half Grid Square Level* of the Japanese population censuses of 2005 and 2015. This protocol allowed getting new knowledge on both the evolution and substitution of building types, which are mostly urban adaptation processes, and on the link between those and population distribution and dynamics. The main findings are as follows.

First, the traditional 15-min walk neighborhoods in Japan, described in the literature as “*hard shell – soft yolk*”, appear to be slowly disappearing. Indeed, these traditional neighborhoods are located between central places that have long been fully deregulated and far outlying areas that have been developed in the form of *Danchi* housings, clusters of single-family homes built by developers or urban experiments (like garden cities). Within these traditional neighborhoods, a replacement of townhouses (single-family homes with close-by neighbors) by small-size collective complexes is occurring. This replacement, although changing the physical appearance of the urban landscape and increasing the compactness of the Japanese city, is not associated with an increase of the population density. Townhouses, traditionally inhabited by families, are thus replaced by small complexes of apartments probably filled by single individuals (“three-mat apartments”). However, what could really endanger these neighborhoods is the deregulation of the ones benefiting from locational advantages. Indeed, the proximity to centers and subcenters and

the designation of *urban function promotion areas* lead to a dynamic of substitution of traditional buildings by high-rise towers, high and narrow buildings, and small collective complexes. On the other hand, the accumulation of vacant lots in the other traditional neighborhoods is also a reality (where the townhouse decrease is correlated to population decline).

Second, despite a global shrinkage of the Japanese population, it appears that people are still eager to move in the Osaka-Kobe City-region and to far outlying areas. This is reflected by the identification of numerous clusters of positive evolutions of small to mid-sized detached houses in the farthest parts of the study area, which are, against all odds, positively correlated with population evolution. Since large-sized single-family houses were already in place in those areas, we are witnessing either a plot sub-division of former large-sized detached houses, a plot consolidation in the favor of developers that subsequently build clusters of single-family houses, or a combination of both. Clusters of newly built detached single-family houses located in the farthest parts of the study area are exactly what the most recent governmental policies are trying to discourage (2014 amendment of the *Act on Special Measures Concerning Urban Reconstruction*).

Third, the center and subcenters are increasingly filled with mid-to-large-sized complexes of “adjoining” buildings, which are mostly narrow towers that have walls often only a few centimeters away from their neighbors. These buildings do not bear a specific name in Japan, but they could be considered as the collective counterpart of the *Kyōshō Jūtaku* architectural movement for single-family houses. They are also associated with an increase of population densities in central areas.

To conclude, it should be stressed that the building classification obtained in this research, although based on academic literature, is only one possibility among others. Another conceptualization, focusing on different objectives, could have led to a different outcome regarding class labels, even with the exact same input data and indicators. In addition, more detailed input data, including for example building materials or roof characteristics, could have helped obtain a much more accurate picture of building types. The method could be updated with the most recent ZENRIN data, to evaluate the impact of the 2014 amendment of the *Act on Special Measures Concerning Urban Reconstruction*, especially regarding the clusters of newly built detached single-family houses. The method could also be tested in other countries but, since the lifespan of buildings is usually much longer outside of Japan, a wider gap than 10 years might be required.

Finally, changes in the street network should also be integrated when assessing morphological processes in the Japanese city. Although minority, transformative processes are also at play in Japanese cities, especially in deregulated areas. Some of the building substitutions analyzed in this article would then more appropriately be accounted for within transformative rather than adaptive processes.

Acknowledgements

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Endnotes

- 1 Global Cities Initiative <https://www.brookings.edu/articles/redefining-global-cities/>.

- 2 ZENRIN is a private map information company that holds the top share in the Japanese market for local residential and car navigation maps. <https://www.zenrin.co.jp/product/category/gis/basemap/zmaptown/index.html>.
- 3 Missing values for the number of floors have been replaced by one-story buildings.
- 4 <https://www.stat.go.jp/english/info/guide/201503ver/04.html>.

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