

A Comparative Study of Transit-Oriented Development Projects in China and the
United States

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Abstract

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United States

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Transit-Oriented Development (TOD) is an efficient planning tool in dealing with urban sprawl and promoting public transportation implemented across the world. This thesis studies how different TOD cases perform in five various built environment aspects and urban design in China and the United States. The study starts with discussing the TOD definition and some precedents around the world in the literature review. By reviewing some scholarly papers and reports, I developed two different evaluation standards for both the built environment and urban design in TOD communities. With a primarily descriptive analysis of the physical environment, the thesis includes two chapters evaluating the built environment and urban design in different cases. Based on the data from local governments and visual site visits, I can

explore the relationship between TOD communities and the whole built environment - how are the TODs' performances in different built environment aspects, what are the differences between various cases, and how local context promotes the development of a TOD community. Finally, the thesis concludes with some recommendations for future TODs.

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1. Introduction

1.1 Problem Statement

Transit-Oriented Development (TOD) is a planning concept whose implementation in North American cities has significantly expanded since its first introduction by Peter Calthorpe in the 1990s. The original purpose of the strategy was to increase the density, pedestrian-friendliness, and transit accessibility of suburban areas after decades of sprawling, resource-consuming, and automobile-dependent development since World War II (Calthorpe 1993). Many cities in the United States and Canada have successfully implemented the TOD concept, such as Portland, San Francisco, and Vancouver. In the later years, many Asian and European cities have also adopted TOD as a planning tool to manage the dense population and heavy traffic, including Hong Kong, Singapore, Paris, and London.

TOD includes so many different fields in research, resulting in many efforts that have been made in these fields, such as transportation management, regional planning, land value, and land use. For example, Michael Duncan has measured the influence of TOD on San Diego's condominium housing market and found that the proximity to the station with a pedestrian-oriented environment has a significant impact on housing value (Duncan 2011). Besides, Ratner and Goetz have analyzed TOD data in Denver, and evidence indicates that the TOD resulted in a significant increase in residential dwelling units, retail spaces, office spaces, and the average density in the

Denver urbanized area (Ratner and Goetz 2013). This thesis mainly focuses on using two sets of tools to analyze urban morphology and urban design in various TOD cases implemented worldwide. Urban morphology is the study of the city as a human habitat. Buildings, gardens, streets, parks, and monuments, are among the main elements of morphological analysis (Moudon 1997). Five aspects influence urban morphology based on the five 'Ds' built environment aspects mentioned by Ewing and Cervero: density, diversity, design, distance to transit, and destination accessibility (Ewing and Cervero 2010). Regarding the urban design analysis, I will concentrate on a small block scale analysis using the urban design score sheet provided by Ewing and Clemente in their research. The tool to measure urban design qualities is to move from highly subjective definitions to operational definitions that capture the essence of five different urban design qualities: Imageability, human scale, enclosure, complexity, and transparency (Ewing and Clemente 2013). Many cities in developing countries also face urban expansion, high population density, and transportation congestion issues. They are seeking a more sustainable solution by implementing TOD, and this research can potentially guide those cities. The analysis could be different and further developed for various urban contexts in the future.

In this paper, through case studies, I select two TOD cases for research both in the United States and China. The cases in the United States are Hudson Yards TOD in New York City and Northgate TOD in Seattle, and the cases in China are Chengdu

East Railway Station TOD in Chengdu and Kowloon Station TOD in Hong Kong. Hudson Yards TOD is located in the central area of Manhattan Island, one of the places with high population and living density in the world. There are also many commercial, retail, and residential units around this area, making it a mixed-use community. Northgate TOD is close to Northgate Mall in the north part of Seattle. I will analyze the entire community based on the Northgate light rail station about to be completed in 2021. There are many single-family houses, open-air parking lots and a shopping center, which consists of a typical suburban development example after World War II. Kowloon TOD is similar to Hudson Yards TOD. It is also located in the central area of Hong Kong, gathers a large number of residents, and provides a variety of community services and facilities. As a newly developed TOD case based on a high-speed rail station in China, Chengdu TOD hopes to build a more walkable community to serve residents in the neighborhoods near the high-speed rail station while taking on the task of regional connectivity.

However, these TOD examples that have been built or are about to be completed have some problems that interest me to explore, which is also why I will analyze these four cases' urban morphology and urban design.

First of all, Hong Kong and New York TOD communities have similar urban forms. In order to pursue high density and accommodate more people, a large number of multi-story mixed-use buildings have been constructed. Nevertheless, starting from

the transit characteristic of a TOD community, Hudson yards TOD is only centered on a subway station, and the public transportation routes operating here are not complicated. Therefore, this TOD project does not emphasize the attributes of transit.

Due to the limited city scope of Hong Kong, urban construction there prefers to develop vertically. Therefore, there are many examples of vertical development in Kowloon TOD, such as different public transportation modes on different floors of the entire transportation center. In urban design, the vertical development can be reflected in the construction of pedestrian bridges to reduce the impact of people passing through streets on ground vehicle traffic. However, whether such a high-density and vertical urban structure can bring an excellent experience to the residents needs to be proved by more studies.

Then, Chengdu TOD is a typical Chinese TOD model centered on a high-speed railway station that China is currently vigorously developing. However, to meet many regional transportation tasks, such a transportation hub is immense in terms of station area and scale, and traffic users may spend much time just traveling inside. In addition, the large number of railroad tracks will also cause difficulties for pedestrians to pass through the entire community. More problems such as railway noise and community safety issues caused by a large number of travelers are all that need to be solved under this TOD model.

Finally, Northgate TOD is a community that is transforming from a car-oriented community to a transit-oriented community. In recent years, many mixed-use buildings have been built here. The area of Northgate mall has also been re-planned and designed into a higher density, more versatile suburban integrated community. However, many ground parking lots and single-family houses still exist here. Some roads do not even have exclusive sidewalks, which significantly affects the walking experience in the neighborhood.

Based on the problems these TOD communities have, the purpose of the thesis is to identify and compare urban morphology and urban design characteristics in the four different TOD cases. More specifically, this thesis will explore density, diversity, design, distance to transit, and destination accessibility in the built environment to analyze the TODs' urban morphology (Cervero and Kockelman 1997a; Ewing and Cervero 2010). Then, more focus will be on five urban design aspects (Ewing and Clemente 2013), including imaginability, enclosure, human scale, transparency, and complexity. The four TOD cases are distinct from each other for different development backgrounds, history, physical environments, and policies, which will also be discussed when analyzing the 'five Ds' aspects. There is less research interest in analyzing and comparing various aspects in the built environment and urban design of different TOD cases. It would be valuable and fill the gap on how different cases attempted to achieve transit-oriented development and influence different aspects of the built environment and the urban design.

1.2 Research Questions

The Master's thesis will focus on assessing the urban morphology and the urban design of four transit-oriented development areas in China and the United States. Built environment five 'Ds' aspects framework and urban design score sheet will be two tools for the assessment process. There are three questions that I am interested in studying.

- How can the two tools (Five 'Ds' framework and urban design score sheet) be applied for comparative analysis of TOD across a wide range of urban contexts both in China and the United States
- What are the characteristics and differences of the four TOD cases on the five 'Ds' urban morphological factors?
- What are the characteristics and differences of the four TOD cases on the five urban design factors?

In order to answer the research questions in a better sequence, the Master's thesis contains three parts, six chapters, and an abstract. The first part contains three chapters which include introduction, literature review, and methodology. The first chapter will introduce the thesis's background, problem statement, and research questions. The next chapter will discuss TOD-related topics and research in detail.

The literature will further establish the significance of the thesis and provide information on related urban design and built environment theories. Chapter three is a detailed introduction and description of the report's method of analyzing and comparing the different cases from five different urban morphological factors and five urban design aspects. The second part of the thesis is about the detailed introduction, analysis, and comparison of the four cases. Chapter four discusses each case's background, history, social and economic contexts, including detailed descriptions of existing station situations, TOD region boundaries, and future planned developments within the TOD region. Also, data related to the five urban morphological factors will be collected, analyzed, and compared between different cases. Next in the thesis comes to chapter five; based on the urban design score sheet, virtual site visits will be conducted. Data will also be analyzed and compared on different urban design aspects. The third section of the thesis is the conclusion and discussion part. The sixth chapter will conclude from the thesis's subject, methodology, and comparative results in both the urban morphology and urban design perspectives. In the end, I will also discuss the critiques for the two sets of tools in analyzing and comparing TOD's urban morphology and urban design.

2. Literature Review

The chapter will comprehensively discuss literature related to Transit-Oriented Development, built environment behaviors, and the relationship between TOD and urban design qualities. I will develop this chapter in the following sections:

1. Origins and definitions of Transit-Oriented Development;
2. TOD practices in cities around the world;
3. Research on the relationship between TOD and urban form;
4. Research on the relationship between TOD and urban design;
5. Assumptions and limitations of the two assessment tools.

2.1 Origins and Definitions of Transit-Oriented Development

2.1.1 Origins of Transit-Oriented Development Concept

Transit-Oriented Development (TOD) was first outlined by the American urban designer and architect Peter Calthorpe in his book *The Next American Metropolis: Ecology, Community, and the American Dream* (Calthorpe 1993). Originally, the purpose of TOD in North America was to fight against the rapid urban sprawl. With different contexts and more implementations around the world, TOD has become an urban planning tool to maximize the use of public transportation, encourage mixed land uses, and provide walkable community resources. According to the Transit Cooperative Research Program Report 102, different local transit agencies and governmental development departments will have different definitions when

constructing a TOD project (Goodwill and Hendricks 2002). Also, some different names were used in different contexts, such as transit-sensitive land use, transit-adjacent development, transit-focused development, etc. (M. Zhang 2007). However, no matter how different researchers or stakeholders used the term, the general concept is looking forward to building dense, mixed-use, pedestrian- and transit-oriented communities by using land use and transportation planning tools.

Later in 2001, Calthorpe and Fulton indicated that a successful TOD should meet the following four criteria, which are very important and guides for the future of TOD implementation (Calthorpe and Fulton 2001):

1. Decrease traffic congestion at a local or regional scale;
2. Make investments in transit more efficient in terms of costs and operations;
3. Increase the pedestrian friendliness of neighborhoods through urban design;
4. Increase mobility by increasing options for walking and offering viable housing alternatives to traditional suburban development.

Instead of focusing on building a new transit-oriented village or small town, Sara J. Hendricks and Julie Goodwill identified several approaches to fulfill the transformation from car-centered to transit-oriented communities, such as focusing transit-oriented development around park-and-ride lots, offering development

incentives, crafting TOD design guidelines, ensuring pedestrian and bicycle accessibility, and so on (Goodwill and Hendricks 2002).

2.1.2 Definitions of Transit-Oriented Development

TOD definitions are broad, conceptual, and vary from different scholars. Although multiple elements in social, economic, cultural, environmental, and other dimensions should be included in the definition, TOD's tangible physical characteristics make the concept measurable by quantifiable indicators that the thesis will research. From the first formal TOD definition by Peter Calthorpe, there are more definitions, including physical characteristics about the built environment:

- Peter Calthorpe defined TOD as “mixed-use community within an average 2,000-foot walking distance (10 minutes walking) of a transit stop and core commercial area. TODs mix residential, retail, office, open space, and public uses in a walkable environment (housing use: 60%, core commercial/employment use: 25%, and public use: 15%), making it convenient for residents and employees to travel by transit, bicycle, foot, or car” (Calthorpe 1993).
- Bernick developed a more detailed definition of TOD in 1997. He identified a half-mile buffer zone around the transit station and a quarter-mile transit village

extending from the transit station based on the original definition given by Calthorpe (Bernick 1997).

- Later, Cervero et al. concluded some of the TOD features “mixed-use development”, “development that is close to and well-served by transit”, “compactness”, “pedestrian and cycle-friendly environs”, “public and civic spaces near stations” and “stations as community hubs” (Cervero, Ferrell, and Murphy 2002).
- Moreover, some of the government transportation departments applied different definitions to TOD. For example, Maryland DOT defined TOD as “A place of relatively higher density (more than 50% multi-story apartments) that includes a mixture of residential, employment, shopping and civic uses and types located within an easy walk of a bus or rail transit center.” (Maryland Department of Transportation 2000). California DOT concluded TOD like this: “Moderate to higher density development, located within an easy walk of a major transit stop (usually within 5 minutes walking), generally with a mix of residential, employment, and shopping opportunities designed for pedestrians without excluding the auto. TOD can be new construction or redevelopment of one or more buildings whose design and orientation facilitate transit use” (California Department of Transportation 2001).

- Dittmar et al. described TOD as “a mix of residential, commercial and other public services, at medium to high densities, within a half-mile radius around transit stations” (Dittmar and Ohland 2004).
- The Institute for Transportation & Development Policy, a nonprofit organization that promotes sustainable and equitable transport worldwide, proposed eight key words - walk, cycle, connect, transit, mix, densify, compact, shift - that define TOD in its latest TOD 3.0 standard report (ITDP 2017).

2.2 TOD Implementations around the World

There are a couple of examples dealing with the relationship between TOD and urban or suburban development around the world. This literature review section focuses on some precedents that are considered to be successful in their specific economic, geographic, and cultural backgrounds.

2.2.1 Transit-Oriented Development in North America

Since transit-oriented development is a North American-derived concept, it is widely discussed under US cities in the 1990s and 2000s. However, the idea of orienting new developments along a transit system is not a new one in the US (Hank and Gloria 2003). TODs in the US aimed to prevent urban sprawl and low-density automobile-oriented suburbanization by emulating the forms of pre-automobile-era streetcar and commuter rail suburbs. It is a sustainable urban development solution

considering public transit, pedestrian, cyclists, and built environment characteristics (Belzer and Autler 2002; Bertolini, Renne, and Curtis 2009). European countries like Sweden and the United Kingdom also applied TOD concepts into station constructions before the initial introduction by Peter Calthorpe. In Sweden, Mattias Qviström & Jens Bengtsson have presented a case study of a Swedish town called Skurup with ambitious plans for TOD. They found that before Peter Calthorpe introduced the TOD concept in the 1990s, the town had developed strategies focused on rural-urban linkages and the interpretation of the railway and its role in the town, which became very influential for sustainable development of the town in later decades (Qviström and Bengtsson 2015). Salford Quays in the United Kingdom was a re-development project on the site of the abandoned Manchester Docks from the late 1980s, which aimed to build a mixed-use, residential, office, retail, and leisure site for local residents (Knowles, Ferbrache, and Nikitas 2020).

Arlington County in Virginia is one of the nation's best TOD successes of the past three decades, according to the TCRP report 102 (TCRP 2004). Arlington County is a county in the Commonwealth of Virginia, situated in Northern Virginia on the southwestern bank of the Potomac River directly across from Washington, DC. Since the 1970s, the county has become a popular place to live, work, and shop because of the high-density development along its two Metrorail corridors: Rosslyn-Ballston Corridor in the Metrorail's Orange Line (runs east and west) and Jefferson-Davis Corridor in the Metrorail's Blue Line (runs north and south). The following transit

network map (Figure 1) shows the two metrorail corridors and the transit network countywide.



Figure 1: Arlington County Transit Network (“MTP Transit Update Board Report” 2016)

Since 1960, over 31 million square feet of gross floor area (GFA) of office space and nearly 30,000 living units have been built in the County, and over three-quarters of them have been constructed around the Metrorail corridors (TCRP 2004). Unlike other postwar car-oriented suburban sprawl developments, TOD began in Arlington with planning efforts for the Rosslyn-Ballston Metrorail corridor, which aimed to

concentrate development around public transportation. Apart from this corridor, planners and government officials assumed that Arlington would continue to grow, so they focused on the public rail system construction and considered it the best strategy to deal with the growth in the future (Arlington County Government 2021). For example, Rosslyn transit station area study in 1977 addressed providing enough sidewalk to facilitate access to the Metro Station and prioritizing the construction of the commute bikeways to the Rosslyn Metro Station (Arlington County Government 1977). Another key to the development strategy was the use of “incentive zoning.” Developers received density bonuses for developing particular public elements, such as public plazas or allowances for bus stops. As a result, some high-density housing and offices were built within a quarter-mile radius of the metro station, providing easy access to work and living. Along the two corridors, sector plans are essential for station-wide development, developed after 1980 for each of the Metro Station areas within the corridor areas to maintain and enhance each neighborhood’s separate and distinctive characteristics as they evolved into “urban villages.” According to the sector plans, Rosslyn, Ballston, and Crystal City Stations have developed into business centers; Court House Station serves as a governmental center; Pentagon City Station has become a regional shopping center; Clarendon Station has the function as an “urban village” with small stores and restaurants; and Virginia Square Station has gained a cultural and educational focus (TCRP 2004). Due to the long-term and prospective development strategy, there are three corridors in the County right now, and two of them rely on various metro rail stations. Arlington County is now one of

the region's centers for commercial and high-density residential uses. According to the Arlington County Department of Community Planning, Housing and Development, 51% of Arlington's residents live in planning corridors, which make up 22% of the County's land area, and 85% of Arlington's population growth is forecast to occur in the planning corridors in the future. 69% of jobs are located in the planning corridors. In terms of transportation, there are 11 Metrorail stations in the County that average 89,545 entries and 88,106 exits daily, and 31% of Arlington's residents take the train to work (Department of Community Planning, Housing 2020).

2.2.2 Transit-Oriented Development in Europe

In Europe, there are also prior TOD examples. Vallingby in Stockholm was designed as a garden community near the railway infrastructure called the "ABC" area (arbete-bostad-centrum). It is a mixed-use community with residential uses, working places, and commercial areas (Stojanovski 2020). This example was known as a progressive approach towards what would be later called TOD.

Another successful example of implementing TOD concepts is the Copenhagen hand-shaped land-use transportation system, also known as the Finger Plan. The city of Copenhagen is the capital city of Denmark, located in the eastern region of the country on the island of Zealand. At the end of 2020, the city has a population of 799,541, while the larger great Copenhagen urban area has a population of 1,349,193 within 615 square kilometers of the total urban area (Statistics Denmark

2021). As the commercial, industrial, cultural, and political center of the country, the Danish government has figured out a lot of regional planning documents after World War II to ensure the greater Copenhagen's development and the whole national interests. The Finger Plan was conceived in the post-war years from 1945 to 1948 when the land use pressure outside of the city center was limited, and the plan was initiated by the private urban planning lab and implemented by a group of planners in the semi-independent regional planning office (Sørensen and Torfing 2019). The municipal planning in the greater Copenhagen area is still under the influence of the Finger Plan. Public transportation connects major cities and towns along with the fingers, making the whole region a great transit-oriented development paradigm.

As the following figure shows (Figure 2), the five fingers on the Finger Plan extend from the city center on the palm to the fingers on the north, west, and south sides, connecting the historical towns of Denmark. When the plan was carried out, these cities and towns were planned to be connected by a comprehensive, coordinated development of regions. With the continuous expansion of urban areas, the road and railway system connected all the small towns on the five fingers. They used green wedges exempt from urban development to separate different fingers (Cahasan and Clark 2004). Every railway station on each corridor would be the focal point for the high-density population, housing, and shopping facilities to relieve the stress of Copenhagen's CBD.

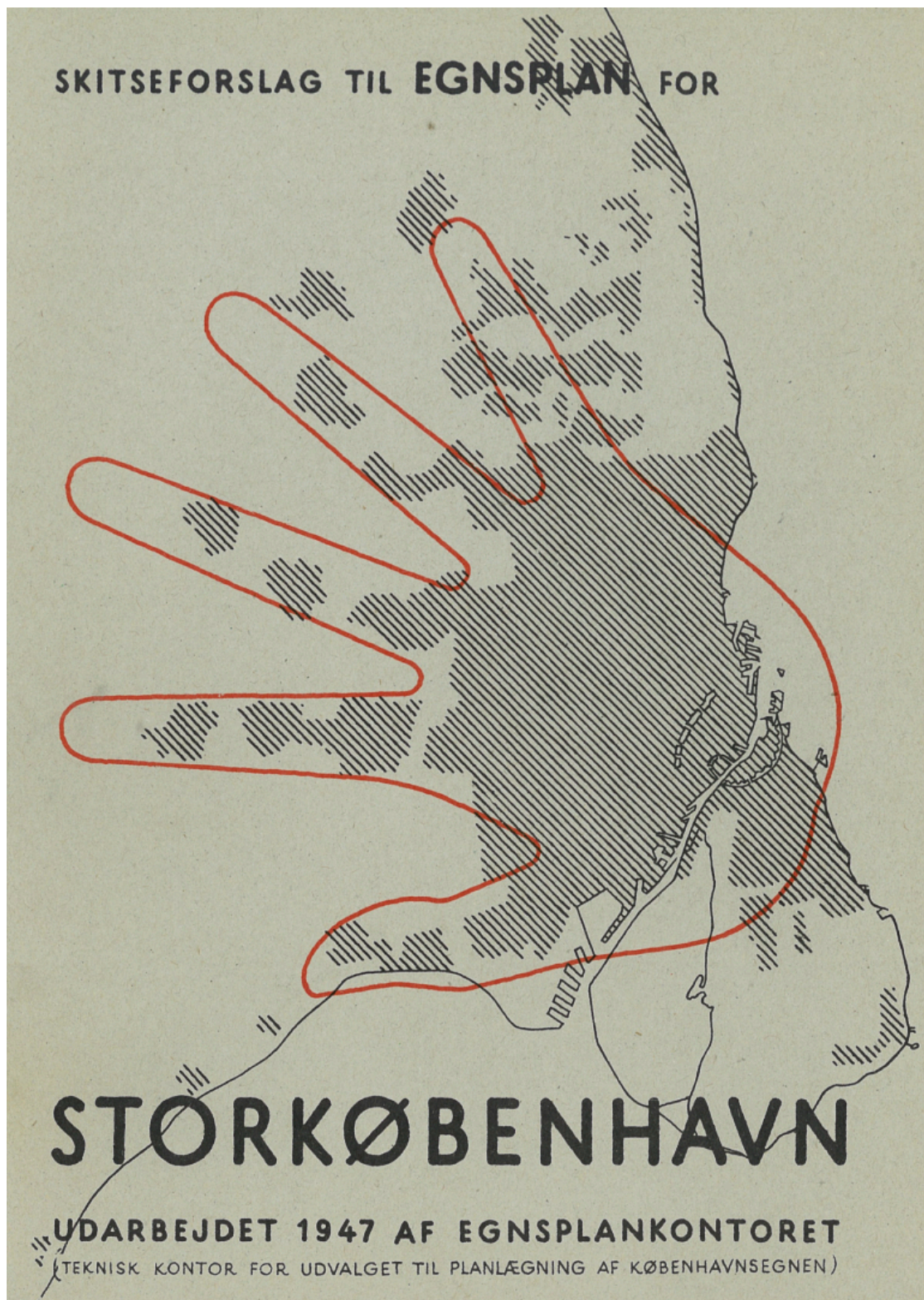


Figure 2: Copenhagen's 1947 Finger Plan. (Egnsplankontoret 1947)

In the 1990s, the Denmark government needed significant initiatives and investments to strengthen the national capital and international competition. As a result, the Ørestad New Town project was approved as one of the four mega projects in the Greater Copenhagen area. Ørestad New Town (Figure 3) is an essential example of TOD after the original Finger Plan in the area, which forms a new ‘finger’ of planned urban development for Copenhagen (Knowles 2012). Like other finger corridors, Ørestad TOD is highly accessible by public transportation and bicycles, and car parking is highly restricted for residents and visitors.

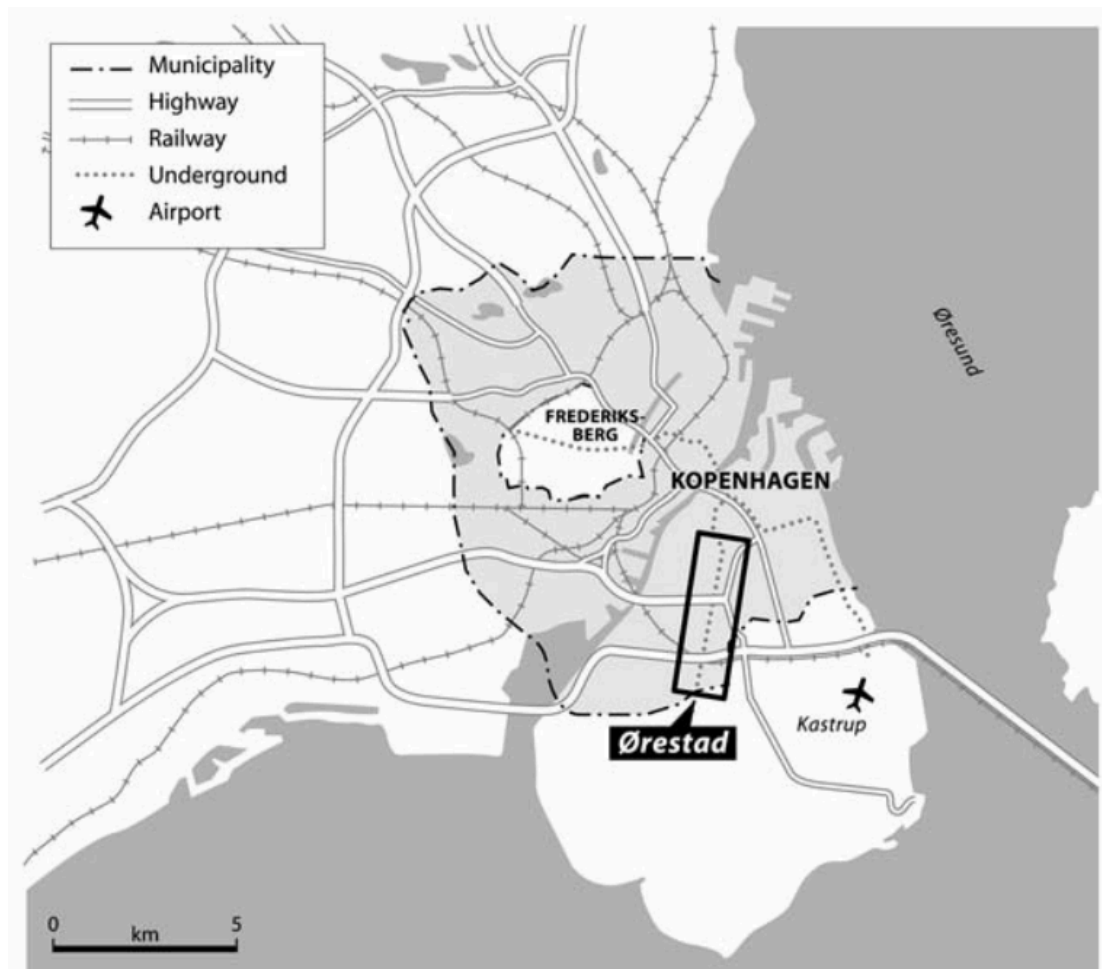


Figure 3: Ørestad location in the Greater Copenhagen area (Majoor 2008)

Apart from the rail corridors in the Greater Copenhagen area, another key policy that made it an impressive TOD example is the “Proximity-To-Station Policy.” Peter Hartoft-Nielsen concluded four main contents of the policy as follow (Hartoft-Nielsen 2002):

1. Workplaces should be within 600 meters from the transit stations, which will ensure working people can get to the offices in 10 minutes by walking;
2. Resident areas should be within 2000 meters from the transit stations, which will ensure residents quickly get around in the TOD community by foot or bicycle;
3. Public and commercial services should be closed to the stations;
4. Green open spaces between the fingers should be achieved easily.

In the Greater Copenhagen area, many planning and related urban, suburban, and rural development policies have created a comprehensive and advanced system of public transit-oriented, bicycle and pedestrian-friendly, urban and regional development.

2.2.3 Transit-Oriented Development in Asia

There are many successful TOD practices in Asia as well, and some are considered textbook examples of TODs that scholars worldwide have widely studied. Unlike TOD practices in America and Europe, TODs in Asia mainly address the high population density issue in urban built-up areas.

Singapore has widely been considered as an excellent example for implementing transportation and land use planning. Mees stated that Singapore has multi-modal planning, which means TOD takes advantage of the very high accessibility provided by both the rail function and on-street feeder modes. The city is generally regarded as the epitome of successful TOD (Mees 2014). In addition, Cervero (Cervero 1998) listed Singapore as one of the representative Asian sustainable transport metropolises in his book, which were also recognized by Newman and Kenworthy (Newman and Kenworthy 1999), Schwaab and Thielmann (Schwaab and Thielmann 2002), and other researchers.

In 1971, according to the first city-wide Concept Plan (Figure 4 upper), a ring-shaped city and the principle of transit-oriented new town development were initiated by the Urban Redevelopment Authority (URA). After revising by URA in 1991 (Figure 4 lower), a continuation of the Concept Plan 1971 was released (Urban Redevelopment Authority (URA) 1971; 1991). Based on the ring-shaped city, five radial “corridors” were added to strengthen the constellation’s urban form. It is similar to the Finger Plan in the Copenhagen area discussed in the previous section. Different centers are distributed along rail transit to balance occupation and residence and evacuate the population to reduce congestion in the city center (Niu et al. 2019).

1971 CONCEPT PLAN

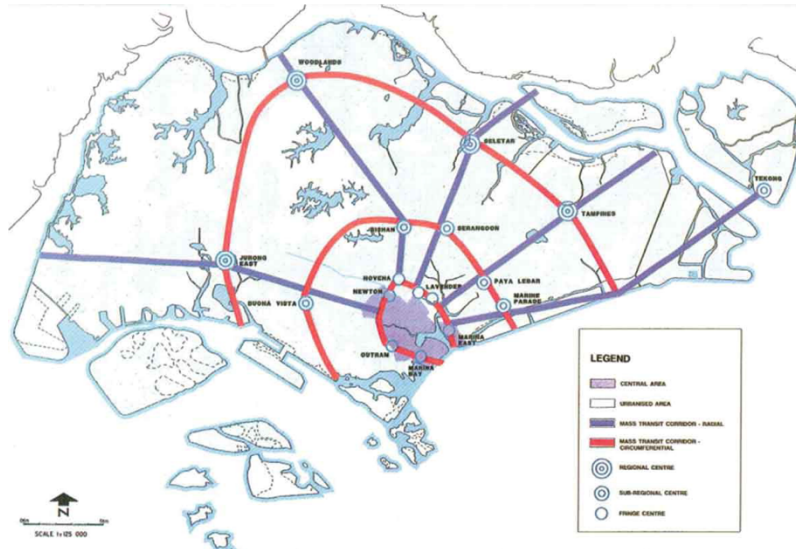
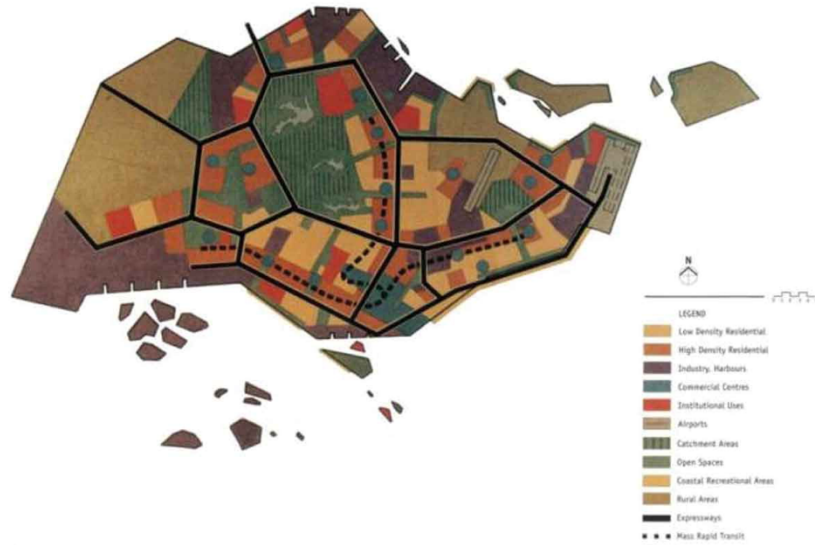


Figure 4: Concept Plan of Singapore 1971 (upper) & 1991 (lower) (Urban Redevelopment Authority (URA) 1971; 1991)

In terms of the influence of the TOD planning mode in Singapore, scholars have discussed it from various perspectives. Perry Yang and Seng How Lew concluded that the urban population in Singapore was gradually distributed over an extensive area with an increasing number of new towns with a lower density of population. On the one hand, the public housing developments decentralized population density in

the city center along with designated nodes and corridors. On the other hand, the centralization in the city center area benefited from the accessibility provided by the MRT system (P. P. J. Yang and Lew 2009). Also, they considered that urban design of transit-oriented new towns is also important, and according to their observations on different new town typologies, they stated that Singapore's new towns have been moving to a more transit supportive pattern with more openness of landscape to enhance the walkability (P. P. J. Yang and Lew 2009). However, some other scholars have criticized Singapore for not being pedestrian-friendly. Barter mentioned that one of Singapore's difficulties is the narrow alternatives to cars (Barter 2013). With the significant development focus on the urban rail system, it becomes the only alternative mode to car travel. However, various complementary transportation modes are also important in an integrated transport system, such as car sharing, cycling, buses, and even walking, which have been relatively ignored in Singapore. Besides transportation difficulties, Smith criticized public housing for being too uniform without architectural diversity. Also, the open spaces between the concrete high-rise public buildings are relatively restricted and useless, which results in a bad experience for walking in these blocks (Smith 2014).

2.3 Relationship between TOD and the Urban Form

Built environment means a human-made urban environment where people live and work. Urban planners usually use a variety of terms when discussing different aspects of the built environment. Although these terms and aspects are

interchangeable sometimes, the distinctions among them also need our discussions.

For example, urban design in the built environment can be the city's design at a particular scale and some concrete structures within the scale. The transportation system is also an important part of the built environment that influences the daily commute of residents, which includes the consideration of the physical infrastructures like roads, pedestrian sidewalks, bicycle lanes, public transportation systems, and so on (Handy et al. 2002). So, the transportation system belongs with the overall built environment content, and much research is focusing on how transportation planning influences the overall built environment.

By comparing the different impacts of built environment factors on vehicle miles traveled (VMT) in four US cases, Zhang and Hong et al. found that encouraging more compact, mixed-use, infill developments and smaller city blocks with various planning and policy tools can be effective in reducing VMT per person, as well as addressing traffic congestion, energy consumption, and environmental quality issues (L. Zhang et al. 2012). According to another recent research, built environment factors can also impact traffic safety, which pointed out that built environment variables including population, vehicle miles traveled, big box stores, intersections, and bus stops have a positive association with the crash frequency (Saha, Dumbaugh, and Merlin 2020). These policy-relevant variables of the built environment should be carefully treated when designing a TOD neighborhood because pedestrian-oriented is always important in a TOD region, which needs to

consider their safety when walking or traveling. The built environment also influences travel behavior. A case study of Buffalo, New York, has demonstrated that intellectual growth like promoting mixed land use development, high-density development, and dense street networks appears to be a valid way to encourage non-vehicle travel and transit usage (Tracy et al. 2011). A similar study has been conducted in China about how the built environment affects travel behavior differently between household members because of the unique household registration system. The results show that the built environment influences travel behavior significantly differently between the household head and other household members. For example, changes in the built environment do not influence car travel duration or frequency of the household head but significantly influence other household members (S. Yang et al. 2019). Although there are many examples discussing the relationship between the built environment and transportation planning mentioned above, most of them are concerned with the interactive influences between each other. They have not paid attention to the relationship between the built and transit-oriented development communities where walking or public transportation is the primary mode of residents' travel.

As a vital transportation planning and neighborhood design tool, TOD is also under the influences of different built environment aspects. There has been extensive research on the physical characteristics of a TOD development and its potential influences on regional economic development, the housing market, land use, and so

on. TOD influences both the public and private sectors because it yields benefits. The TCRP report identified primary and secondary classes of benefits and recipients of benefits. For example, the public sector will benefit from increased ridership and farebox revenues when implementing TOD. The private sector will benefit from increased land values, housing rents, and real estate performance (TCRP 2004). In terms of TOD's effects, there are numerous aspects discussed by researchers. Most of the evidence shows that the TOD impacts residents' travel choices. A case study of Santa Clara County's light-rail corridor found TOD residents patronized transit as their predominant commute mode more than five times as often as residents countywide (Gerston 1995). Also, TOD will impact citizens' patterns to choose the residential location and housing prices. Pengjun and Shengxiao stated that high housing prices nearby transit stations might force people to live far away from them (Zhao and Li 2018). So, promoting affordable housing near transit centers can contribute to diversity and equity in the communities when it comes to TOD projects.

However, this thesis focuses on the built environment expressions and urban design aspect of a TOD project. Urban design is a crucial aspect of a TOD project, closely related to its functions and aesthetics. Curtis, Renne & Bertolini defined the meaning of urban design in TOD to emphasize the shaping of a pedestrian-friendly mixed-use environment to create the convenience of using public transit (Bertolini, Renne, and Curtis 2009). After extensive research on which built environment elements are the most important for a successful TOD project, Kockelman and Cervero identified

“three Ds” (Density, Diversity, and Design) as a measurement of evaluating the built environment elements (Cervero and Kockelman 1997b). Later in 2001, Ewing and Cervero added another “two Ds”: Destination accessibility and Distance to transit (Ewing and Cervero 2001). Also, they identified five principal components when analyzing transit-oriented design. They are a mix of land uses, availability of convenience services, accessibility of services, perceived as safe and aesthetically pleasing (Ewing and Cervero 2001). Each principal component has several independent variables that need to be investigated when evaluating the transit-oriented design. For example, restaurants, banks, childcare centers, drug stores are independent variables under the principal component called the availability of convenience services. In 2010, they did another research stating that demand management could be a sixth D, and demographics can be the seventh D, even though it is not part of the environment (Ewing and Cervero 2010).

2.4 Relationship between TOD and the Urban Design

Urban design has developed in response to the limitations of the philosophies and design paradigms, rationalist and empiricist, of modern architecture and urban planning (Lang 2005). An excellent urban design project can bring together diverse functions and users, whereas good intentions with bad design would not improve, or even a detriment to the city or neighborhood planning (Cooper Marcus and Sarkissian 1986; Cooper Marcus and Francis 1998).

TODs are trying to accomplish many goals in the built environment for different types of users. The users include people who live, work, shop, or visit there. As user-oriented development projects, TODs should always consider their aesthetic feature because they provide both transit and an inviting and attractive environment for pedestrians and bicyclists (Seigman 2003; Dittmar and Ohland 2004). Many large-scale built environment features like transit service and housing have been discussed in the previous sections. The urban design stage of a TOD is where the goals and ideas of TOD are fitted into real-world constraints of space, time, and money (Jacobson and Forsyth 2008).

Dunphy discussed some of the urban design features in the book *Developing around Transit: Strategies and Solutions That Work*. For example, they pointed out that transit stops should be “attractive, comfortable, and sheltering” as well as well-located with an accessible walking distance. Also, they thought development and planning approaches should “encourage every price point to live around transit”, which means the importance of variety and complexity around the transit center. Besides, safety was also mentioned by them as a foundation of creating inviting public spaces, and designers could arrange more good lighting to avoid dark spots (Dunphy 2004).

2.5 Assumptions and Limitations

According to the literature review in the previous section, I assume that this five 'Ds' urban morphological framework and urban design scoring sheet can compare TOD cases across different national, social, and economic contexts.

However, I found that these two frameworks still have some limitations. The first is the lack of consideration of socio-economic factors in the urban morphological framework. Although the five 'Ds' aspects can describe most of the existing conditions of the built environment, the analysis of socio-economic background can explain the cause of the existing conditions and differences between different TODs. As a result, researchers can use the framework to evaluate the advantages and disadvantages of different TODs and whether TODs serve the whole community. In addition, the urban design scoring sheet does not carefully define how to select streets but rather generally mentions that the urban streets with commercial and mixed-use buildings can be scored using the sheet. This thesis will compare the streets in the four places with commercial and mixed-use buildings. However, due to differences in culture, construction standards, and economic background, the differences in the urban design caused by the differences have not been reflected in the scoring table.

Even though these two frameworks have the above limitations, I still chose them as my assessment frameworks for comparative analysis of TODs in China and the United States. On the one hand, many researchers have used these two frameworks

to analyze TOD cases of different socio-economic backgrounds and got good results. It can be considered that these two frameworks are suitable for TOD studies of different socio-economic backgrounds. For example, Bruce used the '5Ds' framework to analyze the construction characteristics and principles of Hong Kong's TOD and applied the principles into the TOD construction of Hexi New City in Nanjing (Bruce 2012). In addition, because China's urban design and TOD research started relatively late, a large amount of TOD planning and design experience draws on the cases of the United States and Europe. As a result, Chinese TOD's design principles are similar to those of the United States and Europe. Therefore, the urban design scoring sheet based on American urban design research is also of practical significance for China's TOD design assessment.

3. Methodology

This chapter is an explanation of the research questions and a detailed introduction of research methods. The thesis is an exploratory study on how the five 'Ds' urban morphological framework and the urban design score sheet can be used to characterize different transit-oriented development projects both in China and the United States. The methodology consists of the descriptive analysis and comparative studies of the urban morphology and urban design in the four different transit-oriented development neighborhoods.

The descriptive analysis of the TOD cases is from two different perspectives. The first analysis applies Cervero's five 'Ds' aspects of the built environment. The second urban design analysis applies the urban design score study from Reid Ewing and his co-researchers, which only concentrates on five different urban design qualities that influences pedestrians' perceptions of the block. The five 'Ds' framework includes assessing the TOD area's density, diversity, design, distance to transit, and destination accessibility. The urban design score framework includes aspects of imageability, enclosure, human scale, transparency, and complexity of a TOD project. I, as the observer, through data gathering from government websites, virtual site visits from online maps, and analysis of maps and other planning documents, will discuss the current development and situations of the four TODs and their surrounding areas on urban morphology and urban design.

3.1 Approaches to Address the Research Questions

The key focus of the thesis is to use the five 'Ds' urban morphological framework and the urban design score sheet to characterize and compare different TOD communities in China and the United States. Based on the literature review in the previous chapter, the topic is limited to focusing on a specific TOD project or several different TOD projects in the same area; therefore, this research intends to explore some TOD cases worldwide and explore the differences among them. The following approaches can answer the three research questions raised in Chapter 1.

- How can the two tools (Five 'Ds' framework and urban design score sheet) be applied for comparative analysis of TOD across a wide range of urban contexts both in China and the United States

According to the case studies in the second part of the thesis, I will apply the five 'Ds' urban morphological framework and the urban design score sheet to analyze different TOD projects. The data will be collected and analyzed to understand the differences in urban design and urban morphological aspects. Data will be the government land use data, housing data, demographical data, and virtual field observations of the physical environment within different TOD areas.

- What are the characteristics and differences of the four TOD cases on the five 'Ds' urban morphological factors?

For each case, I will analyze on the five 'Ds' urban morphological aspects. Then, I will also compare the situations in different TOD communities by different urban morphological aspects. The characterize and compare process will explore whether the five 'Ds' urban morphological framework fully represents the built environment situations in different TODs and whether more factors or elements need to be discussed in further research.

- What are the characteristics and differences of the four TOD cases on the five urban design factors?

I will conduct the analysis about urban design qualities by implementing the urban design score sheet from Reid Ewing and his co-researchers for each case. I will also be the main observer of the urban design elements using online map tools to have several virtual site visits. Then, I will also compare the situations in different TOD communities by different urban design qualities. According to the characterize and compare process, I will explore whether the urban design score sheet fully represents the urban design situations in different TODs and whether more factors or elements need to be discussed in further research.

Finally, according to the results and the differences between different TOD cases on the built environment aspects and urban design qualities at the neighborhood level,

some key factors and elements will be defined as the critical parts for driving and encouraging future TOD constructions at the end of the thesis.

3.2 Research Methods

3.2.1. Combination of Theoretical and Empirical Research

Transit-Oriented Development is a design concept derived from the urban planning field in the United States, and the built environment-related research is also mainly concentrated in Europe and the United States. Therefore, to evaluate the impact of TOD implementations on the built environment and urban design, it is necessary to read numerous relevant literature and case studies focusing on these areas. These documents include books, journals, academic papers, website materials, government planning policies, design documents, etc. Focusing on the TOD theories, discussing the relationship between TODs and the built environment aspects and the urban design field is also essential, which is the primary theoretical study of TOD.

At the same time, as efficient urban design research, TOD research follows the logical thinking of "raising questions-theoretical research-empirical research-drawing conclusions" in the process. Therefore, when studying the relationship between the built environment, urban design, and TOD built-up areas, empirical research will also be conducted through data collection and analysis from different cases.

3.2.2. Combination of Comparative and Case Studies

By analyzing and comparing different aspects of the built environment in various TOD build-up zones, it is clear that the TOD model is not only a narrow transportation planning tool but a part of comprehensive urban planning that will concentrate on population, employment, and transportation facilities. By comparing different TOD models worldwide and analyzing their development background, history, city context, and various aspects of the built environment, I can identify the key built environment and urban design factors that have an essential impact on TODs.

3.2.3. Combination of Qualitative and Quantitative Research

This thesis will use the logical induction method to explore the different built environment aspects within a TOD community. On this basis, I will further explore the interaction between TOD build-up regions and the specific urban block design. At the same time, the mix-method of qualitative and quantitative research will be conducted in analysis. Applying the evaluation system for the different urban built environment aspects and the urban design will help conduct descriptive and scoring research on different TOD build-up areas.

3.3 Research Data

3.3.1 Primary Data

To explore and understand the current urban landscapes in each of the study areas before more in-depth studies, I will include several times of field observations. Due to

the cases being spread worldwide, the observation will be dependent on visual 3D maps or 2D street plans from websites or software like Google Earth, Google Maps, Openstreet Maps, Mapbox, and Gaode Map (高德地图). Major shopping centers, residential clusters, office buildings, community services, and other public spaces within the study area will be studied, and these locations are essential for the later evaluation on the aspect of community design around the TOD region. All the estimated distances or urban design elements are measured through these online mapping tools. This part of data collection aims to identify the actual locations and the availability of different urban design elements and services within case study areas.

3.3.2 Secondary Data

According to the discussion in the literature review section, impacts and before-after analysis has been conducted for various transit-oriented development projects.

Information on these related topics and TODs can give me a brief idea of what data they have been collecting and where to find them. This research first looked at the density and diversity at each study area, which needs various demographic and land information data. By collecting data about population, land area, and land uses, I can determine the population density, residential density, land use diversity, and other indicators to evaluate the first 'two Ds'. The data sample for this part is mainly from city government open data or transportation operation companies of these TODs. Others may be from previous research that also focused on the cases in this thesis.

3.4 Study Areas

Four TOD cases will be included and closely studied in the thesis: Northgate Station in Seattle, Hudson Yards Station in New York City, Chengdu East Railway Station in Chengdu, and Kowloon Station in Hong Kong. Besides these four transit stations, the neighborhoods within the 600-meter radius circle will be selected at the four study areas to conduct the urban morphological analysis. A particular street in each area will also be selected for the urban design study. All the selected cases and neighborhoods are shown in the following figures.

At Hong Kong Kowloon study area (Figure 5), the study area has shifted to the left of the reference 600-meter circle to include the Kowloon historical and cultural park considering that people can get to the park by pedestrian bridge from the Kowloon station. The reason for including the park is that it provides passengers or visitors with more purpose of using the station. It also serves as an important open space for the TOD users and the people who live in the more east residential clusters.

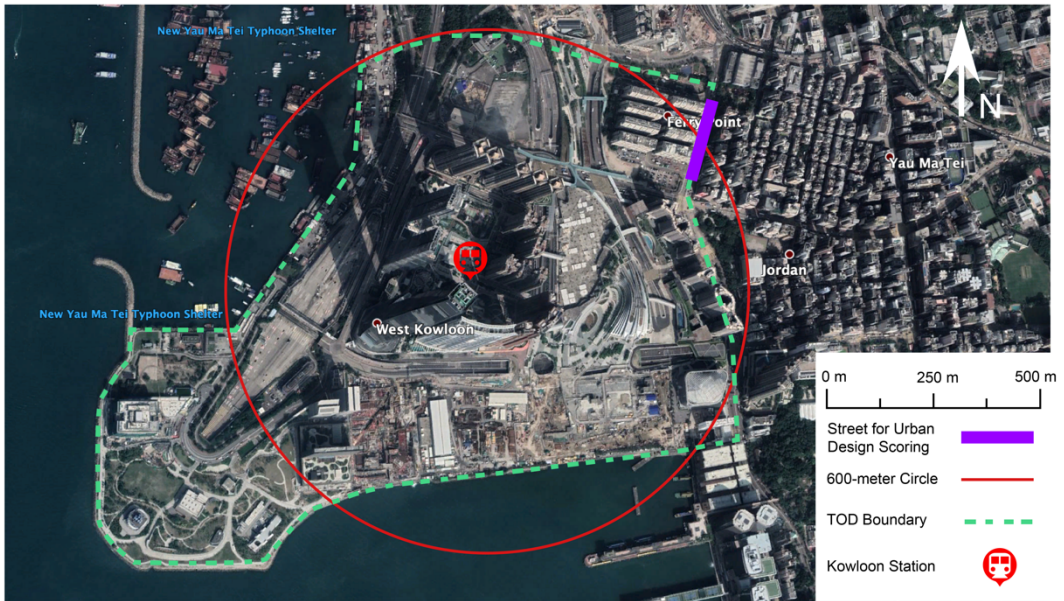


Figure 5: Hong Kong TOD Study Boundary

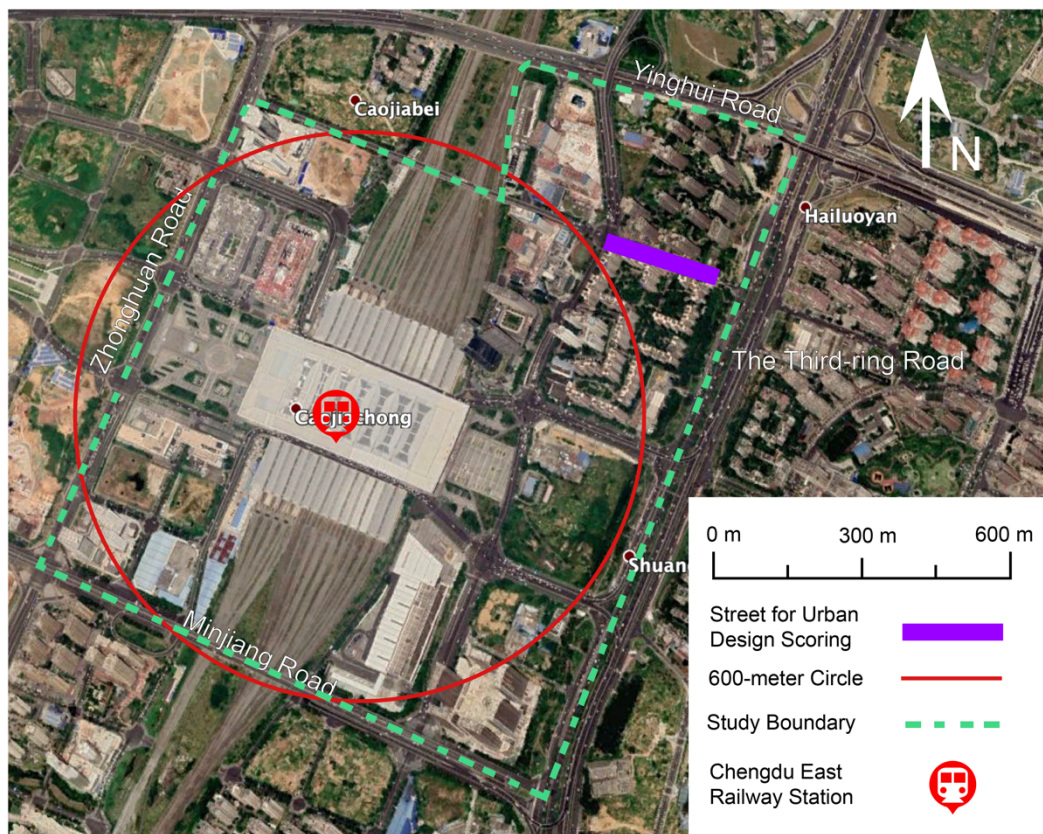


Figure 6: Chengdu TOD Study Boundary

The area delineated Chengdu East TOD area (Figure 6) is larger than the circle by 600 meters. I want to include the northeast corner of the area in the analysis because there is the principal residential area of the entire TOD area. Yinghui Road bounds the entire TOD area to the north, the city's main Third-ring Road to the east, Zhonghuan Road to the west, and Minjiang Road to the south.

Unlike Chengdu TOD, the area of Hudson Yards TOD (Figure 7) in New York City is smaller than the entire 600-meter radius circle. One reason is that the Hudson River to the west reduces the overall area of the study area. In addition, the blocks in the northeast corner are mainly the entrance of the 495 Highway, which is not considered a part of the study area. Therefore, the northernmost street of the entire area is West 38th Street, the west is 12th Ave, the east is 9th Ave, and the south is West 25th Street.



Figure 7: New York City TOD Study Boundary

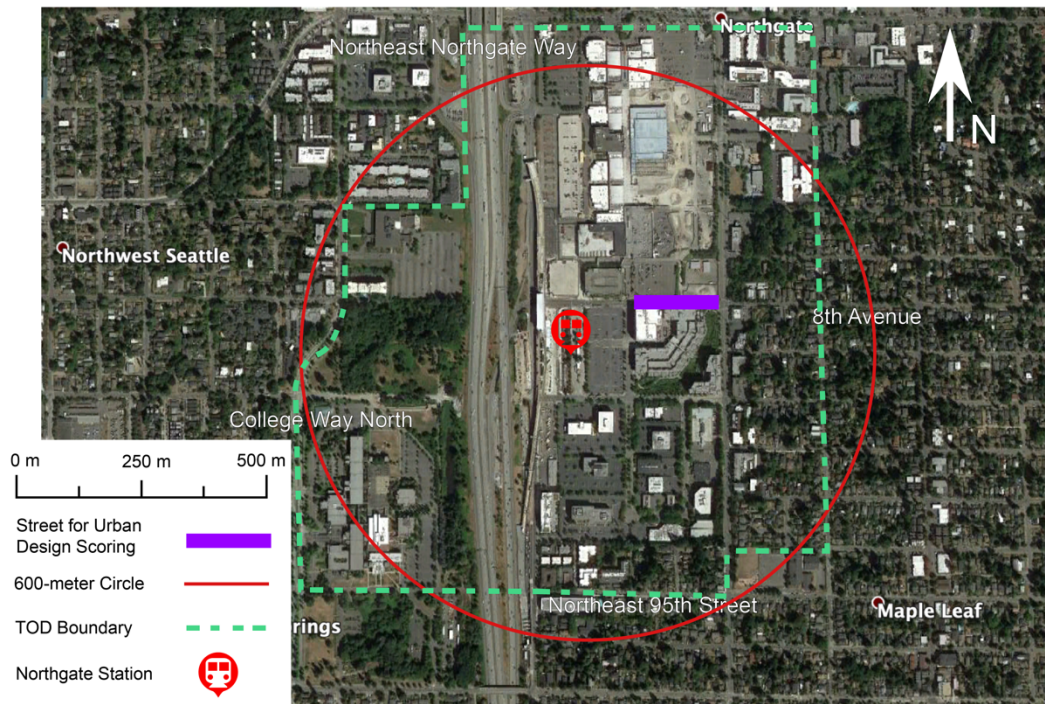


Figure 8: Seattle TOD Study Boundary

The Northgate TOD study area (Figure 8) in Seattle contains the interstate-5 highway that runs from the north to the south and divides the entire region into two parts, east, and west. The North Seattle College mainly occupies the west part, and a large part of the east belongs to the Northgate Mall. There are also some single-family housing, multi-family and mixed-use apartments, and office buildings in the southeast.

Therefore, the northern boundary of the entire area is Northeast Northgate way, the east is 8th Ave, the south is Northeast 95th St, and the west is College Way North.

According to the literature review, I select all the four study areas for the following reasons:

1. According to the research subject, all the study areas developed a transit-oriented development concept based on a subway transit station. All the stations are located within the city's central areas. For example, Hudson Yards is located in Central Manhattan near Central Park, and Kowloon Station is built in the central business district area and near large tracts of residential areas.
2. In order to reduce the deviation and ensure the accuracy of the analysis, all the four selected study areas are of a similar scale. Besides the subway stations, heavy rails assume the role of regional connectivity, which brings complexity and diversity to the definition of the transit center in transit-oriented development concept. For example, the Hong Kong Kowloon Station TOD area includes the Kowloon subway station and the surrounding West Kowloon High-speed Railway Station, which can provide rail services to Guangzhou, Shenzhen, and even Beijing in Mainland China cities. Chengdu East Railway Station was originally a regional railway station hub, and then subways and complex bus lines were built.
3. Except for Seattle, the selected cities have similar urban populations, urban areas, and regional population densities. On the one hand, I can analyze the influences of TOD projects on both built environment and urban design under similar demographic and geographic backgrounds. At the same time, selecting Seattle as a typical TOD representative in low-density and suburban

areas can also compare and analyze the similarities and differences with TOD models in high-density urban built-up areas.

4. The four selected TOD areas have highly mixed land-use types and multiple functions such as commercial, residential, office, and recreational open spaces. At the same time, there are high-quality urban design and related new development projects around the transportation center.
5. The four selected TOD projects have multiple transportation facilities.

Northgate in Seattle is the least, but people can also take the city light rail and use the bus service from here. People who live, work, or visit here can access different destinations through different modes of transportation. There are destinations like grocery stores and community service centers within the TOD region. People can also reach airports or city central business districts outside the range of TOD by multiple public transportations.

3.5 TOD Assessment Frameworks

Over the past decades, TOD has gained popularity as an urban planning tool to solve urban problems like traffic congestion and allocate high population density, even though the original purpose of developing TOD was to gather people living and working in a pedestrian-friendly transit-oriented circle. At this time, various scholars, city planners, and organizations worldwide support the application of TOD in both urban centers and suburban areas. It is not only because the TOD concept has gained success in most cities around the world but also because it will promote the

sustainability and accessibility of TOD neighborhoods and increase the diversity of built environment elements. As discussed in the literature review, many articles, reports, and plans pointed out the potential benefits of TODs in various aspects, like the influences on transit ridership (Cervero 2007), land value (Higgins and Kanaroglou 2018), and traffic efficiency (Lee et al. 2019), etc. However, little empirical research has been done to measure the outcomes of TODs around the world, especially the outcomes in neighborhood urban design qualities. Therefore, applying the urban design score sheet and five 'Ds' urban morphology analysis will help people know if the two assessments work well worldwide.

3.5.1 TOD Analysis on the Built Environment Five 'Ds' Aspects

Transit-Oriented Development outcomes are challenging to evaluate, while many professional sources in the literature section have been working on developing a list of indicators to help people know the efficiency of a specific TOD. TOD assessing framework on the urban morphological 'five Ds' aspects is based on the research from Cervero and Ewing in 2010 (Ewing and Cervero 2010). They provided a good source and starting point for analyzing built environment aspects in diverse urban areas. However, there are only three 'Ds' (density, diversity, and design) in his earliest research in 1997 (Cervero and Kockelman 1997b). Cervero's meta-analysis of the built environment and travel behavior literature existing at the end of 2009 added another two 'Ds' as measures when analyzing travel and the built environment (Ewing and Cervero 2010). Each of the five 'Ds' is useful in analyzing the urban

morphology. It is also valuable for assessing TOD projects because TOD can be an essential development form within the urban boundary to address urban sprawl, travel congestion, and other transportation issues.

In the following years, researchers have defined the 'sixth D' as demand management and a seventh component as the high frequency of public transit in the TOD (Cervero and Day 2008; Ewing and Cervero 2010; Cervero 2013). Still, Cervero has also defined a 'seventh D' as demographics (Cervero 2013). However, there remain considerations and discussions about the sixth or the seventh factor, I will not include either demand management or demographic in this thesis. For example, some researchers defined safety and aggregated neighborhood characteristics as the sixth and seventh factor of urban morphology, which considered the neighborhood lighting, crime, and environmental factors in forming the framework (Zapata-Diomedes and Veerman 2016). The definitions of the 'five Ds' will be explained in the following paragraphs:

- Density

Density is usually a variable of interest per unit area (Ewing and Cervero 2010; Bruce 2012). Some commonly used attributes of the density could be population density, dwelling unit density, and employment density. In the thesis, density is the population density around different TOD regions, the residential housing unit density, and commercial area density (Table 1).

- Diversity

Diversity refers to the differentiation of land-use types in a specific boundary around the TOD or the degree to which different land-use types represent the region's total land area (Ewing and Cervero 2010; Bruce 2012). To get more details in diversity, there are also some commonly used attributes like entropy measures of diversity, jobs-to-housing and jobs-to-population ratios. In this thesis, the number of different land-use types near the transit center and the proportion of different land-use types are two indicators to analyze the diversity of different TOD regions in this thesis (Table 2).

- Design

The design will be the most important part of built environment evaluation in the thesis. With more consideration given to the design aspect, there will be multiple categories in this broad factor. Firstly, design means the design of the street network characteristics within the TOD area. As Cervero mentioned in his article, usually in an urban area, a street network can be the scale of straight roads and boulevards. However, in suburban areas, there are more curved streets like loops and cul-de-sacs. Street network design refers to the block sizes, the number of four-way intersections, and the number of intersections per unit of area. Another category aims to evaluate if the TOD is pedestrian-friendly, concentrating on elements like a pedestrian crossing, street trees, street width, sidewalk width, bicycle lane, and

building setbacks (Ewing and Cervero 2010; Bruce 2012). I will consider the block size, the total length of main roads and bicycle lanes, the number of sidewalks, the number of four-way intersections, and pedestrian crossings in the thesis (Table 3).

- Distance to transit

Distance to transit always refers to the distance from the residences or workplaces to the nearest rail station, bus stop, or subway station. It could be the average shortest distance from living or working spaces to the nearest transit stop within the TOD region. Also, other measurements like transit route density or coverage, the average distance between transit stops, or the number of transit stops per unit area could be discussed to compare the situation of distance to transit (Ewing and Cervero 2010; Bruce 2012). Some common attributes like distance from the residences or workplaces to the nearest transit stop, transit route density, distance between transit stops, number of stations per unit area are used in distance to transit study. This thesis will consider three different indicators to analyze the distance to transit: the average walking distance to the transit center, the number of secondary transit stops, and the number of operational transit lines in the TOD region (Table 4).

- Destination accessibility

Destination accessibility means how accessible for different places inside or outside the TOD region that people would often go (Ewing and Cervero 2010; Bruce 2012). More specifically, the outside destinations may be the downtown area, airport, central

railway station, etc. The inside destinations could be convenience stores, pharmacy stores, restaurants, or other community services. So, for these outside destinations on a large scale, destination accessibility can be the transit time to airport or downtown areas. For the inside local destinations, destination accessibility can be the number of stores or recreational places within the TOD region (Table 5).

Table 1: Density Indicators

Group	Indicator	Calculation
Density		
	Population Density	Total population/Total land area (people/square kilometers)
	Residential Density	Living units/Total land area (units/square kilometers)
	Commercial Density	Commercial floor area/Total land area

Table 2: Diversity Indicators

Group	Indicator	Calculation
Diversity		
	Land Use Types	Number of land use types next to the transit center
	Land Use Proportions	Proportion of one specific land use type (residential, commercial, etc.)

Table 3: Design Indicators

Group	Indicator	Calculation
Design		
	Average Block Size	Total land area/number of blocks (square kilometers)
	Length of Main Roads	The total length of main roads within the region (meters)

	Length of Bicycle Lanes	The total length of bicycle lanes within the region (meters)
	Number of Sidewalks	The total number of sidewalks between blocks within the region
	Number of Four-way Intersections	The total number of four-way intersections within the region
	Number of Pedestrian Crossings	The total number of pedestrian crossings within the region

Table 4: Distance to Transit Indicators

Group	Indicator	Calculation
Distance to Transit		
	Average Walking Distance to Transit Center	The total walking distance to transit center from different blocks/total number of walking routes (meters)
	Number of Secondary Transit Stops within the Region	The total number of the transit stops (bus/streetcar/subway stations) within the region
	Number of Operational Transit Lines	The total number of the operational transit lines within the region

Table 5: Destination Accessibility Indicators

Group	Indicator	Calculation
Destination Accessibility		
	Transit Time to Airport	The quickest transit time to the local airport (minutes)
	Transit Time to Downtown Area	The quickest transit time to the downtown area (minutes)
	Number of Grocery/Convenience Stores within the Region	The total number of grocery/convenience stores within the region
	Number of Recreational places within the Region	The total number of recreational places within the region

3.5.2 TOD Analysis of Neighborhood Urban Design

Transit-Oriented Development is essential for building a walkable and pedestrian-friendly neighborhood, influencing local urban design qualities on a human scale. According to the report on Measuring Urban Design Qualities by Reid Ewing, several aspects of urban design were carried out in detailed analysis (Ewing et al. 2006; Ewing and Handy 2009; Ewing and Clemente 2013). In the previous section, I discussed the measurements of the urban morphology, which are much more general, such as the neighborhood density and diversity. Also, the urban morphology assessment lacks details when focusing on the detailed street design that pedestrians can see and feel. In order to realize the small-scale urban design characteristics in different TODs, more focus will be put on the streets or blocks of the TOD neighborhood when considering the urban design qualities because streets are busy places with people walking, shopping, dining, and engaging in daily activities.

Otto Clemente and Reid Ewing have worked out an urban design score sheet to measure essential urban design qualities of streetscapes (Ewing and Clemente 2013). The report provides a mixed qualitative and quantitative method to analyze several critical urban design aspects. It then provides guidance on how to measure and calculate different urban design qualities.

- Imageability

According to Ewing and Clemente, imageability is an urban design quality that makes a place distinct and memorable. So, a place has a high imageability when special building types and street identities capture people's attention (Ewing and Clemente 2013). However, imageability is a term firstly introduced by Kevin Lynch in his 1960 book, *The Image of the City*. And it is a measurement of how easily a physical object or environment will evoke a clear mental image in the mind of any person observing it (Lynch 1960). Imageability is related to "sense of place" that landmarks are an important component of it. Gordon Cullen (Cullen 1961) asserts that a characteristic visual theme will contribute to a cohesive sense of place and will inspire people to enter and rest in the space. For example, the street in the following figure (Figure 9) at Hudson Yards TOD community could be rated high in Imageability because of the memorable and artistic building.



Figure 9: The Vessel at Hudson Yards TOD Community (“The Vessel at Hudson Yards Is Closed After a Third Suicide” n.d.)

- Enclosure

Enclosure means the degree to which streets and public spaces are visually defined by buildings, walls, trees, and other vertical elements. So, a place has a high enclosure when there is a high proportion of vertical elements according to Ewing and Clemente. Cullen (Cullen 1961) states: “Enclosure, or the outdoor room, is, perhaps, the most powerful, the most obvious, of all the devices to instill a sense of position, of identity with the surroundings...It embodies the idea of hereness.” In an urban setting, enclosure is formed by lining the street or plaza with unbroken building fronts of roughly equal height, and the buildings become the walls of the room, while the streets and sidewalks become the floor that people can use to get around in the room. Enclosure also reflects the density in the urban area. For example, at low suburban densities, buildings become less important in defining the community because they are only 1-2 floors high with large gaps between different buildings.

- Human scale

Human scale refers to the physical size of street elements that match the size of humans. Building details, pavement texture, street trees, and street furniture are all physical elements contributing to the human scale. Building floor is an important criterion to assess the human scale in the urban design. Alexander et al. (Alexander,

Ishikawa, and Silverstein 1977) state that any building over four stories tall are out of human scale. Lennard sets the limit at six stories instead (Lennard and Lennard 1987). Human scale can be also defined by human speed and street trees according to other researchers (Kay 1997; Arnold 1993). Alexander et al. also motioned that the recognizable lengths are important when setting the limits of human scale for social interaction (Alexander, Ishikawa, and Silverstein 1977).

- Transparency

Transparency refers to how people can see or perceive what lies out of the current street or the block. In the TODs, transparency means how much people can perceive outside of the TOD region. Physical elements that influence transparency include walls, windows, doors, fences, landscaping, etc. (Ewing and Clemente 2013). The most classic example of transparency is the shop display windows that invite passersby to look into and then come into the shop. However, blank walls or reflective glass windows are two examples of design elements that do not provide enough transparency. The following figure (Figure 10) is an example to show the low transparency in Hong Kong. Because of the high density of buildings in Hong Kong, the city tends to develop in a vertical direction. Overpasses and brick-walled buildings along the streets will make people feel like they are in a confined space.



Figure 10: Street view at Kowloon TOD in Hong Kong, rating low in transparency

- Complexity

Complexity refers to the visual richness of a place that is not the same as the diversity in the built environment. The complexity of a region depends on the variety of the physical environment, like the numbers and kinds of buildings, various architectural ornamentations, different landscape elements, and street furniture (Ewing and Clemente 2013). According to Jacobs and Appleyard (A. Jacobs and Appleyard 1987), narrow buildings in varying arrangements add to complexity, while wide buildings subtract. Allan Jacobs (Allen Jacobs 1993) refers to the need for many different surfaces over which light is constantly moving in order to keep eyes engaged with the streets.

However, at the very beginning, Ewing and Clemente identified three more urban design qualities through literature review, such as Linkage (the physical and visual connections from building to street) and Coherence (a sense of visual order and arrangement of buildings, landscaping, street furniture, and other physical elements). Then, they obtained video records of relevant research blocks, showed these videos to expert panel members for viewing, and used surveys to record their evaluation of relevant urban design qualities. Five criteria for selecting urban design qualities to operationalize were set, and they are significant relationship of the quality to overall walkability ($p \leq 0.05$); ability to measure the quality with at least moderate inter-rater reliability ($ICC \geq 0.4$); ability to explain overall variations in the quality to a moderate degree with measurable scene variables (explained portion > 0.3); ability to explain scene-specific variations in the quality to a substantial degree with measurable scene variables (explained portion > 0.6); and ability to measure these same variables with at least moderate inter-rater reliability ($ICC > 0.4$) (measuring the urban design). Through analysis, only the above five urban design qualities meet all the above criteria, so others such as linkage have very little potential for operationalization, and they will be given no further consideration (Ewing and Clemente 2013).

At last, Ewing and Clemente provided a scoring sheet (Table 6) that can be used on field observations to record measurements and calculate urban design quality scores. The scoring sheet summarized field measurements and provided a multiplier to be applied to each relevant physical feature in order to compute an overall urban

design quality score. According to their research, data on urban design in New York City were collected by a field team in the University of Columbia who audited a total of 588 block faces, and the team used Ewing and Clemente's descriptions of various urban design characteristics in the five urban design aspects to validate the accuracy of these five urban design aspects through a field survey of the 588 neighborhoods. Finally, the coefficient of each urban design characteristic is calculated to modify the scoring model of the entire urban design. These coefficients are the multipliers of each indicator in the final scoring sheet. Since then, some scholars have verified the accuracy of the entire scoring model through research in other places. For example, Hamidi and Moazzeni (Hamidi and Moazzeni 2019) measured all urban design features associated with each quality using Ewing and Clemente's field manual and used the coefficients from the original study to compute the value of urban design qualities in Dallas, TX, and found that imageability and complexity significantly influence pedestrian volume in downtown areas, which is also in agreement with the original research in New York City.

Based on the scoring sheet, I will use Google Map, Google Earth, and Gaode Map (高德地图) as tools to conduct the virtual site visit, and I will make sure the maps that I will use are in a similar period to reduce the deviations. These online tools are challenging to measure, like the number of people and noise level in the imaginability part, and I will estimate numbers based on the neighborhood residential density in the built environment analysis part.

Table 6: Urban Design Qualities Score Sheet (Ewing and Clemente 2013)

Measuring urban design qualities scoring sheet				
Group		Value	Multiplier	Multiplier*Value
Imageability				
	Number of courtyards, plazas, and parks		0.41	
	Number of major landscape features		0.72	
	Proportion historic building frontage		0.97	
	Number of buildings with identifiers		0.11	
	Number of buildings with non-rectangular shapes		0.08	
	Presence of outdoor dining		0.64	
	Number of people		0.02	
	Noise Level		-0.18	
			Add constant	2.44
			Imageability Final Score	
Enclosure				
	Number of long sightlines		-0.31	
	Proportion street wall (one side)		0.72	
	Proportion street wall (opposite side)		0.94	
	Proportion sky (ahead)		-1.42	
	Proportion sky (across)		-2.19	
			Add constant	2.57

			Enclosure Final Score	
Human Scale				
	Number of long sightlines		-0.74	
	Proportion windows at street level		1.1	
	Average building height		-0.003	
	Number of small planters		0.05	
	Number of pieces of street furniture and other street items		0.04	
			Add constant	2.61
			Human Scale Final Score	
Transparency				
	Proportion windows at street level		1.22	
	Proportion street wall		0.67	
	Proportion active uses		0.53	
			Add constant	1.71
			Transparency Final Score	
Complexity				
	Number of buildings		0.05	
	Number of basic building colors		0.23	
	Number of basic accent colors		0.12	
	Presence of outdoor dining		0.42	
	Number of pieces of public art		0.29	
	Number of walking pedestrians		0.03	
			Add constant	2.61

			Complexity Score	
			Final Total Score	

One street will be selected for virtual visiting and recording all the above physical elements in each case. The street I select is in a general urban or suburban area with mixed-use buildings, small retails, and public places, and all the TOD cases have these types of functions. After picking the general area I want to assess, I will establish the boundaries of a specific street that I will focus on. The length of the street is about 300 meters, which is longer than the 300 feet mentioned by Ewing and Clemente, because all the study areas have long blocks in length. Although I will conduct the site visits by online map tools, I will also be visiting the study street virtually several times to make better and accurate measurements. However, depends on the results from only one street, I cannot make solid conclusions to state the urban design qualities of the overall TOD area. Further study about various streets and multiple times of physical site visits should be conducted if I want to conclude the urban design qualities of the four cases. So, my findings about urban design qualities are more as a way of demonstrating the use of urban design score sheet assessment rather than a conclusive analysis of different TODs.

4. Case Analysis on Urban Morphological Factors

4.1 Hong Kong - Kowloon Station TOD

4.1.1 TOD's Background in Hong Kong

Hong Kong is a special administrative district of the People's Republic of China and the world's most important financial center. The city has only 1.11 thousand square kilometers of territory, which is one-sixteenth the capital city of China, Beijing, but also has just one-third the population of Beijing, which makes Hong Kong one of the most densely populated cities in the world. Regarding transportation, Hong Kong is famous for its high-efficiency MTR (Metro Transit Railway) system. Hong Kong is not like most of the mainland China cities (Beijing, Wuhan, etc.) as regional transportation hubs that have multiple regional high-speed railway lines to provide connections with other cities across the country, but operated by the MTR Corporation Limited (MTRCL), the transit system in Hong Kong consists of multiple transportation modes, such as light rail, heavy rail, and buses. The large population and frequent use also make MTRCL as one of the profitable metro systems around the world.

In terms of TOD, researchers have analyzed how TOD concepts have been used in metro system construction and influenced residents' everyday lives. One reason MTRCL can make much profit is the "Rail+Property" development program.

According to Cervero, more than half of the income to railway operators comes from

property development, both from housing and commercial development. There are also 35,000 additional weekday passengers because of the transit-oriented pedestrian-focused design (Cervero and Murakami 2009). Based on the comprehensive development of all kinds of transportations, the whole city can be regarded as a transit-oriented development city, relying mainly on light rail and subways and franchised buses and minibuses for feeder purposes. As Chow pointed out, apart from the macro-level regional transportation infrastructure design and micro-level community TOD design, the meso-level of new town design is also common in Hong Kong. The Tseung Kwan O new town could be a unique integrated transport and development way of using the TOD concept and emphasizing urban development simultaneously (Chow 2014).

Kowloon is the most populous urban area in Hong Kong, located directly north of Hong Kong Island. Although Kowloon is one of the densest areas in Hong Kong, residents and working people can also rely on high-efficient public transportation (Tsuen Wan line and Tung Chung line) and TOD design for daily uses.

4.1.2 Kowloon Station TOD Data Analysis

The quantitative data of built environment evaluation indicators are collected from various resources (Google Earth, Google Maps, Hong Kong Statistics Bureau, Hong Kong Geodata Store website), which are shown in the following table (Table 7).

Table 7: Hong Kong Kowloon Station TOD Urban Morphological Factors Results

Sheet

		Hong Kong - Kowloon Station
Total Land Area		1.1 km ²
Factors	Indicators	
Density		
	Population Density	16,031 ppl/km ²
	Residential Density	9,865 units/km ²
	Commercial Density	0.19
Diversity		
	Land Use Types around the Transit Center	5
Design		
	Block Size	0.12 km ² /block
	Length of Main Roads	4131 m
	Length of Bicycle Lanes	0 m
	Number of Sidewalks	71
	Number of Four-way Intersections	7
	Number of Pedestrian Crossing	26
Distance to Transit		
	Average Walking Distance to Transit Center	524 m
	Number of Secondary Transit Stops within the Region	19
	Number of Operational Transit Lines	38
Destination Accessibility		
	Transit Time to Airport	29 min
	Transit Time to Downtown Area	13 min
	Number of Grocery/Convenience Stores within the Region	12
	Number of Recreational Services/centers within the Region	13

The total land area is 1.1 square kilometers, which is the medium size TOD neighborhood compared to the other four cases because it includes the West Kowloon Cultural District near the waterfront. People in the region mainly live around the Kowloon and Austin stations, and high-rise mixed-use buildings result in high population and residential densities.

As the following graphic shows (Figure 11), there are five different types of land uses, which are 1) comprehensive development mixed-use area; 2) open space; 3) residential; 4) government, institution, or community; 5) and transportation use.

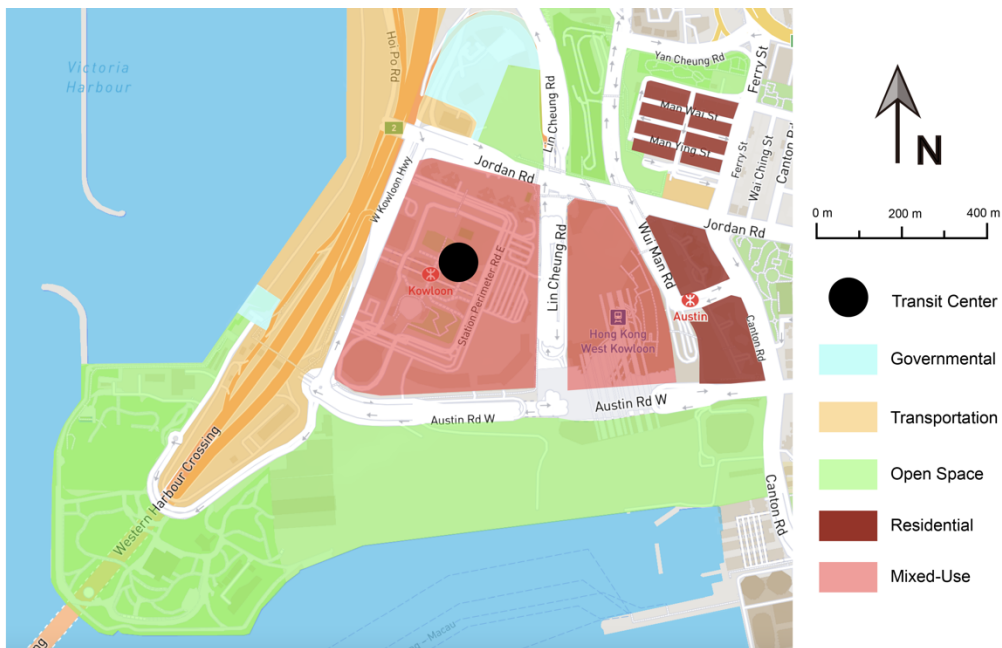


Figure 11: Kowloon TOD Neighborhood land use

Apart from the diverse land uses, this is also a pedestrian-friendly project with 71 sidewalks beside the main road or inside the comprehensive development area. The pedestrian crossing helps people quickly go around the neighborhood without worrying about the traffic. Some of them are pedestrian bridges over main roads (Figure 12), which not only increases the accessibility of pedestrians but also decreases the influences on the ground traffic. However, as the following figure shows (Figure 12 & 13), the TOD neighborhood lacks bicycle lanes because of the impact use of land, which is not friendly to cyclists.



Figure 12: Wui Man Road View (Next to Kowloon transit center)



Figure 13: Ferry Street View (In the northeast part of the TOD neighborhood)

Regarding distance to transit, the average walking distance to the transit center (Kowloon MTR Station) is 524 meters because the pedestrian bridges and crossings help a lot in reducing the walking distances. Besides the transit center, residents also have other options of taking minibuses or buses to their destinations or the transit center instead of walking. The 19 secondary transit stops, including Austin MTR Station and other bus stops, operate 38 transit lines covering the TOD neighborhood.

It is also convenient to go anywhere in Hong Kong from Kowloon Station because of the developed public transportation system. As from the table (Table 7), it only takes less than a half-hour to the airport by the airport line and takes around 10 minutes to Central in Hong Kong Island, one of the most important financial centers in Asia.

There are 12 convenience stores and grocery stores for daily shopping purposes within the neighborhood and 13 recreational places to go for relaxation.

4.2 New York City - Hudson Yards Station TOD

4.2.1 TOD's Background in New York City

More than a century ago, New York City developed an integrated railroad network to suburbs from Manhattan. It is one of the earliest cities in the US to develop transit-based villages when railroads sprouted throughout the country. These transit villages present some features of transit-oriented development like developing communities around transit centers. For example, Westchester County, as a largely agricultural area at the north of New York City, is the home to several railroad suburbs that arose in the late 19th century: Mount Vernon, White Plains, Scarsdale, and Bronxville. The railroads strengthened these ties and hastened the county's transformation from an agricultural center to a constellation of industrial towns and commuter suburbs (Bernick 1997).

However, there are some obstacles while developing transit villages in New York City. Most suburbanites accept the idea of park-and-ride instead of living within walking distance of a suburban station. As a result, some transit officials fear converting surface parking near transit stations to transit-based housing. Some other obstacles related to macroeconomic and political aspects also influenced the development of transit villages in New York City. Because of the pressing and

potentially explosive urban problems, such as crime and poverty, transit villages were not the priority in the nation's biggest city (Bernick 1997).

The New York City Subway opened in 1904 provides 24/7 rapid transit service across Manhattan, Queens, The Bronx, and Brooklyn, controlled by the Metropolitan Transportation Authority (MTA). MTA is North America's largest transportation network, serving 15.2 million people in the 5,000-square-mile area running from New York City through Long Island, southeastern New York State, and Connecticut (MTA 2020b). Some researchers have discussed TODs in New York City. Liu et al. conducted a study that proposes a framework to address dynamics of transit-oriented development by enhancing a conventional TOD typology by adding measures detailing the spatiotemporal dynamics of activity at transit stations in New York City (Liu, Singleton, and Arribas-Bel 2020). By comparing TODs in Hong Kong and New York City, Loo et al. confirmed the value of TODs in generating railway patronage under different socioeconomic contexts (Loo, Cheng, and Nichols 2017). Apart from these professional researches, MTA collaborates with property owners and municipalities across the city to promote transit-oriented development that increase accessibility and provide housing, retail shops, office, and public facilities. For example, the MTA TOD team, working with the developer, determined that both subway customers and the Bank of China Building on Sixth Avenue would benefit from a subway entrance on 39th Street rather than 40th Street. As a result, a subway

stair relocation project has been conducted to provide subway customers a more conveniently accessible new entrance on 39th Street (MTA 2020c).

4.2.2 Hudson Yards Station TOD Data Analysis

The quantitative data of the Hudson Yards TOD region’s built environment evaluation indicators are collected from various resources (Google Earth, Google Maps, New York City Open Data, and New York Planning Department), shown in the following table (Table 8).

Table 8: New York City Hudson Yards Station TOD Urban Morphological Factors

Results Sheet

		New York City - Hudson Yards
	Total Land Area	0.75 Km2
Factors	Indicators	
Density		
	Population Density	16,952 ppl/km2
	Residential Density	14,535 units/km2
	Commercial Density	0.43
Diversity		
	Land Use Types around the Transit Center	4
Design		
	Block Size	0.03 km2/block
	Length of Main Roads	5,223 m
	Length of Bicycle Lanes	3,963 m
	Number of Sidewalks	121
	Number of Four-way Intersections	27

	Number of Pedestrian Crossing	144
Distance to Transit		
	Average Walking Distance to Transit Center	430 m
	Number of Secondary Transit Stops within the Region	17
	Number of Operational Transit Lines	5
Destination Accessibility		
	Transit Time to Airport	60 mins
	Transit Time to Downtown Area	5 mins
	Number of Grocery/Convenience Stores within the Region	11
	Number of Recreational Services/centers within the Region	19

According to the table, the total land area is 0.75 square kilometers, which is the minor TOD neighborhood compared to the other four cases. The north boundary of the TOD region is the Lincoln Tunnel across the Hudson River, and to the west side is the 12th avenue along the Hudson River. The south and east boundaries are 24th Street and 9th Avenue, respectively.

Although Hudson Yards TOD has a similar population density as the Kowloon Station TOD, it has much higher residential density and commercial density because more high-rise mixed-use apartments have residential and commercial functions (Figure 14). For another reason, there is a historic and cultural district in the Kowloon Station designated as an open and recreational space near the waterfront, which vastly decreases the density in Kowloon Station TOD.



Figure 14: 10th Ave Street View in Hudson Yards TOD neighborhood

According to the New York planning department, there are also five different types of land uses around Hudson Yards Subway Station (Figure 15), which are 1) residential apartment area; 2) open space; 3) mixed-use area; 4) commercial area; 5) and transportation use.

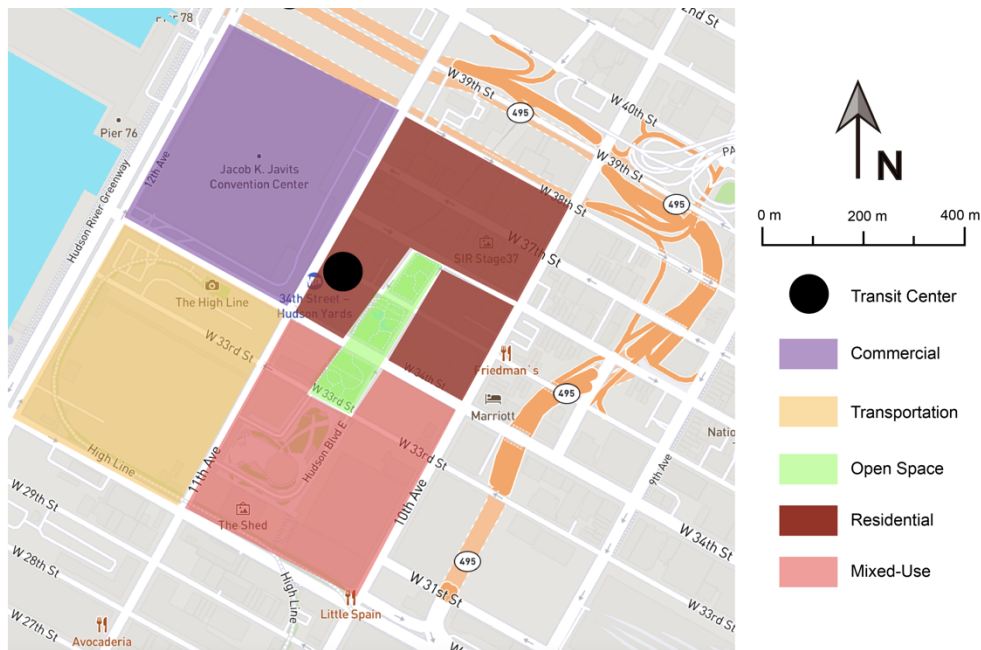


Figure 15: Hudson Yards TOD Neighborhood land use

In terms of the landscape design and public open space of the entire TOD built-up area, Hudson Yards TOD is the best among all the cases. The scenic trail along the Hudson River separates pedestrians and vehicles, and a dedicated bicycle lane can also prevent cyclists, pedestrians, and vehicles from interacting with each other. The landscape trail along the river at 12th Ave, the High Line Park (Figure 16), and Chelsea Park add green and plant elements to the entire community. Javits center and other small art galleries enrich the artistic atmosphere of the community, making it an important tourist destination on Manhattan Island.



Figure 16: High Line Park in Hudson Yards TOD Neighborhood

The blocks near Hudson Yards are tiny because of so many horizontal and vertical roads, with an average of only 0.03 square kilometers per block. Because of these horizontal and vertical staggered roads, vehicles can easily pass through the entire region. At the same time, enough sidewalks on both sides of the road and pedestrian crossings at intersections (Figure 17) ensure the safety of pedestrians, which makes the whole region more pedestrian-friendly. Pedestrians can also feel the vitality of the entire block while walking. The ground floors of mixed-use buildings (Figure 18) in the neighborhood provide various forms of service facilities such as restaurants and convenience shops for pedestrians eating or buying, strengthening the service characteristic of the entire TOD neighborhood.



Figure 17: Intersection between W 34th Street and Hudson Boulevard E



Figure 18: Mixed-use buildings on one-way W 26th St

There are many important transportation centers around 34St Hudson Yards. The New York Penn Station, which is only two blocks away from it, serves as the main inter-city rail transportation station in New York City and serves more than 600,000 people every day in 2019 (MTA 2020a). However, it is about 700 meters away from Hudson Yards Station, which will not be within the scope of this study. Regarding distance to transit, the average walking distance to the transit center (34 St Hudson Yards Station) is 430 meters, which is the shortest distance compared with other cases. In addition, there are a large number of one-way streets in this block (Figure 18), and sometimes cyclists need to occupy the motor lanes and drive together with vehicles, which increases the unsafe factors on the road. Only two bus lines are operating within this region and with the other two subway lines making up all the public transportation lines in the area. In general, it is necessary to provide people with more choices of running lines to reduce the number of people's transfers and allow them to reach their destinations directly in terms of public transportation. Road facilities, sidewalk arrangements, and crossings are reasonable, giving pedestrians more space for activities, but the bicycle lanes need to be more rationally set up to separate bicycles and cars.

Hudson Yards Station is located in the middle of Manhattan, a neighborhood in the center of New York City. So, passengers can take the subway to important nearby landmarks such as Times Square, Rockefeller Center, and Central Park within ten minutes. However, it takes an hour to get to the JFK international airport. There are

also some convenience stores and grocery stores (Figure 19) around to meet the daily needs of residents nearby.



Figure 19: A Grocery Store Called Hudson Market on the 10th Ave

4.3 Chengdu - Chengdu East Railway Station TOD

4.3.1 TOD's Background in Chengdu City

In 2019, Savills released the “Report on the Transit-oriented Development Potential of Cities in Western China.” The report evaluated the TOD development potential of cities in western China, such as Chengdu, Chongqing, Xi’an, Kunming, Guiyang, and other cities. Track situation, linkage, policy, population, economy, and travel behavior are regarded as the key elements for scoring. For example, the track situation mainly

considers the current and planning status regarding the length of high-speed rail operation, the number of subway lines, the number of subway stations, the density of the line network, and passenger flow. The linkage examines the link between the high-speed rail station and the subway and the proportion of office buildings and shopping malls that connect with public transportation. Chengdu has the highest score among these cities and has good TOD development potential. In 2019, the operating length of Chengdu Metro reached 302 kilometers, with 192 stations, and the station density and line network density were 0.0582 per square kilometer and 0.0916 kilometers per square kilometer, respectively. The proportion of Chengdu's office buildings and shopping malls connecting to subway stations has reached 83.3% and 19.2%. According to the approved future projects, this figure will reach 94.2% and 25.3%, respectively, in the following years (Savills 2020).

According to the "Chengdu TOD Business Model Research Report" jointly issued by the Chengdu Bureau of Commerce and Chengdu Service Industry Research Institute, seven different TOD business models for future development in Chengdu are introduced. Led by TODs, the seven models include fashion consumption, business, creative economy, tourism economy, innovation incubation, exhibition, and living services (Chengdu Bureau of Commerce and Chengdu Service Industry Research Institute 2019).

Based on these reports, the city has launched 13 TOD comprehensive development demonstration projects and accelerated the construction of a four-level comprehensive development system of 16 city-level TOD sites (Figure 20), 45 district-level TOD sites, 125 neighborhood-level TOD sites, and 528 general-community sites (Chengdu Metro 2019).



Figure 20 The 16 city-level TOD sites in Chengdu (Chengdu Metro 2019)

4.3.2 Chengdu East Railway Station TOD Data Analysis

The quantitative data of Chengdu East Railway Station TOD region's built environment evaluation indicators are collected from various resources (Google Earth, Baidu Maps, Chengdu City Open Data, and Chengdu Municipal Bureau of Planning and Natural Resources), which are shown in the following table (Table 9).

Table 9: Chengdu East Railway Station TOD Urban Morphological Factors Results

Sheet

		Chengdu - Chengdu East Railway Station
Total Land Area		1.51 Km ²
Factors	Indicators	
Density		
	Population Density	8,934 ppl/km ²
	Residential Density	7,126 units/km ²
	Commercial Density	0.1538
Diversity		
	Land Use Types around the Transit Center	5
Design		
	Block Size	0.1079 km ² /block
	Length of Main Roads	7,443 m
	Length of Bicycle Lanes	17,342 m
	Number of Sidewalks	58
	Number of Four-way Intersections	10
	Number of Pedestrian Crossing	65
Distance to Transit		
	Average Walking Distance to Transit Center	746 m
	Number of Secondary Transit Stops within the Region	19
	Number of Operational Transit Lines	30
Destination Accessibility		
	Transit Time to Airport	50 mins
	Transit Time to Downtown Area	30 mins
	Number of Grocery/Convenience Stores within the Region	30

	Number of Recreational Services/centers within the Region	8
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As shown in the figure below (Figure 20), the Chengdu East Railway Station buildings are arranged in an east-west direction, and the railway tracks are arranged in a north-south arrangement across the entire TOD area. The north side of the entire TOD is one of the main roads (Shudu Avenue) for traveling into the central city. The east side is the city's major ring road-the third-ring road, which has 14 two-way lanes and implements strict separation of motor vehicles and non-motor vehicles. The entire TOD area is 1.51 square kilometers, and most of the land is occupied by railways and station buildings. There are also hotel clusters, office buildings, residential clusters, and commercial centers around the transportation center. Also, according to the Chengdu planning bureau, there are five different types of land uses around Chengdu East Railway Station TOD region (Figure 21), which are 1) residential apartment area; 2) open space; 3) office area; 4) commercial area; 5) and transportation use.

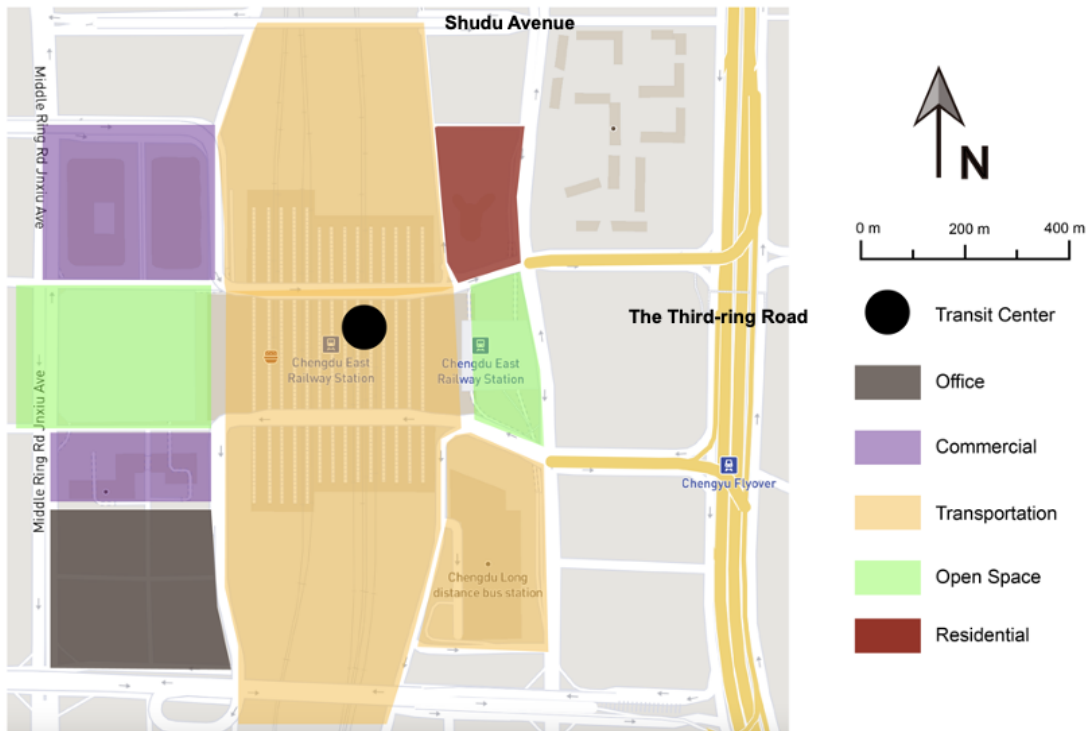


Figure 21: Land Use around Chengdu East Railway Station TOD

Since Chengdu East Railway Station and its attached heavy train tracks occupy a large amount of land, the entire region is divided into two areas located on the west and east of the tracks. In addition, there is some undeveloped vacant land nearby. Although some high-rise mixed apartments provide many living units, the overall population density, housing density, and the proportion of commercial land are also very low compared to Hong Kong and New York City.

This TOD area has a relatively small number of blocks, so the average block size is relatively large, which is 0.1079 square kilometers per block. The average distance is also longer for residents from each block (746 meters) walking to the transit center inside the railway station. The surrounding and some internal roads are at least four

lanes with two-way traffic (Figure 22), which seem to go against the original intention of a TOD neighborhood design: people-centered and pedestrian-oriented travel. However, because the annual passenger flow of this railway station reached 100 million people in 2018, there need to be wider roads and higher road density around to support passengers in the railway station to go to their destinations quickly. At the same time, wide roads do not entirely deprive pedestrians and cyclists of the right to use the road. Almost every road has dedicated bicycle lanes and separate sidewalks on both sides to ensure the convenience of non-motorized vehicle users. In addition, the popularity of shared bicycles has also solved the problem of the last mile in the community, allowing nearby residents to quickly reach the transportation stops from different residential clusters, whether it is a subway station or a bus station.



Figure 22: Four-lane Street with Designated Bike Lanes

Chengdu East Railway Station is located near Chengdu East Third Ring Road. It takes half an hour from this TOD center to the city's commercial center, such as Tianfu Square, Chunxi Road, or the Central Business District area in the high-tech district located in the south of Chengdu. To go to the airport takes about 50 minutes by the subway. Because of a large number of mixed-use apartments (Figure 23), the ground floor of these apartments solves the daily necessities needs of the entire TOD community, such as grocery shopping, restaurants, laundry rooms, etc. However, it lacks entertainment service facilities and community centers that serve the entire community.



Figure 23: Mixed-use Apartments with Restaurants and Grocery Stores on the Ground Floor

4.4 Seattle - Northgate Station TOD

4.4.1 TOD's Background in Seattle

Washington's Growth Management Act (GMA), passed in 1989, influenced Seattle's TOD development at first. The law requires comprehensive plans that consider residential, commercial, and employment growth within urban growth areas and increase transportation efficiency. As a result, TOD is a way to accommodate the growth.

The Puget Sound region of Washington State is a developed region with the most extensive public transportation systems in North America. The primary bus and rail operators in the City of Seattle are King County Metro and Sound Transit. King County Metro mainly serves the people in King County (where Seattle is located) with multiple bus services. At the same time, Sound Transit is a regional transportation agency that operates regional express bus and light rail services.

There is much evidence to support the benefit of building TOD in the Seattle area in terms of academic research. Shen et al. conducted an empirical study about bus transit-oriented development (BTOD) based on cases in King County. The results showed that BTOD could be a possible source of property value creation and tax revenue generation and an approach to sustainable urban development (Shen, Xu, and Lin 2018). Tian et al. measured trip and parking generation at Redmond TOD in

the Seattle region, and the results show that the TOD has 1.7 times more trips made by walking and 3 times more trips made by transit than Seattle’s regional average (Tian et al. 2017). Other than the professional research, there are also some practical constructions made by Sound Transit. The following figure (Figure 24) shows the TOD construction at the Capitol Hill light rail station. By engaging in an extensive community outreach process in partnership with the City of Seattle, the Capitol Hill Community Council, the Capitol Hill Chamber of Commerce, and other community groups, Sound Transit worked with the Capitol Hill Champion to incorporate the community’s vision and priorities in the station planning and construction. The project will include 428 residential units with 178 affordable housing and also includes community amenities such as a daycare center, public plaza, and community room, etc. (Sound Transit 2020)

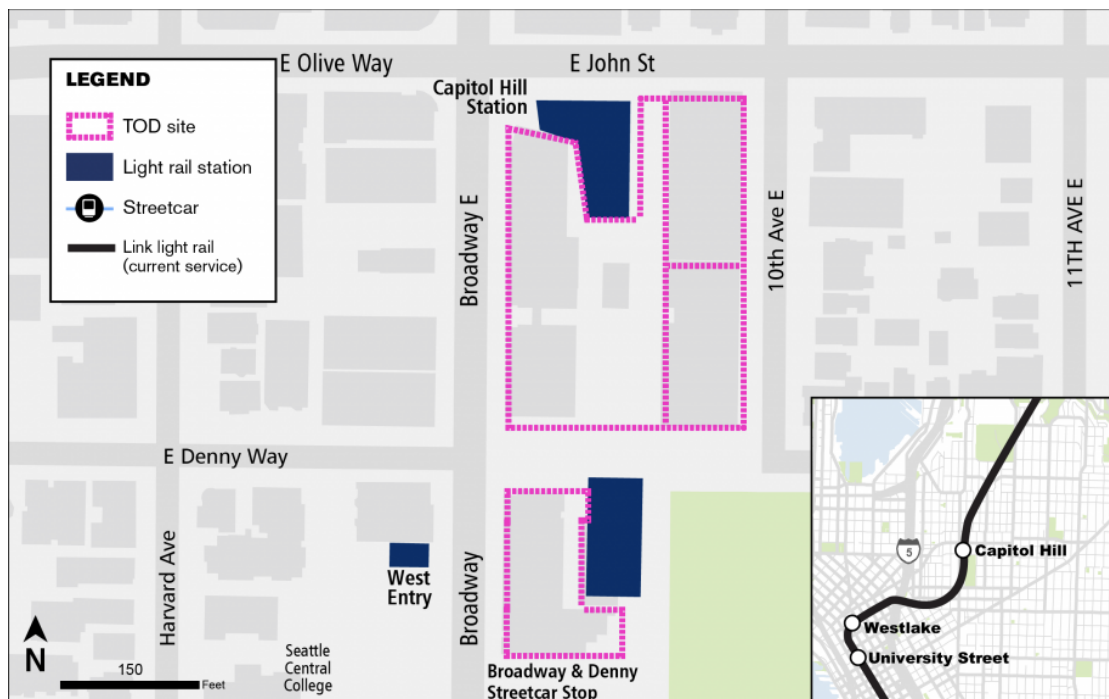


Figure 24: Capitol Hill TOD Site Plan in the City of Seattle

However, some factors challenged and delayed TOD projects in the Seattle area, such as existing land-use zoning (current zoning does not support TOD construction), lack of stakeholder compromise, lack of jurisdictional support, and lack of developer or buyer interest. The Renton TOD project could be an example that made it possible to build TOD only after the city and county provided incentives that helped private developers overcome the cost and financial issue (Shelton and Lo 2003).

4.4.2 Northgate TOD Data Analysis

The quantitative data of Northgate TOD region’s built environment evaluation indicators are collected from various resources (Google Earth, Google Maps, City of Seattle Open Data, and City of Seattle Office of Planning, Community Development), which are in the following table (Table 10).

Table 10: Northgate Station TOD Urban Morphological Factors Results Sheet

		Seattle - Northgate
	Total Land Area	1.15 km ²
Factors	Indicators	
Density		
	Population Density	6,108 ppl/km ²
	Residential Density	1,860 units/km ²
	Commercial Density	0.2131
Diversity		
	Land Use Types Around the Transit Center	7

Design		
	Block Size	0.0767 km ² /block
	Length of Main Roads	4,990 m
	Length of Bicycle Lanes	6,079 m
	Number of Sidewalks	39
	Number of Four-way Intersections	24
	Number of Pedestrian Crossing	49
Distance to Transit		
	Average Walking Distance to Transit Center	619 m
	Number of Secondary Transit Stops within the Region	15
	Number of Operational Transit Lines	9
Destination Accessibility		
	Transit Time to Airport	68 mins
	Transit Time to Downtown Area	23 mins
	Number of Grocery/Convenience Stores within the Region	2
	Number of Recreational Services/centers within the Region	2

Seattle's Northgate Transit Center is still under construction. Currently, only the King County Metro Bus is in operation in the transit center. The Northgate light rail station near the bus station will be opened in October 2021. After that, the entire community will revolve around the light rail station and the bus terminal for development. The total area of the TOD region in this study is 1.15 square kilometers, and the Interstate-5 that traverses north and south divides this TOD region into two areas located on the east and west, respectively. The following land use map (Figure 25) shows seven different land-use types around Northgate TOD's transit center, where

owns the most diverse land-use type compared to the other three cases. The seven types of land use include 1) residential apartment area; 2) open space; 3) office area; 4) commercial area; 5) transportation use; 6) government, institution, and community; 7) and mixed-use apartment area.

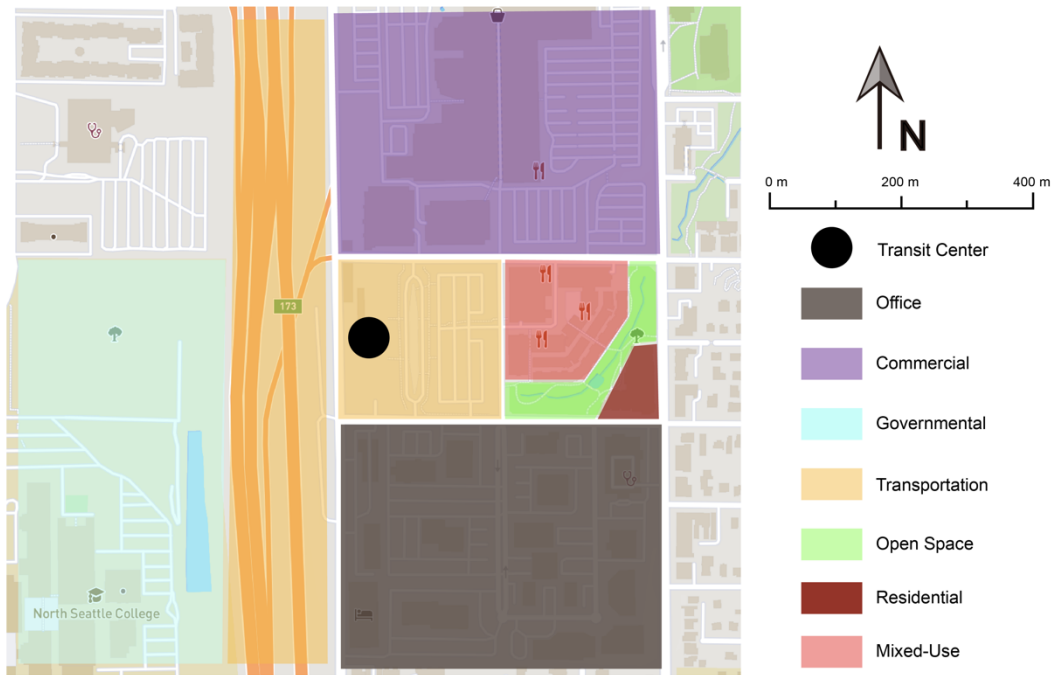


Figure 25: Land Use around Northgate TOD Transit Center

There are many single-family houses on the east side of the Northgate TOD area. The height restriction in zoning also keeps the mixed-use apartment here no more than ten floors. As a result, there are not many living units here, and the population density is also smaller than the number of other cases. However, because Northgate Mall has dramatically increased the gross floor area of commercial use buildings, the gross floor area of commercial land use accounts for 21% of the total land area.

According to the data, Northgate TOD needs further development regarding pedestrian friendliness and bicycle user-friendliness. The most obvious is the area of the single-family houses in the southeast, where the roads have high gradients and are very narrow without enough sidewalk space on the street sides. There will be vehicles parking on the roadside close to the houses, making the narrow roads more compact (Figure 26). Therefore, residents here are more accustomed to traveling by car. People who live in apartments or work in office buildings near the transit center may be more willing to use public transportation because they are closer to it and there is no complicated terrain. In addition, there are still many ground parking lots, which gives people a sense of encouraging car travel (Figure 27). If these parking lots can be developed more reasonably into mixed-use apartments or affordable housing, the utilization efficiency of the entire area and the utilization rate of the transit center can be increased.



Figure 26: Compact Street (NE 100th St) without Sidewalk around Northgate TOD



Figure 27: Ground Parking and Parking Garage near Northgate Transit Center

Another problem is that due to the existence of Interstate-5, the North Seattle College in the west part is completely separated from the Northgate mall and transit center in the east. Students in the college or residents living in the western communities need to detour for a long way if they want to use the transit center. Like the pedestrian bridge that links the University of Washington Station with the campus over Montlake Boulevard (Figure 28), a pedestrian bridge near the Northgate light rail station that directly connects the west and east areas will solve the problem. It will significantly increase the utilization rate of the transit center and encourage people in the western communities to use public transportation in the future.



Figure 28: Pedestrian Bridge Over Montlake Boulevard at the University of Washington Light Rail Station

In addition to the transit center in TOD, there are 15 bus stops in the entire area.

Almost all of the 9 lines run by these stations depart from this TOD transit center. It takes 68 minutes from the transit center to Sea-Tac International Airport. Passengers need to take a bus and then change to the light rail to get to the airport. Once the Northgate light rail is built, it can save about 15 minutes, and the time from here to the downtown area will also be reduced from 23 mins to around 15 minutes. It can be seen from the table (Table 10) that the destination accessibility in the entire region is low because there are only two grocery stores and two recreational services.

4.5 Comparative Study of the Four Cases

4.5.1 Density Comparison

As shown in Table 11, Hudson Yards TOD and Kowloon Station TOD have similar population densities, much higher than the other two because the two cities have a large population, and the two stations are in the central city area. Chengdu East Railway Station TOD region has almost half of the population density as Hudson Yards TOD, and Northgate has the most negligible density with only 6,108 people per square kilometers. The population density can also reflect the residential living unit density in different TOD areas. Hudson Yards has the highest residential density compared to other cases. Kowloon TOD has a little higher density than Chengdu TOD, and all three cases have much higher residential density than Northgate TOD, which is only 1,860 units per square kilometer. Although Hudson Yards and Kowloon Station TOD regions have a similar population density, the residential density in the

Hudson Yards TOD region is almost 5,000 units per square kilometers more than Kowloon TOD area because there are more studio and one-bedroom units' rental apartments in the former TOD region.

Table 11: Density Comparison of the Four Cases

	Hong Kong - Kowloon Station	Chengdu - Chengdu East Railway Station	New York City - Hudson Yards	Seattle - Northgate
Population Density	16,031	8,934	16,952	6,108
Residential Density	9,865	7,126	14,535	1,860
Commercial Density	0.1903	0.1538	0.4343	0.2131

In contrast, more families live together in three-bedroom or four-bedroom units in Hong Kong. Hudson yards TOD region has the highest proportion of commercial space, reaching 43% (0.4343). Many mixed-use buildings have increased commercial use while providing enough residential units. Shops & Restaurants at Hudson Yards is a seven-story and the most prominent mall with 100 shops and 20 restaurants in the TOD regions, which has 93,000 square meters of space, mainly increasing the commercial space in the area. Seattle has the second most significant commercial density because of the large space of the Northgate Mall with 97,000 total commercial floor areas. Chengdu TOD has the lowest commercial density (0.1538). There is only one three-floor commercial building in the entire area, with other smaller retail on the ground floor of mixed-use apartments.

4.5.2 Diversity Comparison

Land use types around the transit center in the entire TOD area are used as an indicator to show the diversity of the built environment, and the results show in the table below (Table 12).

Table 12: Diversity Comparison of the Four Cases

	Hong Kong - Kowloon Station	Chengdu - Chengdu East Railway Station	New York City - Hudson Yards	Seattle - Northgate
Land Use Types Around the Transit Center	5	5	5	7

According to Table 13, Chengdu East Railway Station TOD has the largest total area (1,507,810 square meters), almost two times the size of Hudson Yards TOD (753,847 square meters) in New York City, which is because residential or commercial blocks in China are large, and I include the blocks on the periphery. Another reason for the small total land area in Hudson Yards TOD is because the 600-meter radius of the TOD area encompasses part of the Hudson River, which should be subtracted from the total area.

In terms of the land use proportions of different land-use types, transportation use has the highest proportion in Chengdu East Railway Station, New York City, Seattle's TODs, and the second-largest proportion in Kowloon TOD. Chengdu East Railway

Station TOD's transportation land use reaches more than 42%, the highest transportation use proportion compared to other cases. The station buildings and high-speed rail tracks occupy a large amount of land. Although Northgate TOD in Seattle does not have a large train station, the Interstate-5 as transportation use occupies a large portion of land and divides the TOD region into two parts. Open space land use owns the most prominent land-use proportion in Kowloon Station TOD is because of the large area of West Kowloon Cultural District, which was built as a recreational place near the waterfront. Office use has a minuscule proportion in Kowloon Station, Chengdu East Railway Station, and Hudson Yards TODs, which is far less than that proportion in Northgate TOD because there are many office buildings on the south block of the transit center. The large tract of Northgate Mall increases commercial land use in the TOD region, which is almost three times the proportion of commercial land use in Chengdu or Hudson Yards TODs. Most of the western part of Northgate TOD is the North Seattle College, and the land use type there is Institution, Government, and Community, which contributes a large proportion of this kind of land use in the TOD region.

Table 13: Land Use proportions of Different Land Use Types among Different Cases

Land Use Proportions of Different Land Use Types	Hong Kong	Chengdu	New York City	Seattle
Total	1,054,238 m2	1,507,810 m2	753,847 m2	1,151,581 m2
Residential	12.75%	17.89%	23.04%	15.61%
Open Space	38.37%	4.79%	8.24%	6.64%
Transportation	22.87%	42.76%	34.02%	19.38%

Office	0.93%	1.01%	1.56%	8.01%
Commercial	4.70%	6.27%	6.96%	17.46%
Institution, Government, and Community	2.75%	3.36%	3.40%	11.10%
Others	17.63%	23.92%	22.79%	21.80%

4.5.3 Design Comparison

It can be seen from the following table (Table 14) that Hudson Yards and Northgate TODs have smaller average block sizes than the other two TODs, which is because a large number of horizontal and vertical roads cut the blocks in these two places very small. In contrast, Kowloon and Chengdu East TODs have more large communities. Most of these large communities are semi-public, and the residents or staff inside can enter and use the facilities inside. In addition, Seattle's Northgate Mall occupies an oversized block, making its average block size slightly higher than that of the Hudson Yards TOD region.

Table 14: Design Comparison of the Four Cases

	Hong Kong - Kowloon Station	Chengdu - Chengdu East Railway Station	New York City - Hudson Yards	Seattle - Northgate
Block Size	0.1222	0.1079	0.0341	0.0767
Length of Main Roads	4,131	7,443	5,223	4,990
Length of Bicycle Lanes	0	17,342	3,963	6,079
Number of Sidewalks	64	58	121	39
Number of Four-way Intersections	7	10	27	24

Number of Pedestrian Crossing	26	65	144	49
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The total length of the main roads is similar in these four TODs. Chengdu East TOD has about 7,500 meters of main roads within the region, which is slightly longer than the other three places, and the shortest one is Kowloon TOD, which is only 4,131m. As far as the length of the bicycle lane is concerned, as mentioned earlier, due to the limited land area and extremely high population density in Hong Kong, there are no bicycle lanes in this TOD area. There are only designated bicycle lanes in the outskirts of the city for exercising and viewing. Chengdu East TOD community has the most extended bicycle lane with more than 17,000 meters, which is three times that of Northgate TOD and four times that of Hudson Yards TOD because nearby residents and working people rely on shared bicycles to solve the problem of traveling in the last mile, to achieve quick travel from homes or workplaces to the transit center. In terms of pedestrian friendliness, Hudson Yards TOD is the best. This area has the most pedestrian walkways (121) and crosswalks (144). It is very effective in controlling driving speed and ensuring pedestrian safety. There are fewer pedestrian crosswalks in the Kowloon TOD area because people can use the underground area to reach out to different blocks, which can directly allow subway users to go to different blocks by using the underground walkways when they get out of subways. Chengdu East and Northgate TODs have a similar problem that needs to be improved in pedestrian friendliness. Because of a large area of transportation

land running through the north and south (Interstate-5 in Seattle, high-speed rail tracks and train station in Chengdu), the entire area is divided into two parts, and it is not easy for pedestrians to travel between these two parts.

4.5.4 Distance to Transit Comparison

As the following table (Table 15) shows, the average distance from a block in Chengdu East TOD to the transit center is 746 meters, which is the longest among the four cases, and Hudson Yards TOD is the shortest 430 meters. However, walking distance does not mean the time to walk to the transit center because factors such as the walkway's environment, number of crossings, and traffic volume also need to be considered. Except for the transit center, the four TOD areas have a similar number of secondary transit stops. However, there are less than ten transit routes operated in Hudson Yards and Northgate TODs, far fewer than the 30 routes of Chengdu East TOD and the 38 routes of Kowloon TOD.

Table 15: Distance to Transit Comparison of the Four Cases

	Hong Kong - Kowloon Station	Chengdu - Chengdu East Railway Station	New York City - Hudson Yards	Seattle - Northgate
Average Walking Distance to Transit Center	524	746	430	619
Number of Secondary Transit Stops within the Region	19	19	17	15

Number of Operational Transit Lines	38	30	4	9
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4.5.5 Destination Accessibility Comparison

The four indicators of destination accessibility test the four cases' internal accessibility and external accessibility, respectively. The first two indicators can testify to the external accessibility of the four TOD regions because the calculation is based on the transit time to the outside destinations. From Table 16, we can see that the external destinations of the four regions are well accessible. The time to the airport is about an hour (except for Kowloon TOD, because the overall urban area is restricted small), and the time to the city downtown area is about half an hour (except for Kowloon and Hudson Yards TODs, because they are closed to the downtown area). Inside TODs, people often go to grocery stores or parks to meet the needs of daily life. Analysis of the data shows that Northgate TOD has very few grocery stores or open spaces. Even if there is a large shopping mall, it cannot meet people's daily grocery shopping and necessities needs. In contrast, the other three regions have more grocery stores, public spaces, or recreational services, giving residents in the TODs more internal travel options.

Table 16: Destination Accessibility Comparison of the Four Cases

	Hong Kong - Kowloon Station	Chengdu - Chengdu East Railway Station	New York City - Hudson Yards	Seattle - Northgate
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Transit Time to Airport	29	50	60	68
Transit Time to Downtown Area	13	30	5	23
Number of Grocery/Convenience Stores within the Region	12	30	11	2
Number of Recreational Services/centers within the Region	13	8	19	2

5. Urban Design Scoring

This chapter uses the urban design score sheet to evaluate the urban design quality of the selected TOD neighborhoods. The official name of the urban design score sheet is the "Measurement Instrument for Urban Design Qualities Related to Walkability" (Ewing et al. 2006), and its focus is to evaluate whether urban areas, especially commercial blocks, are suitable for human walking. Like the detailed introduction of the urban design scoring sheet in Chapter 3, this study will study five different urban design aspects in the four TOD case areas and select a representative commercial pedestrian block for each TOD to test the urban design scoring tool.

According to the description in the book *Measuring Urban Design*, we should record urban design elements and details in the study area by several field visits (Ewing and Clemente 2013) However, the cities in this study are located in different countries and regions, and on-site investigations have certain difficulties. Therefore, observations from Google Maps and Google Earth Street View are used instead of on-site investigations. Other researchers have made similar substitutions before. For example, Yin Li used both 2D and 3D GIS in the research to help objectively measure micro-scale street-level urban design features, and the results show that 3D GIS helps to generate objective records for view-related variables like the long line of sight and the sky ratio (Yin 2017).

In terms of the specific research boundaries, the book says, “Although you can apply this manual to almost any street, our methodology has been tested and refined on urban streets and therefore works best on urban streets that have at least some commercial uses” (Ewing and Clemente 2013). Therefore, the streets I chose in these four areas have similar street types and commercial uses. Instead of using the same street length suggested in the book, the streets (Table 17) I chose here are slightly longer than the suggested value, which is about 120 meters long. On the one hand, I want to select as many elements as possible to represent TOD’s urban design to make up for the fact that I could not visit the site physically. On the other hand, because these areas have similar block sizes, I made the study areas have similar lengths to maintain consistency.

I determined the research areas and learned how to measure the elements of urban design qualities in Chapter 3. Then, I conducted the site visits on Google Maps and Google Earth Street View. The results of the four areas are discussed in the following sections.

Table 17: Selected Streets

City	Street Name	Length
Hong Kong	Ferry Street	230 meters
New York City	W 30th Street	230 meters
Chengdu	Jinmahe Road	230 meters

Seattle	NE 103rd Street	180 meters
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5.1 Comparison of the Imageability Scoring

Table 18 shows the imageability scoring results of the four TODs, which help us understand the urban design quality of making a place distinct and recognizable.

Table 18: Urban Design Scoring Results - Imageability

Imageability Indicators	Multiplier	Value			
		Hong Kong	New York City	Chengdu	Seattle
Number of courtyards, plazas, and parks	0.41	3	3	4	2
Number of major landscape features	0.72	0	1	0	2
Proportion historic building frontage	0.97	0	0	0	0
Number of buildings with identifiers	0.11	11	11	7	2
Number of buildings with non-rectangular shapes	0.08	6	7	7	1
Presence of outdoor dining	0.64	0	0	1	0
Number of people	0.02	48	46	56	8
Noise Level	-0.18	3	4	3	2
Add constant	2.44				
Imageability Final Score		5.78	6.36	6.63	4.8

Among the four TOD study areas, Chengdu TOD has the highest overall imageability score, reaching 6.63 points; Kowloon and Hudson Yards TODs' scores are similar, which are 5.78 and 6.36, respectively; Northgate TOD has the lowest score with only 4.8 points. According to the table, the reason for Chengdu TOD to lead the score is

that there are some outdoor dining existing along the street and also a lot of travelers walking along the street to go to the high-speed railway station, while there is no outdoor dining and less walking people in the other three TOD areas. All the outdoor dining places in Chengdu TOD welcome travelers because waiters warmly greeted the travelers to come in for a meal. Ewing and Clemente considered outdoor dining is one of the essential parts to increase the street activity and imageability. This element makes Chengdu TOD lead the other regions by 0.64 points. Another indicator that can significantly improve the imageability score is the proportion of historical building frontage. However, none of these four study areas have significant historical buildings, so they did not widen the gap. By observing and calculating the pedestrians from Google Map Street View, the number of pedestrians in either Chengdu, Hudson Yards, or Kowloon TODs is much higher than in Seattle, which is in line with the difference in population density four regions. For the type of users, there are many residents and public transportation users near Kowloon and Chengdu TODs, and the street in Hudson Yards TOD is more popular with tourists, office workers, and nearby residents.

There are apparent differences in the four places for the natural landscape seen from the street. In Northgate TOD (Figure 29 left), I can see the sloping streets in the distance due to the terrain and the natural landscape of Thornton Creek and nearby woods, which is not seen in other TOD areas. In Hudson Yards TOD (Figure 29 right), I can see the Hudson River in the distance standing at the end of the street,

which adds a natural landscape feature to this area. Kowloon and Chengdu TODs are both in city areas, and all I can see around are roads, buildings, or human-made landscapes. In addition, more identifiers of buildings and various shapes of buildings can also increase the imageability of the entire block. For example, the number of buildings with non-rectangular shapes is set as an indicator to calculate the imageability of urban design qualities, which refers to those buildings that have at least one angle that the passing pedestrians can see. Northgate TOD has only one building with a non-rectangular shape (Figure 30 left). In contrast, other TOD like Hudson Yards' various building shapes (Figure 30 right) provide a higher imageability to the whole area.



Figure 29: Northgate TOD (left) and Hudson Yards TOD (right) landscape features



Figure 30: Northgate TOD (left) and Hudson Yards TOD (right) building shapes

5.2 Comparison of the Enclosure Scoring

In the book *Measuring Urban Design*, the definition of the enclosure is "The degree to which streets and other public spaces are visually defined by buildings, walls, trees, and other vertical elements" (Ewing and Clemente 2013). Therefore, the evaluation of enclosure is based on pedestrians' perception of street openness. This kind of physical openness is determined by vertical elements on both sides of the street like houses, trees, etc. According to the urban design score sheet, I measured the indicators of the enclosure from the long sight line, sky proportion, and other aspects. The results of the four different TOD study areas are shown below (Table 19).

Table 19: Urban Design Scoring Results - Enclosure

Enclosure Indicators	Multiplier	Value
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		Hong Kong	New York City	Chengdu	Seattle
Number of long sight lines	-0.31	2	0	2	2
Proportion street wall (one side)	0.72	0.8	0.8	0.8	0.7
Proportion street wall (opposite side)	0.94	0.5	0.6	0.8	0
Proportion sky (ahead)	-1.42	0.1	0.05	0.2	0.3
Proportion sky (across)	-2.19	0.25	0.1	0.45	0.45
Add constant	2.57				
Enclosure Final Score		2.706	3.42	2.0085	1.0425

In general, Hudson yards TOD score of 3.42 is the highest in the four study areas, while Northgate TOD, also in the United States, has the lowest score, only 1.0425. Kowloon and Chengdu TOD scores are between these two, at 2.706 and 2.8885 points, respectively. The urban design score sheet regards enclosure as a vital part of urban design quality because it guarantees the privacy of people's activities in the block. Therefore, the sky proportion is inversely proportional to the score obtained; the more significant the proportion of the sky that pedestrians can see, the lower the overall score, which is the same as the long sight line indicator.

One reason for Northgate TOD's lowest score is that the long sight line and sky proportion measurements are higher than other TODs. For example, the proportion of sky measured from the front or across is the largest among the four research areas, and there are also two long sight lines. As just mentioned above, these two indicators are inversely related to the final result, so the final score is lower than the other three regions. Moreover, for Hudson Yards TOD, which scored the highest, had

the lowest measured values of these three indicators. The comparison of the sky proportion and the long sight line between these two places can also be reflected in Figures 31 and 32.

Another reason for the lower score of the Northgate TOD enclosure is that on NE 103rd St, only one side of it has buildings, which can also be seen from the right map of Figure 32. So, the value of the opposite side street wall proportion in Northgate TOD is 0, while the other three areas all have street walls on the opposite side of the street.

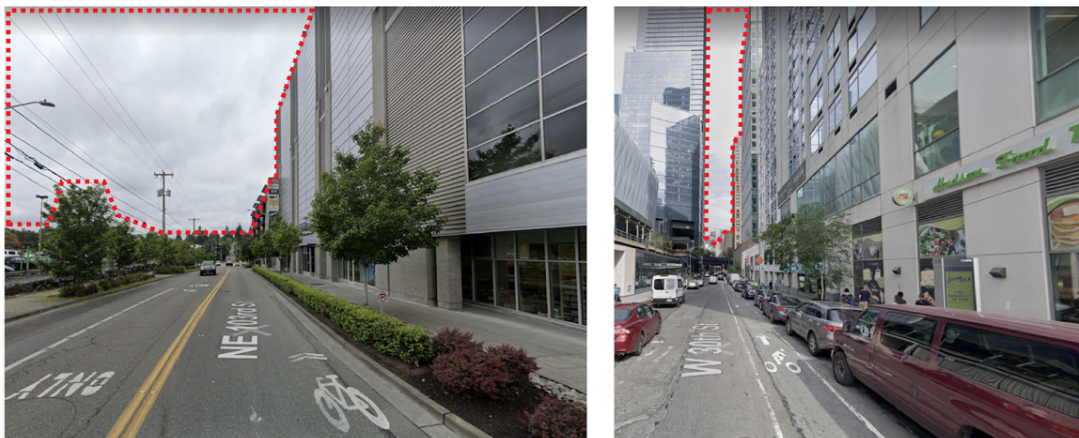


Figure 31: Northgate TOD (left) and Hudson Yards TOD (right) proportion sky
(ahead)



Figure 32: Northgate TOD (right) and Hudson Yards TOD (left) long sight lines

5.3 Comparison of the Human Scale Scoring

The TOD community, as a community that focuses on pedestrian orientation, also needs to consider the design of human-scale elements in community construction.

The details that pedestrians on the sidewalk can pay attention to can be counted as human-scale elements, such as building appendages, street vegetation, public seats, and even trash cans called human scale elements. Table 20 shows the human scale scores of the four TODs.

Table 20: Urban Design Scoring Results – Human Scale

Human Scale Indicators	Multiplier	Value			
		Hong Kong	New York City	Chengdu	Seattle
Number of long sight lines	-0.74	2	0	2	2
Proportion windows at street level	1.1	0.9	0.8	0.7	0.8
Average building height	-0.003	200	350	190	70
Number of small planters	0.05	15	22	19	30
Number of street furniture and other street items	0.04	40	32	28	15
Add constant	2.61				
Human Scale Final Score		3.87	4.82	3.4	3.9

In the four study areas, I found that Hudson Yards’ TOD has the best display of human scale elements, while the human scale score of Chengdu TOD is lower than the other three cases, only 3.4 points. This is because the blocks near Chengdu TOD are huge, and the streets are extensive, so pedestrians cannot experience the

human scale elements on the street. On the contrary, although the buildings near Hudson Yards' TOD are very tall, there are many elements on the sidewalks similar to the pedestrian scale, such as benches, small plants, and human-scale street lights. The comparison between the two can also be seen in Figure 33. From the left of the figure, we can see that street furniture on Chengdu TOD's street far exceeds the human scale, such as the high street light and street trees. Only one street board can be considered as a human-scale decoration. Hudson Yards TOD on the right has six different human-scale street elements, which are road sign, bicycle rack, fire hydrant, street light attached to the building, street bench, and street board. These things significantly increase pedestrian friendliness, and people will not feel very depressed by the large-scale street decorations when walking on the street.



Figure 33: Chengdu TOD (left) and Hudson Yards TOD (right) human scale elements

It is worth mentioning the TOD areas in Kowloon and Northgate. Although the two areas have different building densities, styles, and walking pedestrians, their final scores are similar. Kowloon TOD in Hong Kong has taller and more mixed-use buildings, and Northgate in Seattle has more open areas and vegetation. Kowloon

TOD performs better on indicators that are positively correlated with the final score, such as the number of street furniture and proportion windows at street level because the first floor of mixed-use buildings is open to the public as grocery stores, convenience shops, banks, community businesses or other service places. As a result, the shops need more transparency by using the street windows to interact with pedestrians. At the same time, more street furniture such as bicycle racks and street lights at store entrances are needed to attract passing pedestrians. The streets of Northgate TOD benefit from the surrounding empty natural landscape so that there is more human scale vegetation on the sidewalks. Also, the lower buildings that reversely influence the final score increase the human scale feeling in the entire block. Comparing the two TODs can also be seen in the following figure (Figure 34).



Figure 34: Kowloon TOD (left) and Northgate TOD (right) human scale elements

5.4 Comparison of the Transparency Scoring

This part evaluates the TOD urban design quality in the aspect of transparency, which is aimed at human activities in the neighborhood or beyond the street edge that can be seen by pedestrians passing by. Some of the indicators here use the measurement data from other aspects of urban design, so there is no need to repeat

the measurement. The only difference is that their multipliers are different in the different aspects. Therefore, the five aspects of the overall urban design quality assessment do not exist independently, and they also have mutual influence factors. For example, the proportion of street walls will affect the transparency of the entire block and participate in evaluating the TOD's enclosure.

Table 21: Urban Design Scoring Results - Transparency

Transparency Indicators	Multiplier	Value			
		Hong Kong	New York City	Chengdu	Seattle
Proportion windows at street level	1.22	0.9	0.8	0.7	0.8
Proportion street wall	0.67	0.8	0.8	0.8	0.7
Proportion active uses	0.53	1	0.9	0.9	0.4
Add constant	1.71				
Transparency Final Score		3.874	3.699	3.577	3.367

The results are shown in the table (Table 21). The score gap between the four places is not significant. Kowloon TOD in Hong Kong had the highest score, and Northgate TOD in Seattle got the lowest with only 0.5 points less than the highest. The gap is mainly due to the different proportions of active uses in the neighborhood. This indicator includes actively used buildings with more than five people walking in and out during the observation and other places such as parks, shops, restaurants, hospitals, schools, etc.

As shown in the street view below (Figure 35), compared to the other three TOD communities, Seattle is more restricted with actively used places and had a lower

score as a result. The street view of Northgate TOD in the upper left corner shows that the active use only exists on the ground floor of the distant building. In contrast, the other building is a mixed office and residential building without many people coming in and out even though the ground offices have doors on the street side. The upper right corner is Hudson Yards TOD. As a famous attraction, there are many tourists and nearby residents in High Line Park. It is the most frequently used park on this street. The shopping center and restaurants on the right side are also actively used places. The following two street views are from Kowloon and Chengdu TODs. They have similar structures and uses. As the ground floor of a mixed commercial and residential building, it is always used as grocery stores, convenience stores, banks, and other essential community services, which increase the usage of the entire street.

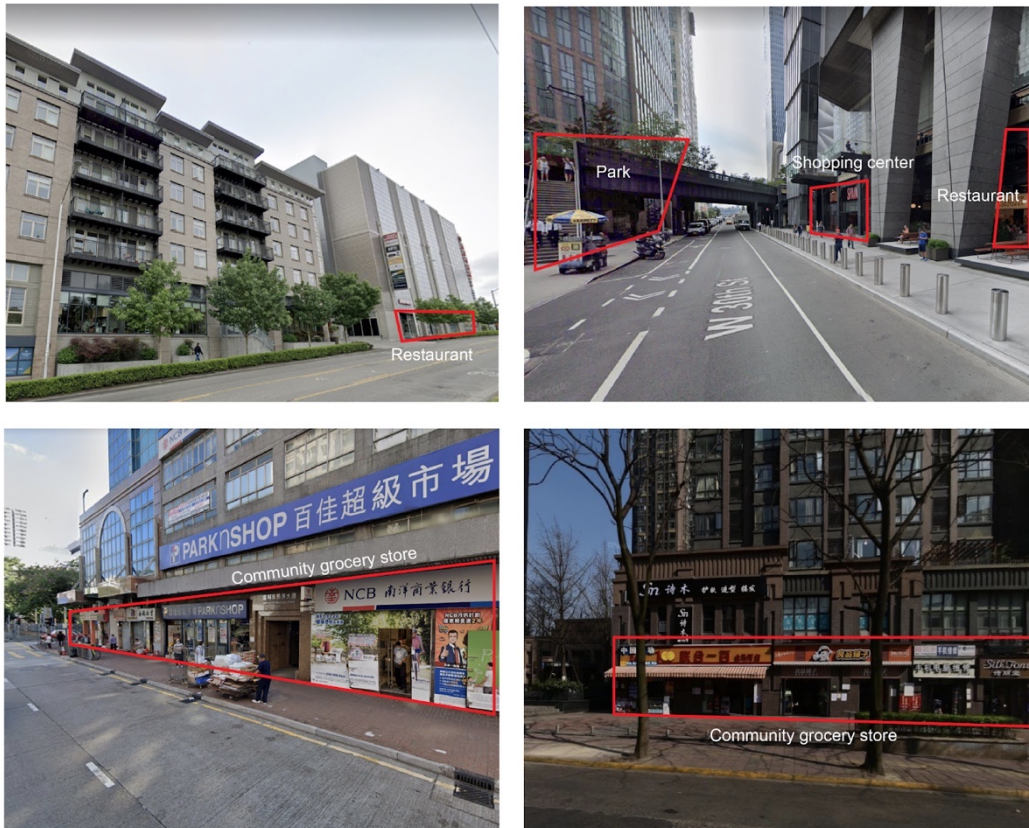


Figure 35: Northgate TOD (upper left), Hudson Yards TOD (upper right), Kowloon TOD (lower left), Chengdu TOD (lower right) street uses

5.5 Comparison of the Complexity Scoring

The last section of examining the quality of urban design is to evaluate the complexity of the block. Different from the consideration of large-scale diversity in the built environment, such as the diversity of land use and zoning, the complexity here refers to the diversity of specific designs that pedestrians can see in the TOD block, such as building shapes, colors, materials, orientation, etc.

Table 22: Urban Design Scoring Results - Complexity

Complexity Indicators	Multiplier	Value
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		Hong Kong	New York City	Chengdu	Seattle
Number of buildings	0.05	12	8	13	6
Number of basic building colors	0.23	7	5	3	4
Number of basic accent colors	0.12	16	9	6	7
Presence of outdoor dining	0.42	0	0	1	0
Number of pieces of public art	0.29	0	3	1	1
Number of walking pedestrians	0.03	48	46	56	8
Add constant	2.61				
Complexity Final Score		8.18	7.49	7.06	5.2

Table 22 is the result of complexity scoring. Hong Kong TOD score of 8.18 is the highest among all cases because the number of buildings and their colors dramatically increases the complexity of the area. Hudson Yards TOD ranks second in complexity because there are three public arts along the street, and Chengdu and Seattle TODs have only one public art in each case. Accent color is the color used for building trims, roofs, street objects, awnings, signs, and so forth (Ewing and Clemente 2013). Kowloon TOD has the most significant recorded values on these two indicators compared to other case areas. Chengdu TOD ranks third, which is only 0.43 points lower than Hudson TOD. New York's monotonous buildings and accent colors make the area lag behind in these two indicators. Nevertheless, the Manhattan area, where it is famous for its large amount of public art, enriches the complexity of the neighborhood by building three pieces of public art.

According to Figure 36, we can see the difference in the colors of the buildings and their attachments between Asia and the US TOD regions. Kowloon and Chengdu

TOD buildings and their attachments are more diverse than those of Hudson Yards and Northgate TOD. The two street photos on the left are in Kowloon and Chengdu TOD regions. We can see accent colors such as blue, yellow, green, and red, and the colors of the buildings are also dark brown and light white. The buildings in Hudson Yards and Northgate TOD areas are more light-colored, such as gray and white, which have no accent color attached to the buildings.



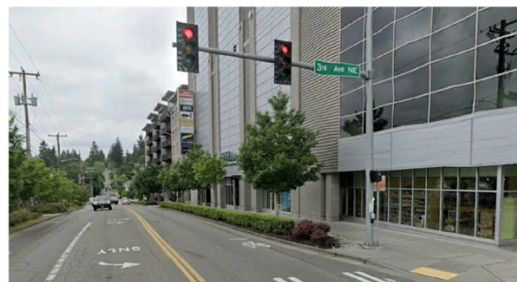
Kowloon TOD Street



Hudson Yards TOD Street



Chengdu TOD Street



Northgate TOD Street

Figure 36: Kowloon TOD (upper left), Hudson Yards TOD (upper right), Chengdu TOD (lower left), and Northgate TOD (lower right) building and accent colors

5.6 Final Total Score

According to Table 23, I can compare and know the score of different urban design quality and the final total scores of different TOD research blocks. The final result shows that the Hudson Yards TOD in New York and Kowloon Station TOD in Hong

Kong are very close, all-around 25 points. Among them, Hudson Yards TOD ranked first with 25.79 points, and Kowloon TOD ranked second with 24.41 points. Chengdu East Railway Station TOD scores third with 22.68 points. The fourth-ranked Northgate TOD in Seattle has a large gap with these three regions, scoring only 18.31 points. The low score has been analyzed in the previous sections, which is mainly reflected in the three aspects of imageability, enclosure, and complexity.

Table 23: Scores of each Urban Design Qualities and Final Total Scores

City	Hong Kong	New York City	Chengdu	Seattle
Imageability Final Score	5.78	6.36	6.63	4.80
Enclosure Final Score	2.71	3.42	2.01	1.04
Human Scale Final Score	3.87	4.82	3.40	3.90
Transparency Final Score	3.87	3.70	3.58	3.37
Complexity Final Score	8.18	7.49	7.06	5.20
Final Total Score	24.41	25.79	22.68	18.31

6. Conclusion

This thesis examines two sets of tools to assess the urban morphology and urban design in different transit-oriented development communities in China and the United States. More specifically, I measured four TODs' built environment characteristics based on the five "Ds" urban morphological framework in the dimensions of density, diversity, design, distance to transit, and destination accessibility. Then, I used the urban design score sheet to characterize the urban design elements in the aspects of imageability, human scale, enclosure, transparency, and complexity. Also, by comparing different outcomes of the gathering data in each aspect of the urban morphology and urban design, I conducted some comparative analysis to show the differences in implementing different TODs.

6.1 Conclusion of the Two Tools

The first research questions raised in Chapter 1 is how can the two tools (Five 'Ds' framework and urban design score sheet) be applied for comparative analysis of TOD across a wide range of urban contexts both in China and the United States.

In general, this thesis identified transit-oriented development as a pedestrian-friendly, transit-centered community with multiple types of land use. As I measured and discussed the physical elements about the five different urban morphological aspects, I can reach a brief conclusion that the typically applied TOD concept in the Western context, such as in the United States, can also be used in the Chinese

context. And for the two research tools, they are both applicable in Chinese and American TOD examples.

The principal function of the transit center in a TOD is to provide various kinds of public transportation. In other words, a transit center that can provide diversified transportation options will become the center of the entire TOD community. When using the urban morphological factors framework to comparatively study the TODs in China and the United States, I found that in the two Asian cities of Chengdu TOD and Kowloon TOD, their transportation centers include different types of public transportation, such as subways, buses, urban rapid transit buses, and taxi distribution centers. In addition, they both provide high-speed railway service for long-distance transportation at a regional scale. These make the total area of the two local transit centers larger than the transit centers of Hudson Yards TOD and Northgate TOD. When I used the urban design score sheet to do the comparative study, I found that American cities like Hudson Yards TOD stress more on TOD construction at a small street and block scale. On the one hand, Americans have become accustomed to traveling in private cars after World War II, making the large railway stations unable to ensure transit efficiency. On the other hand, because of more complex zoning and land use regulations and different development strategies of various transportation operation companies, the size of transit centers is limited, and services such as buses and subways can only be provided to residents within

walking distance in a limited space and walkable distance with various attractive street elements.

In addition to the construction of the transit center, when I either compare the urban morphology or the urban design, I found that the four TODs all increase the vitality and dynamics of the entire community by developing multi-functional land use, building different types of houses suitable for different income groups, and providing public green space. At the same time, to improve pedestrians' walking efficiency and ensure their right of way, wide sidewalks have been set up in the TOD community (Except for the Seattle TOD single-family house area). Finally, Chengdu, Northgate, and Hudson Yards TOD also provide bicycle users with bicycle access signs and exclusive bicycle lanes. There are also bicycle racks and garages on the roadsides to provide temporary storage, which enriches the ways of internal passage. On the other hand, it has solved the problem of the last mile transit for the community residents.

Even if I use these two sets of tools to analyze the characteristics of different TOD regions, it does not mean that these two sets of tools can be applied to other TOD analysis. In the process of comparative research, I found that these two tools have some shortcomings that need improvement:

1. Cervero listed these five 'Ds' elements when studying the factors of urban morphology, but these five 'Ds' do not simply include all the built environment factors. For example, even if the population density is considered in terms of density aspect, the framework does not further include the population composition, population structure, and possible future changes in the population of the entire region.
2. Through the analysis of the five 'Ds' elements of urban morphology, I found that there are some differences in the urban morphology of TOD communities in different regions. If there are different analysis frameworks for different types of TODs, it would give a more intuitive understanding of the built environment in TOD communities.
3. One aspect of urban morphology is the consideration of design. This design and the later urban design score are aimed at completely different scales. However, the design in urban morphology simply analyzes factors such as street length and the number of intersections. There are also many factors such as road width, building height, vegetation coverage related to the large-scale community design that have not been analyzed.
4. As a framework for analyzing the urban form of the TOD built-up area, I can only use this framework to conduct a simple analysis of the current situation

of the TOD area, and cannot use this framework to explain whether the urban form of the TOD area is good or not, whether the community is good and convenient for residents, and whether the transit center increase the use of public transportation. Therefore, more quantitative analysis is needed.

5. In terms of the urban design scoring framework, I could analyze the urban design detail scores of the TOD area by using the framework. However, this scoring framework cannot be applied to all urban street observations. At the same time, the urban design performance of an area cannot be fully reflected in one or several streets. It is necessary to select different streets in the same area for urban design analysis.
6. As far as the five aspects of the urban design score sheet is concerned, whether researchers can fully understand and analyze the urban design still needs to be discussed. Because in Kevin Lynch's view, the five important elements that give shape to the mental representation of urban design are nodes, paths, districts, landmarks, and edges.

6.2 Five 'Ds' Urban Morphological Factors Framework

The second research question is what are the characteristics and differences of the four TOD cases on the five 'Ds' urban morphological factors. In general, the 'five Ds' aspects of these four TOD cases largely depend on the type of transit center and the

people served. TODs such as Kowloon and Chengdu provide city internal transportation services for nearby residents and provide convenience for passengers who use heavy rails to travel in different provinces. Therefore, they mainly consider the diversity within the station site, such as using different modes of transportation on different floors to achieve efficient and fast transfers to different modes of transportation in the station. The TODs in New York and Seattle serve community residents and workers, allowing them to obtain convenient public transportation to relieve the city traffic. Therefore, the different positioning of the TOD site's role is the main factor that causes the difference in the built environment. In addition, the diversity of these four TOD communities is different due to the degree of regional development and the regional and city plan. Finally, there are also differences in their destination accessibility, which means the differences in accessing transportation. Residents near Chengdu TOD can shorten the last ten minutes of walking time by using shared bicycles. New York and Seattle's bus systems are also friendly to cyclists, allowing them to take bicycles for transportation, which solved their last-mile problem. Due to the scarcity of land, Hong Kong does not have bicycle lanes for people to use. Instead, it provides intensively operated community minibuses to transport passengers in the TOD transit center to every residential area.

6.3 Urban Design Score Framework

The last research question is what are the characteristics and differences of the four TOD cases on the five urban design factors. Apart from the urban morphological

analysis of the four TOD cases, this thesis also examines and compares their characteristics in urban design at the community and street scale. More specifically, I measured the TOD's urban design performances based on the urban design score framework in the dimensions of imaginability, enclosure, human scale, transparency, and complexity.

As for the urban design scoring differences between the four cases, TOD indicators from all the five dimensions have been positively affecting urban design in Hudson Yards TOD the most, while Northgate TOD has been positively affected the least because of the lowest score. For example, Hudson Yards TOD has the highest score in imageability and complexity. Although Chengdu TOD has some uniformly shaped street around the station, it also ranked third because of the mixed-use apartments, various types of outdoor dining, street landscapes, and public small squares.

However, there is no single dimension that Northgate TOD scores the highest. For one reason, there is not a high population density so that street activities and small retails are limited. For another reason, a large tracts of vacant surface parking decrease the imageability and complexity in the area. Hudson Yards TOD also got the highest scores in terms of human scale and enclosure, while Hong Kong TOD only did the best in terms of transparency, so it ranks the second.

6.4 Experience for Future Transit-Oriented Development Projects

Based on the analysis, comparison, and conclusions of these four TOD cases from both built environment and urban design perspectives, I have summarized some key points that need to be paid attention to in the future development of TOD.

1. Background Analysis

First of all, background analysis from different levels should be done before any other process. The whole served community and the city level, population, geography, natural environment, topography, economy, future development objects, and other planning documents should be analyzed to delimit a good TOD service area and project goals.

2. Determine A TOD Type

According to the initial background analysis, it is necessary to determine the type of the transportation center. Some common types have been discussed in the thesis. For example, the Chengdu TOD transit center is the regional transportation hub, while the Northgate TOD transit center is the community public transportation hub.

3. Coordinate with Different Stakeholders

When planning and designing a TOD project, urban planners, designers, private property owners, community members, city government, and other related stakeholders should work together to figure out the best plan. Also, challenges may happen during the process because of the communication problem. It is also hard to

convince property owners because they may think the land and property value would be negatively affected by the project.

4. Diversity

Developing diversified land-use types and street activities within the region will increase the community dynamic, facilitate pedestrians and bicycle users to feel the urban design, and better serve the residents nearby. Urban design elements include street furniture, outdoor dining, green plantings, public open spaces, etc. In addition, diversified public transportation options should also be considered within the TOD region. For some people who live further than the radius of 1,000 meters from the transportation center, the provision of shared bicycles or the operation of community minibuses can reduce the time to walk from homes or workplaces to the transportation center.

5. Improve the Efficiency of the Transit Center

As the most important and central part of the entire TOD community, efficient public transportation operations can improve user experience, ensure equity, and reduce crowding in the area due to a denser population.

6.5 Limitations

Although this research design, methodology, and analysis of transit-oriented development can answer the research questions, various limitations also exist and can be identified.

First, the four cases at four different cities between China and the United States can only provide a very broad and general idea of how TODs perform in the four cities as the case number is quite limited and may not be representative of the other TOD communities in the two countries or any other countries in the world. Also, there is only one TOD case selected in each city that cannot represent any other TODs in the same city because of different TOD communities' backgrounds. Other TODs within the four cities and in other cities of the two countries or worldwide should be included in further studies.

Second, the data collection process has a negative impact on the results of this research. The research data in this thesis is used to analyze the built environment performance and urban design score of TOD communities. Some indicators can be calculated based on government data, such as population density, housing density, etc. In contrast, some indicators need to be obtained through observation and records of researchers' visits, such as street vegetation, the number of public art, etc. The data used in this thesis comes from government websites, planning departments, statistical yearbooks, and virtual visits on the street view from Google Maps, Google Earth, Baidu Maps in different cities. Therefore, for the TOD data

collected in different government open data, the reliability of the data will be reduced due to the difference in the measurement standards in different cities and the data publication time. Also, the use of online maps such as Google Maps for virtual street visiting may be different from field observations because it is not real-time and is observed entirely from the perspective of pedestrians. In order to better reduce data errors, future research should try to allow researchers to visit and observe multiple times in the field and averagely record data to reduce data deviation.

Third, the thesis mainly uses the five “Ds” framework and urban design score sheet as the standards to evaluate different TODs. A more standardized tool or framework evaluating the quality of the built environment within the TOD community should be developed. As a result, the evaluation of TODs from both perspectives can combine quantitative and descriptive analysis, which would provide more reliable comparison information between different cases. Also, the study on TOD’s performances on urban design mainly relied on the researcher’s personal feelings about the TOD area. What researchers should do in the next step is consider reactions and feelings from local people living within the TOD area, either from interviews or surveys.

Finally, this thesis did not discuss the solutions to TOD implementation challenges in the four cities, which could be a future research direction.

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