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How will the combining of the elevation of rail lines with urban redevelopment reduce the north–south (east–west) disparity in the city? A case study of Kyoto-Osaka-Kobe conurbation, Japan

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ABSTRACT

Railroads are generally the primary public transportation system connecting the region. However, when a railway crosses a city, it divides it into north-south (east-west), creating the front and rear sides of the city. In Japan, grade separation projects elevate the existing railway lines. The primary purpose is to relieve traffic congestion caused by railroad crossings. However, integrating the north–south axis has also been highlighted. In addition, creating a new centrality to station spheres in mature cities will be an essential guideline for the future formation of an urban structure centered on station spheres by transit-oriented development. This study focused on 12 cases in which an elevated railway line in the Kyoto-Osaka-Kobe conurbation of Japan was combined with an urban redevelopment project. We investigated changes in land use and land prices in the surrounding area. The study results confirmed that the disparity between the front and rear sides tended to shrink. In addition, based on the station's characteristics and area to be redeveloped, a policy for more effective integrated redevelopment and elevation projects was identified. The findings of this study will assist in reorganizing cities into a more sustainable urban structure by eliminating urban fragmentation centered on railway stations.

1. Introduction

1.1. Social background and related works

Over the past several decades, the conurbations of central urban areas in developed countries have expanded by suburbanizing their peripheries. Many suburban areas created in this process have become hostel communities for workers in central urban areas (Dinić & Mitković, 2016; Hartshorn & Muller, 1989; Kadono, 2012). As these societies mature, many developed countries face critical demographic transitions. Demographic stagnation and aging societies have forced leaders of modernized urban areas to confront the issues of environmental adjustment and redesign (Hamel & Keil, 2015; Kötter, 2019; Reicher & Hesse, 2015). Specifically, regions need to optimize their size, facilities, and infrastructure to fit the current demographics characterized by financial distress and an aging population (Dunham-Jones & Williamson, 2011). In our study, we define mature cities and conurbation as the stage following development, growth, and stagnation, but before the start of decline. Hence, the mature city and conurbation currently face considerable issues that have to be overcome to achieve future sustainability. Optimizing and reorganizing urban forms in a mature society is one of the most pressing issues that sustainable cities and societies must resolve in the next decades.

Against this backdrop, transit-oriented development (TOD) has been introduced in many countries in conjunction with compact city policies (Carlton, 2007). TOD aims to create compact, walkable urban spaces centered around public transportation stations and networks to connect neighborhoods, thereby fostering a healthy, low-carbon living environment (ITDP et al., 2017). Mixed land use is often seen as an equally important pillar for reducing traffic (e.g., Bertolini, 1999). This change is crucial in countries with advanced car societies (ESCAP and UN Habitat, 2019). For example, Japan has been developing public transportation since the period of urban expansion after the 1960s (Kadono, 2000; Uma, 2016) and has been motorizing since the late 20th century (Miura, 2004). Japanese and local governments are reconsidering the size of cities and public transportation in a society with a declining population (Suzuki, 2015).

Within this context, a location normalization plan was formulated in

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2014 with the aim of transforming urban structures to form a network, while measuring a city's compactness in Japan. This policy aims to shift to an urban structure suitable for future population sizes, taking sustainability into consideration (MLIT, 2015). Urban and residential attraction areas are established in these plans, and railway stations and lines tend to be used as guidance points (Kadono & Matsune, 2021; Yoon, 2020). However, it has long been highlighted that railway lines divide cities (e.g., Sato, Okada, Nakamura, & Deguchi, 2023; Takano, 2004). Elevating railway lines which is part of a redevelopment plan called the Grade Separation Projects (GSP) in Japan, is one approach to resolve this division (National Council for the Promotion of Grade Separation Projects, n.d.; Street Transportation Facilities Division and Urban Affairs Bureau of MLIT, 2020). In addition to elevation, the undergrounding of railway tracks is an effective means of avoiding urban fragmentation. In fact, elevated tracks are better than tracks running above the ground, and underground tracks, rather than elevated tracks, have a more positive impact on the surrounding area (Lee & Sohn, 2014). However, undergrounding of rail lines is overwhelmingly more expensive than elevating them, although underground tracks have the advantage of a longer building duration (Yamamoto, 2004). Such undergrounding may be considered in developing areas and cities where development pressure is still high owing to population growth. However, in mature cities and areas where the population is declining and financial resources are beginning to shrink, it is necessary to aim more strategically to eliminate urban fragmentation and increase value at a relatively low cost.

Previous studies discuss the centrality of railway stations and the redevelopment and advanced use of station spheres, which are becoming more critical, even in mature conurbations where populations are declining. For example, railway station spheres function as permanent settlements for diverse generations, and residential areas are becoming more compact (Aoki & Kadono, 2020). Furthermore, railway stations can be essential nodes, it is important to simultaneously develop them in combination with urban functions and high-density land-use (Cao, 2022). This has gradually become a focal point in comprehensive transportation and land-use planning strategies (Banerjee & Saha, 2022). In this context, not only the elevation of railways but also the multi-level use of stations and station areas is becoming a complex network of high use, and high use is required (Inamochi, Uehara, & Shiozaki, 2013). The residential area and the necessity of compacting the life activity area around the stations have been previously discussed (Aoki, 2023a; Aoki, 2023b).

The elevation of railway lines increases the value of the surrounding neighborhoods. The impact of elevated railway lines has already been examined and includes a reduction in traffic jams and the improvement in land value by connecting road networks, eliminating certain urban divides, and utilizing underpass space (Nakamura & Muraki, 2006; Nasu, Honma, & Imai, 2023; Saito & Almazán, 2020). What if such a multistorey development is combined with a city redevelopment project? The potential for urban redevelopment to increase the value of space has been noted in terms of walkability and the increase in land value associated with land use transformation (Schlossberg & Brown, 2004; Yamada, 1993).

The results of the GSP are appropriate for the capital cost to be invested. From the perspective of safety and changes in the living environment, it has a small advantage over street rail (Woodcock & Martin, 2016). Fieldwork has been conducted to investigate how the underpass space is being used revealing that, in some cases, it could be used more effectively (Kinoshita, Nakamura, Kinoshita, & Shiino, 1999). Conversely, some studies have followed the planning process and organized changes in use (Doi, 2018). Research has also focused on environmental assessment, such as sunlight and noise, which are considered to be minor problems (Yamamoto, 2004).

Studies on elevated railways focus primarily on analyzing the use of underpass spaces. In some locations underpass spaces are actively used, whereas in others there is low-use of underpass spaces (Nakamura & Muraki, 2006). Simultaneously, the importance of gap spaces has been highlighted (Hormigo & Morita, 2004). Underpass spaces in central urban areas have high connectivity with the surrounding area. However, spaces obtained through elevation projects in suburban areas require better connectivity and are considered more effective (Saito & Almazán, 2020). In particular, the existence and location of roads unfavorable to pedestrians significantly negatively impact the pedestrian environment around stations; therefore, it is necessary to scrutinize street forms from this walkability perspective in the context of TOD (Schlossberg & Brown, 2004).

In this context, the promotion of effective utilization of the area around railway stations, including elevated tracks, has the potential to significantly change the area around stations, for example, by promoting advanced development in the area behind stations, which is isolated from the urban center owing to the problem of urban fragmentation by railways (Takano, 2004). In addition, the elevated railway system will connect roads between urban areas divided by the elevated railway system, which has been confirmed to improve accessibility and land prices (Nasu et al., 2023).

Previous studies have shown that the elevation of railways is positively impacting land prices, in no small part, through the improvement of the surrounding transportation environment. Although there are some issues regarding implementation time and cost, this is one of the most important ways to properly reorganize a mature city. However, in many cases, these studies have mainly focused on a single project. Moreover, the combined effects of elevation and redevelopment have yet to be confirmed. The impact of GSP and URP in an integrated manner needs to be reorganized.

1.2. *Aims and scope*

In reorganizing a mature city around public transportation, it is necessary to examine whether a combination of elevated railway lines and redevelopment can resolve urban fragmentation. This study aims to gain knowledge from past cases to assist in the future restructuring of cities. Specifically, we discuss the advantages and disadvantages of such development from the perspective of increasing or decreasing the disparity in land value between urban areas divided by railway lines, targeting cases in which redevelopment was implemented in the station sphere near an elevated railway station.

Numerous studies have discussed the significance of enhancing the centrality of railway stations and their advanced use in multilayered structures. However, there is a paucity of research on the implementation of elevated railway stations and urban redevelopment as a set. In particular, the impact on the dissolution of urban fragmentation in the east–west (or north–south) direction has yet to be clarified. Therefore, this study, referring to past cases, examines the restructuration of mature cities from the perspective of considering the impact and issues of elevating railway lines and stations by GSP and implementing urban redevelopment projects (URPs) within station areas. This study focuses on correcting disparities in land prices by eliminating fragmentation and increasing regional value. Specifically, this study addresses the following research question: "Is combining GSP and URP effective in increasing station centrality and reducing urban fragmentation in mature cities?" The study hypotheses are as follows:

1. Elevation and redevelopment along the railway lines carried out as a set increase the roadside land prices of the area and eliminate urban fragmentation.
2. The optimal combination of redevelopment and elevation, and the characteristics of the land value structure around the station vary.

1.3. *Study setting and methodology*

1.3.1. *Study setting*

This study examines how the elevation of railway lines and redevelopment of the surrounding areas can help resolve urban fragmentation and restructure a mature city. Therefore, this study focuses on the Kyoto-Osaka-Kobe conurbation, which is the second largest conurbation in Japan, but with a declining population. The Kyoto-Osaka-Kobe conurbation is also an area where many railroad lines divide the city because of conurbation expansion by private railway companies (Kadono, 2000). There are 26 railway lines with 1234 stations. The median value of station users per day was 8914 in 2019 and 7302 in 2021. The first quantile was 1788 and 1513, and the third quantile was 22,907 and 18,502. The number of users decreased because of the COVID-19 pandemic. However, most stations have >1000 users per day.

The study covers a total of 12 stations in this conurbation, where grade separation projects (GSPs) have elevated existing railway lines, and URPs have been carried out around the stations (Fig. 1). These elevated railroad stations and the surrounding tracks are located in the central urban and suburban areas of the conurbation. Suminodo Station was excluded from the analysis because roadside land prices could not be obtained before or after the redevelopment project. The following explanation of GSPs and URPs is based on definitions provided by the Ministry of Land, Infrastructure, Transport, and Tourism (MLIT).

A GSP promotes the integration of urban areas by facilitating urban traffic, eliminating traffic congestion and accidents at railroad crossings, and removing many railroad crossings at once by elevating or undergrounding railways at the intersection of roads and railways as part of road improvement in urban areas. Prefectures and designated cities implement GSPs as part of their urban planning projects. Recently, railway companies have increasingly promoted GSPs in cooperation with local governments. The criteria for adopting GSPs were as follows:

(1) For railroad sections where railroads and trunk roads intersect at two or more places and the distance between the centers of the trunk roads at both ends of the intersection is 350 m or more, railroads and roads must intersect at three or more places simultaneously, and two or more grade crossings must be eliminated.

(2) The sum of the daily traffic volume at the level crossing for any 1 km section of the elevated section must be 20,000 vehicles per day for more than five years.

Based on the Urban Development Law, URPs aim to achieve rational and sound advanced land use and renewal of urban functions in urban areas where old wooden buildings are densely built up. URPs integrate subdivided sites into the existing urban space, construct non-combustible communal buildings, and improve public facilities such as parks, plazas, and streets. URPs are implemented primarily by local governments and third-sector organizations, such as the Urban Renaissance Agency, and by redevelopment companies and associations in some cases. The following are the requirements of the URP:

- URPs create land for public facilities through the joint use of the site and advanced land utilization.
- In principle, the rights of the previous right holders will be replaced by the floor of the new redevelopment building at an equivalent value (right-of-use floor).
- The new floor space created by advanced use (reserved floor space) is disposed and used for project expenses.

Our analysis is divided into three steps. Fig. 2 below shows the analytical framework underpinning our study.

1.3.2. Characteristics of elevation and redevelopment at the subject station

We summarized the outline of cases in which a GSP and URP were implemented proximity. This section summarizes (1) the timing of the GSP, (2) the relationship between the redevelopment area and the station, (3) the scale of the project, and (4) the content and purpose of the project, focusing on the plans for the GSP and the implementation reports for the URP compiled by each municipality. The survey targets were then categorized from each perspective and used in subsequent analyses of land pricing changes.

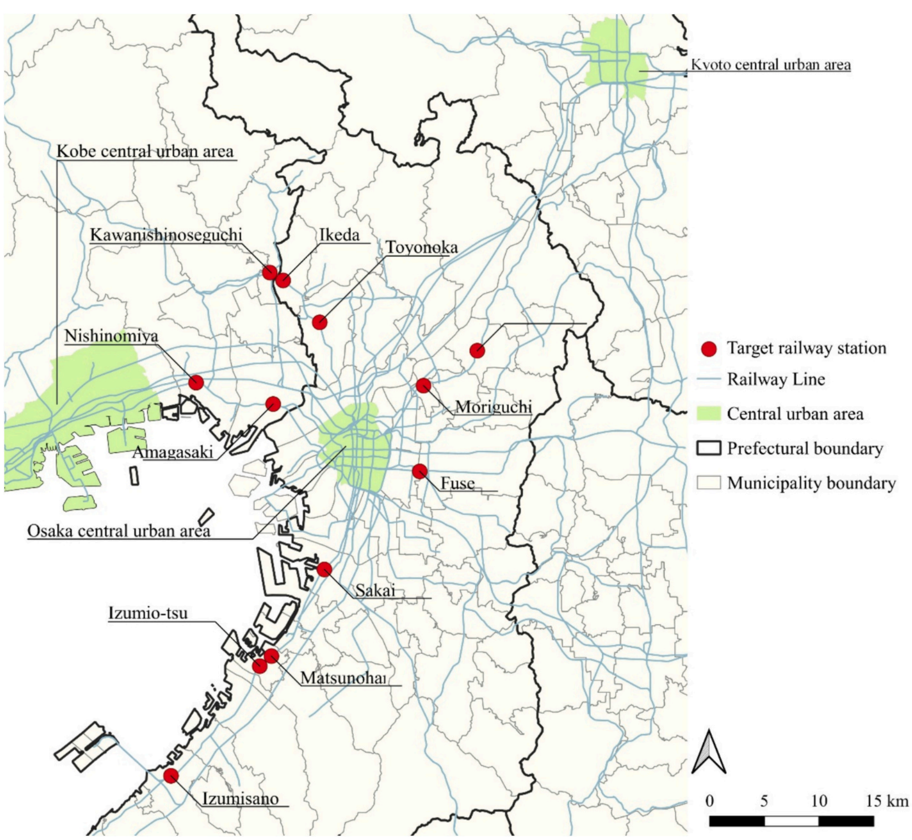

Fig. 1. Distribution of target stations.

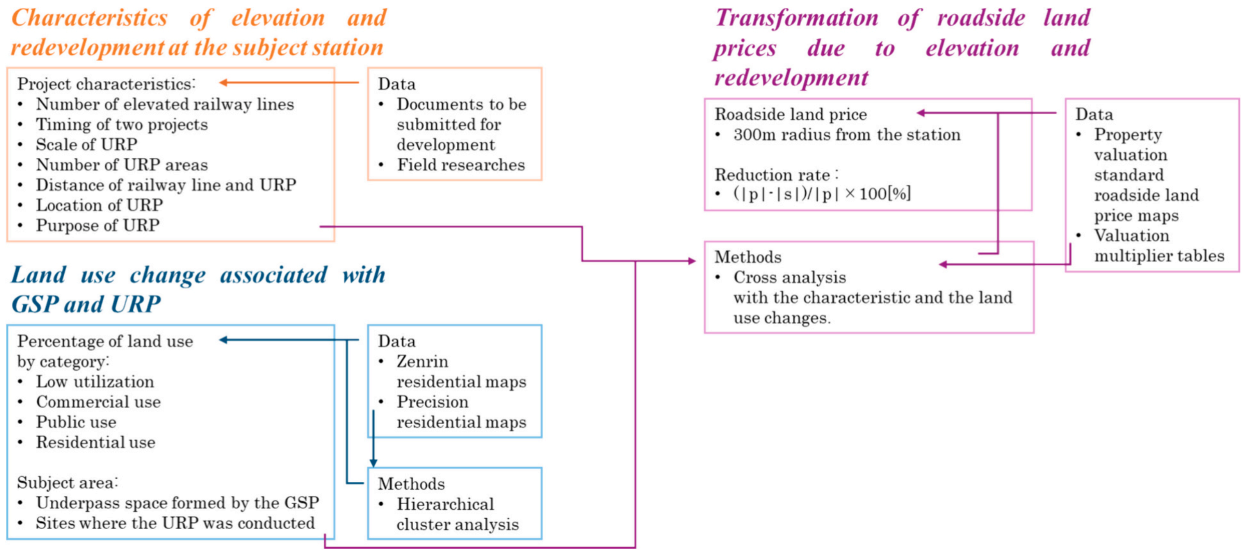

Fig. 2. The analytical framework graph.

1.3.3. *Land use change associated with GSP and URP*

To analyze land use change, we organized the percentage of land use by category in the underpass space formed by the GSP and the change in use at the sites where the URP was conducted. Concerning the land use survey, the number of cases by use was divided into an underpass space and each site where redevelopment took place using Zenrin residential maps and precision residential maps, and the numbers before and after the project were tabulated. We tabulate the percentage increase or decrease in land use in each category (see Note 1) at the URP implemented area before and after the project. The percentage use of the newly formed underpass space was counted in the GSP. Based on these aggregation results, a hierarchical cluster analysis (Ward's method) was used to categorize the change in use by URP and GSP.

1.3.4. *Transformation of roadside land prices due to elevation and redevelopment*

We used roadside land prices as the standard for measuring land prices. Roadside land prices in Japan are the prices associated with each individual road. Roads are divided by span from intersection to intersection or node to node. This price is not the road itself but the value per square meter of standard residential land fronting the road, which is used to evaluate land and other properties in areas where roadside land prices have been established. National and local governments have published public and standardized land prices, instead of the roadside land prices. However, these are only representative data, which make the calculation of prices for specific areas challenging. Moreover, in some cases, these data cannot be traced back to before the project was undertaken. Furthermore, roadside land prices more significantly reflect changes in land prices due to the east–west (or north–south) road connections resulting from the elevation of railway lines (Nasu et al., 2023).

The roadside land prices were collected from streets within a 300 m radius of the stations. The elevated railway line is expected to affect these areas, including the urban areas where the URP was conducted in each urban district across the elevated railway line formed by the GSP. Previous studies define the station sphere based on a 500 m radius or 1000 m radius from the station (Nagoya Urban Institute, 2016; Yamada, 1993). However, the range of the effect of the land price increase following redevelopment is <500 m from the station (Kobayashi & Asami, 2015). Our central concern is to determine the disparity trend of the north-south side of the station. Thus, the target area should cover the same distance based on the axis of the railway line and the station as the centroid. Furthermore, the distance between some target stations is under 1000 m with overlap of station spheres if the station sphere is over 500 m. Instead, the all-target URP is within 300 m from the GSP. If we include over 300 m, we would overestimate the price for the side with URPs and underestimate the opposite side. Therefore, to make the effect of each target GSP clear and estimate the appropriate range of effect, we used a 300 m radius, which avoids overlap, and the diameter from the URP site is under 500 m long.

Post-GSP roadside land prices were collected from property valuation standard roadside land price maps and valuation multiplier tables. In contrast, the pre-GSP roadside land prices were compiled from the roadside land price area maps issued before the start of the project for each station. Each of the maps contains the roadside land prices for each individual road. Thus, in our study we used the average of the prices for each side of a station. The results of the normality test show that the distribution of these roadside land prices is normally distributed.

The primary focus was then placed on the differences in roadside land prices in each urban area before and after the GSP and the reduction in disparities between urban areas. Considering urban continuity, decreasing roadside land price differences between urban areas will lead to the integrated planning and development of a single city. As an indicator, we used the reduction rate of urban fragmentation, which indicates how much the difference in roadside land prices between urban areas divided by the elevated railway line decreased before and after the project. Therefore, the following formula was used to determine the reduction rate in roadside land prices between urban areas separated by an elevated railway line before and after the GSP. These results were compared with the GSP and URP characteristics and land use trends to gain a perspective on future urban development.

$$\text{Reduction rate} = (|p| - |s|)/|p| \times 100[\%] \tag{1}$$

where p is the difference in the average roadside land price between urban areas with elevated railway lines, before the project, and s is the difference in the average roadside land price between urban areas with elevated railway lines after the project.

Fisher's exact test was used to confirm the difference in reduction rates based on the characteristics of the GSP and URP. Fisher's exact text was used because only 12 stations were included in the analysis, so the chi-square test could not be applied as the sample size was too small. In addition, the characteristics of GSP and URP are not appropriate for regression analysis because they are categorical values, not quantitative variables.

2. Findings

2.1. Characteristics of elevation and redevelopment at the subject station

The GSPs and URPs projects either ran concurrently or the URP project started immediately after the GSP project. Most projects covered a single URP area; however, some of the target URPs redeveloped two or more areas around stations. In some cases, multiple development occurred sometimes on both sides of a station and, generally, these projects were carried out before the 2000s. Seven stations had project periods after 2000. Table 1 summarizes the characteristics of the stations and railway lines examined in this study. Fig. 3 shows four of the stations examined in our study presenting different characteristics: Sakai station with a single side development in the adjacent site, Neyagawa station with adjacent and isolated development of multiple sites, Ikeda station with development on both sides of the station, and Fuse station with a single side development at an isolated site.

Based on the characteristics of each project, they were categorized as shown in Table 2. Based on these classifications, we proceeded with the following analysis. First, from the perspective of the GSP, we categorized the target railway lines, their numbers, and their relationships with the project period in which the URP was implemented. In addition, based on the location of the URP and railway stations, we divided the development into two types: 1) those developed only on one side of the railway line, and 2) those developed on both sides of the railway line. Additionally, we categorized cases in which redevelopment projects were developed adjacent to a station, those in which redevelopment projects were developed a short distance away across multiple city blocks, and those in which redevelopment projects were a mixture of both. In terms of URP project areas, in addition to the classification by the number of projects, we divided them into three categories: 1) those with a total project size of <1 ha, 2) those with a total project size of 1–3 ha, and 3) those with a total project size of 3 ha or more, assuming both small- and large-scale developments. Finally, the survey targets were categorized according to the different objectives of the redevelopment projects as follows:

- Facility sufficiency: Projects with the sole purpose of fulfilling urban functions.
- Advanced land use: The primary purpose of the project was to achieve a high level of land use with little emphasis on fulfilling specific urban functions.
- High-level development: Projects that measure the fulfillment of most urban functions and specify high-level land uses.

2.2. Land use changes associated with GSP and URPs

Land use transformation was summarized from the pre-and post-project maps. Based on these results, the percentage of each land use category in the pre- and post-projects are estimated. By comparing pre- and post-land use ratios, we calculate the percentage points for each category. A hierarchical cluster analysis was performed based on the percentage points in each category. The analysis was conducted for each the URP's site and the underpass created by GPS. A dendrogram obtained from this analysis is shown in Fig. 4. As a result, the target stations can be classified into three categories for URPs and four for Underpasses. These areas were systematically developed for each project, and the impact on urban integrity through changes in roadside land prices in the next section, based on the characteristics of the land use assigned to them, provides a perspective from which to examine future development policies in the station sphere.

First, the characteristics of the three URP-based classifications are summarized. Table 3 shows the percentage points estimated by comparing pre- and post-project in each station. The percentage points indicate how much each land use category has increased or decreased after the project. The results show that Group 1 had a relatively strong tendency to increase public use. Among these, Izumisano showed the most significant increase, at 66.67 points. In contrast, commercial use showed a decreasing trend. Group 2 exhibited an increase in the number of points available for commercial use, with 62.50 points for Nishinomiya and 44.68 points for Izumio-tsu. In addition, these stations significantly reduced their low utilization values, suggesting that areas where land was originally underutilized have largely been converted for commercial use. Finally, Group 3 exhibited an increase in both commercial and public use, and included cases such as Fuse and Ikeda, in which there was no significant decrease in use between the two groups. In such cases, the decrease in low utilization was slight. Based on these trends, the URP classification in this study is as follows:

- Group 1: Public-purpose
- Group 2: Commercial-purpose
- Group 3: Balanced

Next, we summarized the category trends based on the land use ratio in the underpasses formed by the GSP. In general, underpasses are not developed for residential use. Table 4 shows the percentage points at the underpass estimated by comparing pre- and post-project in each station. In Group 1, almost all the underpass areas had low utilization. In Group 2, a specifically low utilization rate was identified; however, the development was primarily for commercial use. In particular, Fuse had the highest value at 82.81. Group 3 had a good balance of development in each category except for residential areas. Specifically, the percentage of public use tended to be higher than that of other groups. Finally, Group 4 showed a different trend from Group 2, but with an even higher percentage of low utilization. For example, more than half of the respondents in Toyonaka and Izumisano, 57.14% and 55.33%, respectively, reported low utilization. Based on these trends, underpass utilization in this study was classified as follows:

- Group 1: Low-utilization
- Group 2: Commercial-utilization
- Group 3: Public-included
- Group 4: Commerce and low-utilization

Applicable stations were organized based on a combination of groups obtained from the cluster analysis (Table 5). The combinations with the most significant numbers of applicable stations were URP: Group 3 and Underpass: Group 2. In this combination, various urban functions are well-balanced on the redeveloped site, and the underpass is heavily used for commercial purposes. However, no stations have been developed for commercial use in URP or Underpass. In contrast, Amagasaki focuses primarily on public use. Amagasaki falls under URP Group 1 and 3. Toyonaka and Izumisano are in the Commerce and low-utilization group for underpass utilization but public use is approximately 10.0%. Mtasunohama and Izumio-tsu also exhibited different URP development trends, although both underpass groups have low utilization. Mtasunohama emphasizes public use, whereas Izumio-tsu focuses on commercial use.

2.3. Transformation of roadside land prices

The average roadside land prices at the subject stations were summarized. Of the 12 target stations, those where development took place on only one side were considered the redevelopment and non-redevelopment implementation sides. In cases where the URP took place on both sides, roadside land prices were collected for both urban areas within a 300-m radius of the railway line, defined as the south/west side and the north/east side. For convenience, when discussing all stations on one and both sides of the development, the redevelopment implementation side and southwest side were considered the front side. In contrast, the non-redevelopment implementation and northeast sides were considered the rear sides. Table 6 summarizes the average roadside

Table 1
Characteristics of URPs.

	Overview of the project			Purpose of the project							
	Year started	Year completed	Scale	Improvement of civic activity bases	Improvement of residential environment	Improvement of commercial environment	Improvement of public facilities	Convenience improvement	Advanced land use	Disaster Prevention	Renewal of urban functions
Kawanishinoseguchi											
A	1979	1988	0.66 ha	–	YES	YES	–	–	–	–	–
B	1987	2003	0.82 ha	–	YES	YES	YES	–	–	–	–
C	1981	1990	5.94 ha	–	YES	–	YES	–	–	–	–
D	1993	2002	0.30 ha	YES	–	–	–	–	–	–	–
E	1988	1999	1.05 ha	–	–	–	–	–	–	–	YES
Ikeda											
A	1983	1986	1.33 ha	–	–	–	–	–	YES	–	YES
B	1979	1987	1.11 ha	–	–	–	–	–	YES	–	YES
Toyonaka	1994	2001	0.56 ha	–	–	YES	–	–	YES	–	YES
Amagasaki											
A	2008	2011	0.50 ha	YES	YES	YES	–	YES	–	YES	–
B	2000	2002	0.90 ha	–	YES	–	YES	–	–	YES	–
Nishinomiya	1999	2003	0.5 ha	–	–	–	–	–	–	–	–
Moriguchi	1983	1986	3.57 ha	YES	–	YES	YES	–	–	–	–
Neyagawa											
A	1982	1987	2.10 ha	YES	–	–	–	YES	–	YES	–
B	2009	2012	1.50 ha	–	–	–	YES	–	–	–	YES
Fuse	1992	1997	1.10 ha	–	YES	YES	YES	–	–	–	YES
Sakai	1990	1994	2.23 ha	–	–	–	–	–	YES	–	–
Izumisano											
A	1989	1993	0.62 ha	–	–	–	YES	–	–	–	YES
B	2002	2006	2.23 ha	–	YES	YES	YES	–	YES	–	YES
Matsunohama	1998	2000	0.55 ha	YES	YES	YES	YES	–	YES	–	YES
Izumio-tsu	1991	1995	2.56 ha	–	YES	YES	YES	YES	–	–	YES

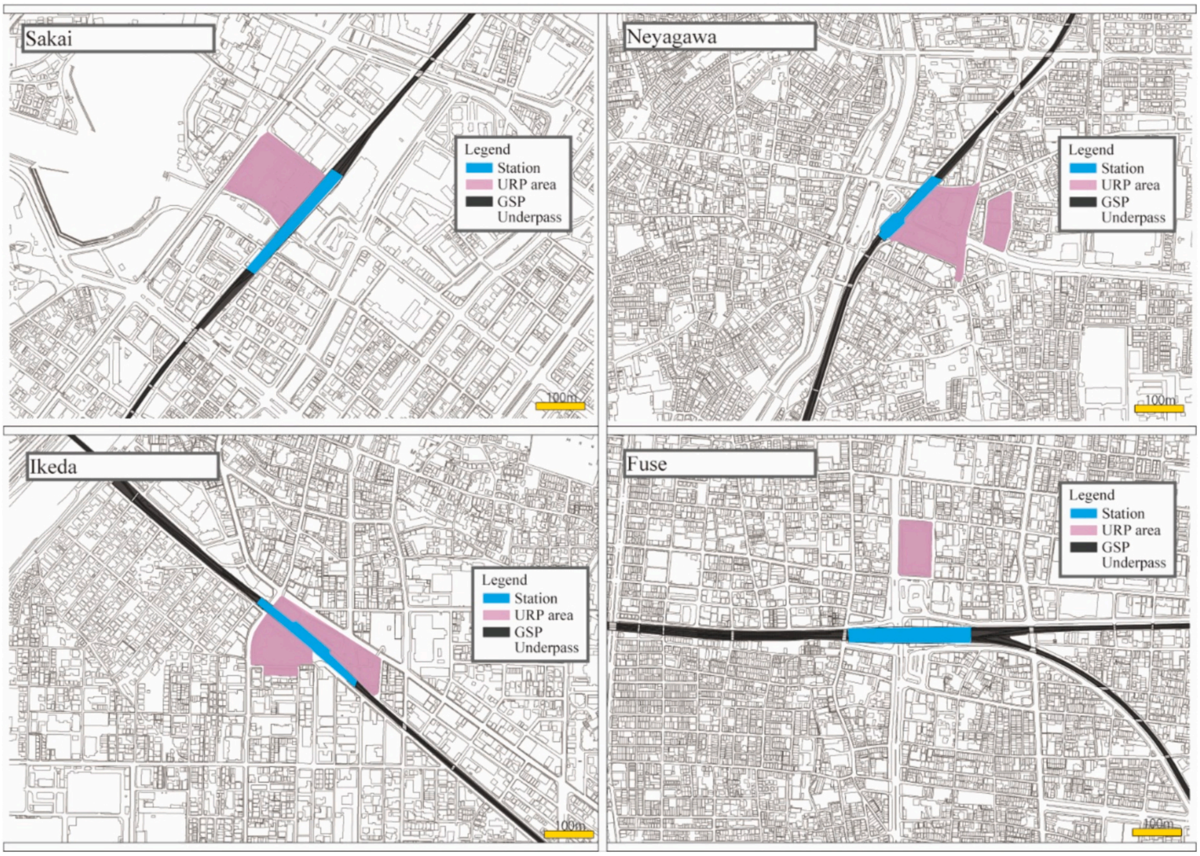

Fig. 3. GSP and URP areas at the target stations.

Table 2
Categories based on URPs and GSPs.

	Railway line	Number of elevated railway lines	Timing of two projects	Scale of URP	Number of URP areas	Distance of railway line and URP	Location of URP	Purpose of URP
Kawanishinoseguchi	Hankyu-Takarazuka	Multiple-lines	Overlapped	>3 ha	Multiple	Mixed	Double-sided	Facility Sufficiency
Ikeda	Hankyu-Takarazuka	Single-line	Overlapped	1 to 3 ha	Multiple	Adjacent	Double-sided	Advanced Land Use
Toyonaka	Hankyu-Takarazuka	Single-line	Overlapped	<1 ha	Single	Adjacent	Single-sided	Advanced Land Use
Amagasaki	Hanshi-Main rail	Single-line	Separated	1 to 3 ha	Multiple	Mixed	Double-sided	Facility Sufficiency
Nishinomiya	Hanshi-Main rail	Single-line	Overlapped	<1 ha	Single	Isolated	Single-sided	–
Moriguchi	Keihan-Main rail	Single-line	Separated	>3 ha	Single	Adjacent	Single-sided	Facility Sufficiency
Neyagawa	Keihan-Main rail	Single-line	Overlapped	>3 ha	Multiple	Mixed	Single-sided	Facility Sufficiency
Fuse	Kintetsu-Main rail	Multiple-lines	Separated	1 to 3 ha	Single	Isolated	Single-sided	Facility Sufficiency
Sakai	Nankai-Main rail	Single-line	Separated	1 to 3 ha	Single	Adjacent	Single-sided	Advanced Land Use
Izumisano	Nankai-Main rail	Single-line	Overlapped	1 to 3 ha	Multiple	Isolated	Single-sided	High-level development
Matsunohama	Nankai-Main rail	Single-line	Overlapped	<1 ha	Single	Adjacent	Single-sided	High-level development
Izumio-tsu	Nankai-Main rail	Single-line	Separated	1 to 3 ha	Single	Adjacent	Single-sided	Facility Sufficiency

land prices at stations with one-sided development before and after the project, and the amount of change. The same form is summarized in Table 7 for the two-sided development.

Based on these results, the change in land value in terms of roadside land prices generally showed an increase in value on both the front and rear sides. However, both sides tended to show a decrease at Izumisano, Matunohama, and Izumio-tsu. Fuse is unique in that the land values on the redevelopment implementation side increased, while those on the non-redevelopment implementation side decreased, albeit only slightly. However, at Toyonaka and Sakai, land prices on the redevelopment implementation side increased by >100 before and after the project. Conversely, the non-redevelopment implementation side tended to have

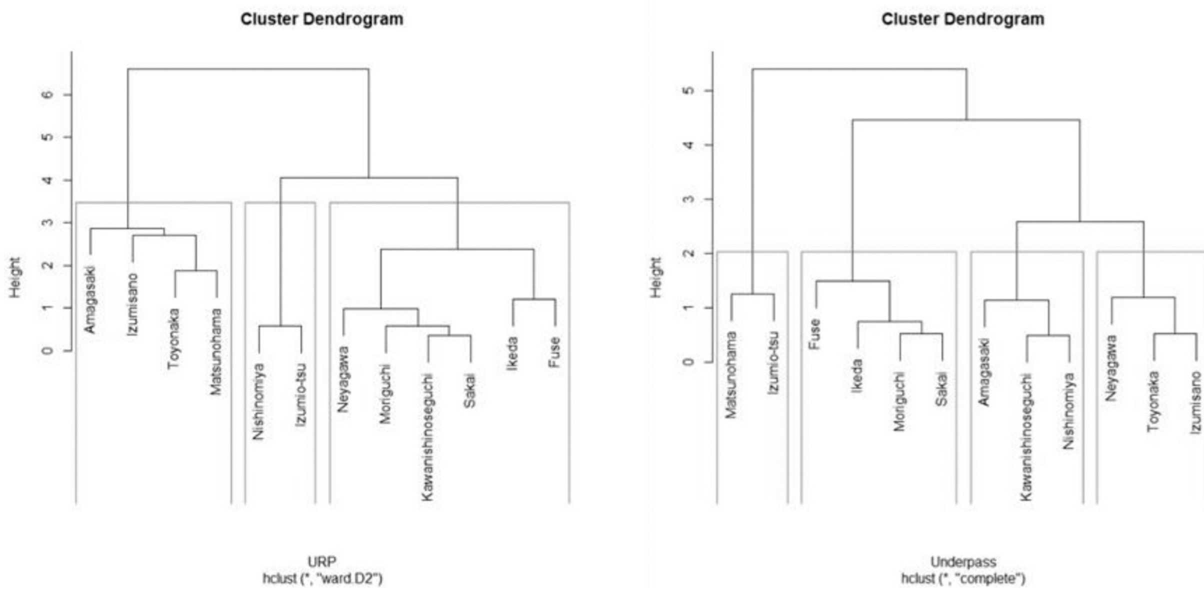

Fig. 4. Dendrogram by URP and Underpass land use.

Table 3
Stations in each URP cluster and corresponding percentage points obtained by comparing land use pre- and post-project according to land use category.

	Commercial Use	Public Use	Residential Use	Low Utilization
Group 1				
Amagasaki	−56.43	32.86	0.00	23.57
Izumisano	−40.74	66.67	−7.41	−18.52
Toyonaka	−15.40	27.60	−8.32	−3.88
Matsunohama	3.38	40.00	−38.88	−4.50
Avg.	*−27.30*	*41.78*	*−13.65*	*−0.83*
Group 2				
Nishinomiya	62.50	12.50	−33.33	−41.67
Izumio-tsu	49.68	13.89	−29.73	−33.84
Avg.	*56.09*	*13.20*	*−31.53*	*−37.75*
Group 3				
Neyagawa	26.57	21.68	−55.94	7.69
Moriguchi	42.26	15.34	−51.65	−5.94
Kawanishinoseguchi	28.51	19.20	−47.58	−0.12
Sakai	32.46	20.02	−46.11	−6.37
Ikeda	19.23	−1.92	−36.54	19.23
Fuse	36.07	0.00	−34.29	−1.79
Avg.	*30.85*	*12.38*	*−45.35*	*2.12*

All values above are in percentage points.

Table 4
Stations in each underpass cluster and corresponding percentage points obtained comparing land use pre- and post-project according to land use category.

	Commercial Use	Public Use	Residential Use	Low Utilization
Group 1				
Matsunohama	0.00	0.00	0.00	100.00
Izumio-tsu	20.00	0.00	0.00	80.00
Avg.	*10.00*	*0.00*	*0.00*	*90.00*
Group 2				
Fuse	82.81	4.69	0.00	12.50
Ikeda	66.67	14.29	0.00	19.05
Moriguchi	64.29	10.71	0.00	25.00
Sakai	72.73	9.09	0.00	18.18
Avg.	*71.62*	*9.69*	*0.00*	*18.68*
Group 3				
Neyagawa	15.38	23.08	0.00	61.54
Kawanishinoseguchi	30.77	23.08	0.00	46.15
Nishinomiya	30.00	26.67	0.00	43.33
Avg.	*25.38*	*24.27*	*0.00*	*50.34*
Group 4				
Neyagawa	51.72	10.34	0.00	37.93
Toyonaka	33.33	9.52	0.00	57.14
Izumisano	33.33	13.33	0.00	53.33
Avg.	*39.46*	*11.07*	*0.00*	*49.47*

All values above are in percentages.

a smaller increase than the redevelopment side; however, in Nishinomiya, a significant increase of 101.89 was observed. In Sakai and Nishinomiya, there was a significant difference in roadside land prices between the redevelopment and non-redevelopment implementation sides. In Sakai, redevelopment implementation increased significantly, while non-redevelopment implementation showed a minor increase. In contrast, in Nishinomiya, the opposite was true: while the non-redevelopment implementation side increased significantly, the increase on the redevelopment side was more minor. The three cases in which URPs were performed on both sides also showed significant increases in value, such as 119.07 in Ikeda and 93.78 in Kawanishinoseguchi. In contrast, in some cases such as on the northern and eastern sides of Amagasaki, the increase was approximately 24.75.

Based on these characteristics, Table 8 summarizes the differences in land prices between the front and rear sides; that is, the disparities that emerge in the urban divide. The reduction ratio was calculated as the ratio of the difference before and after the project. The project was divided into three classes based on the rate of reduction. Class was defined as expanded if the reduction rate increased, as high shrinkage if the reduction rate was above the median, or as middle shrinkage if the reduction rate was below the median. The results are shown in Tables 6 and 7.

Kawanishinoseguchi showed an extremely high reduction rate (98.71%) followed by Kawanishinoseguchi, Toyonaka, Nishinomiya, Matsunohama, and Izumio-tsu. The first two stations experienced land price increases on both sides, whereas the latter two experienced land price decreases on both sides. Izumisano Station belongs to Class: Expanded, with no significant change in the division between the two sides (−8.04), and the original difference between the two sides was minor at 34.73.

Most stations implemented URPs on the urban side where land values were relatively high before the project. However, there were cases where URPs developed in areas where land prices were initially low, such as Toyonaka, Neyagawa, Fuse, and Sakai. Nishinomiya and

Table 5
Group combinations.

	Underpass			
	Group 1: Low-utilized	Group 2: Commercial-utilized	Group 3: Public-included	Group 4: Commerce-and-low-utilized
URP				
Group 1: Public-purpose	Matsunohama	–	Amagasaki	Toyonaka Izumisano
Group 2: Commercial-purpose	Izumio-tsu	–	Nishinomiya	–
Group 3: Balance	–	Ikeda Moriguchi Fuse Sakai	Kawanishinoseguchi	Neyagawa

Table 6
Land price change pre- and post-projects (single-sided).

	Redevelopment implementation side			Non-redevelopment implementation side		
	Previous (a)	Subsequent (b)	Difference (a - b)	Previous (a')	Subsequent (b')	Difference (a' - b')
Toyonaka	85.14	234.63	149.49	197.41	278.71	81.30
Nishinomiya	273.05	315.51	42.46	224.47	326.36	101.89
Moriguchi	88.69	182.21	93.52	73.04	172.94	99.89
Neyagawa	66.06	134.29	68.23	136.32	172.36	36.04
Fuse	170.86	196.60	25.74	198.36	173.89	−24.47
Sakai	59.52	192.43	132.91	113.65	159.62	45.97
Izumisano	133.01	91.67	−41.34	98.28	54.15	−44.14
Matsunohama	195.12	83.45	−111.67	180.11	79.31	−100.80
Izumio-tsu	245.19	95.37	−149.83	206.03	100.13	−105.90

Prices are shown in thousand-yen per square-meter.

Table 7
Land price changes pre- and post-projects (double-sided).

	South and west side			North and east side		
	Previous (a)	Subsequent (b)	Difference (a-b)	Previous (a')	Subsequent (b')	Difference (a'-b')
Kawanishinoseguchi	143.45	202.81	59.36	108.58	202.36	93.78
Ikeda	128.75	247.82	119.07	153.18	232.16	78.98
Amagasaki	112.68	186.35	73.67	230.41	255.16	24.75

Prices are shown in thousand-yen per square-meter.

Table 8
Urban fragmentation and reduction rate.

	Urban fragmentation in previous ($p = \mid a - a' \mid$)	Urban fragmentation of subsequent ($s = \mid b - b' \mid$)	Reduction rate ($(p - s) / p \times 100$)	Class
Single-sided				
Toyonaka	112.27	44.08	60.74	High-shrinkage
Nishinomiya	48.58	10.85	77.66	High-shrinkage
Moriguchi	15.65	9.28	40.72	Middle-shrinkage
Neyagawa	70.26	38.08	45.81	Middle-shrinkage
Fuse	27.50	22.72	17.39	Middle-shrinkage
Sakai	54.12	32.81	39.37	Middle-shrinkage
Izumisano	34.73	37.52	−8.04	Expanded
Matsunohama	15.01	4.13	72.45	High-shrinkage
Izumio-tsu	39.17	4.76	87.86	High-shrinkage
Double-sided				
Kawanishinoseguchi	34.87	0.45	98.71	High-shrinkage
Ikeda	24.43	15.67	35.87	Middle-shrinkage
Amagasaki	117.73	68.81	41.55	Middle-shrinkage

See Table 7 for *a, b, a'* and *b'* in the table.

Izumio-tsu are examples of stations where the URP was originally conducted with high land prices. However, the high and low land prices were reversed after the project was completed. In contrast, at Fuse and Sakai, the URP was implemented with lower land prices, resulting in a reversal of the gap between the two sides. Prior to the project, Toyonaka and Amagasaki were identified as stations where the difference between the front and rear sides was significant. Although Amagasaki is not classified as a high-shrinkage station, it had the second highest reduction rate among the middle-shrinkage stations after Neyagawa. Although these two stations were originally significantly fragmented, the addition of the GSP and URPs significantly reduced the gap. The stations with the smallest differences between the two sides were Moriguchi and Matusnohama.

2.4. Land value reduction rate from GSP and URP perspectives

We assessed whether the reduction rate was related to the GSP and URPs. Table 9 summarizes the applicable stations by class for each development type characteristic identified previously. No significant differences were observed between groups. However, the relatively high shrinkage can be attributed to the overlap of the URP and GSP implementation periods, the number of URPs being single-site developments, and the relatively small scale of the URPs.

Table 9
Fisher's exact test associated with reduction rate and redevelopment characteristics.

		Class			
		Expanding	Middle-shrinkage	High-shrinkage	*p*-value
Railway line					
Hankyu-Takarazuka	$N=3$	0	1	2	0.8788
Hanshi-Main rail	$N=2$	0	1	1	
Keihan-Main rail	N = 2	0	2	0	
Kintetsu-Main rail	$N=1$	0	1	0	
Nankai-Main rail	$N=4$	1	1	2	
Single-line	$N=10$	1	5	4	1.0000
Multiple-lines	N = 2	0	1	1	
Timing of two projects					
Overlapped	$N=7$	1	2	4	0.2424
Separated	$N=5$	0	4	1	
Scale of URP					
<1 ha	N = 3	0	0	3	0.1263
1 to 3 ha	N = 7	1	4	1	
>3 ha	N = 2	0	2	1	
Number of URP area					
Single	N = 7	0	3	4	0.3687
Multiple	N = 5	1	3	1	
Distance of railway line and URP					
Isolated	N = 3	1	1	1	0.7078
Adjacent	$N=6$	0	3	3	
Mixed	$N=3$	0	2	1	
Location of URP					
Single-sided	$N=9$	1	4	4	1
Double-sided	N = 3	0	2	1	
Purpose of URP					
Facility Sufficiency	N = 6	0	4	2	0.3247
Advanced Land Use	N = 3	0	2	1	
High-level development	N = 2	1	0	1	

In Figs. 5 and 6, the reduction rate for each station that falls under the group obtained based on URP and Underpass is plotted. First, looking at the trends of the groups based on URP, the stations with relatively high reduction rates correspond to Group 2, which focuses on commercial development. These were Izumio-tsu and Nishinomiya, where land prices on the front and rear sides were reversed before and after the project. In contrast, Groups 1 and 3 exhibited a wide range of reduction rates. Kawanishinoseguchi, in Group 3, was a unique case among the stations covered in this report, with five URPs located near a single station. Therefore, Group 1 exhibited a relatively higher reduction rate. Among these, Toyonaka and Amagasaki were cases where the disparity between the two stations was significant before, and the division between their sides was greatly reduced.

In the category based on the land use of the underpass space, Izumio-tsu and Matsunohama fell into Group 1. In these cases, the underpass space was poorly utilized, however, the reduction rate was high. Therefore, it was not necessary to use it for commercial or public purposes. However, when the underpass is utilized primarily for commercial use, stations with a relatively middle-shrinkage reduction rate were clustered together. In addition to Kawanishinoseguchi, Nishinomiya and Amagasaki fall into Group 3, which includes relatively more public use, and the difference between the front and rear sides tended to narrow, although not as much as in Group 1.

According to our findings, hypotheses 1 and 2 are both supported. The analysis associated with the relationship between URP and GSP characteristic, land use transition, and reduction rate suggest that there is an optimal combination of redevelopment and elevation in different cases, as mentioned in hypothesis 2. The reduction of urban fragmentation was proven for hypothesis 1. However, in the case of a decrease in overall municipal land values, URPs and GSPs do not necessarily lead to an increase in station area land values.

3. Discussion

In this study, we analyzed the impact of the combination of an elevated railway line and URPs on surrounding land prices in the Kyoto-Osaka-Kobe conurbation to gain a perspective of how to eliminate urban fragmentation and acquire station centrality, which can inform the restructuring of mature cities in the future. The results showed that in general, the combination of grade separation and URPs could correct the

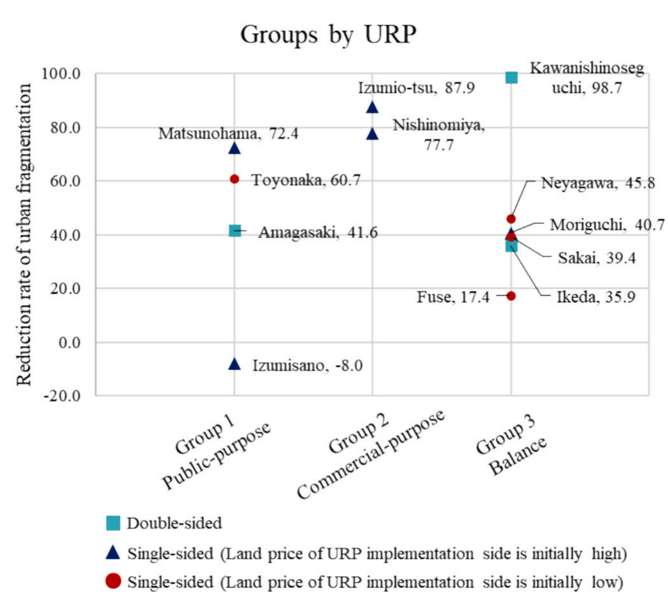

Fig. 5. Reduction rate of each URP group.

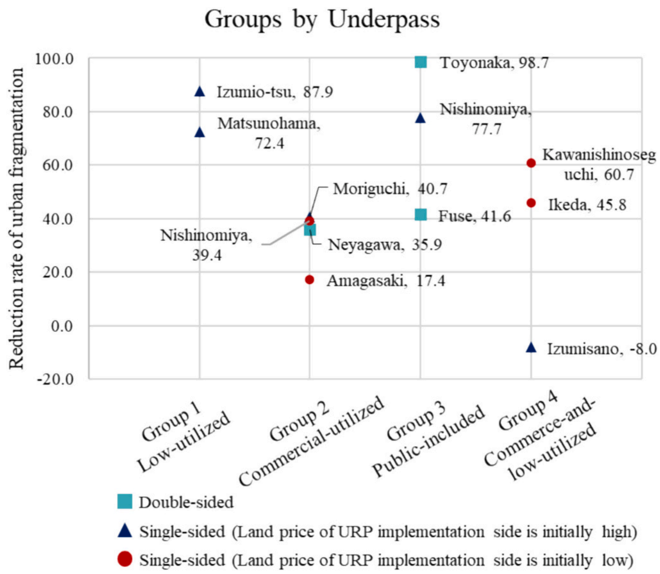

Fig. 6. Reduction rate of each Underpass group.

land price disparity between the two sides of an urban area divided by a railway line. In some cases, the reduction rate was as high as 80% or more of the pre-project level, and even in cases where the difference was 100 or more of the pre-project level, the difference was significantly reduced. Kawasnishinoseguchi is an example of considerable reduction, with a reduction rate of 98.71%, which almost eliminated the division. However, this station was the only rare case in which five URPs were undertaken on both sides of the line, which may have had the most significant impact on the results. Although the division would be greatly reduced if redevelopment projects of various sizes were undertaken on both sides of the railroad tracks, it is not difficult to imagine how difficult it would be, financially or in terms of land availability, to implement such a large number of redevelopment projects in conjunction with the elevation of all railway station spheres.

However, except for Fuse, where the land price in one area increased, the land price on the other side also increased. In particular, even when redevelopment was implemented on the side where land prices were high in the past, the gap with the urban area on the other side of the railway tracks did not widen, and a shrinking trend was observed. In some cases, such as Nishinomiya and Izumio-tsu, land prices on the rear side increased more than those on the front side, reversing this trend. These stations had single URP areas and single-sided developments. Even if the development of Kawanishinoseguchi cannot be achieved, URPs and elevated railroad lines can be expected to increase land prices in a unified manner up to the other side of urban redevelopment implementation. In this context, land prices at all stations along the Nankai railway line, except Sakai, exhibited a downward trend on both sides. This may be due to land prices (see Note 2). However, these stations also have favorable reduction rates, suggesting that they contribute to the elimination of urban fragmentation.

Nishinomiya and Izumio-tsu, where land prices reversed between the front and rear sides, also experienced high reduction rates. These stations are examples of commercial URPs. Elevating the line while developing commercial use on one side can have a more significant ripple effect on non-redevelopment implementation than on redevelopment implementation. As a result, urban unity will increase while separating places in which people live on the rear side from places in which they conduct their daily lives, such as commercial activities, on the front side. The city's situation has moved from division to the sharing of urban roles. When developing an area with high land prices in the pre-project stage, one development approach is to focus primarily on commercial uses and aim for a spillover effect to the rear side by elevating the land.

However, there are cases where a URP has been carried out in urban areas where land prices were initially low. These were the cases of Neyagawa, Fuse, Sakai, and Toyonaka. In Fuse and Sakai, redevelopment implementation exceeded non-redevelopment implementation after the project, narrowing the gap. These stations belong to the same group in both the URP and Underpass. In URPs, development is conducted with a mix of uses, whereas in Underpass, land use is focused on commercial uses. By including public and other uses in addition to commercial uses in the redevelopment area, the roadside land prices increased and a ripple effect was considered to have spread to the other side through the active use of the underpass implementation side. Unlike Nishinomiya, characterized by an area with relatively little land use is targeted for URPs, a higher reduction effect can be achieved by converting the underpass to commercial use while mixing commercial and public uses.

In the case of Toyonaka and Amagasaki, in which there was a significant disparity between the front and rear sides before the project, URP and GSP must be considered from different perspectives. In such cases, public use is the primary focus of URPs. The significant disparity is seen as having been corrected by making the underpass public (Amagasaki) or commercial (Toyonaka). The effective use of underpasses for specific purposes, obtained through public development and elevation, could lead to the dissolution of the wide-open urban divide and increase a city's unity. However, this policy is unlikely to apply to Izumisano, in which the differences may be greater.

Although we attempted to standardize the impact of the GSP and URP category characteristics on the reduction rate, we found no significant differences in specific categories. It was difficult to determine the contribution of individual developmental characteristic categories to the reduction rate. A complex combination of factors, including use transformation, the size of the gap between the two sides of the station where development occurs, and the characteristics of the side where the URP occurs, can reduce the resulting differences in land prices and unify the city. Elevation and redevelopment projects along railway lines are considered to have a nonlinear relationship concerning improving land prices and reducing disparities. As discussed previously, it is necessary to develop an appropriate combination of projects based on the characteristics of each station.

3.1. Implications for managerial practice

The results of this study provide important insights for railway operators and municipal administrations in redeveloping areas around railway stations. In addition to elevated projects along railway lines, redevelopment projects in the vicinity of stations are particularly important in solving regional disparities while eliminating physical fragmentation through elevation. In this case, the redevelopment area and the space under the elevated railway line should be specifically developed for commercial or public use. However, the combination of land uses in the GSP and URP must be carefully considered as it also depends on the nature of the original subdivision. First, the combination depends on the size of the gap between the two sides along the railway line; second, it depends on whether land prices on the side in which development land could be secured are higher (or lower) than those on the other side; finally, it depends on the extent to which it is desirable to deliver the ripple effects of development to the opposite side. It is necessary to develop a project combining railway line elevation and redevelopment using this knowledge to form a compact and centripetal station sphere in the future.

3.2. Contribution to scholarly knowledge

This study provides an essential new perspective on compact cities and the TOD research context. The issue of urban fragmentation by railways and highways and the use of elevated railways to solve this problem has long been discussed. However, while there have been references to the physical fragmentation caused by elevated railway lines, that is, traffic congestion and low east-west (or north-south) traffic, there has been limited discussion on the correction of disparity in land prices. In this regard, improving the attractiveness of station spheres will be of great importance, as the expanded conurbation is converted to a compact urban structure. Hence, it is crucial to consider a case in which an elevated railway line and redevelopment are integrated, and to examine whether their combination can correct the disparity and improve land prices. This study may include a perspective on sustainable urban planning, particularly in mature developed countries.

4. Conclusion

This study confirms whether the combination of URPs and GSP scan achieve urban unity. Although it has been argued that railway lines divided cities in the past, it was found that elevating railway lines and redevelopment in the station sphere can increase the value of a mature city while increasing its unity. The findings of this study show that in addition to the already discussed benefits of elevating railway lines, such as reducing traffic congestion and promoting east–west traffic, elevated railway lines can also add value to the land by integrating it. Furthermore, the significance of combining the project with a URP was summarized, and it was found that there are multiple compatibilities between the characteristics of each station, development site, and land use of the underpass space. The study results will contribute to future URPs.

This study is limited to a case study analysis of the Kyoto-Osaka-Kobe conurbation in Japan. However, the study findings may be applied to urban areas worldwide which are divided by railway lines, highways, or main thoroughfare. In addition, combining land use in projects, such as URPs and GSPs, may provide insights for integrating rail lines and cities when adding centrality to urban areas. In countries and regions where urban development is promoted, the combination of land use in projects such as URPs and GSPs can be considered when laying out routes.

This study has some limitations. Only 12 stations were considered in this study. As mentioned in the previous section, a larger sample size is needed to clarify the nonlinear and complex relationships and achieve statistical significance. However, because different target conurbations may have different attractiveness and development pressures to attract people in the first place, the analysis must be conducted using statistical processing methods that consider such differences in assumptions. In addition, it is possible to determine the difference between the cases of undergrounding and elevation. Furthermore, it will be necessary to separately confirm whether the actual movement of people occurs between the front and rear sides of the city based on GPS and other human flow data. To eliminate urban fragmentation, these issues will need to be addressed in future studies.

4.1. Note

- The subcategories in each category are as follows;
  - Commercial use: department stores, supermarkets, retail stores, restaurants, entertainment facilities, other service facilities, and offices,
  - Public use: parks, plazas, sports facilities, assembly halls, halls, nursery schools, senior care facilities, banks, post offices, and hospitals,
  - Residential use: detached houses, apartment buildings, and other residential functions,
  - Low utilization: unused land, parking lots, bicycle parking, material storage, and warehouses.
- One characteristic of the Kyoto-Osaka-Kobe conurbation is that land prices tend to be higher in the northern areas than in the southern areas. According to data from the Osaka Prefecture's Fixed Asset Valuation Council, in some cases, land price standards in municipalities located south of Osaka City are less than one-tenth of those in the north (Osaka Prefecture Fixed Asset Valuation Council, 2023). Recently, municipalities with declining land prices have become located across boards in the southern part of the city. Therefore, even if the GSP and URP revitalized the station sphere, the relative decline in land prices, including those in the surrounding areas, was considered to have resulted in a decline in land prices on both the front and rear sides of the city. However, as the reduction rate was positive, it contributed to the elimination of urban fragmentation.

CRediT authorship contribution statement

Takashi Aoki: Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Conceptualization. **Hidea Yoshida:** Data curation, Conceptualization. **Takashi Yokota:** Supervision. **Emiko Itami:** Visualization.

Declaration of competing interest

None.

Data availability

Data is not available on online.

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