International Journal of
High-Rise Buildings
www.ctbuh-korea.org/ijhrb/index.php

International Journal of High-Rise Buildings
March 2023, Vol 12, No 1, 35-47
https://doi.org/10.21022/IJHRB.2023.12.1.35

Research on the Correlation Between Rail Transit Entrances and Urban Form in High-Density Areas

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Abstract The transport system and its infrastructure are not only the fundamental means of sustaining the operation of contemporary cities, but also important drivers for the evolution of urban form. Rail transit, critical to improving the operational efficiency and optimizing the spatial layout in cities, is one of the critical conditions for high-density areas with limited land and concentrated resources to be compact to take on complex challenges. As a node element of infrastructure, rail transit entrances are the most important points connecting the rail transit system with urban space. Although influenced by urban form, their quantity and location also influence and shape the evolution of urban space form. Based on the development gap of high-density areas in various contexts, focusing on various rail transit stations in Asia, this research analyzes the correlation between rail transit entrances and peripheral high-density urban form in a delicate, dynamic and granular way. The research considers both horizontal and vertical perspectives, in combination with the urban evolution process in time series, to explore the development trend of high-density urban form in Asia from the aspect of correlation, and building a new foundation for research on urban form, suitable for different types of cities.

Keywords High-Density City, Infrastructure, Rail Transit Entrance, Transition, Urban Form

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1. Introduction

Recognizing the sustainable benefits of a compact development pattern, cities have started high-density development in terms of mixed land uses, pedestrian-friendly design, sustainable transport and other modes. To this day, the scale, layout and other macroscopic forms of high-density cities in the world have been more or less stable. However, given increasing requirements for public health, public transport and greening becoming higher, the urban form is changing at a more microscopic level, closer to individual needs (Barrett and George 1996). Amid the development of the transportation network, the entrances connecting rail transit with urban space increase and penetrate into the blocks gradually. While being influenced by urban space, the rail transit entrances limit the distribution of natural movement in the space and evolve as part of urban form elements, to significantly influence urban interface, space viewshed, business opportunities and other aspects in a more concrete and microscopic way. According to a few scholars, rail transit entrances are correlated with macroscopic factors, including the overall urban transport plan and the economy, but little research on the correlation with urban space form has been conducted (Lahoorpoor, B. et al. 2020; Huang, R. et al. 2017).

In view of the above-mentioned status quo, background and research gaps, this paper aims to explore the rational correlation between entrances and urban form in the context of inventory renewal, characterized by the following two novel features: (1) Delicate and microscopic: this paper analyzes urban elements at the microscopic level, such as lot configuration, spatial layout and street design, within 100 meters' radius of the entrances. (2) Dynamic: this paper explores the evolution law of urban form in different periods from the perspective of "time-space" dynamic evolution, and accordingly studies the correlation with the entrances.

The sequence is as follows. Section 2 proposes three types of high-density cities (Section 2.1), and elaborates on the urban form elements and the analytical framework in high-density cities of different scales (Section 2.2). Section 3 analyzes and studies the timeline-based urban form in the light of sample stations in three cities of different types. Chapter 4 summarizes the correlation

between various rail transit entrances and urban forms. Finally, Chapter 5 draws the main conclusions of this paper.

2. Methodology

2.1. Study Area

As Asia is greatly threatened by population challenges, the research focuses on high-density and mature cities in Asia. Based on the analysis on the basic overview of some Asian cities (see Figure 1) and the scholars' classification methods for high-density cities according to layout form, density index, spatial model, etc. (Patel, S. B. 2011; Jabareen, Y. R. 2006), high-rise and high-density cities are classified into three categories: (1) High-rise compact type: cities of high-rise compact type, such as Tokyo, built on the basis of efficient and accessible public transport due to the limited urban area and large population. (2) High-rise open type: cities with buildings of increased height for provision of floor space, laying stress on open space and landscape zones in the process of development, such as Singapore. (3) High-rise vertical type: cities of the vertical type, with a terrain-based layout due to limited building area, such as Chongqing.

As the development course of the three urban forms shows, the urban form of Tokyo is radially distributed with "multiple cores and multiple circles" and correlated with public transport; Singapore has a multi-level urban cluster structure, with a landscape-to-built-space ratio of about 50 percent, and the urban structure of Chongqing is a "cluster network in series," which connects spatial clusters by way of the public transport system in series. This paper selects three stations with high-density surroundings, a long history, or remarkable characteristics in three cities: Shibuya Station in Tokyo, Japan, Dhoby Ghaut Station in Singapore, and Zengjiayan Station in Chongqing, China, for further case studies (see Figure 2).

2.2. Urban Elements

Urban form, a sign of the endogenous elements of urban development, shows the concrete morphological characteristics of real cities, such as geometric form, functional pattern, spatial organization and architectural features (Handy et al. 1996). Resolution, form elements and time are three key characteristics of urban form.

Defining the resolution is the premise of "form studies" (Schirmer, P. M. 2015). Based on the urban form classified by scholars such as Conzen, this paper carries out a classification of the urban form at the macroscopic, mesoscopic and microscopic levels. (Conzen, M. R. G. 1960). The urban form at the macroscopic level usually emphasizes the two-dimensional urban form, urban layout, and the relationship with the countryside; the mesoscopic level is the structural skeleton including the road network, axes, and nodes in the urban clusters; the microscopic level mainly includes the combination of specific spatial and physical elements, which is the focus of this research.

Form elements are the details of urban form. In order to objectively represent urban elements to support evidence-based research, technical tools may be used to capture urban elements in terms of functions, transport, buildings, and so on, by means of feature quantification. The functional form is an "attached network" projected on the space form, and its urban elements include the distribution state of functions, land use value, and functions usage. The data, such as POI (point of information) and heat maps, can be obtained through a network map platform. "Traffic form" mainly refers to the correlated characteristics of road space, and its elements can be quantified by combining graphic information systems (GIS) and space syntax. "Architectural form" is the overall correlation form of building groups, including variation, density, intensity and

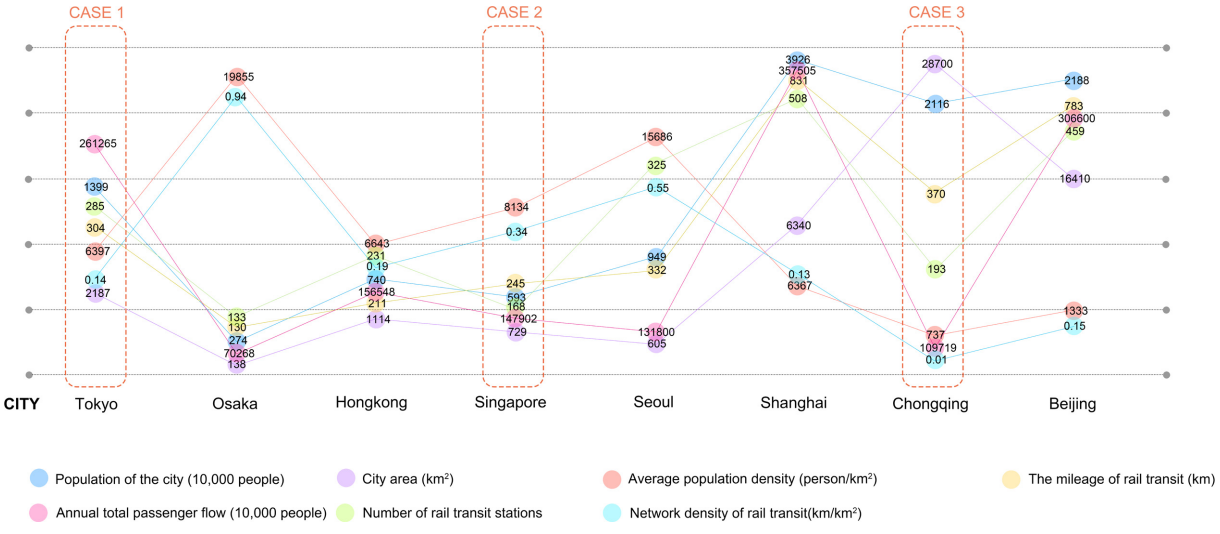


Figure 1. Basic Overview Data Diagram of Some Asian Cities.

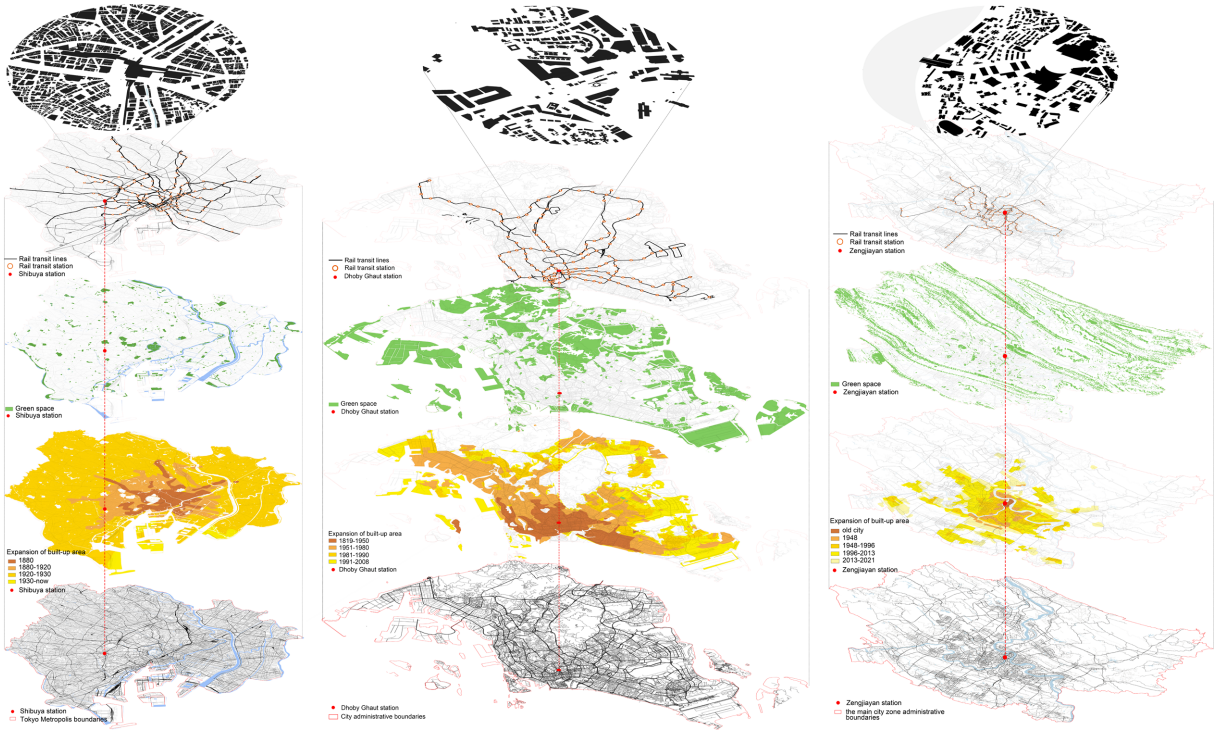


Figure 2. Urban Form Development Course of Tokyo, Singapore and Chongqing.

other indicators. Besides, the urban elements at the microscopic level are related to the ground-floor street interface, viewshed range, space form and other perspectives of people (W Chen, et al. 2021; Elzeni, M. M. et al. 2022), and can be analyzed with tools such as street view maps and viewshed analysis (see Figure 3).

Time is a research dimension of urban form. This paper introduces the concept of time, and divides the time from the opening of rail transit entrances into the early stage, middle stage and late stage (Zhao, C. et al. 2020). Thus, the research on the urban form of the sample stations in different periods reveals the spontaneous consciousness and impact mechanism of urban form elements and entrances (see Figure 4).

3. Case Study

3.1. Shibuya Station, Tokyo (High-Rise Compact Type)

Shibuya Station, first opened in 1885, was relocated to its existing location in 1920. The station is a junction of nine rail transit lines, with a daily passenger flow of more than 3.3 million people, with 50 entrances and extensive surrounding infrastructure (see Figure 5).

According to the quantitative analysis on the network form within the influenced realm[1)] around the rail transit station by Depthmap software, the opening of the entrances of Shibuya Station effectively improves the convenience and traffic capacity of the surrounding roads (see Figure 6). According to the analysis, the depth of the surrounding roads decreases significantly with time, and it is at the lowest within the influenced realm. Besides, the number and choice of roads has increased somewhat, and the indicators of different roads tend to be balanced gradually. This means the opening of entrances improves the average traffic capacity of roads and redistributes it evenly, in response to the overcrowded state of some roads.

For further analysis, the research focuses on two spatial objects - the Hachiko Entrance and the East Entrance (see Figure 7). Hachiko Entrance lies at the square with the Hachiko statue, and its nearby Shibuya Crossing is known as one of the busiest pedestrian crossings in the world. After the entrance was put into service, the parking lot on the square was gradually transformed into a resting space containing chairs, pools, landscape settings and other infrastructure. Moreover, with the development of zoning, the setting of straight walking paths is accompanied by the creation of a centripetal communication space with a sense of enclosure. Regarding the functions, as a result of economic benefits and safety issues brought by heavy crowd flow, the types of operation, such as commercial activities and security, increase gradually.

The East Entrance is a hub connecting with other public transport means. After the entrance was put into operation, the connecting position that was at the middle

[1)] Influenced realm around rail transit station: It is a series of urban spaces that are affected or radiated with the station as the core, and the realm is within 3-minute walking distance from the entrances to the urban space at the average walking speed of 1.2~1.5 m/s, according to the urban space characteristics.

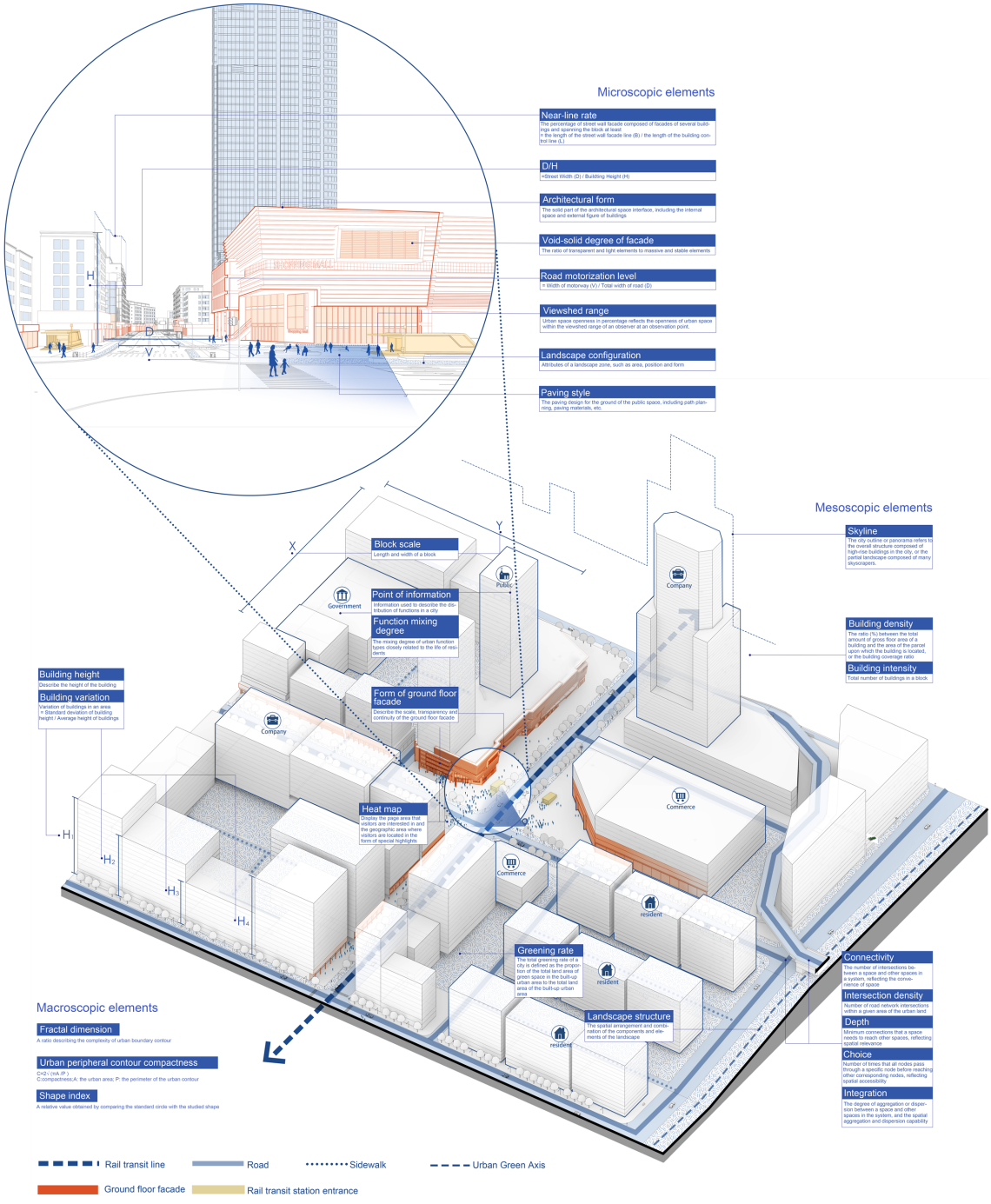


Figure 3. Urban elements diagrams.

of the wide road at the early stage was gradually detached and transformed into an independent complete space directly connected with the entrance, to better separate pedestrians from vehicles. The width of the roadways near the two entrances was appropriately narrowed. Particularly, the overall width of the East Entrance was decreased by nearly one third of the initial width. But the width of sidewalks has been widened, indicating that the city has turned its attention to the comfort of the pedestrian space while ensuring an appropriate traffic capacity.

3.2. Dhoby Ghaut Station, Singapore (High-Rise Open Type)

Dhoby Ghaut Station, opened in 1987, is located in the Museum Planning Area of Singapore, as the largest three-line interchange hub in Singapore. Several entrances of the station are directly connected to Plaza Singapura, and another two entrances located in the Dhoby Ghaut Green are integrated with other functions of the eponymous leisure center for residents (refer back to Figure 5).

The opening of entrances enhances the resource

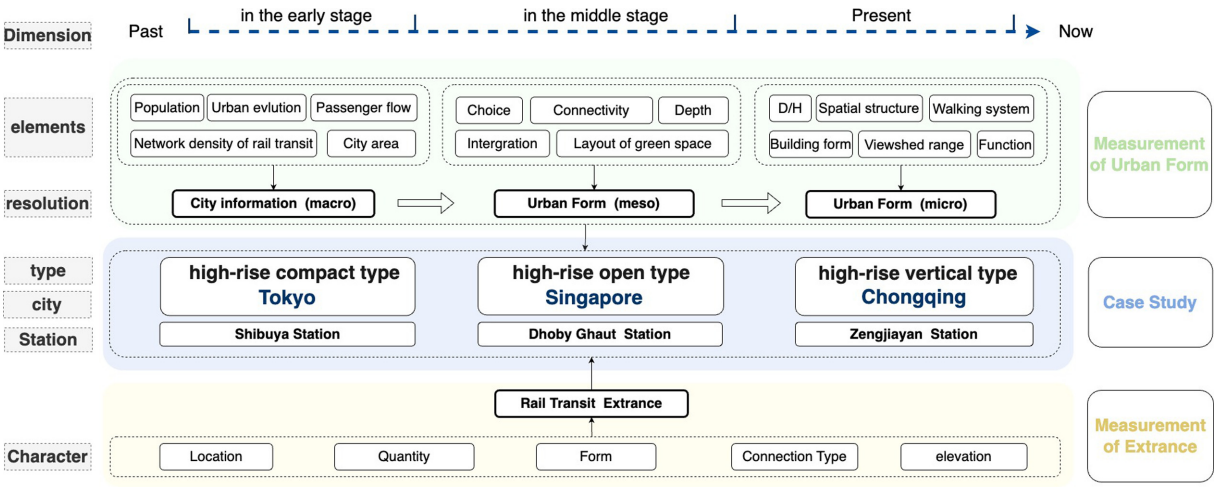


Figure 4. Analytical framework of the study.



Figure 5. Satellite Map of Shibuya Station, Dhoby Ghaut Station and Zengjiayan Station. The background is from Google earth.

integration of the road network within the influenced realm (see Figure 8). Over time, the road network integration around the entrances of Dhoby Ghaut Station has significantly improved, indicating the boost of topological accessibility and aggregation of road space.

Entrance B is located in the Dhoby Ghaut Green, while Entrance E located in the Plaza Singapura, and is directly connected with the mall's main entrance (see Figure 9). After the opening of Entrance B, the Dhoby Ghaut Green changed from a grass lawn to a more town-square-like environment, integrating diversified functions, such as business, exhibition hall and open-air stage. Moreover, in order to enhance the experience of walking to the bus stop on the south side of the park, a series of covered corridor spaces are arranged in the park to connect the rail transit entrance with the bus stop. Plaza Singapura where Entrance E is located has been renovated several times. The roadway on the west side of the entrance was reconstructed into a pedestrian square, the façade of which is provided with a canopy, extending to the bus stop on the south side of Entrance E, for the sake of all-weather connection. The total width of the main road (Orchard Road) where the two entrances are located has not changed significantly, but some traffic lanes have changed into sidewalks, which decreases the motorization level of the road.

3.3. Zengjiayan Station, Chongqing (High-Rise Vertical Type)

Zengjiayan Station, opened in 2004, lies next to Jialing River, Yuzhong District, Chongqing City. It was the first two-line interchange station integrating a station and a bridge in China. The entrances of the station not only present the complex spatial characteristics and diversified transport system of Chongqing by connecting urban spaces with different elevations, but also highlight the historical context of Chongqing by combining an underground passage (that used to be an air-raid shelter) more than 400 meters long, and several historical buildings (refer back to Figure 5).

As a mountain city built in response to landscape features, the influence of the entrances on the road network is limited by number of access points but comprehensive wherever those points occur (see Figure 10). The analysis results of Depthmap show, after the opening of the entrances, the connection increased greatly, in spite of no significant change in the depth of the road network. The reason is that small changes in the main road network and

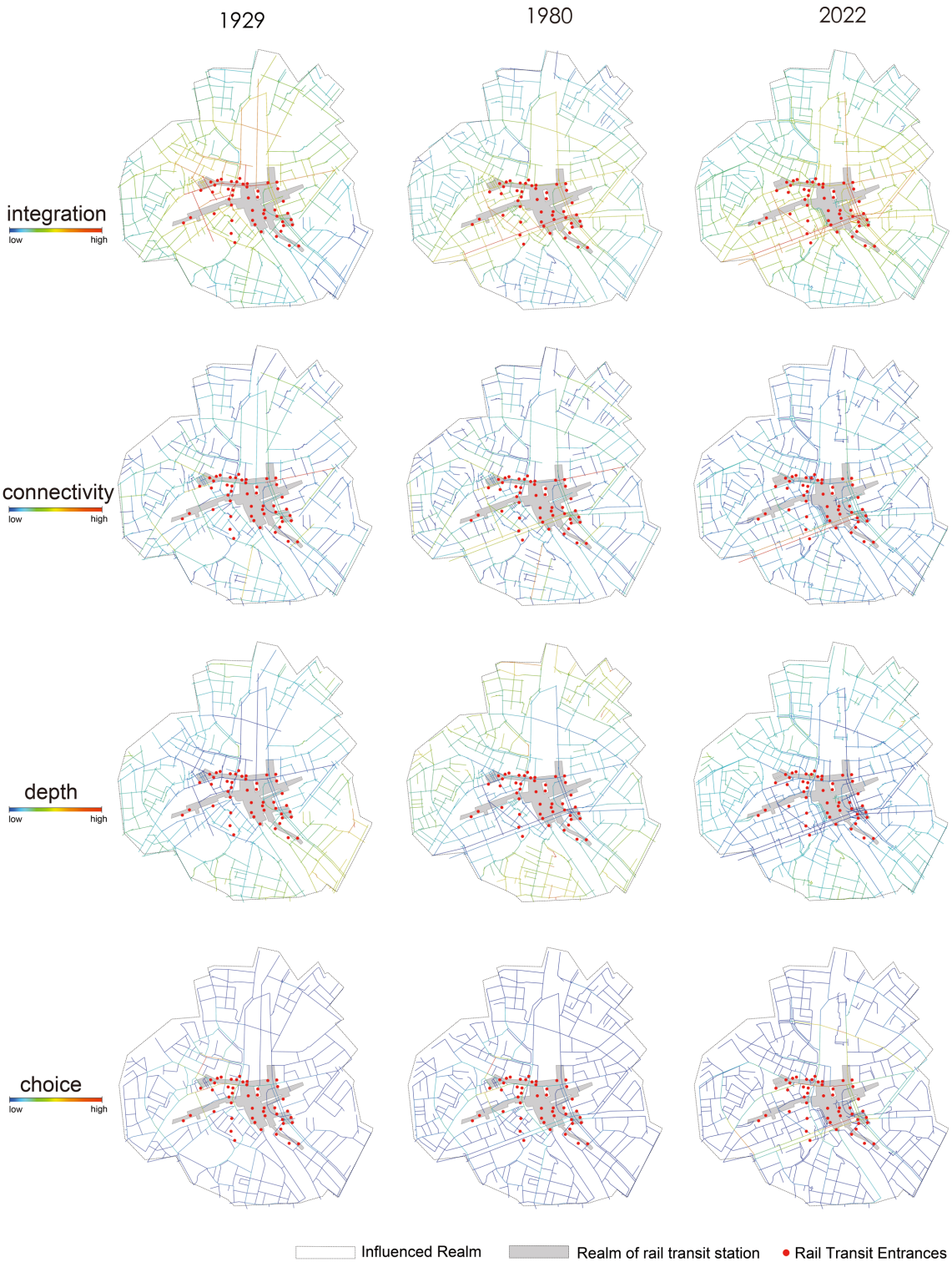


Figure 6. Analysis of Road Network Form within the Influenced Realm of Shibuya Station.

gradual improvement of some minor roads were made, especially the pedestrian system. Therefore, with limited road network changes, most of the entrances are situated in the road space, with high road network integration and connectivity, to improve the traffic efficiency of public transport.

Entrance 2, located at the intersection of the starting end of the north section of Zhongshan 4th Road, is integrated into the square's green landscape in the form of a freestanding structure, thus becoming a landscape node and cultural symbol of the city. However, in the early operational stage of the station, this space was only an

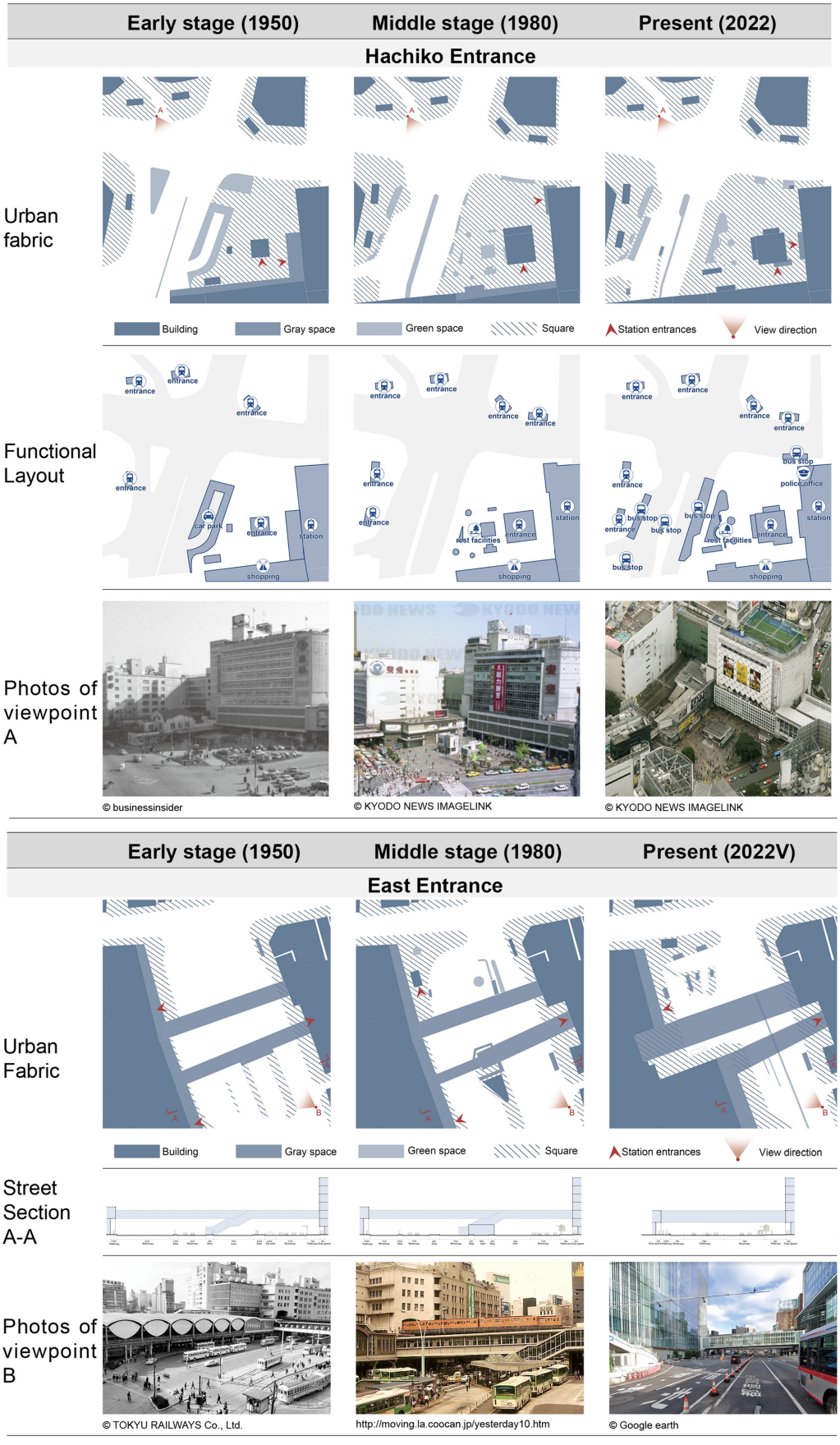


Figure 7. Evolution of Urban Form around Hachiko Entrance and East Entrance of Shibuya Station.

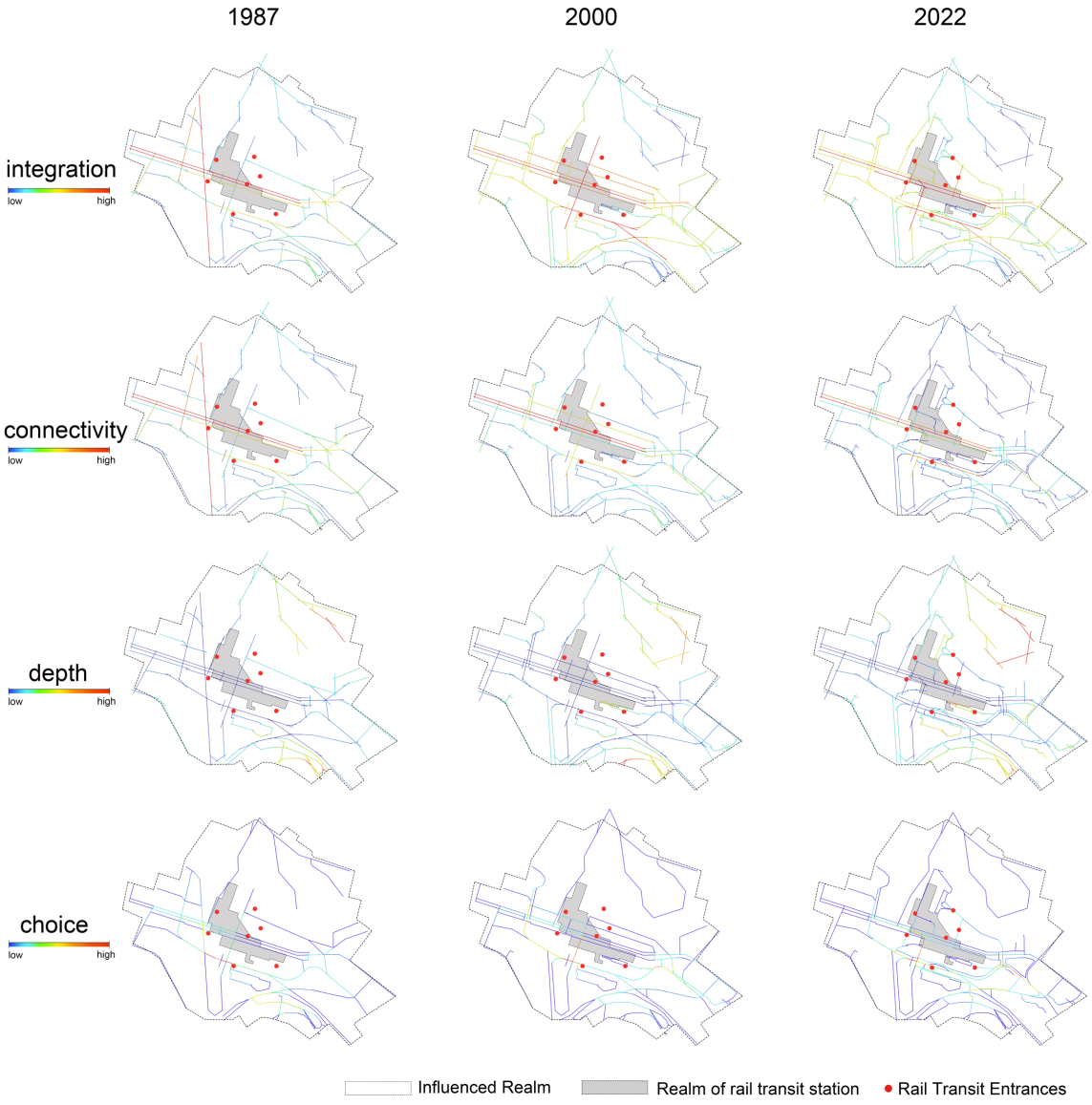


Figure 8. Analysis of Road Network Form within the Influenced Realm of Dhoby Ghaut Station.

undeveloped green space, and the original Entrance 2 was located on the other side of the sidewalk of Zhongshan 4th Road. Over time, a pedestrian system connecting Binjiang Road, Zhongshan 4th Road and Zengjiayan Bridge has been built around the entrance, which gives rise to the continuous expansion of pedestrian space and the establishment of a pedestrian square overlooking Binjiang Road. In addition, the entrance is relocated at the square, and the entrance hall is positioned under the square. Thus, an underground passage (formerly an air-raid shelter) connects the station hall with the entrance hall (see Figure 11).

4. Results and Discussion

4.1. High-rise compact type: building a distinct and efficient transport system

Rail transit with large traffic capacity is a key to relieving the traffic pressure of compact cities. Depending on heavy passenger flows, rail transit entrances propel cities to develop efficient and distinct traffic forms.

The control of traffic volume, the essence and purpose of the entrances' influence on the road network form of motor vehicles, are mainly reflected in the traffic capacity of the road network, the total road width, and the level of motorization. First, the entrances balance the traffic capacity of the road network to some extent. Decentralizing the location of several entrances can better balance the traffic volume of adjacent roads. Second, exceedingly wide roads around entrances can be narrowed to control the use of motor vehicles. Finally, entrances may affect the motorization level of roads to an extent, because the increased proportion of sidewalks can meet the demand of the increased pedestrian flow for non-motorized roads.

Rapid crowd decentralization is the primary task of the

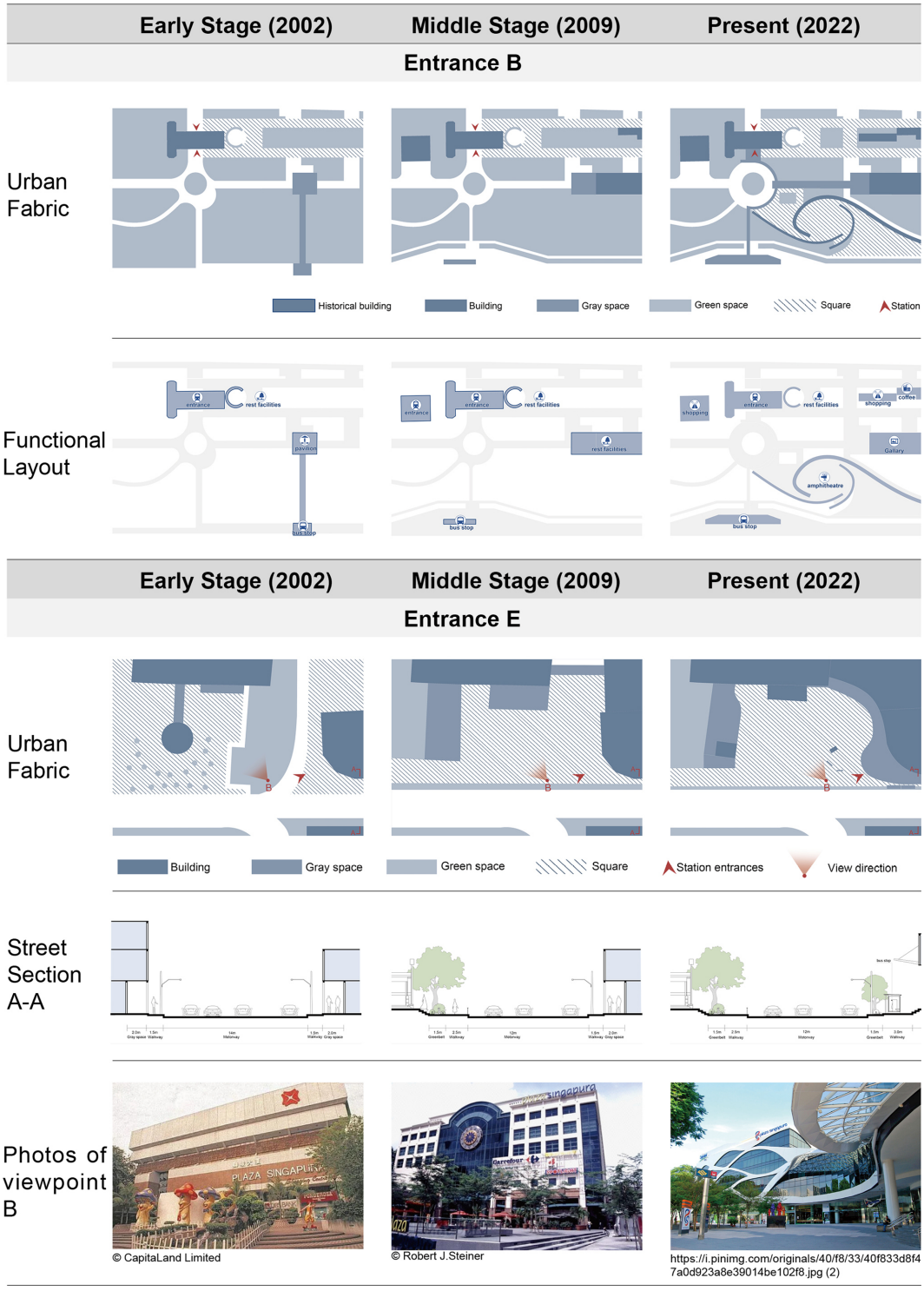


Figure 9. Evolution of Urban Form around Entrances B and E of Dhoby Ghaut Station.

urban space around entrances. On the one hand, the pedestrian space around entrances is continuously expanded to accommodate the constant flow of pedestrians. On the other hand, pedestrians with different behavioral requirements (rest, connection, fast movement) can be separated into flow lines with spatial partitions, for effective crowd diffusion within a limited space.

4.2. High-rise open type: shaping a diverse and comfortable landscape structure

Cities of the high-rise open type lay emphasis on the integration of cities, people and nature. Thus, rail transit stations including their entrances are always combined with green landscape space, which creates a comfortable walking experience and drives the integration of greenery

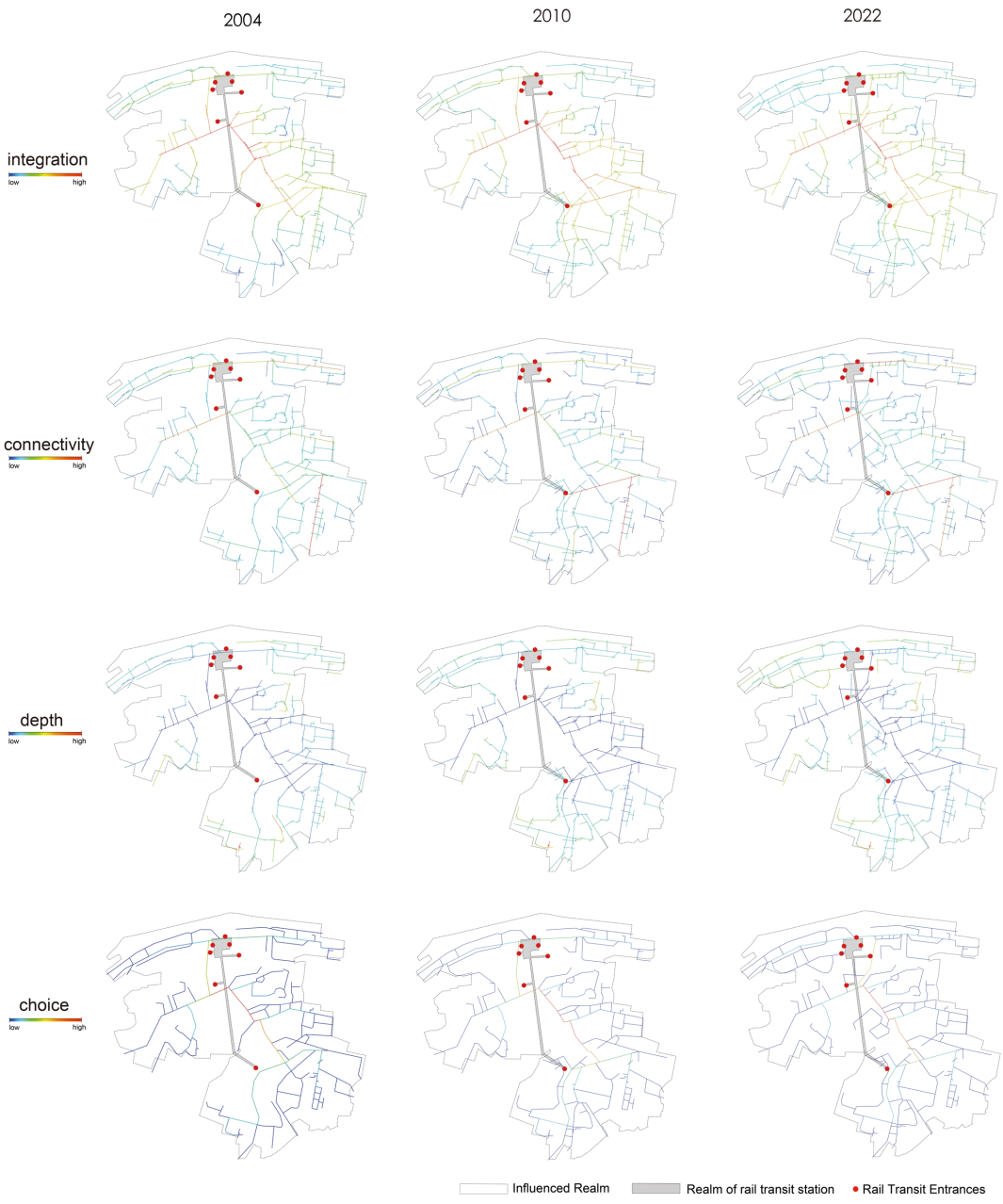


Figure 10. Analysis of Road Network Form within the Influenced Realm of Zengjiayan Station.

and human life.

Entrances facilitate the functional diversification of green space. The pedestrians from the entrances, i. e. the traffic nodes, enter the green space and inspire the vitality of the site. The pausing and dwelling of the pedestrians bring more functional possibilities for the green space - commercial (such as shopping and catering) and public/ civic (such as a reading room, an open-air stage, or an art gallery), and the site can eventually be transformed into a community recreation center.

Besides, the entrances also push the construction of the pedestrian system in the green space to connect various functions inside and outside the green space. As part of the park design, a covered walkway system, gradually established, in combination with the green space structure optimizes the walking experience of pedestrians.

4.3. High-rise vertical type: developing a multi-dimensional and interactive spatial framework

Special terrain conditions restrict the urban construction, but shape the urban characteristics and individuality. After the natural landscape is transformed to suit the rail transit stations with the urban development, the rail transit entrances are distributed on undulating land and characterized by vertical 3D spatial distribution. Moreover, as time goes on, the entrances consolidate the stereoscopic

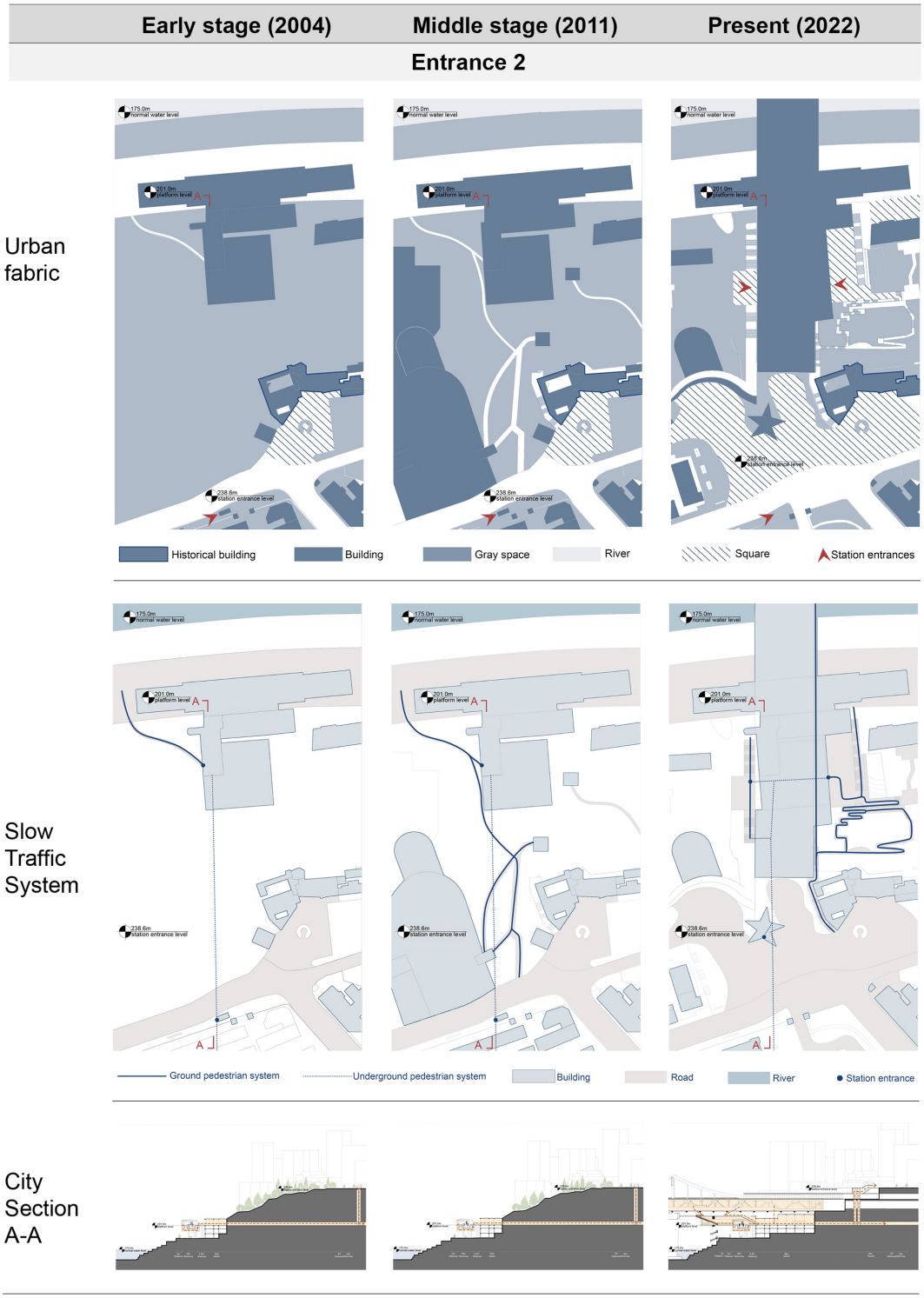


Figure 11. Evolution of Urban Form around Entrance 2 of Zengjiayan Station.

and multi-dimensional urban morphological characteristics of mountain space.

The entrances with different elevation differences propel the establishment of the urban stereoscopic slow traffic system. Due to the demand of pedestrians for "continuous" and "independent" space in the walking environment, the accessibility of the entrances is constantly improved, and the walkability of the surrounding urban space is also continuously improved. Thus, a pedestrian system is gradually established to connect the spaces with different heights, where the entrances are located.

In addition, the entrances also enhance the correlation between different levels of space. The establishment of vertically distributed entrances means the generation of

space nodes with different elevation differences. Owing to the spontaneous and social activities of pedestrians at such nodes, the view shed, appearance, dimensions and other factors become important contributors in the design of the nodal space form.

4.4. Discussion of results

After the opening of entrances, high-density cities of various forms exhibit the same spatial evolution characteristics. First, the urban form shows the expansion of urban pedestrian space based on the safety needs of people. In order to bear the pressure of pedestrian flow at the entrances, new evacuation nodes have emerged in the urban space, and the non-motorization level of roads has been improved. Second, as economic and social values produced by the pedestrian flow make influences on the functional distribution, there are more types of operation, such as commercial activities and public services, around the entrances. As a result, the urban form is actually represented as the combined influences of security, the laws of behavior and economics, which have become the basic support for the evolution of the urban form.

Second, due to the ontological differences of urban forms, the opening of entrances has intensified the morphological characteristics of various cities. Relying on explicit traffic forms, such as multi-level pedestrian systems and separation of pedestrians and vehicles, cities of the high-rise compact type ensure the traffic efficiency of many pedestrians at the entrances. Cities of high-rise open type attach importance to the combination of entrances and green space, and their integration into the public life of residents. Cities of high-rise vertical type have gradually established the multi-dimensional links between different levels of space around the entrances.

5. Conclusions

The increase in urban design accuracy is closely related to the improvement of urban form, and cities tend to adapt to the opportunities created by the entrances in a precise and subtle way. As the interface node of the terminal in the transport system, the entrances affect the direct spatial experience of city people and the specific behavior of the human scale. What's more, as a resource aggregation node in the urban system, the entrances push forward the mutual interaction and adaptation between the high-quality production and life needs and the carrying capacity of the spatial system.

The entrances promote the user-friendly transformation of urban form. The walkable area and its role in the urban space are gradually increased as the entrances support and respect walking. Furthermore, the entrances promote cities to pay attention to user needs (rest, viewing, communication) of pedestrians, and the infrastructure, with different functions improving gradually.

Therefore, as the point of penetration, the entrances finally get involved in the urban form by means of public services. Only relying on better services, the improvement or supply of public goods, public resources and some other quasi-public goods in the cities can drive the development of urban form in a better direction. The essence of urban form elements is the public value of urban open space and the public service system of cities. The evolution of the urban form is ultimately to promote the development of public services in the direction of optimizing fairness to the people. This is essential and historically inevitable for social stability and sustainable growth.

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