Department of Architecture and the

Built Environment

# Establishing the Evaluation Framework of Underground Public Space Quality Assessment (UPSQA)

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## ABSTRACT

Evaluating and improving the quality of Underground Public Space has become more significant for urban public realm utilisation, particularly in high density built urban areas. There is a necessity for a more scientific systematic evaluation approach to assess the quality of underground public places based on users' experience. Current literature shows that assessment criteria for traditional surface public places have a major impact on underground spatial design. However, an integrated research approach to debating the fundamental elements and key factors of underground public space is needed. Hence, this thesis aims to explore the key theories and practical cases to develop a matrix of qualitative assessment criteria for underground public places through a new research approach. 4 categories, 10 attributes, 46 indicators have been identified by SPSS Amos.

Firstly, the fundamental philosophical hypothesis is proposed, including discussions on underground public space quality assessment methods. Secondly, the definition and advantages of mixed method design have been investigated. Thirdly, the rationality of the case study is summarised as a preferred method in this research. Finally, a pilot study is conducted on Beijing Yonganli Metro Station to verify the feasibility of the research method and adjust the study design for the proposed case study. Besides, specific assessment frameworks obtained by different methods have been compared and analysed side by side. This is also one of the analysis strategies adopted for the present study.

In this research, Explore EFA (Exploratory Factor Analysis) and CFA (Confirmatory Factor Analysis) were used to rank and weight the indicators of the underground public space quality assessment system framework through literature review, professional interviews and three questionnaires. The analysis results of Chapter 5 to evaluate and score the design quality of underground public space around Guomao Station in the CBD area of Beijing have also been used. The author obtained three different results through three methods, and analysed and discussed the case results evaluated through the existing assessment criteria system.

The research summarised a set of indicators of the quality evaluation system for the underground public space constructed and proposed the underground public space quality evaluation framework by analysing the design elements that affect underground space quality. Finally, the underground public space quality evaluation system has been applied and verified by taking the underground public space in Beijing's CBD area as an example. The final assessment results of the case indicated that people

generally believe that high-quality places still have room for updates and improvements in the evaluation framework.

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# 1 Introduction

Urban underground public spaces as an important and fundamental part of the city play a vital role in **liveability**, **vitality**, **inclusivity** of the city. Hence, assessing the quality of underground public spaces is crucial to the success of urbanisation. The extensive use of underground space in modern times began with the introduction of underground transportation facilities. However, possibly due to concentration on different technologies and the efficiency of the underground space, one of the most important aspects was ignored during this time – i.e., the **human factor** (Besner, 2017, Venugopal et al., 2020). Functionality and mobility are no longer the main focus; nowadays, human **comfortability** is more crucial than ever (Carmody and Sterling, 1993).

Today, functionality and mobility are not the only quality features; human comfort is more important than ever (Carmody and Sterling, 1993). For instance, people have more choices than ever before in many areas, including their choices of vehicles. The comfort and usability of a product have become an increasingly important feature in people's judgement of quality. Hence, it is reasonable to ask: What is the overall status of underground public space? Are there any potential obstacles? Possible obstacles include: the high cost of development; psychological aspects, such as people’s negative perception of underground space; issues surrounding safety; and use in terms of the complexity of the underground public space (Wang and Shu, 2000). As an efficient, flexible, safe, and friendly environment, uncertainties regarding the use of underground open space need to be clarified.

One of the critical potential impediments to its use is people's perception of underground space. Many implemented projects have resulted in poor physical and psychological satisfaction, and it should be acknowledged that a positive attitude towards underground public spaces is quite rare. Often, the negative perception of underground space is the result of prejudice or a specific experience with existing underground space that is not explicitly focused on the physical and psychological qualities of these spaces (Romanova, 2016). There are countless examples of this, for example, the underground tunnels in London, Paris, and Barcelona are. These cities are now seriously considering reconstruction and new methods for the design of metro stations.

Fortunately, underground spaces are better represented in some cities in Canada, e.g., the Montreal metro, where planners and designers have recognised the advantages and added value that underground spaces provide for urban infrastructure. Montreal's planning demonstrates that public facilities can be successfully placed underground (Durmisevic, 1999). Vancouver designers have also paid particular attention to entrances to underground spaces by providing small 'entrance squares' that gradually extends down from the ground to the actual entrance, creating a more natural transition from one area to another (Durmisevic and Sariyildiz, 2001).

Another Canadian example is a long-term development plan known as the 'PATH' and developed by the City of Toronto. The entire system continues to expand and by 2035 will travel through downtown Toronto and extend outwards from the city's financial centre. The new PATH satellite area will cover the main transportation centres through which the metro line passes; its network will cover the waterfront, major parks and green spaces, hospitals, and universities, and provide access to vibrant communities and green street spaces (Zhou et al., 2017). The case of Toronto provides further evidence that underground space can provide people with a more significant proportion of life, work, and entertainment functions, combined with the city's ground service.

## 1.1 Research background and definition of the problem

Previously, unground space has been primarily used for mining, storage, and transportation. Nevertheless, underground space has giant expanded over the recent decades, partially caused by the shortage of land space in some mega cities along with improving architecture and engineering technologies (Zhou and Zhao, 2016, Soh et al., 2016, Su et al., 2020). With reference to the development of underground space, if people do not utilise such space, the urban form of human civilisation is unimaginable (Besner, 2002). Since ancient times, the use of underground space has concentrated on services to maintain human activities, e.g., sewage and water supply. From water distribution sites and cellars of the first urban civilisation to the sophisticated public utilities and service networks of every city today, urban underground space has emerged and developed as a necessary condition for urban evolution despite difficulties. Due to the growth of the world's population and the accelerating urbanisation process worldwide, the future of the city is increasingly dependent on the potential development of urban underground space. Depending on the specific economy, population, and geographic conditions, the ratio, scope, and form of underground use by global cities vary widely; technical, political, and cultural factors further interfere. However, despite each city's particularity, the development of the urban underground space has become a general and rapid developmental trend.

Due to intrusions of unmapped tunnels and pipelines in many cities' foundations, a comprehensive replacement of these has become necessary. In response, it is necessary to implement a rational plan to guide the city's underground expansion. Many governments and municipalities have adopted '*out-of-sight-out-of-mind approach*' (Besner, 2016, Montazerolhodjah et al., 2015). Nowadays, more local governments support long-term policies for sustainable urban development, including coordinated actions in the development of urban underground space. It is the responsibility of those who control both the underground and the aboveground space to check whether the activities carried out under their control cause damages to the city or the economic environment. Thus, the authorities must ensure both the realisation of underground development and the needs of current and future generations. It is necessary to promulgate effective local regulations and specific rules and measures and cooperate with the official plans to implement underground space use.

Since underground construction is more than an engineering issue, the critical step is to incorporate it into local economic and environmental issues, including the city's fiscal and budgetary environment, to better utilise urban underground space. Countries should incorporate underground development strategies into reliable business, technology, planning, and social information, often through public-private partnerships. Local governments should also promote the internalisation of the extra cost of using underground space more sustainably. This should base on the principle of users, public or private, first paying the price to use this natural 'resource', the big city should achieve the goal of sustainable development, rather than the best offer by selling space, but by renting the best space use.

With the development of underground space in urban planning, several important issues have surfaced. In addition to technical aspects regarding construction, quality must be assured in terms of human use factors. On the one hand, underground public space could be readily integrated into the entire urban environment; on the other hand, the actual quality of these spaces needs to be improved. The current research involves an understanding of such quality issues.

The quality of underground public spaces is closely related to the perception of space through various psychological prisms. It is sensitive because of the negative association of these spaces (Carmody and Sterling, 1993). The information related to quality and perception is inherently vague and challenging to assess; this point acknowledges a considerable knowledge gap in this regard. People's stereotypes of underground space make them biased towards underground space, but the trend is for designers to try different solutions to overcome the negative perceptions people hold. Therefore, the psychological aspects of underground public space and its relationship with spatial characteristics play an essential role in this study. Simultaneously, information processing and knowledge maps of such soft data also play an essential role.

## 1.2 Research gap

In the literature, some psychological aspects related to underground space have been given more attention than others, these include: legibility (Passini, 1992); safety (Korz et al., 1998; Boolean, 1997; Galen, 1999); colour; lighting; energy-saving; and humanised design (Carmody and Sterling, 1993). These studies provide valuable knowledge; however, there remain unresolved problems. For example, in single direction research, more attention is paid to the technical aspects, such as tunnelling, material, ventilation technology, while the relationship with other aspects is ignored (Besner, 2016). They were here seen as isolated experiences, while the underground space experience depends on the interaction of different aspects. Carmody and Sterling in 1993 and Sanja and Sevilpropose in 2000, they have researched in the strategy of humanised design of underground space. However, this was based on qualitative research and did not propose comprehensive classification and indicators that affect the quality of underground public space. Vischer (1989), pointed out that one of the difficulties in setting environmental standards for a group of users is that 'objectively quantifiable building standards do not take into account the psychological aspects of building performance' (p. 46). The psychological aspect becomes problematic because the characteristics of qualitative features tend to be vague, and thus present challenges in their description.

This suggests an urgent need for a more objective assessment of spatial quality and the definition of fuzzy concepts.

Carmody and Sterling (1993) argued that different aspects of underground space need to be integrated into the design. The authors proposed a classification of the underground space and the psychological impact involved. Thus, they suggested that the design concept of underground space should be people-oriented from five aspects: (1) exterior and entrance design; (2) layout and spatial configuration; (3) interior design elements and systems; (4) lighting; and, (5) safety. They put forward influential elements for each classification. Their framework system included specific indicators and was not specifically proposed as a design standard for underground space. Nonetheless, this work has essential significance to the design of underground space because it proposes that such space should be designed for people. However, the disadvantage is that it does not form a complete system framework indicator that can guide underground space design projects or evaluate the built underground space.

Durmisevic and Sariyildiz (2001) identified three determinants of quality metrics: functional, psychological, and structural. In their research, data on psychological aspects and user experience were collected. They proposed content for humanised design and that the underground space should pay attention to psychological feelings, which has considerable significance to an evaluation of the underground space from the psychological aspect. However, the study did not propose a complete quality evaluation system indicator and did not specify the evaluation criteria.

Wu (2006) believes that it is necessary to integrate the characteristics of underground public space from the aspects of technology, environment, and space. The researcher suggests that underground public space's influencing factors can be divided into psychological and physiological aspects, but there is no further quantitative analysis of such classification.

Yu's (2015) book on the design and assessment of low-carbonisation of underground space was also based on green building on the ground. It focuses on the low-carbon design of underground space. Meanwhile, Cao (2015) proposed that the humanised design of underground public space be divided into physiological factors, psychological factors, and emotional factors, but there is no precise quantitative index for a standard of humanised design in the literature. Therefore, the system is not easy to operate, neither in design nor in evaluation.

At present, the research on the quality evaluation standard of underground public space at home and abroad is minimal. Hong (2018) studied the theory and method of green building design in underground public space, but the evaluation index system of underground public space did not quantify the index, and the study was based on ground-level green building design standards. Hong's (2018) study focused on energy conservation and emission reduction in underground public spaces, and the design of underground public spaces has not been undertaken from a human use perspective. This study puts forward the sustainable design and evaluation standards for underground space, but it has two shortcomings. Formulating the design evaluation standards is mainly based on green building standards, rather than more extensive research on the ground and underground public spaces. Also, the method for establishing quality evaluation indicators is one single literature review, which only has a short discussion on the method of indicator sets.

Currently, the research on underground public space design methods focuses more on the technological aspects, such as natural lighting and ventilation design. It does not form a comprehensive design and evaluation system. Most of the methods introduced remain at the level of theoretical overview and lack more in-depth discussion. Although these design method strategies have specific referential significance for the quality evaluation standard of underground public space, there is no research which focuses on such a quality evaluation. On the other hand, the study of underground public space design methods often only points out some design strategies or reflections, such as *'A Study on the Design and Development Strategies for the Underground Space underneath Public Land in the Core Area of Beijing CBD'*, *'The research of humanism urban public space design'*. These studies were mostly based on qualitative research, and there was a lack of quantitative research in the area. For example, Wang studied the design of underground public spaces suggest the introduction of natural light and the design of sinking courtyards to improve the environment of these spaces (Wang, 2008b). However, they did not suggest the most suitable depth for a sinking courtyard, or what type of glass is better for natural lighting, and there was no further in-depth discussion of how to achieve the suggestions put forward. Such research methods employed tend to be singular, mainly employed to investigate some domestic and foreign cases. Thus, they do not reflect the intersection of computer technology, environmental psychology, ecology, and other multidisciplinary methods. Hence, this research will focus on humanised design to evaluate underground public space quality from the urban design perspective. It will be based on user preference to establish the evaluation system indicators.

## 1.3 Research Questions

This thesis focuses on the quantified assessment criteria of the quality of underground public space. The research aims to address the following key questions:

- **Main question**

**How can the quality of underground public space be assessed to promote the development of high-quality urban space?**

In current generations, the status of urban underground space is becoming more and more prominent. For the urban public space of non-traditional significance, its essence still has the attributes of urban public space, but at the same time, it has the characteristics of underground space. Therefore, evaluating the quality of underground public space is of considerable importance to the overall improvement of urban space quality..

- **Sub-questions**

**1) How to identify the quality of underground public space?**

Due to the particularity of underground space, quality underground public space must be defined and its significance to discussions for the metro and the surrounding underground buildings.

**2) What is the relationship between underground public space and public space on the ground?**

Underground public space could reflect its value to the city, and it has a relationship with the urban public space, the metro, and the buildings around the metro.

**3) How can the underground public space quality evaluation factor be determined in order to build an underground public space quality evaluation system?**

The study determines the impact factor and calculates its weight through the expert interview, questionnaire, and factor analysis, and it discusses how the evaluation system could apply in practice. Finally, the research takes the underground public space around the Guomao metro station in Beijing's CBD as an example to explore how quality assessment can be applied in practical projects.

## 1.4 Research Aims and Objectives

Through the study of the particularity of underground space, the interpretation of the design evaluation elements of both underground and aboveground public space, and the study of successful cases of underground space development, it is expected to propose underground public space design from four aspects: **exterior connection**; **space safety; interior environment**; and **operation.** The public space quality assessment system also provides a specific methodological basis for the humanised design of underground public spaces.

The research studies both the design elements of underground space and urban public space and the factors affecting underground public space quality. It also analyses the relevant indicators that affect its evaluation. The purpose is to construct an underground public space quality evaluation system, designed specifically for the purpose, which can meet the characteristics of underground space and be used in practice. This will promote the application of humanisation and low-carbon design in the development of underground public space. It will provide an evaluation standard for the quality evaluation of underground public space. Meanwhile, it will lay a solid foundation for the development and construction of high-quality underground public space.

User is the central figure in terms of human factors, and the user's perception of the underground space is the starting point for the design. To understand more specific design issues, surveying users of these spaces is crucial to identify areas of existing underground design problems. Because the precise scientific method has developed very well, technical problems could be solved through quantitative analysis and precise calculations (Bobylev and Sterling, 2016). Dealing with the linguistic features involved in ergonomic design is not an easy task because the expressions used are not precise and the features discussed are conceptual rather than physical (Besner, 2017). The research has shown that the wet, closed, dark context, among other characteristics of the underground space (Wang and Shu, 2000), tend to bring some discomfort to people's physical and psychological perception (Qian, 2016). Therefore, creating a humanised underground space environment can make people feel relaxed and safe and then attract more people to enter and use it, is vital (Besner, 2017).

In the low-carbon design of underground space, with the continuous deterioration of the human living environment, the harmonious development of humans with nature has become a theme for people around the world (Yu, 2015). Due to its particularity, underground space will bring massive resource consumption in development, construction, and operations management (Bobylev, 2016). If mishandled, it could cause damage to the surrounding environment (Besner, 2002). Hence, underground space should be reasonably developed and utilised with the same standards as aboveground space development as a part of the urban space.

With its large population, Chinese cities are significant consumers of energy and become the focus of this research. Most buildings in the country's cities consume high energy levels with low energy efficiency (Wan, 2013, Yu, 2015). Therefore, applying the green concept to the design of underground public space, conducive to resource conservation and environmental protection, and in line with future development trends and requirements, is of vital interest (Yu, 2015).

The primary purpose of this study is to explore the importance of underground public space and construct an underground public space quality assessment. The underground public space assessment based in the Beijing CBD verifies the significance of an underground public space quality assessment system in an actual project evaluation. The research objectives are:

1) to translate the characteristics of humanised design and low-carbon design of urban underground public space and examine the quality indicators developed in urban design discourse;

2) to establish the role of underground public space measurement elements in design support for people, including humanised design and low carbon design elements;

3) to recognise the role of underground public spaces as a significant component of urban space, thereby promoting the basis of better policy and urban design interventions to design new, and redesign existing, underground public spaces.

## 1.5 Structure and organisation of the thesis

This thesis is organised into four interrelated parts to provide sufficient information regarding the study on quality assessment criteria of underground public space. Part 1 includes the first three chapters that outline the research background and provide a review of the literature.

Chapter 1 presents the background to the study, the objectives, and the theoretical background related to the context. This is followed by the discussion of the state of the art of the study and the structure of the thesis. This chapter also shows the possibilities of the study of the underground space alongside the complexity of the urban design field.

Chapter 2 introduces related theories and makes a further review of the use of modern underground space, defines the concept of underground public space, and separates the spatial combination theory of architecture and the urban theory and psychology of urban planning. The study of the theory of environmental behaviour is carried out. Finally, to explore the influence of urban-related theories on underground public space design, the theoretical support for the quality evaluation standard of underground space is provided.

Chapter 3 presents people's need to use underground public space. It discusses the value and benefits of underground public space. The design or evaluation index system of underground space and urban public space has also been reviewed, laying the foundation for establishing a quality evaluation framework of underground public space.

Part 2 begins with Chapter 4, which presents the research methodology chosen for this study. The author gives reasons for a case study approach to be applied and shows the inquiry strategy used to demonstrate and assess the research outcomes. Thus, it introduces and justifies the selection of case studies for this research.

Part 3 is the core part of this article, including Chapter 5 and Chapter 6. The third part puts forward the quality evaluation standard of urban underground space, determines the quality and method of evaluation and the last section of chapter 5 and chapter 6 is discussed. Chapter 5 discusses the content of quality assessment standards, and chapter 6 discusses the case analysis results. The sixth chapter uses the results to establish the quality evaluation model of urban underground public space and quantitatively evaluate urban underground public space's safety. The evaluation score can be used to express the quality level of underground public space under normal conditions. Through the investigation of sub-indices, data support is provided for improving the environmental quality of underground public space. Chapter 6 takes the underground public space around Beijing Guomao metro station as an example to analyse and verify the quality evaluation indicators and evaluation methods.

Part 4 includes Chapter 7, which involves literature, theory and underground public design practice to support its importance and contribution (Sholihah, 2016).

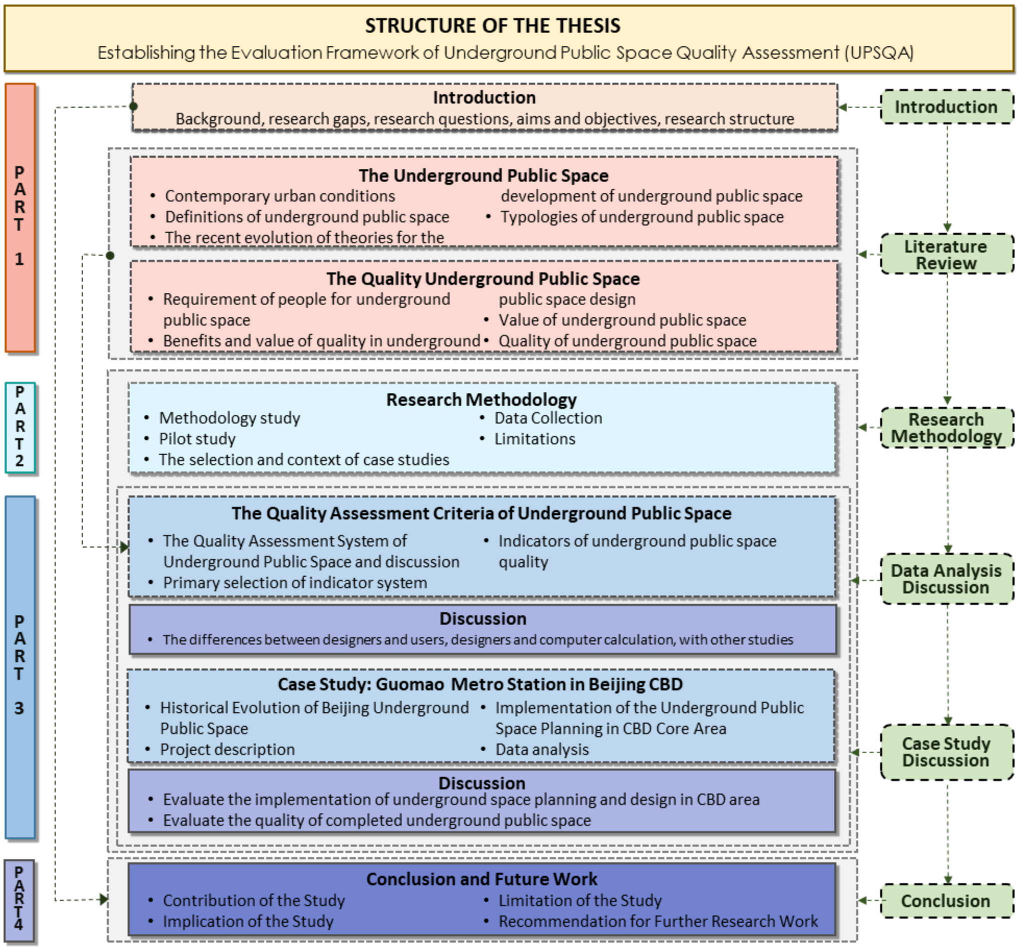



Figure 1-1 The structure of the thesis.

# 2 The Underground Public Space

This chapter focuses on the literature that considers the development of urban underground public space and the **value** and **contribution** made by urban theories. It also presents the concept of urban underground public space as one type of urban public space and identifies its relation to urban design discourses. When the research discusses underground public space, it debates the development of cities and urban public spaces. For underground public space, the rapid increase of high-rise buildings and the rapid development of rail transit are two of the most important influencing factors (Wan, 2013). The development and utilisation of such spaces in the past few decades provide an extension to the city and help solve the problem of insufficient land for urban construction (Reynolds and Reynolds, 2015). The future of underground space should be **sustainable**, **flexible**, **liveable**, and **inclusive** (Admiraal and Cornaro, 2018). Urban underground space construction provides a way to meet these requirements.

A hundred years ago, the unhealthy living conditions in the industrial city slums of Europe and later North America horrified social reformers. Bothered by the impoverished popular districts of 1890s London, a court reporter named Ebenezer Howard came up with a visionary and utopian plan for what was probably the first 'green city' the Garden City (Besner, 2017). He envisaged a series of new self-sufficient towns, built in the countryside, and surrounded by agricultural belts that would supply the inhabitants with food. The Garden City would have its own industry to provide local employment. People would be drawn away from the overcrowded big cities by promising a better life in such towns.

From the 1900s, the French architect Eugène Hénard denounced the anarchic congestion of the urban underground beneath streets and suggested burying the urban traffic, the fluids, waste, and goods in a gallery with multiple floors (Besner, 2017). Hénard's visions already prefigure the separation of the traffic and the segregation of the functions, which his contemporaries later proposed. However, in contrast, the American father of suburbia, Frank Lloyd Wright dreamt of replacing traditional cities with spacious low-density housing linked by highways in 1930. He assumed that each family would own a car. This plan soon became the sprawling reality of post-War North America, which resulted in a traffic issue in the late twentieth century.

Inspired by Hénard, in 1937 the French architect Edouard Utudjian founded the 'International Permanent Committee of Underground Technologies and Planning' based on observations of chaos in the big cities of that period, to promote better use of underground space. Moreover, the imminence of the Second World War created a need for shelters intended to protect the population. Unfortunately, other thinkers firmly rejected this option, such as Lloyd Wright, who favoured a purely functionalist approach and modern solutions to relieve congestion in cities. They liked to put vehicle possession at the focal point of their arrangements, with skyscraper mathematical squares set in open parkland navigated by extraordinary roadways.

The Swiss architect, Le Corbusier, put car ownership at the heart of his plan for a 'Radiant City' (Wan, 2013). Instead of sprawling cities, he favoured high-rise geometric blocks set in open parkland traversed by great highways. Le Corbusier believed that cities must be concentrated, only concentrated cities have vitality, and the problems caused by crowding can be solved by many high-rise buildings and ground, air, underground multi-storey High-efficiency transportation system(Corbusier, 1929). The utilisation of underground space in the city not only load the traffic function but also load the city traffic. This vital function drives the development of other city functions and realises the city's three-dimensional development, which has organic coordination of various functions. Though different in their visions, Howard, Wright, and Le Corbusier have three things in common. All wanted to open more green spaces and revealed a will to segregate human functions into separate areas for living, working, shopping, for sport, and leisure. On their side, Hénard and Utidjian wanted a re-appropriation of the city by vertical segregation of the urban functions. This is an idea that remained eccentric until the end of the 1950s.

Simultaneously, municipalities bulldozed older, central, mixed-use districts under the aegis of 'slum clearance' and created segregated and soulless 'new towns' and sprawling car-dependent suburbs. There was, predictably, a backlash. One of the fiercest critics was the Canadian Jane Jacobs who, in the late 1960s, argued against segregation and uniformity and for variety and diversity of cities to retain their natural, organic vitality. Pavement were important social spaces where people could interact; older buildings gave character and should be repaired not replaced; and many of the areas designated as slums were vital functioning communities that should be improved, not demolished. However, what Jacobs and others did not foresee was how corporate power would play in shaping cities as neo-liberalism politics took hold after the 1970s. This often resulted in developments which are neither socially nor ecologically sustainable (Besner, 2002).

The thinking of modern urban layout originated from the park movement in the early 19th century (Yuan, 2013). The park movement promoted thinking about the urban greening system and urban layout. The role of underground space is still a basic shelter and supplement to the Ministry of Transport. However, later underground national metros and municipal pipeline networks need to consider various land use, population distribution, and existing and future transportation facilities that for the necessary city development. The underground construction must consider the coordination of underground space and the spatial scope of the underground passage, and the connection between the underground platform and the ground building. The construction of these transportation facilities requires pre-arranged and planned construction and requires an overall plan based on multi-factor integration. Therefore, considering urban transportation facilities and municipal public facilities is the earliest system consideration in cities. The arrangement of these facilities is difficult to use on-site perception knowledge to dispatch visible entities, but it needs to be done before construction. Adequate coordination and arrangements require a unified pre-arrangement of various land and municipal facilities in the city (Besner, 2007). Overall, these methods are not what traditional architectures can provide. The engineer's knowledge system also provides more information about the system layout, which is the core thinking method inherited from later urban planning. Underground space planning, especially metro and underground pipeline network planning, was produced in the early stage of modern urban planning and promoted modern urban planning development(Wang, 2012).

## 2.1 Contemporary urban conditions

This section will explain the main challenges of contemporary cities, why people use underground space and the development trend of underground space.

### 2.1.1 Challenges for urban areas

Cities are the product of the highly advanced and materialised civilisation and scientific and technological awareness of human society (Wan, 2013). Since the second industrial revolution, represented by the introduction of the steam engine in 1870, science and technology and urbanisation allowed city itself to develop and change continually. It is the common wish of everyone to make the city a better place for humankind. Since the 1950s, the three significant crises facing humanity, 'population', 'poverty', 'pollution', and the accompanying social issues that have emerged during social change, have made urban issues increasingly prominent(Wan, 2013). The contradictions between cities, populations, and the environment are becoming increasingly dangerous (Li, 2013). The deterioration of the living environment and the depletion of non-renewable resources have become real urban problems and an uncommon sense of crisis in the future (Table 2.1). Indeed, problems associated with population, food, land, resources, environment, employment, medical care, and education, which are regularly highlighted in cities, are becoming increasingly severe (Tong, 2005).

Table 2-1 Urbanisation and Trends in the Modern World (Wan, 2013:2)

| Year | World population (Billion) | Cities population (Billion) | Urbanisation |
|---|---|---|---|
| 1800 | 9.06 | 0.27 | 3.0 |
| 1850 | 11.71 | 0.7 | 6.0 |
| 1900 | 16.08 | 2.19 | 13.6 |
| 1950 | 25.13 | 7.21 | 28.7 |
| 1960 | 30.2 | 10.2 | 33.9 |

| | | | |
|---|---|---|---|
| 1970 | 36.8 | 13.8 | 37.5 |
| 1980 | 44.37 | 17.3 | 39.0 |
| 2000 | 62.1 | 31.8 | 51.3 |
| 2020 | 81.0 | 62.5 | 77.2 |

With the advancement of urbanisation and rapid increase in urban populations, underground space has come to be regarded as a valuable land resource for any city. It has the potential to alleviate pressures on urban surface space and to solve urban problems. From 1950 to 2018, the world's urban population increased from 751 million to 4.2 billion; by 2030 it is expected there will be 43 megacities with more than 10 million inhabitants each (UN, 2018). Such population growth and large agglomerations of people in the same place have led to an increase in demand for infrastructure when there are increasing efforts to improve energy efficiency and raise public awareness of the need to protect the environment (Broere, 2016). Professor Salingaros (2006), a Dutch urban research scholar, believes that compact cities change the disorderly expansion of cities, being a more fundamental way. However, high-density development, high-rise buildings, and ultra-high-density huge cities of compact cities are not what people want (Wan, 2013). Small-scale, medium-density, proximity to farmland and nature, an environment that fully reflects the history and regional culture, and more, compact cities that conform to the scale of human nature and can create high-quality lives are the development direction. As Figure 2-1 the goal is embodied in the spatial form of T1 – T6 represented by the 'Smart Code' of American New

Urbanism, and the urban spatial form of T3 in the middle (Duany et al., 2006). It is widely believed that quality public places are essential assets for urban liveability and sustainable development, and can bring both short and long-term benefits to society, human health, the environment, and the economy (CABE, 2004; Beck, 2009).

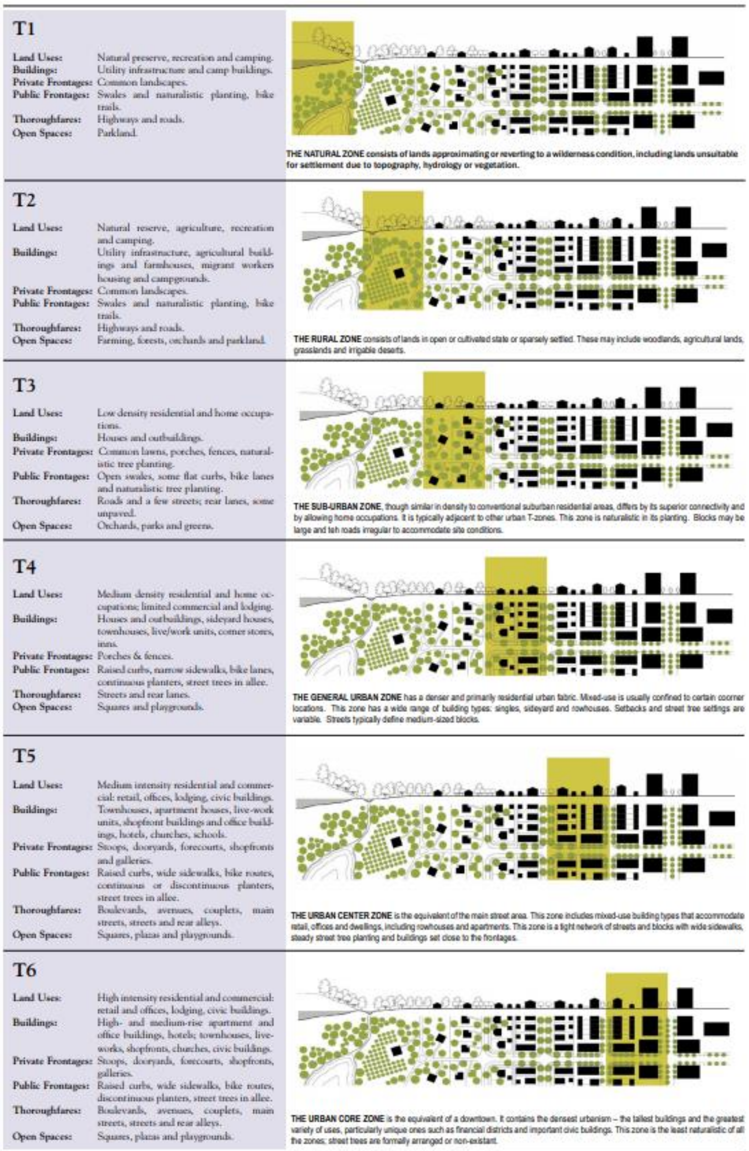



Figure 2-1 'Smart Growth' refines 6 types of compact cities (Duany et al., 2006:3)

*Figure source: http://myweb.facstaff.wwu.edu/zaferan/SmartCode6.5.pdf*

The main challenge for today's urban designers is to create functional urban spaces that can adapt and respond to diverse, intense, mixed, dynamic, competitive, and original urban conditions (Cho et al., 2015; Carmona et al., 2012). The ways of analysis, design, redesign, and use of urban space require quantitative and qualitative reconceptualisation. In high-density environments, where densification may not be conscious due to scarcity of land, the role of quality public space in sustainable urban development becomes critical (Wan, 2013; Cho et al., 2015). Over time, the spatial, economic, and social and cultural conditions of many cities have formed a unique platform for exploring high-density urban forms where the primary purpose is to optimise the available space by maximising capacity while challenging the possibility of retention to improve quality and liveability in such environments (Besner, 2016).

Consequently, this research aims to challenge the limits of irreversible, multifunctional (infrastructure and commercial space) development up to which the performance and vitality of urban underground space would remain satisfactory, or even improved. Thus, the broader aim is to explore ways of assuring a holistic approach to making our cities liveable, sustainable, and inclusive, while not losing one to the other in the process of urban underground public space development.

### 2.1.2 Why use underground space

The concepts of sustainable development, environmental protection, and natural resource conservation gradually emerged between 1970 and 1987 to cope with the increasingly explosive urbanisation situation, aimed at coordinating economic and social development (Besner, 2002). The term 'sustainable development' was first introduced by the World Conservation Union (IUCN) in 1980. It was defined in 1987 by the United Nations Commission on Environment and Development's 'Our Common Future' report (commonly known as the Brundtland Report) as (Nations, 2013):

'The development of meeting current needs without compromising the ability of future generations to respond.'

There are three main objectives of sustainable development: ecological integrity; equity between nations, individuals, and generations; and, economic efficiency, described as follows (Nations, 2013):

1) to improve social equity, meet the basic needs of current and future human communities, and improve the quality of life;

2) to improve economic benefits conducive to the optimal use of human, natural, and financial resources;

3) to maintain the integrity of the environment, i.e., to combine all actions of human communities with the protection of the ecosystem.

As far as cities are concerned, the challenge for sustainable development applications lies in plans, policies, and regulations (Nations, 2013). In short, all interventions aim to implement the basic goals of these three aspects in a balanced manner. To achieve the development of sustainable human settlements and provide appropriate housing and essential services for all, all actors within and between countries from the public, private, voluntary, and community organisations, cooperative sectors, non-governmental organisations, and individuals partnerships are essential (Besner, 2002). Multiple methods also defined these standards by international organisations over the years, including local round table discussion about the cities, the environment, and the economy (Besner, 2002). In concrete ways, metropolitan and local governments attempt to adhere to some basic principles, described as follows.

- Favouring compact cities

As a result of the economic expansion of the 1990s, highway congestion and prolonged daily travel times have increased public awareness of the negative aspects of suburban growth. This has led to an emergence of anti-growth sentiments that have focused on diverting new projects to the inner circle and the populated areas of older suburbs, and mixed-use development for transition services. The goal is to control spread and reduce dependence on cars. In North America, the apparent trends are towards more compact urban forms and more creative reuse of existing buildings and structures. In mixed-use development, there is also a tendency to mix and layer houses.

- Maximising the advantage of the 3rd dimension of the city

In urbanised areas, there is a contrast between spaces available and the spaces required for various functions. The choice of underground space for infrastructure, combined with a compact urban shape, may have significant advantages and is an attractive option.

Environmental reasons are the decisive factor in realising new infrastructure projects underground, especially for transportation infrastructure and parking lots. In most metropolises, transportation has become a significant problem due to the seemingly ineffective public transport organisation. More and more vehicles are causing traffic jams every day, polluting the air and colliding with pedestrians. To meet this urgent need to move around the city, undergrounds have been built, highways constructed in depressions or tunnels, and underground parking facilities created. For example, The Marunouchi area of Tokyo, Japan, effectively guides and controls the aboveground urban design process and the underground pedestrian system. It incorporates a mixture function of the metro, underground pedestrian, commerce, and parking; it has built vehicles suitable for high-density population and employment areas. The urban centre area will be reconstructed simultaneously and continuously expanded in the development process, from decentralising to unified planning, dialogue, negotiation, and flexible and coordinated development, which is a gradual development type (Figure 2-2).

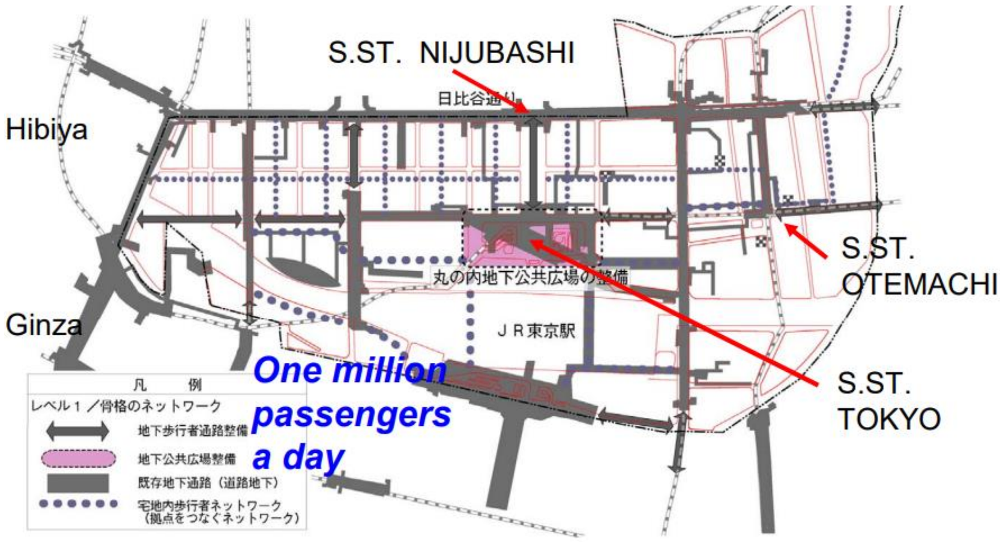



Figure 2-2 Tokyo Marunouchi overground buildings and underground pedestrian system

*Figure source: Okuni, M., 2009. The Sustainable Urban Design and Underground Networks in Tokyo, Madrid and Bilbao. In Proceedings of 12TH International Conference of The Associated Research Centres For Urban Underground Space (ACUUS2009), Shenzen (pp. 83-89).*

In the next 25 years, the world population will increase to 8.5 billion. More than 80% of the population will live in countries currently described as 'developing' (Hunt et al., 2016). Construction of buildings and roading has risen rapidly, invading the landscape, and making 'horizontal expansion' a prominent feature of development over the past decade. Often, this growth appears to be out of control, which in most cases has led to a reduction in environmental quality. The 'solution space' for improving the urban environment is enormous; this study concentrates on underground public space, which is considered an important area for future planning (Durmisevic, 1999).

Understanding the importance of underground space utilisation requires an understanding of urban development trends and the direction of contemporary planning (Durmisevic, 1999). Cities are becoming a 'user-unfriendly' environment due to traffic congestion, increased noise and air pollution, and a scarcity of green and leisure areas. Continued expansion of city boundaries does not solve the problem; it only delays and makes it worse. For cities, the expansion of infrastructure and mobility has only become a concern since the early 2000s. Questions remain: how can these concerns be resolved to improve the overall quality of life in the cities and ensure a healthy urban environment (Durmisevic, 1999)?

There are numerous benefits to utilising underground space which can be summarised as follows (Chow, 2002):

1) it results in effective land use and environmental improvement – it realises the potential of underground space in congested urban areas and

frees up ground space for other uses, such as parks and entertainment venues;

2) it adds to the beauty of the environment – i.e., it removes useless structures, such as parking lots, roads, and shopping malls, from the horizon;

3) it offers sustainable development – there is no need for external cladding and finishing, which can effectively cut the number of materials required and save costs;

4) it saves energy – it uses the ground's natural insulating characteristics to absorb noise and energy and allows more efficient heating or cooling and energy storage.

In some cases, underground space is the result of a lack of floor space or location issues. Its use provides the facility to build where it is not possible to have a ground-level facility, either because of insufficient space or because the community does not accept the construction of ground-level facilities at that location (Durmisevic, 2002). Many types of facilities are or must be placed underground because they are undesirable on the ground, e.g., utilities, storage of unwanted materials, and parking. Underground solutions also allow people to build near existing facilities or other places which cannot be built upon, thereby providing better services to users. The use of underground space helps provide a safe, environmentally sound, fast and unobstructed urban public transport system; moreover, it is often necessary to separate different transport activities. Corridors are usually required to be graded, and placing a corridor underground usually has a much smaller impact on existing communities (Carmody and Sterling; 1993, Su, 2008). In important urban transportation hubs, multiple levels of transportation facilities can be grouped to provide convenient connections between them.

A further advantage of underground space is that it can isolate users from all types of climate. Compared to extreme surface temperatures, the soil temperature or rock below ground provides a moderate and uniform thermal environment (Tong, 1998). For example, food preservation can be enhanced through moderate and constant underground temperature conditions, and it has the ability to maintain a sealed environment. Underground structures are naturally protected from severe weather (hurricanes, tornadoes, thunderstorms, and other natural phenomena). They can also resist structural damage caused by floods, although special isolation measures are needed to prevent the structure itself from being flooded. Besides, underground structures have some inherent advantages in resisting seismic motion. They are less affected by surface seismic waves, as noted during the Kobe earthquake in 1995, and previously noted in San Francisco and Mexico City earthquakes. Because they are designed to support essential ground loads, they can generally resist seismic loads better. A small amount of ground cover is very useful in preventing airborne noise. The earth protects itself from noise and vibration by absorbing the vibration and vibrational energy of an explosion. Thus, in the event of an explosion, radioactive dust, or an industrial accident, if underground structures can exclude or filter contaminated outside air, they can become valuable emergency shelters. The main security advantage of underground facilities is that access points are often restricted and easy to secure. Compared with ground installations, multi-purpose service tunnels are less susceptible to the external environment and will only cause minor interference to the ground when repairing or maintaining installed equipment (Yu, 2015).

Underground space also offers several advantages in terms of protecting the environment. These are essential aspects of the design of a facility with low environmental impact. Compared to equivalent surface structures, structures that are wholly or partly underground have less visual impact. There is an increasing need to place all utility services underground, primarily due to visual impact considerations and concerns about protection from the elements. In some cases, underground structures retain natural vegetation. As a result, the damage to local and global ecological cycles is small. Traffic tunnels remove vehicles from ground level streets, reduce traffic noise and air pollution, and can relieve the ground street portion for other purposes. Underground car parks and shopping centres leave space for recreation areas and playgrounds on the ground (Cui and Lin, 2016).

### 2.1.3 Current tendencies in urban underground space development

Understanding the importance of underground space utilisation requires consideration of urban development trends and the direction of contemporary planning. In this way, it is possible to imagine its place in future planning concepts. While people understand its importance, it is also necessary to prove rational use of this uncultivated land (Durmisevic, 1999).

By the 21st century, over half of the world (55%) live in urban settings and a quarter of the world's population will be living in big cities and metropolitan areas (UN-DESA, 2018). Due to population inflow towards the cities, which has been most apparent during the past century, the existing infrastructure is insufficient to satisfy the growing demand for efficient transport facilities. Due to developed technology, underground metro-systems were introduced in major cities to relieve the pressure from the surface, provide more efficient transport, and encourage more extensive public transport use. However, somewhere along the way, perhaps a result of preoccupation with efficiently mastering different techniques for building underground, the human factor, one of the most critical aspects, was neglected (Durmisevic and Sariyildiz, 2001; Besner, 2017). Certainly, underground space is widely used worldwide, despite different motivations for its use. In London, London's transport and utility infrastructure has continued to increase below ground level, the Jubilee Line Extension (1999); Crossrail, which is currently under construction (partially opening 2019) (Reynolds and Reynolds, 2015). Although London’s residential, recreation and retail land uses are still primarily at the ground or above ground level, interest seems to be growing in utilising below-ground spaces. Such as The Canary Wharf Group recently added a predominantly basement level retail space at Jubilee Place, connecting to an existing mall and train station beneath a cluster of office towers (Reynolds and Reynolds, 2015, Admiraal, 2015).

To solve traffic problems, London built the world's first metro; to save space, the world's first underground parking and commercial centre, the Rockefeller Centre, was built in New York; and, to combat cold weather and create an efficient transportation system, Montreal built a shiny new underground city. The development of underground space in these cities has now entered a different stage. For example, in London, although its residential, recreational, and retail land uses remain primarily at the ground or aboveground level, interest seems to be growing in utilising below ground spaces (Reynolds and Reynolds, 2015). New, or renewal projects, such as Canary Wharf, make efficient use of underground space and focus on integrating aboveground and underground space. Montreal's underground city has entered the stage of renewal and renovation, and the transformation of the underground space has placed more emphasis on the human experience. In contrast, China's underground space utilisation is still at a stage of rapid expansion. China is the largest of the developing countries, and it faces urbanisation challenges and the need to create liveable cities for its citizens (Bobylev and Sterling, 2016). It has become one of the top developers of urban underground space in some aspects, such as metro and underground commercial complexes (Chen et al., 2018). Although the initial purpose of urban underground space development in China was to improve the movement of people in the urban environment (Qian, 2016), the characteristics and developmental trends of urban underground space have changed. There are three main aspects to current trends: function integration; three-dimensional connection; and multi-district integration (Chen et al., 2018).

As the final valuable resource of a city, the efficiency and effectiveness of using underground space are gaining more attention from architects, urban designers, and scholars (Chow, 2002). Initial awareness of the underground space manifest in the London Underground, which opened in 1863. Among moves toward underground urbanism (Delmastro et al., 2016) which took shape in the 1930s, the French architect Edouard Utudjian set up GECUS (Groupe d' études et de coordination de l' Urbanisme souterrain) in 1933. The objective of GECUS was the promotion of better use of underground space in cities (Besner, 2017). In 1941, a 19-building complex was built at the Rockefeller Centre in New York, which created the world's first underground parking area that increased the efficiency of the space by making it multi-purpose. However, the function of underground space has since changed.

## 2.2 Definitions of underground public space

This section defines the concept and research scope of underground public space and further clarifies the research object and scope of the thesis. The underground public spaces mentioned in the subsequent chapters are based on this defined scope.

> *'Underground space refers to a space that is situated below ground level. Surface space is accordingly defined as space (whether built or unbuilt) that is above ground level. Ground-level is usually defined as the natural elevation of the surface of the ground, which may be artificially either raised or lowered' (Rönkä et al., 1998).*

Public space is defined as:

> *'All those parts of the built and natural environment where the public has free access. It encompasses: all the streets, squares, and other rights of way, whether predominantly in residential, commercial, or community/civic uses; the open*

*spaces and parks; and the public/private spaces where public access is unrestricted (at least during daylight hours). It includes the interfaces with key internal and external and private spaces to which the public normally has free access' (Bradshaw et al., 2004).*

Urban underground space services, or urban functions, can be summarised as: storage (e.g., for food, water, petroleum, industrial products, waste); industry (e.g., manufacturing); energy production (e.g., geothermal energy procurement); transportation (e.g., railways, highways, pedestrian tunnels); supply of utilities (e.g., water, gas, electricity, and communications); waste treatment (e.g., wastewater pipes); and, provision of both public (e.g., shopping malls, hospitals, parking lots, civil defence facilities) and private space (e.g., cellars and residential homes and garages (Bobylev, 2009).

Underground buildings depend on the land use of the ground space above. Thus, there are two types of underground space below a building, namely private space and public space. However, each country has its particular characteristics, e.g., in Japan, the government stipulates that deep urban spaces below -50m are public resources (Jia and Peng, 2012)(Kishii, 2016).

Urban functions divide underground space into three types: transportation, infrastructure, and public space. Regardless of ground or underground space, urban public space allows for urban mobility; therefore, these spaces have common attributes which all services are provided for public use. Urban underground public space is a collection of architectural spaces in different fields, including business, entertainment, and sports. Many users can share such functional spaces because they serve people and their internal spaces to pay attention to physical and psychological spaces.

Expanding the above definition of underground public space includes those areas that are public or partially public, such as underground roads, commercial streets, and sidewalks (Meng, 2008). Importantly, underground public space connects metro stations with urban public spaces or buildings. It is the product of a combination of urban public space, metro transportation, and underground buildings. Also, underground public space is the embodiment of comprehensive utilisation of underground space. The Canary Wharf project in London, for example, shows that underground public spaces are often created to connect underground buildings and public transportation. Furthermore, to combine commercial, parking, and transportation functions in the connection process, the PATH project in Toronto has created an underground public path which connects most of the underground buildings in the urban area. Its connected network mixes the functions of the underground public space. This 'underground passage' has more than 30 kilometres of sidewalks that connect 1,200 shops, and more importantly, it is only a 10-minute walk from the city's Union Station (Belanger, 2007).

Based on a comprehensive analysis of the main points of these related concepts, Belanger (2007) believes that the concept of 'urban underground public space' should have the following main points summarised as below:

- It is a concept that exists below the ground plane and has the morphological characteristics of the space body (such as point, line, surface, or a combination of the above forms), which distinguishes it from public space on the ground;
- It is also an underground public place. 'Public' determines that urban underground public space connects with citizens and their lives. It must provide public places for living services and social interaction for the residents of the broader strata in the city. Of course, 'public' also means the sharing of benefits and ownership, indicating that it is supported by legal and social consensus;
- Urban underground public space is the product of the complexity of the terms 'underground space', 'public space' and 'urban'. Thus, it is constrained by various factors in the city; it must carry out urban activities, perform urban functions, reflect the image of the city, solve urban problems, and so on;
- Urban underground public space is a carrier at the material level and a carrier connected with human activities, or a carrier of the relationship

between various functional elements of the city. Public spaces have multiple goals and functions;

- Underground public space is also an essential object in the protection of public space resources and other resources;

- In the historical development of urban public space, changes have been due to the development of urban functions and changes in the content of citizens' lives.

To sum up, urban underground public space refers to the public space between underground construction entities and metros in cities (see Figure 2-3 below). It is a place for urban residents to conduct public communication activities and serves most people at some level. The underground public space also bears the complex activities and multiple functions of the city. It is an essential carrier of urban ecology and urban life and contains a variety of goals consistent with various other sustainable land-use methods. Moreover, it is dynamic and changing.

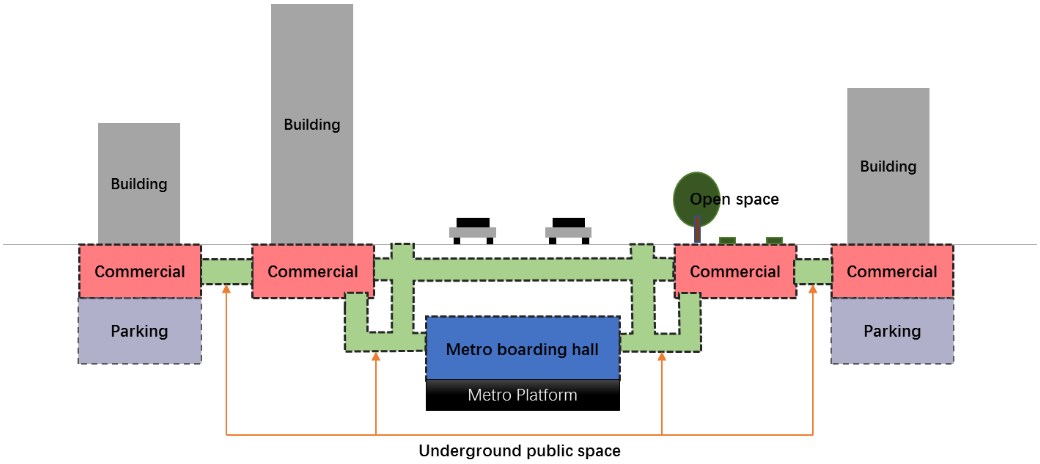



Figure 2-3 A conceptual diagram of underground public space around a metro system

*Figure source: drawing by author.*

## 2.3 The recent evolution of theories for the development of underground public space

A search of the Elsevier Science database of literature from 1790 to 2000, reveals that initially the term 'the underground' was used to describe a metro - the first metro opened in London in 1863 and came to be known as the London Underground. The original spatial organisation of the underground distributed space in points or lines does not represent the characteristics of the city. The concept of underground space was first proposed at the 1980 International Rock Mechanics Conference. Subsequently, scholars began to pay attention to the use of underground space and its relationship with the city (development value, economic significance, number, and availability of resources), making land more valuable. Some resources can increase the value of a plot through the judicious use of underground space (Yuan, 2013). Looking back at the development of underground space, many great architects have significantly impacted its development. The following review is taken from an architect's perspective and considers the influence of the theory of urban development on the use of underground space.

In 1882, the 'linear city' (Fig 2-4) was an urban plan with an elongated urban structure (Rogers and Armstrong, 1969). This type of city consisted of a series of functionally parallel departments. Typically, the city would be built parallel to the river so that the prevailing wind would blow from residential to industrial areas (Tufek-Memisevic and Stachura, 2015). he main contribution of the utilisation of underground space is the construction of a significant arterial transport route, for which urban traffic construction can occur above or below ground, or even in the air (Wan, 2013, Asplund, 1984). This was the first time that the 'linear city' theory has studied the development of underground space and the overall development of the city from a macro perspective.

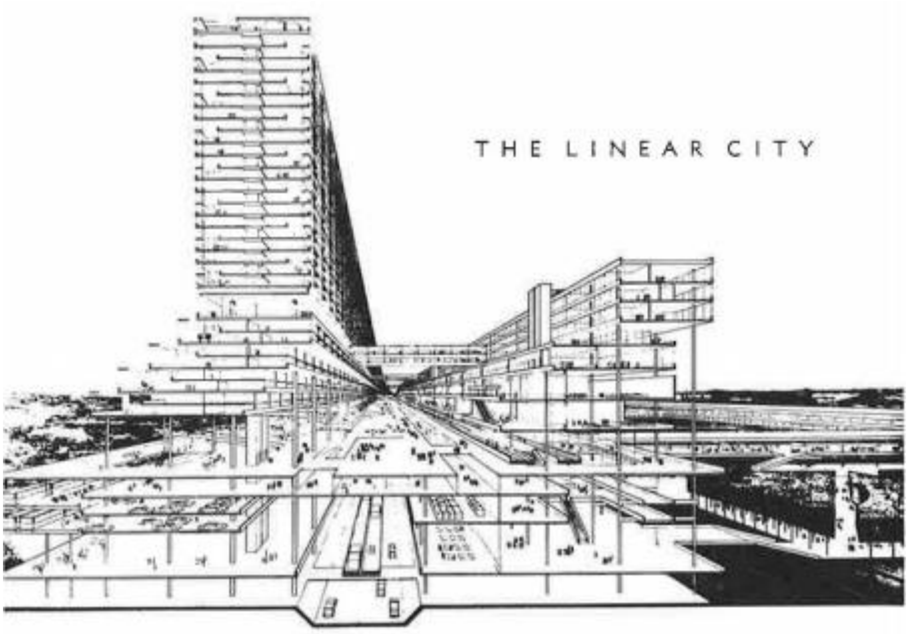



Figure 2-4 'Linear city' theory

*Figure source: Rogers, A.C. and Armstrong, B.D., 1969. Linear City and Cross-Brooklyn Expressway. Highway Research Board Special Report, (104).*

Meanwhile, as alluded to above, Hénard pointed out in his 'city of the Future' theory (Figure 2-5) that the streets would include pipes for gas, electricity, compressed air, drinking water, and pneumatic tubes for letters and telephone lines (Novotny and Brown, 2007). Each floor would have a bathroom with hot and cold water. Vacuum-powered wall ducts would remove smoky or polluted air from apartments. Rubbish would be thrown into underground rubbish bins, while service trucks would bring the garbage to railings below the street. The theory proposed an underground system replace the urban transportation system to save urban land, and the landscape used to improve the urban environment. Moreover, separation of the pedestrian system from the vehicle system would be achieved. This theory has had a profound influence on the theory of urban underground space design.

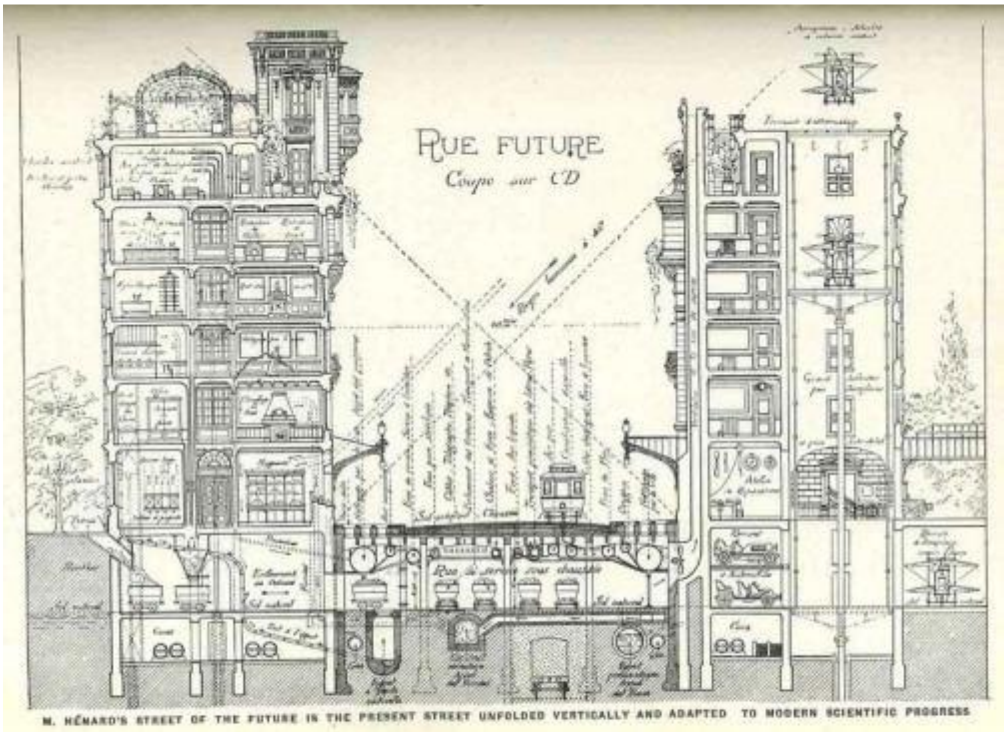



Figure 2-5 Illustration of Hénard's ‘street of the future’

*Figure source: by Eugène Hénard (1849-1923) from his The Cities of the Future, published in American City, January, 1911.*

In the early 1900s, French architect Eugène Hénard condemned the city's anarchic congestion below the streets and suggested burying urban traffic, liquids, waste, and items in multi-story galleries. Hénard's vision foreshadowed the separation of traffic and other functions, which his contemporaries eventually proposed and adopted (Besner, 2002).

It has been seen that Swiss architect Le Corbusier placed car ownership at the core of his Radiant City program. One of his main ideas was to separate pedestrian and vehicle traffic in vertical directions (Colquhoun, 2008). The Ville Radieuse program (Fig 2-6) is committed to the idea of achieving harmony in industrialism by finding the right balance between individual, family, and national public order; between architectural forms and open spaces; between cities and nature. Meanwhile, with the support of 'Slum Cleanup', the municipality overthrew the old central mixed-use area, isolated it, and plunged it into a deadly 'new town' with suburbs full of cars. However, how corporate power would play a role in shaping cities as neoliberal politics flourished after the 1970s was not foreseen. The result is often socially and ecologically unsustainable development (Besner, 2002).

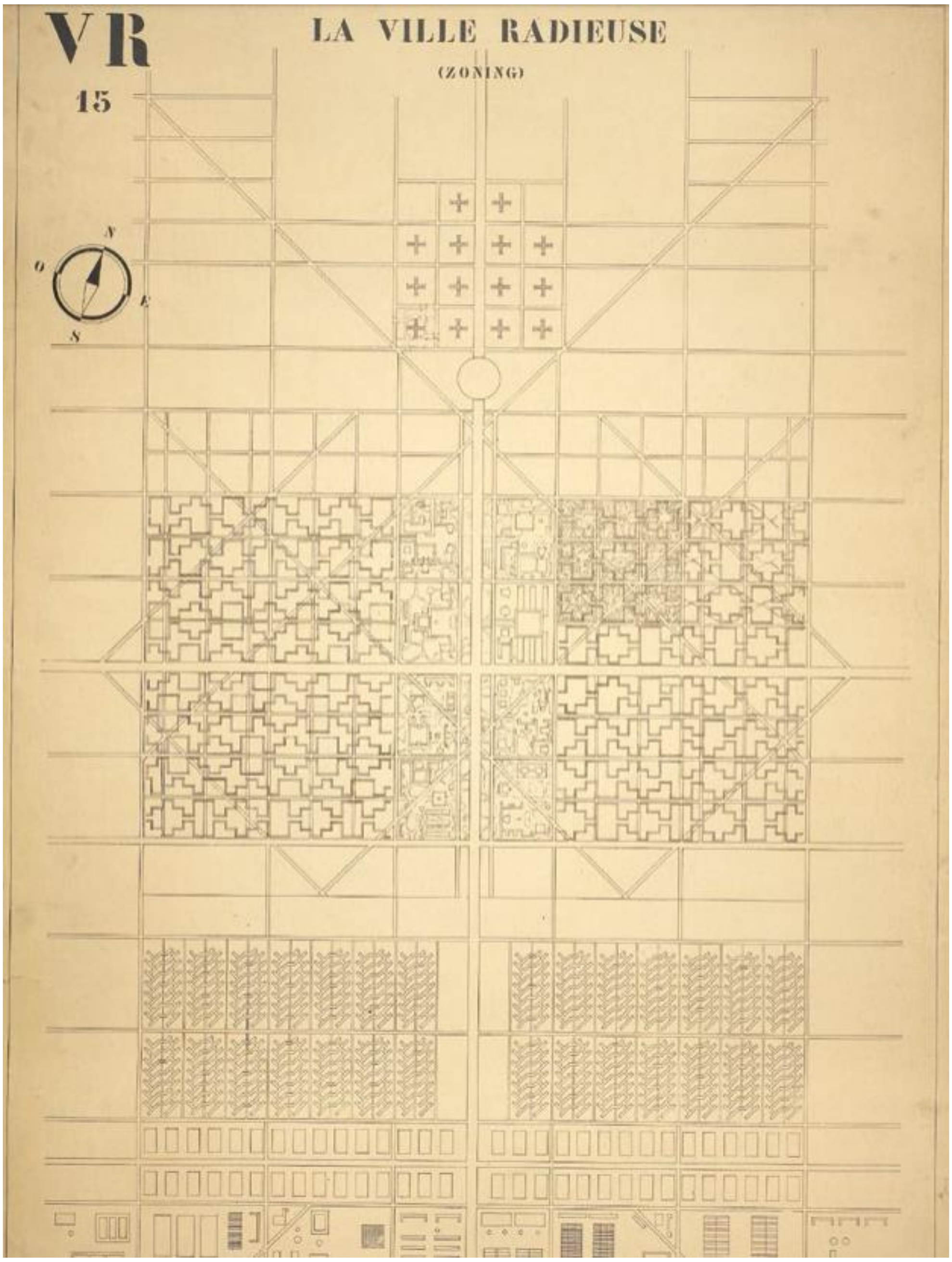



Figure 2-6 Le Corbusier, Radiant City (Ville Radieuse)

*Figure source: Le Corbusier's vision translates with near clarity in the Alton East 1952-1955 & Alton West 1954-1958, housing projects in Roehampton, London.*

In 1983, the 'Two-Level Town' theory was introduced to guide the separation of pedestrians and cars. The theory suggests two levels: motor vehicle traffic and non-motor vehicle traffic in vertical layers, allowing vertical separation of people, construction, and traffic space (Asplund, 1984). The 'two-storey city' theory indicates that urban dimensions are no longer confined to the plane dimension. The development of urban underground space helps to protect urban history and culture and enlarge urban space resources and accesses underground geothermal and water resources (Najjaran et al., 2006).

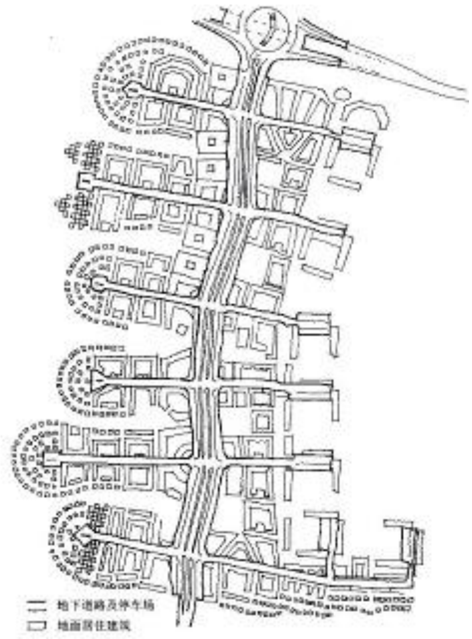



Figure 2-7 Floor plan of the underground level of Lindeborg's 'Double-Deck Town'
*Figure source: Wang Wenqing, 2012: 14, Urban Underground Space Planning and Design. Nanjing: Published by Dongnan University.*

In 1993-1997, Transit-oriented development (TOD) developed to expand liveability in housing, transportation, and shopping choices. At its core, TOD strives to make places work well for people. While some 'liveability' may conjure up the idea of vague and unimportant concepts irrelevant to such 'nuts and bolts' issues as prosperity, liveability and quality of life are increasingly viewed as closely connected to economic development. The theory argues that the community boundaries should be around a quarter of a mile from the bus and commercial facilities, making them suitable for walking. The community's design and layout emphasise the creation of a good walking environment while encouraging public transportation.

Compact, or short-distance, cities were a concept of urban planning and urban design that promoted relatively high-density living through mixed land use (Wan, 2013). Such cities are based on an efficient public transportation system and have an urban layout that, according to advocates, encourages walking and cycling, low energy consumption, and reduced pollution (Burton et al., 2003). Urban expansion in this way is due to reduced dependence on cars and the need for less infrastructure (and lower per capita prices) (Dempsey et al., 2010; Samers, 2004). Underground space is an essential urban resource for solving urban problems and can enhance density, quality of life, and the immediate surrounding environment.

Sustainable cities, or eco-cities, are described as cities designed with environmental impacts in mind, aiming to reduce energy, water, food inputs, and heat and air waste outputs to lower human pollution (via $CO_2$ and methane emissions) and water pollution (Register, 1987). The sustainable city theory supports the rational use of underground resources, reasonable land use which combats urban sprawl, compact cities, and access to deep geothermal energy and shallow underground heat exchange. It also aims to improve urban infrastructure efficiency (transport, water, other) (Russo and Comi, 2012).

The theory of smart cities, discussed by Angelidou (2014), is to integrate the city's development vision securely by integrating ICT and IoT technology to manage urban assets and promote urban information technology to improve the efficiency of cities' services. For underground space, smart cities use more information and communication technologies to make more efficient use of existing urban underground infrastructure (Angelidou, 2014).

In 2016, 'Liveable Cities' theory has been committed to improving transportation and land use, implementing open space and environmental policies and operating plans, and supporting grassroots initiatives to make cities safer, healthier, and more accessible. The aim is to utilise underground space to compress and promote high-quality public space and improve the city's green and leisure areas by placing infrastructure below ground (Roo et al., 2011).

Many urban design theories have had a significant impact on the use of underground space. These include linear cities; multi-level streets; multi-level cities; secondary cities; transit-oriented development (TOD); restructured cities; sustainably developed cities; zero land use; smart cities; and liveable cities. Table 2-2 provides details of the evolution of these design theories in relation to underground public space development. These theories have had a significant impact on the use of underground space. By reviewing the development of urban design theory, the underground space utilisation shows that the gradual combination of urban functions has provided enormous spatial resources for urban development.

Table 2-2. The recent evolution of theories for underground public space development

| Year | Scholar | The projects | The theories | Main ideas |
|---|---|---|---|---|
| 1882 | Arturo Soriay Mata | K. Tange's Tokyo | Linear City | The linear city was an urban plan for an elongated urban formation. The city would consist of a series of functionally specialised parallel sectors. Generally, the city would run parallel to a river and be built so that the dominant wind would blow from the residential areas to the industrial strip. |
| 1910 | Eugene Henerd | Multi-Level-Street in Chicago | Multi-Level-Street | In the 'City of the Future', the streets included conduits for gas, electricity, compressed air, drinking water, pneumatic tubes for letters, telephone lines, and so on. There were bathrooms with hot and cold water on every floor. Vacuum powered wall conduits would remove smoky or polluted air from the apartments. Garbage would be thrown down tubes into bins below ground, and service carts would carry it away on rails below the street. |
| 1922 | Le Corbusier | La Défense, Paris | Multi-Level city | Le Corbusier's ideas on urbanism were published in La Ville Radieuse (The Radiant City) in 1935. One of his main ideas was the separation of pedestrian and vehicular traffic using vertical levels with underground streets for heavy traffic, ground-level buildings and streets for pedestrian traffic, two great arterial roads for 'fast traffic' to bypass the city centre to include railway, metro, and airport terminals. |

| | | | | |
|---|---|---|---|---|
| 1983 | Hans Asplund | Lindeborg | Two-level Town | Again, the vertical direction of the levels allowed the separation of pedestrian and cars into basic motor vehicle traffic and non-motor vehicle traffic vertical layer. |
| 1993 | Calthor pe | American Metropolis | Transit-oriented developmen t (TOD) | The design and layout of the community emphasises the creation of a good walking environment while encouraging public transportation. |
| 1997 | Bernick and Cervero | American Metropolis | Transit-oriented developmen t (TOD) | TOD is a compact layout which functions as a combination of community centres and transportation sites. Reasonable design encourages people to use public transportation and make fewer car journeys. In such a community, bus stops extend outwards approximately 400m apart, or five minutes walking distance, so that public facilities and public space are easily accessed. |
| 2000 | UNHPS | Hong Kong | Inclusive city | The concept of inclusive cities emphasises the balance and unity of urban development in the fields of economy, society, governance, culture, etc. |
| 2007 | Wilbank s | New York | Resilient city | The flexible technologies of energy, transportation, and construction systems rely on advanced information technology and communication services. |
| 2010 | Bobylev | San Sebastian | Compact city | The compact city, or city of short distances, is an urban planning and design concept which promotes relatively high residential density with mixed land use. |
| 2012 | Sterling | Curitiba | Sustainable city | A sustainable city or eco-city (also 'ecocity') is a city designed with consideration of environmental impact, inhabited by people dedicated to minimising required inputs of energy, water and food, and waste output of heat, air pollution - CO2, methane - and water pollution. |
| 2013 | Vahaah o | Helsinki | 0-land use | The concept of '0-land use' is an idealistic approach to urban growth and development using only underground space. The concept originates from Helsinki, Finland, where significant advancements in underground space planning have been made(Vahaaho, 2013). |
| 2014 | Bobylev | Indore | Smart city | Greater use of information and communication technologies enable more efficient use of existing urban underground infrastructure facilities (e.g., water sewers). |
| 2016 | Hunt | San Francisco | Liveable city | The ‘Liveable City’ is dedicated to improving transportation, land use, open space, and environmental policies, running programs, and supporting grassroots initiatives to make cities safer, healthier, and more accessible. |

## 2.4 Typologies of underground public space

The definition of underground public space includes those areas that are public, or partially public, places such as underground roads, underground commercial streets, and underground pedestrian ways. Underground public space is an important place to connect metro stations and urban public spaces or buildings (Xi, 2012). It is also the combination of urban public space and underground rail transit and underground construction. In addition, the underground public space is also a manifestation of comprehensive utilisation of underground space. There are many examples which show the frequent use of underground public spaces in urban design. As discussed, examples are Canary Wharf in London, where the efficiency of the underground space has increased as a result of its connective construction (Chow, 2002, Gordon, 2001); and the 'Underground Path' in Toronto which has more than 30 km of connected walkways linking 1200 stores and, importantly, is just a 10-minute walk from the city's Union Station (Bélanger, 2007).

The efficiency and effectiveness of using underground public space in international metropolises are becoming a notable feature, especially in high-density urban areas, such as Central Business Districts (CBDs). As a result of tall buildings with high building and working population densities, those areas have more demands to improve public service facilities, public transportation, parking, and municipal infrastructure (Wan, 2013). Therefore, they use all the possible available space, which includes underground, to increase the effectiveness of such places. In Tokyo, Roppongi Hills, one of Japan's most important business centres, integrates residential, office, hotel, commercial, and cultural facilities. It has a total construction area of 771,000 square metres, a building density of 13%, and a building plot ratio of 8 to 1. The residential building can accommodate 837 households, and the underground parking capacity is for 2,762 cars. The underground space scale exceeds 20% of the total construction area; it has been highly developed and utilised, meanwhile the green space on the ground represents 22% of the total construction area and includes 9,000 square metres of green roofs (Dong, 2014). Roppongi's underground space is multifunctional that accommodates food, retail, parking, and underground pedestrian ways. This has left more space to increase the green landscape above ground and roof gardens to improve environmental quality.

### 2.4.1 Related theories of urban public space

Different functions classified the early use of underground space. Caves, stores, and tombs were the first forms of underground space used by humans, which the main function was for shelter and storage (Golany and Ojima, 1996). With the development of human society and the emergence of cities, underground space began to be used for underground infrastructures, tunnels, and metros. The organisation was mono-functional so that just one function, such as transport, infrastructure, or other simple functions predominated (Durmisevic and Sariyildiz, 2001). With the prominence of urban problems, underground space utilisation has begun to develop in the direction of complex urban functions (Phoenix room, 2014, Yuan, 2013). The organisation is now multi-functional (see Table 2-3) as the main transport function combines with retail, leisure, and office infrastructure around metro stations (Durmisevic and Sariyildiz, 2001).

Table 2-3 Examples of functional typologies

| Type | Contents | Examples |
| --- | --- | --- |
| Mono-functional | Cinemas<br>Sport centres (gyms)<br>Libraries<br>Museums<br>Schools<br>Religion<br>Odeum<br>... | Underground Film Club, London<br>Gammel Hellerup Gymnasium, Denmark<br>Joe and Rika Mansueto Library, Chicago<br>Extension of Staedel Museum, Frankfurt<br>'Hannah Arendt' High School, Bolzano<br>Solar Powered Mosque, Serbia<br>Palau de la music reform, Barcelona<br>... |

New theories about cities have affected underground public space development in terms of spatial form shifts, from vertical point space and linear space to a comprehensive space form (Xiang, 2010). In the 19th Century, affected by urban planning theories, such as the Garden City(Howard, 2013) Movement and Multi-level City, the early use of underground space in Europe was mainly implemented to solve traffic problems and provide municipal facilities (Besner, 2017), thus having a mono-functional use. During World War Ⅱ, deep level shelters were constructed below existing underground rail station tunnels, and people who lived in London used underground spaces for defence purposes (Admiraal, 2015). During this time, the spatial organisation of underground space use was linear, i.e., one transport system. Meanwhile, North American cities began to use underground space for people's use; they used underground pathways combined with metros and single building basements to construct complex composite forms (Besner, 2017). The spatial organisation of underground space use is that of multiple spaces connected to comprehensive transport junctions, or a city's CBD.

As Table 2-4 shows, the classification of urban public space has important referential significance for underground space classification. Based on different spatial patterns affected by urban public space, urban space can be classified by elements of morphology and function.

Table 2-4 Classification by different theories

| Year | Scholar | Book title | Spatial classification |
|---|---|---|---|
| 1960 | Kevin Lynch | The image of the city | Paths, edges, districts, landmarks and nodes (Pike, 1981, Lynch, 1960, Lynch, 1984) |
| 1971 | Jan Gehl | Life between buildings: using public space | Walking, standing, sitting, seeing, hearing, talking, a pleasant place in every respect and soft edges (Gehl, 1971) |
| 1971 | Christian Norberg Schulz | Existence, Space, and Architecture | Centre and place, direction and path, area and domain (Norberg-Schulz, 1971) |
| 1979 | Rob Krier | Urban space | Squares and streets (Krier and Rowe, 1979) |
| 1984 | Aldo Rossi | The architecture of the city | Block of houses surrounded by open space; a block of houses connected to each other and facing the street, constituting a continuous wall parallel to the street itself; a deep block of houses that almost totally occupies the available space; and houses with closed courts and small interior structures (Rossi et al., 1982, Rossi and Eisenman, 1982) |

| | | | |
|---|---|---|---|
| 1990 | Camillo Sitte | The art of building cities | Open centre of public places, the enclosed character of the public square, the form and expanse of public squares, the irregularity of ancient public squares and group of public squares (Sitte and Justement, 1946) |
| 2010 | Matthew Carmona, Tim Heath, Taner Oc, Steve Tiesdell | Public Places Urban Spaces | Urban space is described from six dimensions: morphological; perceptual; social; visual; functional; and temporal (Carmona, 2010) |
| 2012 | Lesley Bain, Barbara Gray, Dave Rodgers | Living Streets: Strategies for Crafting Public Space | The public space is separated from the places to move through, materials, intersections, bicycle facilities, signage, street furniture, street trees and landscaping, swales and rain gardens, 'curbs, gutters, and alternatives', and parking (Bain et al., 2012) |
| 2013 | Silvia Serreli | City Project and Public Space (Urban and Landscape Perspectives) | The elements that give shape to the new way society is organised in the contemporary city are three: semi-gods and rechristen, the glorious thirty, and new globalisation. (Serreli, 2013) |
| 2015 | Jiwei Lu, Yu Zhuang | The design of urban underground public space | In the design of urban underground public space, the underground public space is divided into metro station area, underground street, sunken plaza and atrium. |

### 2.4.2 The functional typologies of underground public space

Underground public places can be categorised into their functional organisation, i.e., mono-functional, and multi-functional (Durmisevic and Sariyildiz, 2001). The mono-function in underground public space does not include private areas, such as residential buildings. Therefore, mono-functional space is categorised into four types: commercial; transport; leisure; and disaster prevention (Xing, 2015). Multi-functional space combines two or more mono functions (see Table 2-3 and Table 2-5 for examples).

Table 2-5 The types of underground public space by the function

| Type | contents | Case studies |
|---|---|---|
| Multi-function | Commercial street<br>Transportation Hub Area<br>Shopping mall | Taipei East Mall, Taipei<br>Hong Qiao transportation Hub Area, Shanghai<br>Canary Wharf Station, London |

1) Mono-function

- Commercial

To enhance the efficiency of transport and to convenience passengers, some large-scale office buildings and department stores set up entrances and exits to nearby metro stations in their underground space (Xing, 2015). In some areas where shopping malls and metro stations are connected, multi-functional stores have been established. This facilitates the use of the environment and increases the number of pedestrians, which a pedestrian street can be developed (Wang, 2013). An underground public street in Japan, for example, often leads to various buildings and metro stations, it can be accessed throughout the day and can be passed through freely, thereby alleviating the congested traffic problems which occur in Japanese cities above ground.

- Transportation

The large-scale development and utilisation of underground space in many cities around the world started with the construction of metro systems(Chow et al., 2002), such as in London, to ease traffic pressure on the city(Han, 2007). The underground traffic space within underground public space comprises underground pedestrian areas, metro stations, and public parking (Wang, 2013). The underground pedestrian system not only solves the problem of people and car shunting and shortens the distance between trains and buses, but also connects underground stations with large public event centres via underground road.

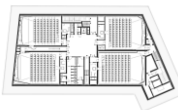
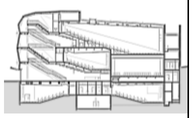
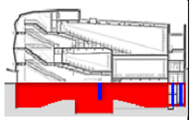
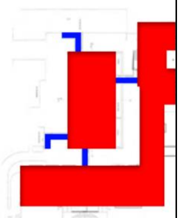
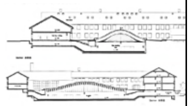
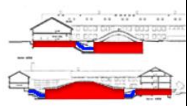
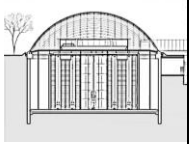
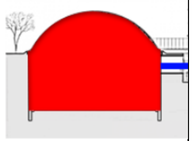
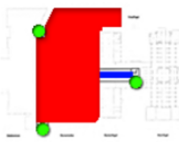
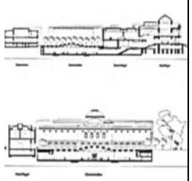
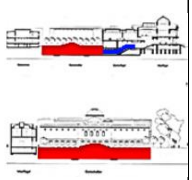
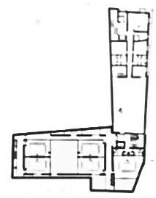
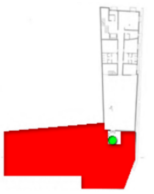
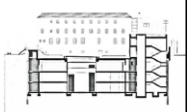
- Leisure

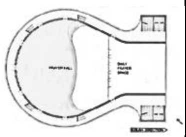
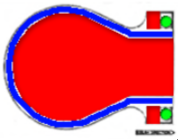
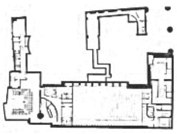
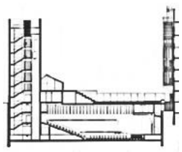
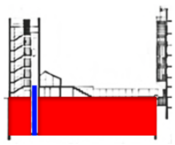
Underground public leisure facilities are usually placed in areas where land resources are scarce and include such functions as theatres, auditoriums, clubs, museums, tennis courts, ice hockey courts, swimming pools (Churchman, 1997). The Gym at George Washington University built in 1979 in Washington D.C., is a fully underground gym with outdoor courts and artificial turf on top of the building. This kind of construction, where culture and entertainment are combined with the development and planning of urban underground space, makes such development more dynamic (Xing, 2015).

- Disaster prevention

The function of disaster prevention concerns civil air defence projects where an underground space is built for shelter in times of war or disaster. In Finland, it is compulsory for property owners to include civil defence shelters in buildings of 1,200 $m^2$ or more. This space is now designed to meet the people's everyday needs, but the transformation is possible for any 'special period'. This enables owners to transform a swimming pool into a defence shelter quickly and economically should the need arise. The public swimming pool area quarried out of the solid rock can be converted into an emergency shelter for 3800 people if necessary (Vähäaho, 2016).

Table 2-6 Diagrammatic analysis of providing mono-functional underground space use.

| Functions | Examples | Plans | Plan model | Sections | Section Model |
|---|---|---|---|---|---|
| **Cinema** | Paris' Alésia Cinema, Paris (Ingenierie et al., 2016) |  |  |  |  |
| **Sport centre** | Gammel Hellerup Gymnasium, Denmark (Phoenix room, 2014, P 96) |  |  |  |  |
| **Library** | Joe and Rika Mansueto Library, Chicago (Murphy/Jahn, 2011) |  |  |  |  |
| **Museum** | Extension of Staedel Museum, Frankfurt (Phoenix room, 2014, P 12) |  |  |  |  |
| **School** | "Hannah Arendt" High School, Bolzano (Phoenix room, 2014, P 26) |  |  |  |  |

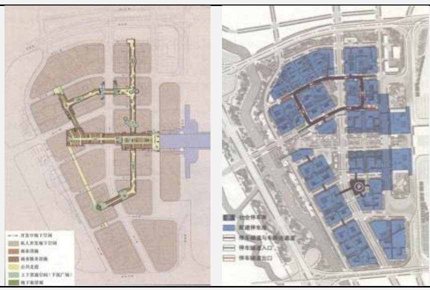
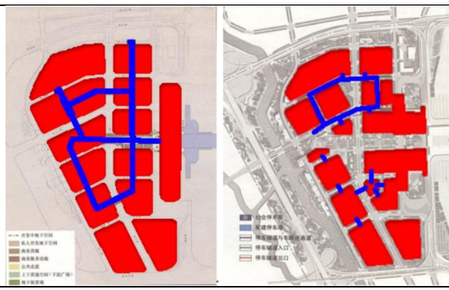
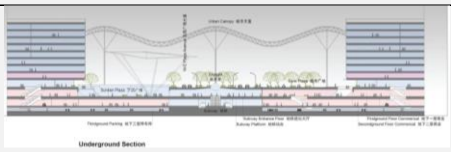
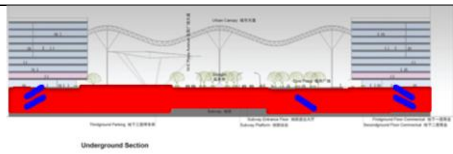
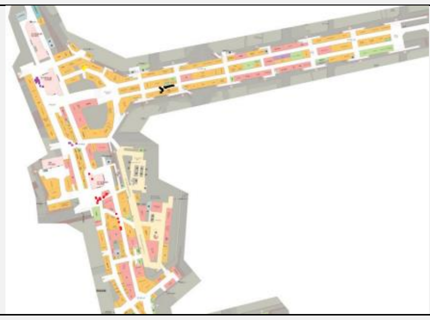
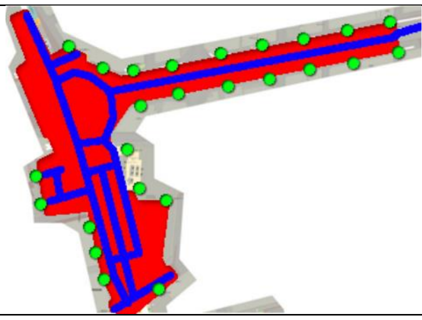
| | | | | | |
|---|---|---|---|---|---|
| **Religion** | Solar Powered Mosque, Serbia (Phoenix room, 2014, P 166) |  |  |  |  |
| **Odeum** | Palau de la music reform, Barcelona (Phoenix room, 2014, P 150) |  |  |  |  |

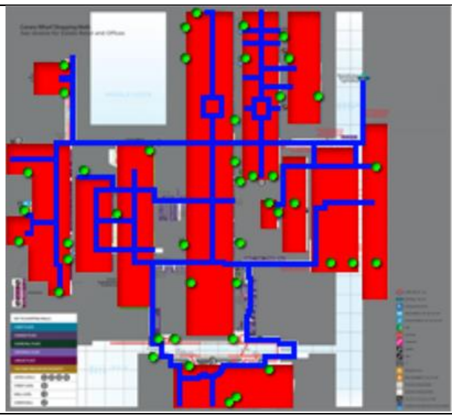
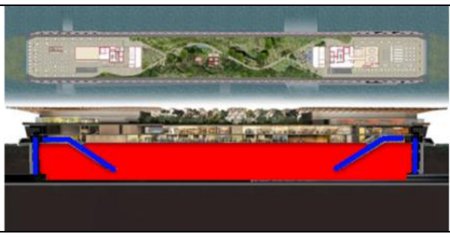
2) Multi-function

In many cases, the utilisation of multi-functional underground spaces occurs in large-scale integrated transportation junctions, underground streets, and underground spaces of a city's CBD and, importantly, they are all connected to underground stations. This can enhance the efficiency of transport and convenience to passengers, e.g., some large-scale office buildings and department stores set up entrances and exits to nearby metro stations in their underground spaces (Xing, 2015a). As Table 2-7 shows, the Hong Qiao transportation junction in Shanghai connects shopping malls, an airport and metro stations. Thus, multi-functional stores have been established. This facilitates the environment and increases the number of pedestrians, where a pedestrian street can be developed (Wang, 2013).

Civil air defence projects that would once have been built specifically for such purposes are now being demanded on the principle of combining peace and wartime needs, i.e., in China, Civil Defence Space combines two or more functions, such as disaster protection along with retail and leisure facilities (Wan, 2013). The underground transportation and underground public service space of the city shall, in this case, and at the same time, serve as shelter from disaster, and thus improve disaster relief and the resilience of the city (Wang, 2013). Table 2-7 shows multi-functional use of underground space.

Table 2-7 Multi-functional analysis of underground places

| Transportation junction, Hong Qiao transportation junction, Shanghai, China (Fangle et al., 2013) | |
|---|---|
| PLANS | PLAN MODEL |
|  |  |
| SECTIONS | SECTION MODEL |
|  |  |
| Underground Commercial Street, Sun Road, Nagoya (Tong, 2005) | |
| PLANS | PLAN MODEL |
|  |  |
| SECTIONS | SECTION MODEL |

| | |
|---|---|
|  |  |
| Canary Wharf Station, London (PLC, 2018) | |
| PLANS | PLAN MODEL |
|  |  |
| SECTIONS | SECTION MODEL |
|  |  |

### 2.4.3 The spatial typologies of underground public space

Underground public places can also be categorised into their spatial organisation(Kandinsky and Rebay, 1979), i.e., node space (Carmody and Sterling, 1993), linear space (Carmody and Sterling, 1993; Wan, 2013), and planar space (Wan, 2013, Shu, 2015b). The node space is a point space. Usually, it is an entrance and exit for the underground space to connect the different forms of space, where decisions would be made to choose a direction to follow. Linear space is a narrow space with a strong orientation, including underground streets(Zhang, 2018) and underground pedestrian ways that indicate the linkage between two nodes. The planar space is open space with underground squares and atriums, where multiple modes may be attached to the edge of the space so that people can move freely, depending on their destinations, see Table 2-8.

Table 2-8. The spatial typologies of underground public space

| Type | Definition | Samples |
|---|---|---|
| Node space | It can be a single building, but it also can be a complex or underground junction space. It is generally used in high-density areas. | Les Halles square |
| Linear space | An underground street which is singly existent or between an underground building and the metro. It is generally distributed below the public road. | Japanese underground commercial street |
| Planar space | It can mix two modes to contribute to connectivity between two underground places. | Rockefeller centre |

1) Node space

Node space is a primary, spontaneous use of underground space, and is the basic element of the complex shape of urban underground space (Carmody and Sterling, 1993). With the development and utilisation of large-scale underground spaces, node space has become the connection point between various underground passageways and urban ground space, e.g., the metro station which connects the ground space and is also a distribution point for the flow of people. Its function is usually for transport as the entrance and exit to underground public space.

- Entrance

The entrance plays a vital role in any architectural design (Carmody and Sterling, 1993). It controls the movements into and out of the building and enclosed structure and the layout of the interior of the building. The entrance to the underground building is no exception. However, for underground buildings, because most or all of their bodies are underground, in many cases, the entrance is the only visible element that is most likely to be connected with other functional spaces through yet other underground public spaces. Therefore, the entrance plays a vital role in the spatial transition and the visual appearance of the building.

- Buildings' connection point

The connection point between buildings is also an essential part of the node space (Durmisevic and Sariyildiz, 2001). Such points include those between the metro station hall and the underground shopping mall(Ronghua and Quanyi, 2012), and between the basement of a private building and the underground public space (which may be a public walkway, for example). There is, moreover, a turning point in the underground walking path.

Thus, node space is seen in the spatial form of an exit or turning point in the underground public space. Traditional underground space entrance functions and forms are singular, and considerations of safety, comfort, and accessibility are weak (Lu, 2015). In this way, they are often perceived as unattractive. For example, the London Underground Oxford Street Station and the Circus Metro Station share combined entrances with a building and the independent entrances. The entrances lack barrier-free access, and the weather impacts the entrance. On the other hand, the new metro station has transformed and built through the regional regeneration project; the construction project of the new metro line has improved the traditional underground building entrances or turning points issues. Designers can evaluate and redesign different underground node spaces by spatial typologies to improve the recognition of underground space.

2) Linear space

Linear space refers to the spatial layout of the city's underground pedestrian areas and walkways as they connect to the metro station (Wan, 2013); it is one of the primary forms of underground public space and offers strong spatial guidance (Carmody and Sterling, 1993). The linear underground space is combined with the construction of metro stations or is built individually. In general, it has a single transport function, such as an underground passage. It also could be an underground commercial street that combines commercial and leisure functions.

The single function of such a space means inefficient, and the costs of development, maintenance, and management are high (Su, 2008b). Furthermore, independent underground passages could make people feel unsafe (Carmona et al., 2012). On the other hand, the underground linear space that combines commercial activity with parking space helps solve parking issues in cities while developing commercial functions, making the underground public space safer, and more attractive.

- Underground pedestrian areas

Initially, underground pedestrian areas were a form of the passageway through a city, but new forms combine with metros and/or underground buildings. When urban roads cannot use the surface crossings, underground passageways or flyovers are applied. However, most of underground passageways are single function use, particularly a long narrow passage way, making people feel unsafe and unattractive. They are not attractive and eventually turn into an abandoned place. This kind of underground pedestrian area which combines with other functions, such as shops, restaurants and service facilities, may attract people and increase vigour in these places.

- Underground Street (Shopping mall)

The underground street is an underground spatial form, which began to appear after the metro; it was originally named 'Underground shopping mall' in Japan because of its similarity to the commercial streets above ground (Kishii, 2016). In the early period of the underground street, the main form these streets took was with shops on both sides of the connecting corridors. After decades of construction, the underground commercial street's function and form have been developed and changed, but the name has continued to be used (Tong, 1998). Facilities on the underground street include underground pedestrian areas, such as corridors to metro stations; main operators, shops and similar facilities; and matching facilities, such as parking (Liu, 2007). As a kind of urban form of public space, the underground street provides more possibilities to connect buildings and metro stations(Liu, 2009b, Dempsey et al., 2010), and different commercial activities have increased the attraction for underground pedestrians.

3）Planar space

With the further development of underground public space use, some large-scale underground space interconnections have become greater demand (Shu, 2015a); thus, they form a multiple underground space pattern. The planar space in underground public space is an open space like a square, or atrium, which typically appears in the development of more central city areas, or urban commercial areas, and is often combined with ground-level urban squares and parks.

- Underground square (outside)

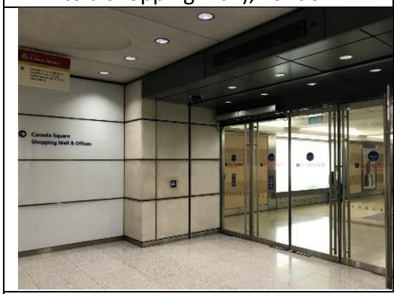
The city square is an open space formed by buildings, roads, or parks; the underground square is a similar space combined with underground buildings and often functions as the entrance and exit to the underground space (Du, 2007). Improving the ventilation and natural lighting of underground spaces and increasing public activities could increase the value of underground land and increase attractiveness. An example is seen in Vientiane City in Chengdu, China, where the underground square provides open space to attract people to enter the building. It can be a connection space as a node to connect the underground space; it can also be a transitional space as the entrance and exit to the underground space. The spacious and open underground plaza moves natural light into the underground space, while the large-scale provides a venue for public events. Also, it can be used to provide identity as a characteristic of the underground public place. The urban public space forms have significant effects on underground public space, such as the squares being used as an entrance, which has changed the general entrance form.

- Underground atrium (Indoor)

The underground atriums have supplied an open space for underground spaces, they break away from a simple spatial form and are a way to create an interior space that is both isolated from and integrated with the external space. The underground atrium space can bring natural factors into the rest of the space, and it uses a large area of light-transmitting material to import natural light, which shelters people from wind and rain and increase the vitality of the underground public space. Besides, it becomes a landmark of underground public space to provide specific identities.

The development and utilisation of highly efficient underground space resources are realised by combining urban underground space functions and spatial components (Xing, 2015a). For example, to solve the urban traffic problem in Paris, in 1962 the Les Halles area was rebuilt, and the metro construction became a turning point, which added vitality and the subsequent revival of the area. The reconstructed Les Halles made full use of the underground space. They adopted a three-dimensional design method to build an underground complex integrating transportation, commerce, entertainment, and other functions under the square, and to organise all traffic through the city centre. In 2002, the mayor of Paris decided to rebuild Les Halles again. The transformation aimed to better integrate multiple urban elements with the entire city of Paris and further upgrade from the Paris Centre to the 'Great Paris' centre. Continuing to assume the role of transportation junction and shopping centres, it also has more possibilities back to the 'public open space': the mall accommodates 6,000m2 of popular cultural service centres, including libraries, music training colleges, and youth newsstands, alongside other facilities which provide entertainment places for the public.

Table 2-9 Spatial forms' examples of underground public space

| Spatial form | Definition | Examples | |
|---|---|---|---|
| Node | Entrance (Lift) | The entrance to Oxford Circus tube station | The entrance to Canary Wharf station (PLC, 2018, P 11) |
| | |  |  |
| | | The entrance to Bond Street Underground Station | Guomao metro station in Beijing |
| | |  |  |
| | | Louvre Museum, Paris (photo by: ParisGuidedTour.com) | Apple Fifth Avenue, New York (Photo by: Eli Blumenthal, Shara Tibken) |
| | |  |  |
| | Building connection | Canary Wharf station (public space to a shopping mall), London | Dong Fang shopping mall, Shanghai |
| | |  |  |
| | | Guomao Station (private building basement to the underground public space, Beijing | |

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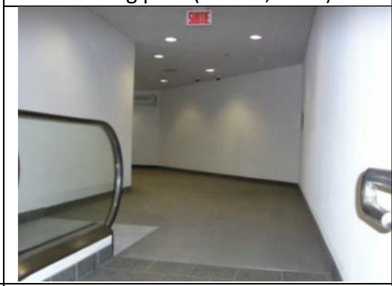
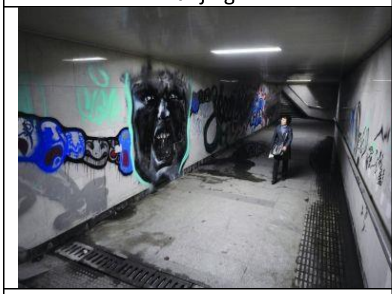
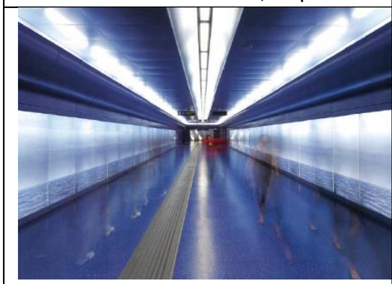
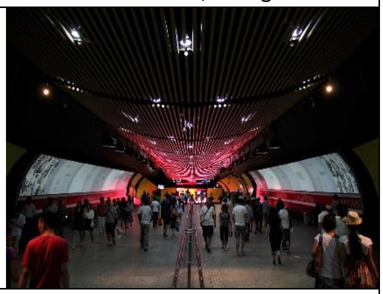
| | | A turning point in the underground walking path (Besner, 2012) | IFC， Shanghai |
| | |  |  |
| Linear Spaces | Underground pedestrian areas | Underground passageways in Nanjing | Underground passageways in Wuhan |
| | |  |  |
| | | Toledo Metro station, Naples | Metro station, Shanghai |
| | |  |  |
| | Underground Street | Nagoya underground street, Nagoya | COEX Mall, Seoul |
| | |  |  |
| | | Lujiazui IFC, Shanghai | Hong Qaio station, Shanghai |

| | | | |
|---|---|---|---|
| Planar spaces | Underground square (outside) |  |  |
| | Underground atrium (Indoor) | Des Halles, Paris | Beijing Oriental Plaza, Beijing |
| | |  |  |

## 2.5 Chapter conclusion

First, explain the main challenges of contemporary cities, why people use underground space and the development trend of underground space. This explains the challenges and potentials of underground public space in urban development. Then, It defined the concept of underground public space according to related concepts, defining such space as space below the surface that anyone can access and use(Ming et al., 2007). Development impact. By reviewing the development of urban design theory, the underground space utilisation shows that the gradual combination of urban functions has provided enormous spatial resources for urban development. Finally, the underground public space is classified according to function or spatial form. The conclusion of the chapter is one of the bases for screening the quality evaluation indicators of underground public space.

Comprehension of urban space includes understanding both inside and outside its spatial limits, which infers vibrant and bright associations between the space and the encompassing setting. Chapter 3 considers underground space from a quality perspective.

# 3. The quality of underground public space

Before presenting existing methods of assessing the value of quality design in an urban environment, this chapter focuses on the need for better underground public space design and what it means to associate value with built environments and quality design in literature. This chapter advocates specific definitions of quality design to outline goals in terms of their relative advantages. It explores the benefits of quality design based on a deeper consideration of the quality of the goals, principles, and guidelines used to achieve quality underground public space.

## 3.1 Requirements of people for underground public space

### 3.1.1 Quality design

The expression of *quality* has two implications in the current context. It represents 'the standard of something as estimated against different things of a comparable kind; the level of greatness of something', and *'a particular property or trademark controlled by a person or thing*' (Oxford and Dictionary, 2015). Applied to urban conditions, it is has been noticeable in the arrangements and naming of urban planning policies and design since the 1990s (Chapman and Larkham, 1999). Urban quality has likewise been utilised as a critical segment in an assortment of related terms, for example, 'great city structure' (Lynch, 1960,P 10); 'urban quality' (Parfect and Power, 1997, Chapman and Larkham, 1999, Trip, 2007, Montgomery, 1998); 'particular nature of urban communities' (Jacobs, 2016); characteristics of a good city' (Jacobs and Appleyard, 1987; Jacobs, 2012); and 'spatial quality' (Moulaert et al., 2011).

Numerous researchers characterise urban quality as 'a perplexing idea due to being multidimensional' (Sholihah, 2016:43). Some researchers give an open and liquid 'sign' on urban quality, though others use hypotheses, markers, and parts to depict it to readers (Jacobs, 1961; Lynch, 1984). Meanwhile, others use contextual investigations that measure urban quality to give readers a more precise definition that should be concerned with improving the design of the physical environment and design for people (Rapoport, 2013, van der Hoeven and van Nes, 2014). The scholar additionally notes that urban quality is certainly not a unitary marvel, yet it is multidimensional and involves 'widespread' container human perspectives, and is culturally explicit (Rapoport, 1983).

In terms of urban quality markers, the term 'imaginative economy and inventive class' proposes six purposes of nature: assorted variety, social connection, credibility, way of life, personality, and innovativeness (Florida, 2002:87). As indicated by Florida (ibid.), nature has three measurements: "What's there", i.e., the setting for the imagination; "Who's there", the types of individuals and networks; and "what is going on", i.e., the energy of the urban space, expressed through the use of the roads and the likes of bistro societies, background and foreground music, and individuals and groups taking part in the open-air exercise which make for dynamic, energising, and innovative undertakings.

### 3.1.2 Requirements

Human behaviour is fundamentally different from physical systems and other biological systems in its essential characteristics. Its distinctive characteristics manifest in the ability to perform self-awareness and self-control, repair behaviour, use symbols, and interact closely with the environment and more. Motivation is the internal driving force that generates behaviour based on human needs. Since the 1930s, Western behavioural psychologists have proposed a number of theories about human needs, including Maslow's hierarchy of human needs, Gestalt psychology, place theory, and ergonomics (Che, 2012b; Wang, 2008b).

#### 3.1.2.1 Maslow's hierarchy of needs

Hierarchy of needs divides human needs into five intertwined levels ranging from high to low. Maslow's theory has come to be known as a 'hierarchy' theory of demand levels (Abraham, 1943; Kong, 2007). Maslow's demand theory provides a frame of reference for the design of the space environment(Abraham, 1943). From this, human behaviour in urban underground public space came to be seen in four levels of needs and corresponding requirements for the functional facilities and environment of underground public space (Maslow, 2005; Maslow, 2013).

The top priority of these needs is physiological needs. Functional facilities, which maintain the physiological needs of the human body in underground public spaces, should be completed (such as toilets and seating facilities). It has the characteristics of comfort, hygiene, convenience, and accessibility. Because the underground space is an enclosed, complex and comprehensive space with a vast flow of people, it is difficult to evacuate during a disaster and rescue is difficult (Che, 2012b). Therefore, a well-organised movement network and the creation of an identifiable guidance system are incredibly effective means to address this issue. In addition, the peak flow of people in the underground station area must be considered due to an unusual number.

Satisfying the individual's physiological needs is crucial to achieving the demand for safety. The second need concerns security requirements: the public space environment must provide suitable areas for individual and group's activities to ensure the corresponding security, privacy, and orderliness of the area and guard against violations (Kenrick et al., 2010; Wahba and Bridwell, 1976). It increases the order, predictability and control in people's life. The family and society (such as the police, schools, businesses and medical institutions) can meet these needs (Tay and Diener, 2011).

The third need is public communication: belonging and love, and respect mentioned by Maslow implied the need for individuals to seek their relationship with the family and society. As members of society, people can only be identified and satisfied in their interactions with others (Wahba and Bridwell, 1976). Therefore, as an essential stage for people's social activities, urban public space should create suitable conditions for public communication (Wahba and Bridwell, 1976; Abraham, 1943(Maslow, 2013)).

Finally, it is about to realise self-worth: in public spaces, people's improvisations are often seen, which reflect people's desire for themselves, i.e., the strong desire to realise and recognise the value. Urban public space should create opportunities to satisfy such high-level spiritual needs (Van Kamp et al., 2003). As a member of society, an individual can only be identified and satisfied in their interactions with others (Xing, 2015a). For people's psychological needs, when designing underground public spaces, complete space guidance should be ensured to form a serialised space to strengthen people's recognition of the space. Attention should also be paid to spatial scale, interface, materials, and colours (Che, 2012b). In consideration of other aspects, the humanised spatial scale is conducive to creating an intimate space. Rich spatial interfaces, diverse materials, and colour choices can enhance the spatial quality and further enhance people's psychological needs in underground public spaces (Li, 2012).

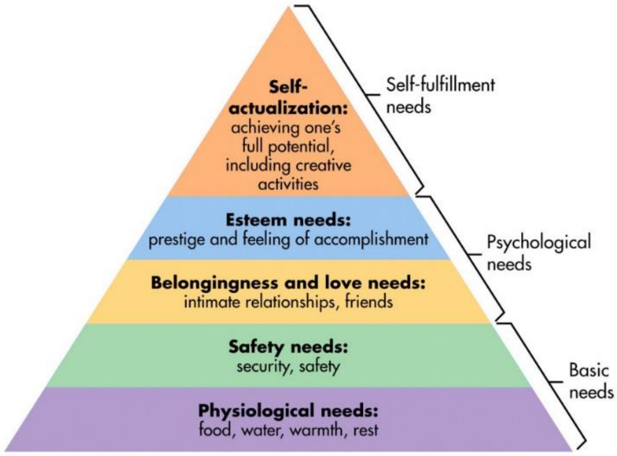



Figure 3-1 Originally Published in Psychological Review, 50, 370-396 (A. H. Maslow 1943).

*Figure source: A Theory of Human Motivation A. H. Maslow (1943) originally published in Psychological Review, 50, 370-396.*

#### 3.1.2.2 Gestalt psychology

Gestalt psychology originated in Germany in 1912. It is one of the mainstream Western psychological approaches, with representative figures include Kaufka, Kohler, and Whitheimer. Gestalt psychology studies the relationship between graphics and the overall organisational structure, emphasising that the integrity of its internal elements determines the integrity of the whole. Gestalt's organisational principles can be summarised as the relationship between graphics and background, proximity, similarity, continuity, and closure (Wang, 2008a; Wagemans, 2015). The core idea is to emphasise the overall unity of things (Koffka, 2013). Gestalt is a term used in psychology. Gestalt has two meanings: the general attributes of things: form; individual entities of things - the separated whole, and form is only one of its attributes. That is to say, 'If there is an empirical phenomenon, each component of it is involved in other components; and the reason why each component has its own characteristics is that it has a relationship with other parts, this phenomenon is called Gestalt. In short, Gestalt is not an isolated and unchanging phenomenon, but a complete phenomenon related to the whole body that has its own complete characteristics. It cannot be divided into simple elements, and its characteristics are not contained in any element (Shan, 2008).

The production and development of Gestalt are unstable. Its influence involves many fields. From the field of design alone, Gestalt theory extracts seven principles: simplicity, intimacy, similarity, closure, continuity, subject and background, and common destiny. In the design of public space in underground stations, rational use of Gestalt psychology principles helps create a whole, unified and harmonious space. The principle of proximity, adjacent or similar elements, stimulates a sense of aggregation that is easy to form. For example, in an underground station's public space, the decorative advertisements on the solid wall can blend naturally with the wall, creating a kind of visual tension without feeling abrupt. The principle of similarity refers to the similarity of objects in terms of shape, material, size, colour, etc., which can easily give people a sense of wholeness visually. In the underground station, the platform layer's structure is often arranged in rows due to functional requirements, using similar principles to form a strong sense of rhythm and sequence. The principle of continuity means that the same elements are arranged continuously, which is easy to form a sense of wholeness. The rational use of the principle of continuity can coordinate the unity of the spatial form and the environment. The principle of closure refers to the unity of different elements within a particular object, forming a whole through the enclosure. For public spaces in underground stations, a closed environment is a necessary condition for construction. On the other hand, it can also provide people with a place to prevent disasters (Che, 2012b).

In the design of underground public spaces, Gestalt psychology's principles can be used to design spaces that are adjacent, similar, and continuous. It addresses the concept that adjacent or similar elements will stimulate a sense of aggregation and quickly form a unity. Moreover, similar object shapes, materials, sizes, colours and other characteristics are easy for visual continuity production (Koffka, 2013; Hong, 2018).

### 3.1.2.3 Place theory (Genius Loci)

Norwegian architect Norberg Schultz proposed that the existence of man is spatial (Norberg-Schultz, 1987). When a man transforms his living space into a building space, he finds a foothold of existence. That emphasised the inherent relationship between architectural form, space and environment, and put forward the theory of 'Genius Loci' (Cooper and Francis, 1998). The theory is to take people as empty subjects and elaborate on the characteristics and attributes of space (Trip, 2007). The theory of place expresses human behaviour factors in the space interface, space form and detailed construction, so that the space environment has an artificial place, and people get a sense of intimacy and belonging in the space (Koffka, 2013; Norberg-Schultz, 1987).

### 3.1.2.4 Ergonomics (Pheasant, 1991)

Ergonomics was founded in the middle of the 20th century. It studies the physical and psychological aspects of humans in the space environment (Pheasant, 1991). It emphasises that the systemic relationship between man and machine, and machine and environment is a 'people-oriented' science (Charytonowicz, 1998). The theory of ergonomics mainly addresses human health and efficacy in the space environment (Che, 2012b). Among them, man is the main body of theoretical research; human physiological habits, psychological characteristics, and the ability to adapt to the environment are the focus of ergonomic research (Wang, 2008b). A machine refers to a material product that a person needs to use or operate, and an environment refers to all material factors around a person (Xing, 2015b). The underground public space environment includes the interior space and the private facilities and artistic elements (Wang, 2008b).

Two representative examples of ergonomic theoretical research are the 'ideal man', proposed by Roman engineer Marco Vitruvius (Carmody and Sterling, 1993), and the 'human modulus scale' created by Le Corbusier (Yuan, 2013). The former seeks harmony of proportions in the body of the person. The ideal position of a circle and a square is determined by the length of a person's limbs, reflecting the design concept that people are the source of scale. Corbusier's 'Human Modular Ruler Second Degree' is a modular scale that conforms to human dimensions by comparing those dimensions and mathematics (Hong, 2018). n the design of underground public spaces, through the study of human dimensions, it reflects the spatial scale, component size, and other aspects, to create a spatial form suitable for human scale (Charytonowicz, 1998).

### 3.1.3 Perceptions

When people are in an underground public space environment, the feelings they receive are all around. Space contains a variety of information. Through information stimulation and past life experiences, people make judgments and evaluations of underground public spaces and then take action (Van Kamp et al., 2003). The underground public space is a comprehensive system including transportation space, leisure and entertainment space, and civil evacuation space (Wang, 2008a). According to the previous chapter's description, through the complex effects of the environment and needs, it affects people's physical and psychological feelings, as well as people's activities in underground public spaces. Therefore, for the design of underground public space, analysis of the influencing factors of the space environment is the premise and basis of this research. While underground public space development brings various benefits to urban construction, renewal, and protection, it also faces inherent disadvantages, such as insufficient natural light and poor ventilation. It leaves people prone to feelings of depression, loss, and insecurity (Xing, 2015b).

The development and utilisation of urban underground space involve many aspects, among which the design of the space environment is a vital link. Compared with the ground-level environment, the underground space environment has clear differences, e.g., space closed, it lacks natural light, and air circulation is poor (Wang and Shu, 2000). These factors impact on human physiology and psychology, coupled with cognitive limitations and physical restrictions; thus, it is challenging to meet the environmental standards required of urban underground space. For a long time, the social psychology of 'the underground space environment [has been] inferior to the ground space environment' (WANG and SHU, 2000, P 656). Therefore, the underground space environment's quality determines the success or failure of underground space use to a large extent. Due to a complex physiological impact on humans, the physical and psychological environments interact and affect, each other. When physiological conditions cannot be fulfilled, adverse psychological reactions are aggravated (Carmody and Sterling, 1993). At the same time, action will only occur when the environment's conditions meet people's needs. Therefore, both the new basic human physiological needs and the conditions for the public's activities in underground public spaces must be provided among the physiological and environmental factors.

## 3.2 Benefits and value of quality in underground public space design

It is currently generally accepted that well-designed and well-managed public spaces are the important property for a liveability and sustainable development to cities, and have social, health, environmental and economic short- and long-term benefits (CABE, 2004; CABE & DETR, 2001; McIndoe et al., 2005; PPS, 2008). Poor urban design can reduce the quality of life, limit employment opportunities, and introduce various unsustainable costs to the community and the city (Cho et al., 2015). Urban underground space has great potential and can significantly improve the quality of life of citizens. It should be a place for gatherings, exchanging ideas, doing business or shopping, studying, or just relaxing (Besner, 2017). The following section discusses the social, economic, and environmental benefits of quality underground public space.

### 3.2.1 Social and health benefits

From the perspective of social interaction, culture is an ordered system of meanings and symbols (Carmody and Sterling, 1993). The social system is a model of social interaction itself. From the perspective of an individual's definition of their world, expression of emotions, and decision-making, there is a process of interactive behaviour at the 'cultural' level, and its solid form is called social structure (Woolley, 2004). From the perspective of human understanding of its experience and its guidance, culture is a construct of meaning; the social structure is the form that behaviour takes, i.e., the network in which social relationships exist (Alzahrani, 2017). Therefore, cultural and social structures are two different abstract concepts of the same phenomenon (Gertz, 1986). Within this system, social psychology and social ideology are linked via five levels, whereby the former is a low-level social consciousness, and the latter is a high-level social consciousness processed by thought (McIndoe et al., 2005).

Therefore, it can be confirmed that there is some connection between social psychology and culture (Wang, 2008b).

Social psychology is formed spontaneously in the practice of daily life and interaction between people, and it is accessible and straightforward (McIndoe et al., 2005). It manifests as public opinion, thoughts and feelings, popular tastes, fashion trends, and the spirit of the time, within a specific time and space (Cho et al., 2015). From a behavioural perspective, culture is the norm on which group members' behaviours are based (Alzahrani, 2017). According to American anthropologist, Havilland, 'Culture is a set of shared ideals, values, and codes of conduct. It is a common standard that makes individual behaviour acceptable to the collective' (Cho et al., 2015, P 283). Therefore, culture is both a product of behaviour and a behaviour system, while the behaviour is the external manifestation of psychology.

In this sense, psychology is a deep reflection of culture (Parfect and Power, 1997). Through culture 'people communicate, continue and develop their knowledge and methods of life' (Montgomery, 1998, P93). Two fundamental characteristics of culture are implied here: continuity and development (Chapman and Larkham, 1999). Continuity refers to culture's inheritance as a social heritage from one generation to the next (Madani-Pour and Madani, 1996). Its consistent characteristics and developmental nature point out that culture itself is continuously formed and developed; it is dynamic and is always in continuation and innovation (Golany and Ojima, 1996). Tradition and modernity are the two poles of this process, and social interaction is usually local (Montgomery, 1998). Culture has prominent regional and national characteristics. At the modern pole, with the advancement of science and technology and the development of transportation, the rapid spread of information makes culture and communication more frequent and diverse, and relatively free from the constraints of time and space (Parfect and Power, 1997). As a result, social and cultural aspects are becoming increasingly global, and cultures are show signs of global convergence (Chapman and Larkham, 1999). Social psychology includes people's trade-offs between tradition and the spirit of the times, localisation and internationalisation (Montgomery, 1998). Therefore, we can think that in a specific time and space, the refined concentration is reflected in the political and social psychology of that time.

Socio-cultural psychology has practical significance to guide and realise the construction of humanised urban public open spaces (Carmona, 2001). On the one hand, it is necessary to seek constraints on external factors to create a suitable microclimate in a social space and create a pleasant interface for different activities in response to changes in terrain and landforms (McIndoe et al., 2005). On the other hand, it is necessary to investigate and consider internal factors, including the specific influence of economic, political, cultural, and other factors (Chapman and Larkham, 1999). Based on the local people's preferences for activities, the appropriate scale and shape of the public space can be determined. Thus materials and colours with regional characteristics, environmental art sketches, and appropriate plants can be incorporated. When shaping a spatial form on a human scale, the appearance of weak links must be avoided. The damage done by some weak links to the image of underground public space cannot be underestimated. Public spaces are open to all people, irrespective of ethnic origin, age, or gender, representing a democratic forum for citizens and society (Cho et al., 2015).

### 3.2.2 Economic benefits

Underground infrastructure is an essential economic driver in cities (Montgomery, 1998, Samers, 2004). Metros, utility tunnels, and sponge city facilities can attract substantial investment, promote employment, and maintain stable and adequate economic growth (Ramadier and Moser, 1998, Lee, 2018). As a technology-intensive industry, large underground buildings form a complete industrial chain of construction machinery and materials. It promotes the transformation and upgrading of upstream and downstream industries to strengthen manufacturing (Chen et al., 2018).

A high-quality public environment has a significant impact on the economic life of the city centre. It is an essential part of any successful regeneration strategy (Johnson et al., 2002, Su, 2008a). Good city design attracts investment and is an important business and marketing tool (McIndoe et al., 2005). Therefore, it is suggested that quality public places can strengthen the local economy (Cho et al., 2015) which can be summarised as following ways:

- attracting tourists;
- responding to the needs of occupants;
- attracting investment through high-quality improvements;
- generating high returns on investment (increasing rent and capital through good urban design);
- reducing management, maintenance, energy, and security costs.

### 3.2.3 Environmental benefits

Perhaps the most significant components of underground improvement is the environmental benefits coming from the utilisation and the inherent highlights of underground space (Mavrikos and Kaliampakos, 2021). The use of the underground space can successfully resolve a considerable lot of the taking off environmental issues of our urban communities such as absence of free surface space and help city specialists accomplish their supportability objectives(Zhou et al., 2017). A manageable utilisation of underground space be required to be accomplished when another metropolitan tissue is made that coordinate into the metropolitan texture. Organisations ought to be apparent and open while public spaces need to exist as much beneath the surface as at grade. An example of this is the New York Lowline park (Admiraal and Cornaro, 2016). Underground public space enhances Environmental benefits by (McIndoe et al., 2005)

- Less pollution and Reduced noise. The construction of the urban underground road system will also contribute to eliminating the pollution of urban air and noise pollution caused by automobile exhaust (Qihu, 2019).

- Reduced land-use. The Lowline project is a private drive in the Lower East side of New York. The venture focuses on the reuse of a previous now un-used underground tramway terminal underneath Delancey Street to make an underground park to offer a truly essential 1 section of land of green public space to occupants (Admiraal and Cornaro, 2016).

- Enhanced sense of safety. In areas with complex transportation, combined with metro station to provide pedestrians with safer walking passages (Li, 2012).

### 3.3 Value of underground public space

In recent decades, the nature of urban planning has been examined within the urban structure literature by numerous writers; for example, Jacobs, Lynch, and Lang (Alzahrani, 2017). Specific characteristics, objectives, and standards must be investigated to observe great urban structure (McIndoe et al., 2005). The nature of the urban plan depends on the nature of the evaluation markers and rules utilised to acknowledge structural results (Lang, 1996) characterises the terms, goals, standards, and rules to show how they are covered in the urban plan. For Lang, 'destinations' allude to 'explanations of what a plan is to accomplish', which is a blend of monetary, conduct, and stylistic perspectives (Lang, 1996, P 7). 'Standards are articulations depicting and, in a perfect world, clarifying the connection between an ideal structure objective and an example or format of the earth' (Bélanger et al., 2007, P 272). At the same time, rules are explanations that indicate how to meet a plan objective (Lang and Lundholm, 1996). He presented two kinds of rules. The first was prescriptive, a rule that decides the essential trait of the result. The second was an exhibition rule, which may be joined by guidance, while the result is accomplished (Lang, 1996).

### 3.3.1 Why people are going to underground public space

> *'Our cities are becoming increasingly overcrowded and congested. With land prices rising rapidly, can greater use of underground space enable us to meet the increasing demand for more buildings and more extensive transport systems?' (Chow, 2002:15)*

There are various advantages to using underground space which can be outlined as follows (Broere, 2016):

- effective land use and improvement of nature – understanding the capability of underground space in clogged urban regions and discharging surface space for different uses, e.g., parks and recreational territories

- stylish – removing ugly structures, such as car parks, streets, and shopping centres from the skyline.

- supportable advancement – removes the requirement for outer cladding, prompting productive utilisation of materials and cost investment funds.

- protection of vitality – utilising the ground's characteristic protecting properties to retain vitality, permitting progressively effective warming or cooling frameworks, or saddling the ground for vitality stockpiling.

### 3.3.2 Integrated design of above ground and underground space

Integration mainly refers to two or more elements or systems that can be distinguished from each other, connected, and interacting. They are distributed in the form of a particular hierarchical structure (Liu, 2006, Mavrikos and Kaliampakos, 2021). They are formed to achieve the overall purpose under the established environmental constraints. Vertical spatial integration can make the city more compact through the multiple use of the ground and underground land so that various functional elements of the city can be vertically distributed, spatial integration, and intensive and efficient use of space(Li, 2013, Liu, 2006). It also helps to save energy resources and improve the urban environment. The sustainable development of the city in the future provides new ideas (Jie, 2009).

The utilisation of underground space has developed to the stage of integration of above-ground and underground space(Linxu, 1998). The integrated development and utilisation of aboveground and underground space can effectively improve land-use efficiency, expand urban space capacity, improve transportation organisation, improve environmental quality, and achieve sustainable development(Roberts, 1996, Liu, 2009a).

At this stage, the integrated development and utilisation of above-ground and underground space mainly includes the following forms:

1) Combining with the construction of comprehensive transportation junction such as metro stations and railway stations, develop large-scale comprehensive underground building spaces with complex functions, integrate underground transportation systems, and improve transportation efficiency(Rong, 2000, Zacharias, 2003).

2) In combination with the construction of large public buildings, the underground space attached to large buildings would be considered as a whole, and integrated design would be carried out to construct a large-scale complex integrated above and below to improve land-use efficiency(Liu, 2009a, Jia, 2015).

3) When comprehensively transforming the old urban area, use integrated design methods to develop underground public space, expand and extend the urban space, and improve the quality of the urban environment(Shang, 2015).

As indicated by the official definition, urbanism concerns work on the physical needs and communication requirements of occupants of urban territories in terms of constructed conditions or, basically, city arranging, otherwise known urban planning (Jia, 2015). The methodology of characterising all the diverse 'urbanisms' on the planet is an interminable one (Barnett, 2011). Krieger (2002) contemplates hypotheses of urbanism to provide knowledge of how urban specialists work. He distinguishes circles in which urbanism happens practically-speaking (POLYZOIDES et al., 2002). These are an extension to the arrangement of interfaces and engineering, a classification of the open approach, the design of the city, the urban structure in the entirety of its variations, the investigation of the framework of the city, scene urbanism, and new urbanism. Krieger (2002) infers that urbanism is less a specific order than an attitude dependent on a promise to urban areas. Therefore, to address this inquiry, inspection of a portion of the underground space businesses can be made (Besner, 2016).

### 3.3.3 Design for people

Underground should also be a place for gatherings, exchanging ideas, doing business, shopping, studying or relaxing (Besner, 2017). Creating well-organised indoor spaces underground and providing users with an engaging experience is as building on the ground (Hunt et al., 2016). In planning and design, attention should be paid to the building's enveloping structure and the space inside the building. Better understanding will help meet pedestrians' needs in terms of what they do and do not like, and safety should be a top priority. Where there is no sense of security, people will not be attracted to the underground space and corridors even if all other design features are provided. Unfortunately, many architects are not sensitive enough, or are completely insensitive, to such needs and claim that addressing the issue may damage aesthetics or increase project costs. Also, to improve security, some developers do not want to connect directly to an already connected metro station or building and have indicated that this means it will be easier to control or manage crowds (Canto-Perello et al., 2013). It is a significant mistake because they limit the number of pedestrians entering the building's basement level and ultimately reduce the building's commercial appeal.

Underground space should consider two basic planning principles to create a welcoming atmosphere for people. The first is to place pedestrians, downtown employees, students, the elderly, and the disabled at the centre of planning work (Su, 2008b). Second, a balance should be maintained between three key functions of underground space: commerce; transportation; society, including indoor public places and street furniture (Besner, 2007, Canto-Perello et al., 2013). However, planning alone is not enough. Cities also need standards and regulations to guide the design and implementation of plans (Shao, 2016):

- universal access rights;
- fire and emergency exit, often embedded in building codes;
- corridor and tunnel opening and closing times; and
- a signage system that improves the readability of the space.

Even if the design fully complies with standards and regulations, successful interior decoration requires proper management. The primary purpose here is to understand who is responsible for the underground affairs of public and private stakeholders. The city's mission also includes collecting consistent data, managing archives and quickly accessing data for free. A city should support open dialogue with developers. It should also ensure coordination among its planners, engineers, and architects, as well as between police and fire departments, metro operators, and utility companies. During underground works alone, New York City did not do enough to notify and monitor contractors to ensure public infrastructure integrity. It is also important to do so after construction and, even more, to continue to do so in the future.

Since underground construction is an engineering challenge and a critical step to achieving better planning, it should integrate with the local economy and environment and include the city's annual budget.

### 3.3.4 Places making

A typical example: the underground commercial mall (Besner, 2002) under the outlined principles, some questions can be asked about a hypothetical future underground commercial mall, built under a commercial street, as frequently occurs in some of the world's largest metropolises. A number of factors must be considered (Shu, 2015b); they include:

1) Cost reduction factors:

Will the surface works of the existing street be preserved or destroyed by the planned underground works? In the latter situation, the cost of rebuilding the surface works of the street should be considered.

Will the actual public utilities under the street be preserved, modified, or rebuilt in the planned underground works? In the latter two situations, the cost of such works must be considered.

2) Time factors:

Will the underground works be sustainable and of high quality, allowing them to withstand the test of time? Such works have to successfully meet specific engineering issues (such as compensating for humidity, infiltration).

Will the underground works be attractive enough for citizens and benefit the largest number of citizens currently and future generations? Will those works defy fashions?

3) Environmental protection factors:

Are the excavated grounds contaminated? If so, what will be the decontamination or the enclosing costs? Where and how will the excavated groundwork be stored? What will be the impact of such storage on the selected storage area?

4) Archaeological and heritage protection factors:

Will the planned excavation works destroy unique archaeological features, and will the planned underground works integrate such archaeological resources?

5) Pedestrian factors:

Will pedestrians find a secure and inviting environment (generous indoor space with natural light and without dead-end or tortuous corridors)?

Will the underground mall users find a friendly environment (with furniture, services, toilets, etc.) and will those with reduced mobility be considered?

6) Public transportation factors:

Will the users and the employees in the sector find faster and more inviting access to and from the metro, including future lines?

Will the underground mall be accessible at the same hours as the metro stations to benefit from the greatest number of users?

7) Commercial street competitiveness:

Will the underground mall impact the pedestrian traffic at the surface (deviated from the street)?

Will the underground mall impact the existing commercial facilities in the city and on the competitiveness of the street itself?

8) The commercial success of the mall street:

Will storekeepers be interested in opening a shop there? Will it be profitable enough to meet the required rental costs?

Will the management of the mall be efficient and allow the best commercial mix?

9) Public investment factors:

Will the required public investments benefit a minority of people (builders, local owners), during and after the construction work?

Will the public investments encourage private investment in the district? How much and over what length of time? Will the available development lands for private investment around the works be estimated? Are they likely to be attractive?

Will private investments allow a return on the public investment made by the city? In which ways and by how much?

Will the municipal legal framework (regulating land usage and private real estate projects) ensure the development of an underground network in the future?

In the 'placemaking' approach, the focus shifts from the physical space toward activities, the local community, and social aspects. The *placemaking* concept originated in the 1960s, and it was based on the pioneering works of Jacobs (1961) and Whyte (1980, 1988), and followed by others, such as Gehl (1996, 2001, 2010). Since 1975, as reported by the Project for Public Spaces (PPS) Association (2008), an extensive placemaking approach has been developed, as well as one of the most comprehensive of the available frameworks for public space. The four key attributes of successful places, presented in their 'Place Diagram', are (PPS, 2008):

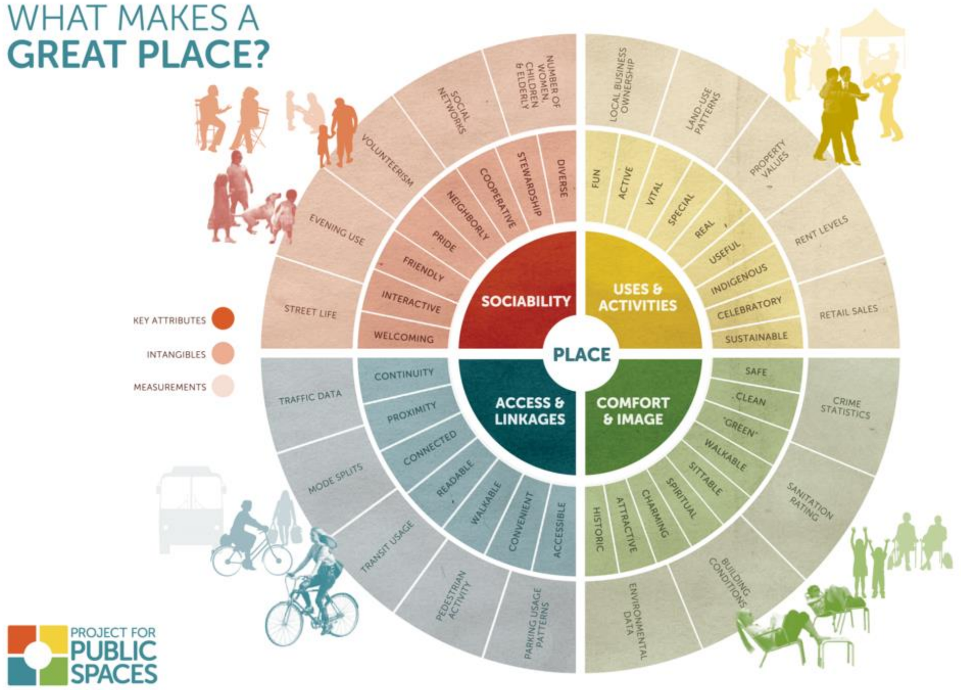



Figure 3-2 'What Makes a Great Place?' Project for Public Spaces (PPS)
*Figure source: https://www.pps.org/reference/grplacefeat/*

- **access and linkages**, including how a place should be visually and physically connected to its surroundings,

- **comfort and image**, addressing more tangible design aspects,

- **uses and activities**, including the main attractors for people to come to a place, and to come back,

- **sociability**, addressing the most difficult quality of place, creates a comfortable environment for social interaction between local users and strangers.

Within each of these four attributes, the PPS further differentiates two groups of criteria: the **intangibles**, which describe the more intuitive and qualitative aspects of space; and measurements, or **tangibles**, which give weight to the quantitative aspects. Finally, the 'Place Diagram' serves as a tool to help people evaluate any public space, either good or bad, and is very easy to use by design professionals, various clients, and laymen, thus providing a platform for integrated placemaking involving all actors.

Another well-known, practical, and frequently referred to placemaking framework based on extensive research into urban life on the streets of Zürich, Copenhagen, Melbourne, and Sydney, among others, was developed by Gehl (1996, 2010). In his work, Gehl continuously explores and re-explores the more sensitive views to understanding and creating better 'lives between buildings' (Gehl, 2011). In Life between Buildings (1996) and Cities for People (2010), Gehl develops a series of arguments and suggestions for making lively, safe, sustainable, and healthy cities with an emphasis on the 'human dimension' (Gehl, 2011: 105). The result is 'the toolbox of principles ' and design recommendations, ranging from the largest scale of city planning to the smallest dimension of qualities at 'eye level' (Gehl, 2011: 81). The criteria for evaluating pedestrian-friendly spaces are categorised into three groups: protection, comfort, and delight. With the recommendations for planners and designers framed in a 'dos and don'ts' manner, Gehl's framework has a highly practical and somewhat instrumental value.

### 3.3.5 Green architecture theory

For buildings, low-carbon design means that the entire design, construction, use, and exhaust links, must consider low energy consumption, low pollution, and low emissions (Besner, 2002). Therefore, while considering the functional design of the building, the easy-to-remove design of the building should be taken into account to save resources. In terms of renewable energy utilisation in underground space, it is difficult to carry out demolition or renewal design due to underground engineering's irreversibility (Jenks and Dempsey, 2005). However, other aspects of the design must still be considered.

- Consideration of site attributes

In the low-carbon design of underground spaces, designers need to consider the attributes of the building environment (Yu, 2015). Because the underground space is located below the ground surface and isolated from the ground, it is darker and damp than the aboveground buildings. Compared with the aboveground structures, its internal space has sealing characteristics, constant temperature, and shading (Besner, 2002; Zhou et al., 2017). The underground public space can be divided into different types such as the space that exists as a subsidiary of the building (such as the underground supermarket) and the independent underground space (such as the underground rail transit space) (Bobylev, 2009). The underground public space that exists as an accessory to the aboveground buildings is mainly connected to the outside world through the aboveground buildings (Liu, 2006).

In contrast, the independent underground space is mainly connected with the city through underground space entrances and exits and open sunken squares (Lu, 2015). In the design of underground space, full consideration of the connection between the underground space and the outside world can effectively strengthen the connection between the underground space and the outside (Zhang, 2015) world, make full use of the advantageous factors available in the site, and realise the purpose of green design (Tang, 2013). Besides, although the specific evaluation indicators are different from the aboveground buildings, the green design of underground public spaces still needs to strengthen the use of land and space (Phoenix room, 2014; Lu, 2015).

- Efficient use of materials

The direct economic benefits of the low-carbon underground space design materials-saving strategy come from the reduction of construction waste (Shu, 2015b). The integration of architecture and interior design can reduce unnecessary material loss and energy consumption in interior design systems. To maximise the characteristics of materials, they should be closely combined with construction, and a new type of building system with high performance, low material consumption, and good durability should be adopted. For example, the using renewable materials and easy assembly and disassembly of materials can reduce the construction cycle, save construction costs, and reduce material waste at the construction site.

- Efficient use of space

Reasonably determine the development depth of underground space to achieve efficient use of land (Yu, 2015). The depth and scale of underground space development are mainly affected by the conditions of urban land use. Due to the high land price and the tight land use in densely populated areas, the value of underground space development is more incredible (Besner, 2002). As the city centre's distance becomes more distant, the value of underground space development also decreases. Wu 2005 affirmed the value of developing underground space in urban centres in his book, and He believes that although the initial investment in underground space development is relatively large when it is within a certain distance from the city centre, the overall development cost is less than that of aboveground buildings (Wu, 2005). Therefore, according to the land-use situation, the development and utilisation of underground space are usually more significant in urban centres and transportation hub areas, while the development and utilisation of underground space are less in areas far from the city centre (Hong, 2018).

- Combination of low-carbon design and BIM

In the early design stages, architects often rely on their experiences to estimate the building energy consumption, which may lead to an unexpected result. A consensus for building energy consumption model has been established here. The development of new technologies today encourages people to contribute to this field. A virtual model created by BIM software contains a database which includes building materials, building components, and building structures. It is combined with energy analysis tools, which architects can achieve accurate calculation in the footprint, energy consumption and energy balance in the planning stage of evaluation.

The assessment of the decarbonisation of underground space has an essential guiding role in the development of underground carbonisation (Li, 2013). The low-carbon assessment of underground space can reflect the low-carbon characteristics of different buildings. It effectively implements related energy-saving strategies, and makes the low-carbon design rule-based, with a more precise evaluation of its low-carbon effect (Bobylev, 2009).

Before applying for an assessment, an underground building should ensure its planning, design, construction, and operation complying with the higher-level building regulations and standards. It is the premise for underground buildings to participate in the evaluation. Underground building evaluation systems covers the essential requirements of functions and building performance. It also focuses on evaluating indicators related to low-carbon performance, such as land saving, water saving, energy saving, material saving, and indoor quality (Yu, 2015). A low-carbon assessment could not be applied when a building fails to meet the relevant building codes and standards.

## 3.4 Quality of underground public space

### 3.4.1 Indicators of Quality underground space design

Different urban underground space quality indicators are expressed in urban underground space planning and design literature. Carmody and Sterling (1993) proposed that underground space design draws on five aspects: exterior and entrance design; layout and spatial configuration; interior elements and systems; lighting and safety patterns; and qualitative indicators that need to be valued by the designer. At the same time, they proposed that underground space design should be based on a human perspective (Carmody and Sterling, 1993). Durmisevic and Sariyildiz (2001) put forward the method and index of underground space quality assessment in a systematic quality assessment of underground spaces and public transport stations, and continue to use the people-oriented design principle of underground space proposed by Carmody and Sterling. Durmisevic and Sariyildiz (2001) proposed evaluation indicators for underground space from three aspects, i.e., its form, psychology, and functionality. In addition to form and functionality, which evaluates underground space from physical factors in the design space, psychological factors are proposed, affecting the results of space evaluation. These are divided into safety and comfort to propose evaluation indicators (Durmisevic and Sariyildiz, 2001).

Later, three scholars (Zhao, 2009; Che, 2012a; and Cao, 2015) proposed design guidelines for the design of underground space from humanised design. In the urban underground public space complex design research, Zhao (2009) proposed that the composite design of underground public space should cover three aspects: physiological environment, psychological environment, and affection requirements. In addition to the physical environmental design requirements of the underground space, the psychological factors affecting such design were emphasised, including art and natural elements (ibid.). Che (2012a), in the humanity design research of underground public space in metro stations, proposed that the design quality of human space in underground space should be controlled from five aspects: safety, legibility, the following principle, comfort, and integrity.

Cao (2015) reiterated in urban underground public space complex planning and humanisation design research that the humanised design of underground space should be designed from three aspects: physiological environment, psychological environment, and affection requirements. Zhao and Cao proposed the specific design control indicators for the underground public space (Cao, 2015, Zhao, 2009a). In research on green architecture, theory and method in public underground space design, Hong (2018) put forward an eleven-point classification index of requirements for the three aspects of low-carbon design and evaluation of underground public buildings, including master plan, sustainability, and interior environment. All main elements and indicators of underground space design have been summarised into the below table (see Table 3-1).

Through the summary of the table 3-1, it is more intuitive to see the status of the design and evaluation indicators of the underground public space. Designers or managers cannot directly and effectively use the existing indicator system. 'The qualitative indicators in underground space design' are difficult to operate. 'The classification of A systematic quality assessment of underground spaces – public transport stations' is incomplete. 'The evaluation indicators in Urban underground public space complex design research', 'The humanity design research of underground public space in the metro station', and 'Urban underground public space complex planning and humanisation design research' are incomplete. 'The evaluation system indicators of Research on green architecture theory and method in public underground space design' lack humanised design content from the perspective of urban design. The content of this section will combine with the design and evaluation of urban public space in the next section, and the quality evaluation framework indicators of underground public space will be used as the basis.

Table 3-1 Main elements of underground space design and indicators (Carmody and Sterling, 1993, Durmisevic and Sariyildiz, 2001, Zhao, 2009a, Che, 2012b, Cho et al., 2015, Hong, 2018)

| No. | Year | Title or Theories | Attributes | Indicators |
|---|---|---|---|---|
| 1 | 1993 | Underground space design (Carmody and Sterling, 1993) | Exterior and entrance design | Terraced building with a hillside entrance |
| | | | | Hillside entrance to an isolated facility |
| | | | | Entrance through a sunken courtyard |
| | | | | Open air structures over stairways and escalators |
| | | | | Above-grade entrance pavilion |
| | | | | Entrance through large above-grade building mass |
| | | | | Open stairways, ramps, and escalators |
| | | | | Glass-enclosed vertical and inclined Lifts |
| | | | Layout and spatial configuration | A system of paths, activity node, and landmark |
| | | | | Building with hillside exposure |
| | | | | Sunken exterior courtyard |
| | | | | Interior atrium space |
| | | | | Building thoroughfare |
| | | | | Short, lively passageways |
| | | | | Zones of distinct character |
| | | | | Interior windows overlooking activity |
| | | | | Hierarchy of privacy |
| | | | | Complex room shapes and interconnected spaces |
| | | | | High and varied ceilings |
| | | | Interior elements and systems | Colourful, warm, and spacious environment |
| | | | | Patterns, lines, and textures |
| | | | | Natural elements and materials |
| | | | | Sculpture and man-made artefacts |
| | | | | Uncluttered furnishings |
| | | | | Mirrors |
| | | | | Alcoves and window-like recesses |
| | | | | Paintings and photographs |
| | | | | Transmitted and reflected exterior views |
| | | | | Clear system of signs and maps |
| | | | | Well-ventilated, comfortable environment |
| | | | Lighting | Natural light through windows and skylights |
| | | | | Transmitted and reflected natural light |

| | | | | | |
|---|---|---|---|---|---|
| | | | | | Artificial light with natural characteristics |
| | | | | | Skylights and wall panels with artificial backlight |
| | | | | | İndirect lighting of ceilings and walls |
| | | | | | Dark, ambiguous boundaries |
| | | | | | Patterns of light and shadow |
| | | | Life safety patterns | | Clear internal organisation and egress system |
| | | | | | Safe vertical egress - stairwells, Lifts, and escalators |
| | | | | | Compartmentalisation and places of safe refuge |
| | | | | | Clear signs and emergency lighting |
| | | | | | Effective detection, alarm, and communication systems |
| | | | | | Effective smoke removal and air handling |
| | | | | | Effective fire suppression |
| | | | | | Fire-resistant construction and restriction of hazardous materials |
| 2 | 2001 | A systematic quality assessment of underground spaces – public transport stations (Durmisevic and Sariyildiz, 2001) | Form aspects | | Material / colour |
| | | | | | Construction and separation walls |
| | | | | | Dimensions |
| | | | | | Furniture positioning and design |
| | | | | | Signing system |
| | | | Psychological aspects | Safety | Overview |
| | | | | | Escape |
| | | | | | Visibility / light |
| | | | | | Surveillance / presence of people |
| | | | | Comfort | Wayfinding |
| | | | | | Attractiveness / maintenance |
| | | | | | Physiological comfort |
| | | | | | Daylight |
| | | | Functionality of the space | | Layout / connectivity patterns |
| | | | | | Adjacency |
| | | | | | Accessibility |
| | | | | | Light |
| | | | | | Temperature / draft |
| | | | | | Air quality |
| | | | | | |
| 3 | 2009 | Urban underground public space complex design research (Zhao, 2009b) | Physiological environment | Air quality | Air-quality control |
| | | | | | Thermal humidity control |
| | | | | Auditory | - |
| | | | | Sense of smell | - |
| | | | | Lighting | Natural lighting |
| | | | | | Artificial lighting |
| | | | | Disaster prevention | - |
| | | | | Barrier-free design | - |
| | | | Psychological environment | Legibility | - |
| | | | | Proportion and scale | - |
| | | | Affection requirement | Art environment | Colour |
| | | | | | Graphic pattern |
| | | | | | Design nodes |
| | | | | | Music |
| | | | | | Fragrance system |
| | | | | | Environmental video |
| | | | | Landscape | Plants |

| | | | | | |
|---|---|---|---|---|---|
| 4 | 2012 | The humanity design research of underground public space in metro station (Che, 2012a) | Safety | Evacuation of pulp | - |
| | | | | Barrier-free design | - |
| | | | Legibility | Leading | Vision guiding |
| | | | | | Signpost |
| | | | | | Transition space |
| | | | | Efficiency | - |
| | | | A sequential principle | Spatial perception | Enclosed space |
| | | | | | Continuity |
| | | | | | Multiformity |
| | | | | Spatial sequence | - |
| | | | Comfort | Interior design | - |
| | | | | Art environment | Space conditions |
| | | | | | Spatial density |
| | | | | | Rest facilities |
| | | | | | Aesthetic |
| | | | Integrity | Spatial integration | Create a theme |
| | | | | | Outstanding theme |
| | | | | | Uniform colour |
| | | | | Service facility | - |
| 5 | 2015 | Urban underground public space complex planning and humanisation design research (Cao, 2015) | Physiological environment | Ecological design (landscape) | - |
| | | | | Barrier-free design | - |
| | | | | Safety design | - |
| | | | Psychological environment | Internal dimensions | - |
| | | | | Internal legibility | - |
| | | | Affection requirement | Art | - |
| | | | | Culture | - |
| 6 | 2018 | Research on green architecture theory and method in public underground space design (Hong, 2018) | Master plan | Land use | The level of integration |
| | | | | | Size and depth |
| | | | | Terrain use | The terrain use |
| | | | | | Use of existing facilities on the site |
| | | | Sustainability | The structure of defence | Fence structure performance |
| | | | | | Building spatial structure |
| | | | | Lighting | The performance of lighting |
| | | | | | The control of lighting |
| | | | | Air-condition-ing system | The performance |
| | | | | | The cold and heat source |
| | | | | Energy use | Equipment energy reuse |
| | | | | | Renewable energy use |
| | | | İnterior environment | Humidity and temperature | Skylight design |
| | | | | | Indoor temperature and humidity |
| | | | | Light environment | Natural light |
| | | | | Sound environment | Enclosure structure sound insulation |
| | | | | | Spatial function layout |

| | | | | | |
|---|---|---|---|---|---|
| | | | | Air quality | Natural ventilation design |
| | | | | | Air quality testing |
| | | | | Psychological environment | İndoor landscape design |
| | | | | | Spatial scale and degree of closure |

### 3.4.2 Indicators of Quality urban public space design

The pointer of urban quality, especially road quality likewise turns into a major concern for the PPS Association. They suggest eleven pointers to be considered for the accomplishment of successful use of public space: attractions and goals; character and picture; use of a dynamic edge; pleasantries; the executives; regular procedures; differing client gatherings; traffic; travel and walkers; the mixture of employments and modes; and, neighbourhood conservation (Project Public Spaces, 2014). In accordance with PPS, Jacobs proposes nine criteria for the designable attributes of public space: a capacity to stroll with relaxation (walkability); comfort; definition; straightforwardness; structures that praise to one another; support; physical characteristics that consolidate to make the eyes move continually; trees; bright beginnings and endings. The research additionally proposes that these nine markers likewise require some quality patrons (Jacobs, 2010).

Varna (2011) proposed in 'Assessing the publicness of public places: towards a new model' to evaluate the publicity of public spaces from five directions: Civility, Amination, Physical configuration, Ownership and Control. Accessibility as a social reality implies that every open spot, made at one point in time and a specific socio-social setting, can be comprehended as an impression of a typically held perspective on the perfect open space (Cho et al., 2015). To get a handle on this 'perfect open space' and use it as a standard to quantify the accessibility of new open places, the analyst assembled and sifted the various originations and definitions in the field (Sholihah, 2016). The research aims to propose a new way of conceptualising the publicness of public space (Varna, 2011).

In BREEAM (Building Research Establishment Environmental Assessment Method) communities, two classification indicators are proposed for urban public space characteristics, namely the public realm, and access to public transport (Haapio, 2012). The goal of BREEAM communities is to reduce the overall environmental impact of development projects and make development goals consistent with local communities' environmental, social, and economic interests (Kubba, 2012). Their evaluation score is based on comparing actual conditions and established sustainable goals and planning policy needs and includes eight aspects: climate and energy; resources; transportation; ecology; business; community; and place-shaping (Haapio, 2012).

The WELL Building Standard is a new evaluation standard for architectural design (Zavada, 2018). Its primary focus is on the 'occupants' health'; thus, its focus is on people, and the LEED green building focuses on architecture

(Zavada, 2018). Many medical experts and psychological research experts participated in developing the WELL building standard, which is more humane (Seville, 2014). The WELL Building Standard sets building performance metrics around seven concepts (Zavada, 2018). These seven essential concepts in the built environment are related to human health: air; water; nutrition; light; fitness; comfort; and spirit. Incorporating these seven concepts can promote the built environment to improve its users' nutrition, fitness, mood, sleep habits, and daily performance (Seville, 2014).

Sholihah (2016) proposed a method for evaluating the quality of traditional streets from four aspects: morphological; functional; visual morphological; and, perceptual. The study concludes that traditional streets have five main characteristics: physical and visual quality; mixed-use urban spaces; multicultural urban spaces; urban cultural paths and public spaces; and traditional street activities as an intangible culture (Sholihah, 2016).

Re-framing urban space proposed an original and holistic conceptual urban space framework (Cho et al., 2015). The book proposed a new idea for evaluating urban design evaluation standards and proposed the author's idea to study underground public space. The Urban Space Framework perceives three similarly significant and associated segments that impact and shape urban space typology and execution, particularly HARDware, SOFTware and ORGware (Cho et al., 2015). Equipment alludes to physical and geometrical properties, i.e., structural estimations of room (Cho et al., 2015). Programming includes utilisations, social, and perceptual estimations of urban space (Cho et al., 2015). ORGware identifies with operational and the board parts of open space (Cho et al., 2015). The hardware, software, and ORGware are associated and unavoidably cover different levels, giving an all-encompassing and complete stage for seeing how new crossbred urban spaces in high-thickness settings work and perform. In such a manner, the Urban Space Framework proposes that excellent urban space execution results from a top-notch plan, an insightful blend of practices, and a great arrangement of enhancements and executives (Cho et al., 2015). The author sorts out the categories and indicators that impact underground public space quality evaluation standards, as shown in table 3-2.

Table 3-2 Categories in urban public space and sustainable building (Crabill, 2009; Varna and Tiesdell, 2011; Kubba, 2012; Seville, 2014; Cho et al., 2015; Sholihah, 2016; Hong, 2018)

| No. | Year | Theories | Attributes | Intangibles | Indicators |
|---|---|---|---|---|---|
| 1 | 2009 | PPS (Project for public space) (Crabill, 2009) | Sociability | Diverse | Number of women, children, & elderly |
| | | | | Stewardship | |
| | | | | Cooperative | Social networks |
| | | | | Neighbourly | Volunteerism |
| | | | | Pride | Evening use |
| | | | | Friendly | |
| | | | | Interactive | Street life |
| | | | | Welcoming | |
| | | | Uses & Activities | Fun | Local business ownership |
| | | | | Active | |
| | | | | Vital | Land-use patterns |
| | | | | Special | |
| | | | | Real | Property |
| | | | | Useful | |
| | | | | Indigenous | |
| | | | | Celebratory | Retail sales |
| | | | | Sustainable | |
| | | | Access & Linkages | Continuity | Traffic data |
| | | | | Proximity | |
| | | | | Connectivity | Mode splits |
| | | | | Readability | Transit usage |
| | | | | Walkability | Pedestrian activity |
| | | | | Convenience | Parking usage patterns |
| | | | | Accessibility | |
| | | | Comfort & Image | Safe | Crime statistics |
| | | | | Clean | |
| | | | | 'Green' | Sanitation rating |
| | | | | Walkable | |
| | | | | Sittable | Building conditions |
| | | | | Spiritual | |
| | | | | Charming | Environmental data |
| | | | | Attractive | |
| | | | | Historic | |
| | | | | Natural and built beauty | |
| | | | | Sunlight and nature | |
| | | | | Geographical boundary | |
| | | | | Eating places | |
| | | | | Ease of access | |
| | | | | Place space | |
| | | | | Variation of levels | |
| | | | | Contemplative resting places | |
| | | | | Central meeting place | |
| | | | | Spaces for events | |
| | | | | Activities, markets, culture | |
| | | | | Vitality | |
| | | | | Heritage and history | |
| | | | | Creative expression | |
| | | | | Diversity in story | |
| | | | | Cultural context | |
| | | | | Mixed and diverse use | |
| | | | | Sense of place | |
| | | | | Varied and interesting retail | |

| | | | | | |
|---|---|---|---|---|---|
| | | | | Sense of longevity | |
| | | | | Family, child and elderly friendly | |
| | | | | Sense of safety and security | |
| | | | | Sense of intimacy | |
| 2 | 2011 | Assessing the publicness of public places: towards a new model (Varna, 2011) | Civility | Physical maintenance and cleansing regime of hard landscaped areas and street furniture | |
| | | | | Physical maintenance and provision of green areas | |
| | | | | Physical provision of basic facilities: public toilets | |
| | | | | Physical provision of basic facilities: lighting | |
| | | | Amination | Diversity of activities | |
| | | | | Presence of street vendors and entertainers | |
| | | | Physical configuration | Macro – Design | Crossings |
| | | | | | Public walkways |
| | | | | | Cycle routes |
| | | | | | Fences |
| | | | | | Sitting opportunities |
| | | | | | Walking opportunities |
| | | | | | Opportunities for active engagement and discovery |
| | | | | | Active frontages |
| | | | Ownership | Ownership status | |
| | | | Control | Control technology: CCTV cameras | |
| | | | | Control presence: police/ guards presence | |
| | | | | Control by design: sadistic street furniture | |
| | | | | Control signage | |
| 3 | 2012 | BREEAM Communities | Public realm | Social and economic wellbeing | Consultation |
| | | | | | Multiple uses for different users |
| | | | | | Shared spaces |
| | | | | | Microclimate |
| | | | | | Local identity |
| | | | Access to public transport | Transport and movement | Compliant transport node |
| | | | | | Proximity to buildings |
| | | | | | Measuring distance |
| | | | | | Multiple services at a transport node |
| | | | | | Multiple transport nodes |
| | | | | | Safe convenient pedestrian route |
| | | | | | Phased developments |

| | | | | | |
|---|---|---|---|---|---|
| 4 | 2014 | WELL Building Standard | Air | 01 Air quality standards | Standards for volatile substances |
| | | | | | Standards for particulate matter and inorganic gases |
| | | | | | Below-grade air quality standards |
| | | | | 02 Smoking ban | Indoor smoking ban |
| | | | | | Outdoor smoking ban |
| | | | | 03 Ventilation effectiveness | Ventilation design |
| | | | | | Demand controlled ventilation |
| | | | | | System balancing |
| | | | | 04 VOC reduction | Interior paints and coatings |
| | | | | | Interior adhesives and sealants |
| | | | | | Flooring |
| | | | | | Insulation |
| | | | | | Furniture and furnishings |
| | | | | 05 Air filtration | Filter accommodation |
| | | | | | Particle filtration |
| | | | | | Air filtration maintenance |
| | | | | 06 Microbe and mould control | Cooling coil mould reduction |
| | | | | | Mould inspections |
| | | | | 07 Construction pollution management | Duct protection |
| | | | | | Filter replacement |
| | | | | | VOC adsorption management |
| | | | | | Construction equipment |
| | | | | | Dust containment and removal |
| | | | | 08 Healthy entrance | Permanent entryway walk-off systems |
| | | | | | Entryway air seal |
| | | | | 09 Cleaning protocol | Cleaning plan for occupied spaces |
| | | | | 10 Pesticide management | Pesticide use |
| | | | | 11 Fundamental material safety | Asbestos and lead restriction |
| | | | | | Lead abatement |
| | | | | | Asbestos abatement |
| | | | | | Polychlorinated biphenyls abatement |
| | | | | 12 Moisture management | Bulk water – exterior management |
| | | | | | Interior bulk water damage management |

| | | | | | |
|---|---|---|---|---|---|
| | | | | | Capillary water management |
| | | | | | Wetting by convection and condensation |
| | | | | 13 Air flush | Air flush |
| | | | | 14 Air infiltration management | Air leakage testing |
| | | | | 15 Increased ventilation | Increased fresh air supply |
| | | | | 16 Humidity control | Relative humidity |
| | | | | 17 Direct source ventilation | Pollution isolation and exhaust |
| | | | | 18 Air quality monitoring and feedback | Indoor air monitoring |
| | | | | | Air data record keeping and response |
| | | | | | Environmental measures display |
| | | | | 19 Operable windows | Full control |
| | | | | | Outdoor air measurement |
| | | | | | Window operation management |
| | | | | 20 Outdoor air systems | Dedicated outdoor air systems |
| | | | | 21 Displacement ventilation | Displacement ventilation design and application |
| | | | | | System performance |
| | | | | 22 Pest control | Pest reduction |
| | | | | | Pest inspection |
| | | | | 23 Advanced air purification | Carbon filtration O |
| | | | | | Air sanitization O |
| | | | | | Air quality maintenance |
| | | | | 24 Combustion minimisation | Appliance and heater combustion ban |
| | | | | | Low-emission combustion sources |
| | | | | | Engine exhaust reduction |
| | | | | 25 Toxic material reduction | Perfluorinated compound limitation O |
| | | | | | Flame retardant limitation |
| | | | | | Phthalate (plasticisers) limitation |
| | | | | | Isocyanate-based polyurethane limitation |
| | | | | | Urea-formaldehyde restriction |

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|---|---|---|---|---|---|
| | | | | 26 Enhanced material safety | Precautionary material selection |
| | | | | 27 Antimicrobial surfaces | High-touch surface coating |
| | | | | 28 Cleanable environments | Material properties |
| | | | | | Cleanability |
| | | | | 29 Cleaning equipment | Equipment and cleaning agents |
| | | | | | Chemical storage |
| | | | Water | 30 Fundamental water quality | Sediment P |
| | | | | | Microorganisms |
| | | | | 31 Inorganic contaminants | Dissolved metals |
| | | | | 32 Organic contaminants | Organic pollutants |
| | | | | 33 Agricultural contaminants | Herbicides and pesticides |
| | | | | | Fertilizers |
| | | | | 34 Public water additives | Disinfectants |
| | | | | | Disinfectant by products |
| | | | | | Fluoride |
| | | | | 35 Periodic water quality testing | Quarterly testing |
| | | | | | Water data record keeping and response |
| | | | | 36 Water treatment | Organic chemical removal |
| | | | | | Sediment filter O |
| | | | | | Microbial Eliminati |
| | | | | | Water quality maintenance |
| | | | | 37 Drinking water promotion | Drinking water taste properties |
| | | | | | Drinking water access |
| | | | | | Water dispenser maintenance |
| | | | Nourishment | 38 Fruits and vegetables | Fruit and vegetable variety |
| | | | | | Fruit and vegetable promotion |
| | | | | 39 Processed foods | Refined ingredient restrictions |
| | | | | | Trans fat ban |
| | | | | 40 Food allergies | Food allergy labelling |
| | | | | 41 Hand washing | Hand washing supplies |
| | | | | | Contamination reduction |
| | | | | | Sink dimensions |
| | | | | 42 Food contamination | Cold storage |
| | | | | | Food preparation separation |
| | | | | 43 Artificial ingredients | Artificial substance labelling |
| | | | | 44 Nutritional information | Detailed nutritional information |

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|---|---|---|---|---|---|
| | | | | 45 Food advertising | Advertising and environmental cues |
| | | | | | Nutritional messaging |
| | | | | 46 Safe food preparation materials | Cooking material |
| | | | | | Cutting surfaces |
| | | | | 47 Serving sizes | Meal sizes |
| | | | | | Dinnerware sizes |
| | | | | 48 Special diets | Food alternatives |
| | | | | 49 Responsible food production | Sustainable agriculture |
| | | | | | Humane agriculture |
| | | | | 50 Food storage | Storage capacity |
| | | | | | Temperature control |
| | | | | 51 Food production | Gardening space |
| | | | | | Planting support |
| | | | | 52 Mindful eating | Eating spaces |
| | | | | | Break area furnishings |
| | | | Light | 53 Visual lighting design | Visual acuity for working |
| | | | | | Task lighting |
| | | | | 54 Circadian lighting design | Melanopic light intensity in work areas |
| | | | | 55 Electric light glare control | Lamp shielding |
| | | | | 56 Solar glare control | View window shading in workspaces |
| | | | | | Daylight management in work areas |
| | | | | 57 Low-glare workstation design | Workstation orientation |
| | | | | 58 Colour quality | Colour rendering index |
| | | | | 59 Surface design | Work area wall and ceiling lightness |
| | | | | 60 Automated shading and dimming controls | Automated sunlight control O |
| | | | | | Responsive light control |
| | | | | 61 Right to light | Lease depth O |
| | | | | | Windows and workspaces |
| | | | | 62 Daylight modelling | Healthy sunlight exposure |
| | | | | 63 Daylighting fenestrations | Window sizes for workspaces O |
| | | | | | Window transmittance in work areas O |
| | | | | | Uniform colour transmittance |
| | | | Fitness | | Stair accessibility |

| | | | | | |
|---|---|---|---|---|---|
| | | | | 64 Interior fitness circulation | Stairs promotion P |
| | | | | | Facilitative aesthetics |
| | | | | 65 Activity incentive programs | Activity incentive programs |
| | | | | 66 Structured fitness opportunities | Professional fitness program - |
| | | | | | Fitness education |
| | | | | 67 Exterior active design | Pedestrian amenities O |
| | | | | | Pedestrian promotion |
| | | | | | Walk score® |
| | | | | 68 Physical activity spaces | Site space designation for offices |
| | | | | | External exercise spaces |
| | | | | 69 Active transportation support | Bicycle storage and support |
| | | | | | Post commute and workout facilities |
| | | | | 70 Fitness equipment | Low-intensity equipment |
| | | | | | High-intensity equipment |
| | | | | 71 Active furnishings | Active workstations O |
| | | | | | Prevalent standing desks |
| | | | Comfort | 72 ADA accessible design standards | Ada regulations |
| | | | | 73 Ergonomics: visual and physical | Visual ergonomics |
| | | | | | Desk height flexibility P |
| | | | | | Seat flexibility |
| | | | | 74 Exterior noise intrusion | Sound pressure level |
| | | | | 75 Internally generated noise | Acoustic planning |
| | | | | | Mechanical equipment sound levels |
| | | | | 76 Thermal comfort | Ventilated thermal environment |
| | | | | | Natural thermal adaptation |
| | | | | 77 Olfactory comfort | Source separation |
| | | | | 78 Reverberation time | Reverberation time |
| | | | | 79 Sound masking | Sound masking use O |
| | | | | | Sound masking limits |
| | | | | 80 Sound reducing surfaces | Ceilings O |
| | | | | | Walls |
| | | | | 81 Sound barriers | Wall construction specifications |
| | | | | | Doorway specifications O |
| | | | | | Wall construction methodology |

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|---|---|---|---|---|---|
| | | | | 82 Individual thermal control | Free address |
| | | | | | Personal thermal comfort devices |
| | | | | 83 Radiant thermal comfort | Lobbies and other common public spaces |
| | | | | | Offices and other regularly occupied spaces |
| | | | Mind | 84 Health and wellness awareness | Well building standard guide® |
| | | | | | Health and wellness library |
| | | | | 85 Integrative design | Stakeholder charrette |
| | | | | | Development plan P |
| | | | | | Stakeholder orientation |
| | | | | 86 Post-occupancy surveys | Occupant survey content |
| | | | | | Information reporting |
| | | | | 87 Beauty and design I | Beauty mindful design |
| | | | | 88 Biophilia I - qualitative | Nature incorporation |
| | | | | | Pattern incorporation |
| | | | | | Nature interaction |
| | | | | 89 Adaptable spaces | Stimuli management |
| | | | | | Privacy |
| | | | | | Space management |
| | | | | | Workplace sleep support |
| | | | | 90 Healthy sleep policy | Non-workplace sleep support |
| | | | | 91 Business travel | Travel policy |
| | | | | 92 Workplace health policy | Health benefits |
| | | | | 93 Workplace family support | Parental leave |
| | | | | | Employer supported child care |
| | | | | | Family support |
| | | | | 94 Self-monitoring | Sensors and wearables |
| | | | | 95 Stress and addiction treatment | Mind and behaviour support o |
| | | | | | Stress management |
| | | | | 96 Altruism | Charitable activities |
| | | | | | Charitable contributions |
| | | | | 97 Material transparency | Material information |
| | | | | | Accessible information |
| | | | | 98 JUST organization | Just participation |
| | | | | 99 Beauty and design II | Ceiling height |
| | | | | | Artwork |
| | | | | | Spatial familiarity |

| | | | | | |
|---|---|---|---|---|---|
| | | | | 100 Biophilia II - quantitative | Outdoor biophilia O |
| | | | | | Indoor biophilia O |
| | | | | | Water feature |
| | | | | 101 Innovation feature I | Innovation 1 proposal O |
| | | | | | Innovation 1 support |
| | | | | 102 Innovation feature II | Innovation 2 proposal O |
| | | | | | Innovation 2 support |
| 5 | 2015 | Re-framing urban space (Cho et al., 2015) | Hardware | Accessibility | Pedestrian access points |
| | | | | | Universal access |
| | | | | | Types and distribution of universal access |
| | | | | | Prioritising the pedestrians |
| | | | | Connectivity | Movement patterns |
| | | | | | Node connectivity |
| | | | | | Sightlines and way-finding |
| | | | | Mobility means | Bicycle-friendly design |
| | | | | | Public transport |
| | | | | | Vehicular access |
| | | | | | Drop-off and taxi stands |
| | | | | Legibility and edges | Spatial layout |
| | | | | | Focal points of activity |
| | | | | | Visual landmarks |
| | | | | | Permeability |
| | | | | Spatial variety | Spatial variety |
| | | | | | Spatial adaptability |
| | | | | Environmentally friendly design | Greenery and water: availability and access |
| | | | | | Greenery: form, pattern and diversity |
| | | | | | Biodiversity |
| | | | | | Environmentally friendly strategies |
| | | | | | Environmental integration |
| | | | | User comfort | Protection from extreme weather conditions |
| | | | | | Variety of shade/sunlight conditions |
| | | | | | Air control and optimization |
| | | | | | Noise control and optimization |

| | | | | | |
|---|---|---|---|---|---|
| | | | Software | Diversity and intensity of use | Diversity of activities: within urban space |
| | | | | | Choice of activities: around urban space |
| | | | | Social activities | Seating amenities |
| | | | | | Seating: condition and variety |
| | | | | | Interactivity |
| | | | | | Intimacy and exposure |
| | | | | Identity (image and character) | Imageability |
| | | | | | History and symbolic value |
| | | | | | Art, culture and alternative culture |
| | | | | | Unique nature |
| | | | Orgware | Provision of amenities, services, public facilities, and infrastructure | Hygiene facilities |
| | | | | | Lighting |
| | | | | | Informational facilities |
| | | | | | Healthcare and social services |
| | | | | Safety and security | Safety and image |
| | | | | | Security |
| | | | | Management and regulations | Rules and regulations |
| | | | | | Access regulation and management |
| | | | | | Time and program regulation and management |
| | | | | | Permissions and management |
| | | | | | Affordability and equality |
| 6 | 2016 | The quality of traditional streets in Indonesia (Sholihah, 2016) | Morphological | Legibility | |
| | | | | Walkability | |
| | | | | Accessibility | |
| | | | | Connectivity | |
| | | | | Diversity | |
| | | | Functional | Liveability | |
| | | | | Vitality | |
| | | | | Adaptability | |
| | | | | Creativity | |
| | | | Visual; Morphological | Form and visual quality | |
| | | | | Transparency and active frontage | |
| | | | Perceptual | Safety | |
| | | | | Imageability | |
| | | | | Place attachment | |
| 7 | 2018 | Research on green architecture | Venue contact Evaluation index | Land use | Degree of integration of underground space |

| | | | | | |
|---|---|---|---|---|---|
| | | theory and method in public underground space design (Hong, 2018) | | | Open area and depth of underground space |
| | | | | Land use | Use terrain |
| | | | | | Use of existing facilities |
| | | | Resource conservation evaluation index | Envelope structure | Envelope structure performance |
| | | | | | Architectural space form |
| | | | | | Window to floor area ratio |
| | | | | Energy use Envelope structure | Air conditioning system performance |
| | | | | | Air conditioning system heat and cold source |
| | | | | Air conditioning system lighting system | Lighting equipment performance |
| | | | | | Intelligent lighting control |
| | | | | Energy use | Equipment energy reuse |
| | | | | | Renewable energy utilization |
| | | | Environmental construction evaluation index | Hot and humid environment | Sunroof shading facilities |
| | | | | | Indoor temperature and humidity |
| | | | | Acoustic environment | Use of natural light |
| | | | | Air quality | Sound insulation performance of enclosure structure |
| | | | | | Space function layout |
| | | | | Environment | Natural ventilation design |
| | | | | | Air quality monitoring |
| | | | | Acoustic environment | Interior design |
| | | | | | Spatial scale and closure |
| | | | | | Landscape design |

Table 3-2 sorted out the relevant design standards or evaluation standards. It contains categories, element and indicators in urban public space that will be re-screened according to the characteristics of underground public space.

Several designs and assessment methods that focus on contemporary cities' spatial and morphological characteristics have been proposed, revealing their potential as planning and design tools. The design perspective is framed by discussing physical configuration and function, space, and use (Carmona et al., 2012). The physical configuration is mainly discussed in terms of territoriality, boundaries, accessibility, visual transparency, time and use control, and regulations or restrictions (Oc and Tiesdell, 1999, Németh and Schmidt, 2007). There are five essential dimensions to good urban form (i.e., sustainable urban space): accessibility; connectivity; density; diversity; and nodes (Talen, 2011). The critical qualities of physical configuration are: connectivity; visual access; thresholds; and, gateways (Varna and Tiesdell, 2011). For Varna and Tiesdell (ibid.), physical configuration refers to micro-design (i.e., the design of the public space itself), while macro design refers to the surrounding environment and animation. Animation involves the extent to which space design supports and meets human needs and how space is actively used and shared among different groups and individuals.

Based on the theory of 'Integrated design of above ground and underground space' mentioned in the previous section, 'Design for people', 'Places making' and 'Green architecture theory', the author constructs a quality evaluation system for underground public space from urban design. When we discuss underground public space, we ought to analyse and study the content of urban public space. In the previous chapters, the author proposed the definition, function classification, and space classification of underground public space to clarify further the content and direction of the evaluation of underground public space. Therefore, urban spatial attributes include **accessibility**; **connectivity**; **mobility**; **legibility**; **margins** (looseness); **spatial diversity**; **environmentally friendly design strategies**; and, **user comfort**.

## 3.5 Chapter conclusion

The quality of underground space design has been discussed extensively in the urban design discourse during the last decades of the twentieth century. This chapter has reviewed the literature on the high-quality design requirements to improve the understanding of the impact of quality underground public space design on outcomes. The value added to underground public space by such design and the different instruments can capture both tangible and intangible outcomes of good underground space design.

Contemporary underground public space design is a complex field. The views of establishing good underground space design are diverse among the different stakeholders. They depend on users' perspectives, rather than on the exact nature of the development. The quality of the design is considered as a key factor that influences people and how they interact.

Determining the value of good design helps add design quality to the decision-making process. This study intends to show the role of quality underground design in developing or delaying, the relationship between people and urban underground public places from the peoples' perspective. It attempts to evaluate underground public space design quality through the application, principles, and guidelines of underground space design; urban spatial attributes include accessibility; connectivity; mobility; legibility; margins (looseness); spatial diversity; environmentally friendly design strategies; and user comfort and eventually, achieve a high quality underground public space.

# 4. Research Methodology

This chapter describes how this study is designed and implemented to contribute to the research techniques and methods of the UPSQAS (Underground Public Space Quality Assessment System). A basic philosophical hypothesis is proposed, including discussions on methods for underground public space quality assessment. The definition and advantages of mixed method design are investigated. The rationality of the case study is summarised as a preferred method in this paper. Finally, a pilot study is conducted on Beijing Yonganli Metro Station to verify the feasibility of the research method and adjust the study design for the proposed case study.

According to the study design, research methods of factor analysis and case study has been selected. A specific framework of the research method refers to establishing an underground public space quality assessment framework in this empirical study. This chapter also explores the reasons for selecting the case, followed by describing the process of data collection. It also introduces how to determine the assessment framework and indicators for underground space and particular data collection methods. Both assessment classification indicators for underground public space assessment and assessment results of space design quality are clarified. Besides, specific assessment frameworks obtained by different methods are compared and analysed side by side. This is also one of the analysis strategies adopted for the present study.

## 4.1 Methodology study

### 4.1.1 Research Method Paradigms

In this study, the quality of the built underground public space is assessed from urban design and practical use by constructing an assessment system for assessing the underground public space quality. However, the difficulty lies in establishing a set of weighted assessment criteria through literature review, professional interviews, and user questionnaires. For research in social sciences, the method should be selected based on theoretical background knowledge, which helps develop appropriate research and data collection strategies (Lundberg, 2003). The research hypothesis must be specified during method selection (Groat and Wang, 2004). However, this may affect the relationship between theory and the data collected (Esterberg, 2002). Research methodology represents how the data is collected. To demonstrate and evaluate the rigorous research results of epistemology and ontology, it is necessary to summarise them. According to Bryman (2003), epistemology involves the nature and scope of knowledge, so it clarifies the potential scope of knowledge and affects its effectiveness. In terms of ontology, it is an organised arrangement of relative knowledge entities that constitute the fundamental knowledge. In this case, researchers can specify categories, social entities and their associated similarities and hierarchies (Eldred, 2008). On this basis, this study also analyses urban public space related to values generated by underground public space. Interviewers and questionnaire participants are also analysed in groups to assign a weight to the assessment system.

The study design begins with the selection of research methods. Three most extensively discussed research paradigms in the literature are qualitative, quantitative, and mixed studies (Creswell, 1994; Groat and Wang, 2002). Creswell (2003) defined the quantitative study as a quantitative approach in which researchers adopted the positivist propositions. To be specific, knowledge (i.e., causality) is developed by using research strategies (e.g., experiments and surveys) and collecting data from predetermined tools that generate statistical data. In terms of methodology, the quantitative paradigm is involved in the deductive process of the inquiry process, which seeks causal explanation (Groat and Wang, 2002:28).

In addition, the qualitative paradigm is a method(Haase, 1995), or an opinion (i.e. politics, problem orientation, collaboration or change orientation), or a combination of them, held by inquirers to put forward their knowledge proposition based primarily on the constructivist perspectives (i.e., the multiple meanings of personal experience, which aims to develop social and historical meanings of theories or models) or engagement opinions (Creswell, 2003:18). This paradigm requires an inquisitive induction process to identify multiple key factors that affect the phenomenon (Groat and Wang, 2002:28).

Decision-making about selecting an appropriate research method should be mainly based on three aspects of research problems, the researchers' personal experience, and the report's audience to be written (Creswell, 2003:21). As mentioned in Chapter 1, this study aims to establish a set of quality assessment criteria for underground public space and examine the quality of the underground public space built in Beijing. Because of the limitations of the existing underground public space evaluation system indicators, the author will establish a new set of assessment criteria based on the existing framework indicators and the quality evaluation standards of urban public space.

In this research, two methods have been utilised to establish the underground public space quality assessment indicator system (UPSQAIS). One is the quantitative comprehensive method; and the other is the qualitative analysis method (Jiang Yun et al., 2005). While the former is a comprehensive design method, the latter is only concerned with design (Yuan, 2009). More particularly, the quantitative comprehensive method is targeted at the formation of an indicator system. Some existing indicator groups have been clustered according to specific criteria. A mathematical approach has been applied to select the required indicators according to the preliminarily proposed indicator system. An indicator system is established by quantitative comprehensive method through the following four basic steps (Mertens, 2014):

1) **Establish a pre-selected indicator set**. Basic concepts and characteristics of the assessment object are defined (Mertens, 2014), The indicators related to the assessment objective are selected to form the pre-selected indicator set based on qualitative analysis. The frequency statistics method is applied to conduct frequency statistics on the existing indicator system of assessment objects, and the indicators frequently utilised are selected; analysis and synthesis of them are fulfilled by a theoretical analysis method.

2) **Preliminarily process the pre-selected indicator system to form a general indicator system**. Characteristics of the evaluated area should be further considered to make the indicator system operable, including the availability of indicator data, calculation method, scope, and content accuracy of each indicator to make the indicator system operable. Besides, importance, independence and completeness of all indicators should also be analysed. In general, the expert consultation method is used to adjust and screen the pre-selected indicator system.

3) **Conduct quantitative analysis of pre-selected indicators**. In line with quantitative analysis, the pre-selected indicators' quantitative characteristics are analysed to select indicators with more appropriate characteristics from the pre-selected indicator set. In this way, an indicator system takes form.

4) **Determine a critical value and select the indicators above the critical value**. Qualitative analysis is conducted on the determined indicators. In-depth system analysis on the assessment object's structure is carried out according to systematic thoughts and the assessment objectives based on the qualitative analysis design method. The assessment object is decomposed into several parts (i.e., sub-systems), and then subdivided step by step. Attributes of each sub-system are deeply analysed until each part can be described and measured with specific indicators. Moreover, these specific indicators are combined to form an indicator system. Usually, an indicator system's assessment objectives are divided into several sub-objectives or sub-sub-objectives, and several indicators reflect each sub-objective. In short, the quality of urban underground public space is the overall objective. A comprehensive assessment model is obtained by transforming qualitative factors into quantitative factors in this study.

### 4.1.2 Research Methodology Framework

According to characteristics of the urban underground public space, the quality of underground public space is embodied in external connections, spatial structures, interior design, lighting, safety, comfort, social functions, activities, characteristics, and management. Therefore, the indicator system for dynamic urban underground space assessment may cover such two aspects. It is necessary to measure various aspects concerned with urban underground space safety at multiple levels when establishing a quality assessment indicator system of urban underground public space. The establishment process of urban UPSQAIS can be summarised as follows: describe the general objective of urban UPSQAIS in detail → establish corresponding criteria → establish a hierarchical structure → establish a pre-selected indicator set → screen indicators by factor analysis → establish an indicator system.

**The General Objective Systematic Decomposition of the Assessment Indicator System.** Based on an in-depth understanding of the urban underground public space, the urban underground public space system is decomposed into several sub-systems using the Analytic Hierarchy Process (AHP). It is a method of applying mathematical theory to decision-making and evaluation. It was first applied in research projects by American Professor Satie in the 1970s. The analytic hierarchy process aims to decompose the target into several levels and elements. Then compare these elements in pairs, score according to the relative importance, and then calculate each element's weight index. It uses a 1 – 9-point system to score the importance of an element. If two elements are equally important, then score 1 point. As the importance of an element increases, its score will continue to increase. Then a judgment matrix is established according to each factor's scores, and the product of each row element of the judgment matrix is normalised to be the weight of the element (Saaty and Vargas, 2012). Characteristics of each sub-system are then analysed and decomposed into concrete elements, and these elements can be described by concrete indicators to establish a hierarchical structure.

**An objective layer is established**. The objective level of the indicator system should comprehensively describe and reflect the general objective of an assessment object. In this research, the quality of urban underground space is taken as a comprehensive objective. To ensure the score to be more accurate, the author intends to subdivide the general objective and thus obtain multiple sub-objectives. In this way, the research object's contribution to the general objective is transformed into that to each sub-objective. The reference system becomes more specific, thus making the score more accurate

**A criterion layer is established.** By referring to the relevant information and discussing with experts, the author holds that urban underground public space quality assessment includes four categories: space functions, site safety, and indoor environment comfort and operation management. These four aspects can be used as the subdivided sub-objectives of the general objective, constituting a criterion layer of the hierarchical structure model.

**A factor layer is established.** The implementation of urban underground public space quality assessment is a wide-ranging and strongly operable task. This work complements the shortcomings of previous studies on underground public space quality assessment, which improve the quality of urban underground public space through a comprehensive assessment.

**A specific indicator layer is established.** The indicator layer is composed of specific indicators.

### 4.1.3 The methods of assessment

Regarding the establishment of UPSQAIS, the research focuses on identifying assessment indicators (Linstone and Turoff, 1975). The research methods may use in the study include Delphi, factor analysis, questionnaire, weight calculation of assessment, and assessment grading criteria. Among them, the Delphi Method is to select authoritative experts in a particular field under strict procedures, distribute questionnaires to experts by investigators on the premise of no horizontal communication among the experts, collect their opinions in multiple rounds based on the analysis of these questionnaires, and finally find out and publicise the largest 'intersection' of expert opinions (Linstone and Turoff, 1975). This is the basis for decision-making. According to Yang (2009), multi-hazard safety of underground space is assessed by some comprehensive methods, such as Delphi and Analytical Hierarchy Process. Liu (2013) established patient satisfaction indexes using Delphi and Analytical Hierarchy Process. In addition, such an approach is adopted by Hong to construct green building design and assessment methods for underground public space (Hong, 2018).

Factor Analysis describes the relationships of several observational random variables by a few unobservable latent variables (factors)(Yuan, 2009). Factor Analysis includes two categories: exploratory factor analysis and confirmatory factor analysis (Yuan, 2009). Wang and Shu identified the factors that affect the urban underground space environment by the exploratory factor analysis (Wang and Shu, 2000). Ma, Yang, Wang and Han analysed public bicycle selection behaviour in Xi'an through exploratory factor analysis and confirmatory factor analysis (Ma et al., 2018). This study will attempt to use factor analysis to quantitatively analyse the factors of the underground public space quality evaluation system.

## 4.2 Pilot study

Pilot research is one of the crucial stages of research projects. They reported on the feasibility of testing project proposals, subject recruitment, and research tools and data analysis process. The researcher concluded that pilot research is necessary and useful in providing a foundation for research projects. Preliminary research can be defined as small research, used to test research protocols, data collection tools, sample recruitment strategies, and other research techniques in preparation for larger research (Hassan et al., 2006). The pilot research in this research that includes two experiments. One is to distribute, manually or online, the existing questionnaires in an experimental way to explore the distribution form of the questionnaire. It mainly targets professional practitioners that test feasibility from the perspective of professionals. The questionnaire can be further improved by testing possible issues of the form and the readability of the indicators in the questionnaire. The other is to test the feasibility of the existing indicators in a metro station that will be tested, for which corresponding adjustments can be made.

The pilot study was conducted at Yonganli Station in the second week of February 2017 to test data collection tools, including pedestrian counting, walking observation and engagement mapping. This pilot study found that the research assistants who are help me to collect data could follow the observation procedure according to the required quality, especially engagement mapping. Besides, it is not difficult for them to conduct simple passer-by observations and pedestrian counting.

A pilot study was carried out during in-depth interviews to test the effectiveness of the method and demonstrate the research assistant's ability to conduct such activities. Two pilot studies on in-depth interview techniques showed that it is difficult to conduct in-depth interviews as recommended since they have never done so before. It was then determined that only key researchers would conduct interviews, ensuring that the optimal results are obtained.

### 4.2.1 The area

The pilot test study was conducted to test the feasibility and validity of the methods. The primary pilot study was carried out in the Yonganli Station at Beijing CBD area.

### 4.2.2 Methods used in the pilot study

Observations were made on three different time points: weekdays, weekends and holidays (Li, 2018). The observation was carried out in two time periods, respectively. One of them was selected to be rush hours in Beijing from 7:30 a.m. to 9:00 a.m (Li, 2018). Through favourable position observation, people's positions and quantities were observed to determine their activities and stay time. This is important because it has the potential to capture and observe user activities to the greatest extent. Through such observation, activities in underground public space, their distribution and the purpose of staying there were recorded.

#### 4.2.2.1 Interviews

In order to learn about the question design of expert interviews, 'answers' to the following five questions are provided: what (action), when or where (scene), who (agent), how he (or she) does (agent), and why (purpose) (Asplund, 1979). The interview was conducted from October 2nd to 11th, 2017, during China's National Day. A total of three interviewees were selected to collect answers. The interviewees selected were engineers. All other languages were translated into English. All records were scripted into Microsoft Word and analysed. The data were coded to interpret the data collected through observation and used to design questionnaires.

#### 4.2.2.2 Surveys

The survey was designed to collect the following statistical information: the user experience of passengers, the time period of using the space, and their preference for underground public space design quality. The interviewees (ordinary residents) were mainly interviewed through a questionnaire survey, and the target audience was designed to be ordinary residents. The questionnaire was designed based on objective questions. In line with a scoring system, interviewees rated all questions based on their own experience. Based on their answers, the author asked some additional open-ended questions and took notes in the questionnaire. Moreover, statistical data of questionnaire distribution is supplemented.

#### 4.2.2.3 Measure tools

To collect data, the following tools were used:

**Video camera:** Activities and behaviour in the aboveground and surrounding building space were recorded at a specific time to obtain more real evidence about the use of underground public space;

**Notebook and sketchbook:** In the course of observation, on-spot record and planar graph drawing were made to form a perception of the underground public space environment.

**Measurement tools:** An air quality tester and electronic distance instrument were used to measure air quality and dimensions of the underground public space.

**Analysis tools:** SPSS factor analysis software was used for exploratory factor analysis, and AMOS was used for confirmatory factor analysis. SPSS (Statistical Product and Service Solutions) is a data analysis software developed by SPSS in 1968. It has an easy-to-operate graphical interface, including standard data analysis methods and multiple statistical data and indicator mapping systems, such as factor analysis, regression analysis (Liu and Lan, 2008). The factor analysis does not apply to all multivariable data in practice. Factor analysis is a collection of methods used to examine how the basic structure affects the results of some variables that need to be measured. It can integrate similar factors and reduce the overall data volume. At present, factor analysis using SPSS software is mostly used at the economic and social levels, such as consumer habit research, market survey research, product classification. Through factor analysis, multiple complex data can be integrated and reduced into different factors. Develop important indicators to provide a basis for managers to find the problem in a short time and make decisions (Liu and Lan, 2008). The SPSS provides 4 pieces of statistical data to determine whether the factor analysis applies to observable data. Those meeting the screening standards include the KOM (kaiser-meyer-olkin) measure of sampling adequacy, Bartlett test of sphericity, anti-image correlation matrix, and communalities.

AMOS is the abbreviation of 'matrix structure analysis', called 'moment structure analysis' in English (Arbuckle, 1994). The AMOS software for structural equation model analysis integrates two statistical analysis functions: dimensionality reduction analysis and linear regression analysis. The dimensionality reduction analysis can condense them into several representative variables based on the correlation between many investigated variables and determine the weights to obtain a comprehensive score. Although this method of determining weights is still controversial, it is currently a more scientific method (Ma et al., 2018).

### 4.2.3 Discussions

The pilot study is helpful to test the feasibility of research methods. It provides small-scale testing for methods and procedures used in case studies. This section briefly summarises what has been learned from experimental research.

In the pilot study, the author first observed users in the pilot area, and there were significant differences among these users on weekdays, weekends, and holidays. Due to the location of Beijing Metro Line 1, which passes through the most important tourist attractions in Beijing, such as Tiananmen Square, Beijing Railway Station and CBD, the users are diverse during different time periods. For this reason, their purposes and needs are also different. Therefore, the original observation period (rush hours from 7:30 a.m. to 9:00 a.m.) is replaced with three durations of observation:

1. 7:30 a.m. to 8:30 a.m. in the morning peak,
2. 10:00 a.m. to 11:00 a.m. in off-peak hours in the morning, and
3. 12:00 a.m. to 1:00 p.m. in the lunch break time.

Based on the experience of the first interview and expert advice, the range of interviewees was adjusted. Interviews from a single group of people may make the results of the interview seem objective. Eventually, interviewers expanded from designers to teachers, project stakeholders and designers.

In the pilot study, the way to distribute questionnaires among users of the space changed from the on-spot distribution of paper questionnaires to online distribution of electronic questionnaires. Because the user seems to be somewhat reluctant during the on-spot questionnaire collection, the recovery rate was too low (only 4 of the 50 questionnaires distributed on the test day). As a result, the author quickly changed to online distribution in social software community after the test was released. The target population extended from the people surrounding the metro station to all kinds of populations taking the metro to ensure user experience has covered sufficient user types. For questionnaire questions, the respondents suggested that they could not understand the technical terms, or some statements were ambiguous. For example, the interviewees did not understand what accessibility, nodes, and connected space mean, so the author added explanations of such terms in the questionnaire question options later.

## 4.3 The selection and context of case studies

This section listed possible cases and explained why the places in Beijing in China are selected as a case for this research. After that, the contexts of the case are described.

### 4.3.1 The selection of the case studies

It is crucial to select the right cases for empirical research. Being typical, diverse, extreme, deviant, influential, most similar, and most different are the seven case selection techniques (Seawright & Gerring, 2008). Yin (2013) also summarised four case study methods related to the number of cases selected. In summary, according to the case study standard, one case is selected from the listed cases, i.e., the underground public space around the Guomao Station of Beijing Metro Line 1.

Beijing is the People's Republic of China's capital and one of the most populous cities in the world. As of 2015, the Census Bureau had an estimated population of 21,705,000 in Beijing (Zhang et al., 2018). Due to the high density of urban development in China and the limited land available for development, many urban governments have chosen public transport as their preferred transportation systems to promote urbanisation and growth (Wan, 2013). The public transportation system in Beijing provides an effective way for residents to achieve all kinds of purposes. It is approaching its maximum capabilities (Wang, 2006). The metro system in Beijing has a fast transportation network to serve its suburbs. The network includes 18 lines, 334 stations, and 554 kilometres (344 miles)(Li, 2012). It is the world's largest metro system, both in terms of rail mileage and passenger capacity (Chen et al., 2006). The route map and station diagram of Beijing Metro are shown in Figure 1. Metro is the system with the world's highest annual passenger capacity. In 2014, the number of trips reached 3.41 billion (9.2786 million per day on average), and the passenger capacity during peak hours was calculated to be 11,559,500 (Zhang et al., 2017). Given the present situation of the CBD, the railway traffic accessibility is low on its eastern edge and northwest corner. In this context, the Metro Lines 6 and 14 to be laid out may alleviate low-density stations.

The Guomao Station of Beijing Metro Line 1 is in the CBD area of Beijing. It is the most connected station between the metro station and the surrounding underground buildings and one of the busiest metro stations. The author chose it as a case mainly due to its representative complexity. According to the types of users, Line 1 passes through the most famous tourist attractions in Beijing, Beijing Station, the city's busiest transportation hub, and the CBD where business and commerce are most developed. Compared with the pedestrian traffic in the surrounding streets, the underground space itself has been well utilised. Zacharias (2014) has reported the pedestrian flow in the underground system, the daily pedestrian peak in the surrounding streets, and at the end of the workday. Therefore, it has the most diverse types of users with a wide range of needs here. The case study will cover many variables, rely on multiple sources of evidence, and integrate and triangulate them under the guidance of previous theoretical propositions presented in the literature review (Yin, 2013). In this study, the purpose of the case study is to examine whether underground public space quality assessment criteria can be applied.

#### 4.3.2 The context of the case studies

The largest underground space in Beijing is The Central Business District (CBD), which is CBD for short. In Beijing, the CBD is divided into 18 blocks. The total planned land area is about 4.0 square kilometres, of which the core area is about 30 hectares. The total aboveground and underground area are 4.1 million square meters, with the aboveground construction area of about 2.7 million square meters and the underground construction area of about 520,000 square meters. The underground space is divided into five floors to separate pedestrians from vehicles. This space accommodates underground transportation systems, commercial streets, public buildings, infrastructure, storage space and civil defence space. A resource-sharing underground parking system will be built. The underground parking lots of adjacent construction lands would be connected as far as possible. No. 2

Basement below the CBD core area is the floor connecting the parking lots. The underground vehicle distribution rings can be constructed by using the space under the urban roads to ease ground traffic congestion (Qian, 2016).

The Guomao Station is located at the heartland of CBD under the Guomao Bridge on the East Third Ring Main Road. It is a station connecting underground space at the east and west sides of the East Third Ring Road and the north and south sides of Jianguomen Outer Street. Guomao Station as Fig 4-1 is designed in combination with the existing bridge and the development and construction. As a result, the aboveground and underground transportation network in this area can play its role in gathering and transformation in the underground station. Massive streams of people pass commercial, cultural, business, transportation, and other complex facilities, thus forming an activity centre with a large people flow. Guomao Station is a transfer station between Beijing Metro Line 10 and the existing Metro Line 1. This station's central part has a strike consistent with that of the East Third Ring Middle Road. The surrounding buildings, mainly commercial buildings, are relatively dense. A passage between the Metro Line 10 station and the underground shopping mall of the World Trade Centre is under construction. Once the construction is completed, it may significantly reduce the walking distance for workers in the World Trade Centre. No. 3-5 Basements are designed for parking lots, machine rooms, heat and power lines, providing 100,000 square meters of space for civil air defence and disaster relief (Qihu, 2016).

Figure 4-1 The master plan of underground space around Guomao station
*Fig source: (Chen et al., 2006)*

The current CBD centre is composed of its core area, the surrounding CCTV Tower, International Trade Centre and Yintai Centre form as Fig 4-2. The business office is a double-cross layout within 7 square kilometres (Chen et al., 2006) covering CBD east area. The CBD core area faces the Jianguomen Outer Street, surrounded by the East Third Ring Road in the west, Zhenzhi Road in the East, Guanghua Road in the north and Jianguo Road in the south. It is an important representative showing the functional image of the CBD.

The core area includes 18 plots and 19 buildings, among which the highest building is CITIC Tower, with the height gradually decreasing outward. According to the plan (Fig 4-2), aboveground and underground construction building areas are 2.7 million square meters and 1.4 million square meters, respectively. The total construction building area reaches 4.1 million square meters. The underground construction building area is more than half of that of the aboveground, and a great deal of infrastructure is built underground.

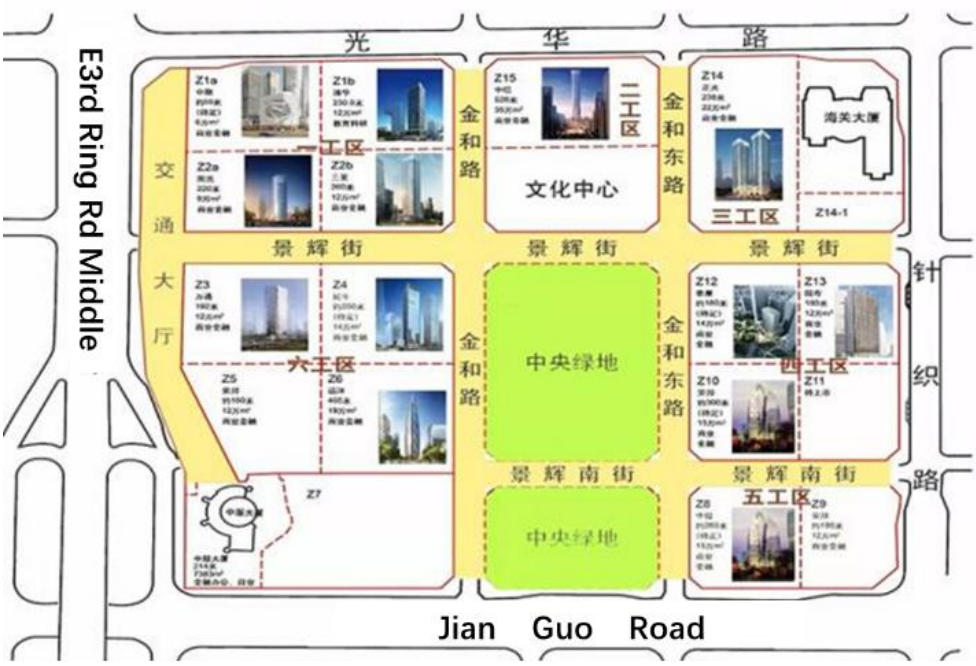



Figure 4-2 Location of the CBD core area

*Fig source: (Zhang, 2015)*

In addition to each building's independent underground space, the infrastructure project of the CBD core area will also be public space. This part is located under the central public green space and roads in the CBD core area of Chaoyang District, with a length of about 500 meters from north to south, a width of about 600 meters from east to west, and an area of about 520,000 square meters in the underground public space (see figure 4-3). The underground space mainly consists of 3 to 5 floors, and the most central and largest part consists of 5 floors. According to the layout, the first floor underground, with a 3-meter interlayer, is 8 meters high for commercial purposes; the second floor underground is 5 meters high for commercial facilities and parking lots; the 3rd to 5th floors underground is 3.6 meters high for parking lots, civil air defence projects and machine rooms.

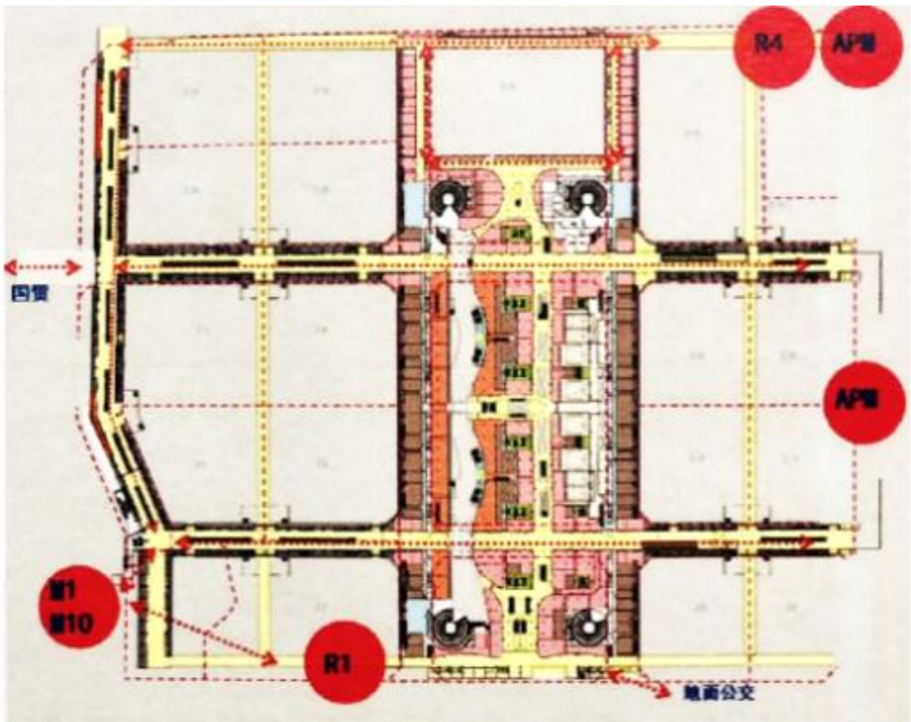



Figure 4-3 Masterplan of CBD core area

*Fig source: (Zhang, 2015)*

The metro transfer area of the whole Guomao Station is the most complex in the CBD area and has the largest connected area. Moreover, Guomao Station is one of the busiest transfer stations in Beijing, with a daily passenger flow of more than 300,000 people as Fig 4-4. Its peak transfer volume has been growing. During the peak period in 2014, the transfer volume was about 10,000 people per hour, and in 2015, it exceeded 20,000 people per hour. This is far beyond the predicted passenger flow. With such a huge transfer volume, the two-way transfer was completed only in an 8 m wide transfer channel, and the height difference transfer of 6.4 m needed to be completed in a narrow channel. According to the preliminary forecast, the peak passenger flow in this area will increase from 67,000 to 153,000 people per hour, with an increase of 86,000 people per hour with the establishment of the CBD core area. Additionally, the whole day passenger flow will be raised from 420,000 to 960,000 people. The great passenger flow pressure and a huge risk of treading contributed to the renewal and reconstruction of the transfer node. However, due to the construction and reconstruction of the Guomao Bridge Area for nearly 30 years, both planning and construction of its surrounding areas become mature; and the underground pipelines are quite complicated. The underground Metro Lines 1 and 10, and the foundation of Guomao Bridge are mutually intercrossed and restricted. Consequently, the renewal and reconstruction of the underground space of the Guomao Station are still in progress.


Figure 4-4 Masterplan of Guomao station (left) and the Model of Guomao area

*Source from: photo by author (Left) and photo by author (Right)*

*Fig source: photo by author*

## 4.4 Data Collection

### 4.4.1 Delphi

Delphi Method, or 'expert-defined procedural survey method', was created and developed as a decision-making method in the 1940s (Linstone and Turoff, 1975). According to Herm and Dalke (1975), Delphi Method is to select authoritative experts in a specific field under strict procedures: (1) distribute questionnaires to experts by investigators on the premise of no horizontal communication among the experts, (2) collect their opinions in multiple rounds based on the analysis of these questionnaires, and (3) finally, find out and publicise the largest 'intersection' of expert opinions.

In the process of constructing the UPSQAIS, the opinions and suggestions from experts and scholars who design underground space, especially urban underground space, should be collected by Delphi Method based on the preliminarily established indicator system. Firstly, the main research problem, namely, the establishment of the UPSQAIS is determined; secondly, experts are selected based on the identified research problem. In this study, architectural experts have been selected, especially the authoritative experts and scholars in the field of underground space design; thirdly, based on the balanced scorecard, a preliminary indicator system (i.e. the expert questionnaire in this study) is designed from ten perspectives of exterior and entrance friendly design, spatial configuration, Friendly interior design, lighting, life safety, user comfort, sociability, activities, identity and management. Finally, three rounds of expert consultation are conducted in the form of telephone, email and visit. Upon completing each consultation, the consultation results will be dealt with carefully and serve as the basis for the next consultation. By analogy, the consultation will be repeated three times in the same method. According to the three consultations' feedback, the result of this expert-defined procedural survey will be determined. Combined with this result, the indicators defined based on the balanced scorecard will be selected and optimised, which provides a scientific basis for the preliminary design of the follow-up questionnaire.

### 4.4.2 Factor Analysis

Factor Analysis was first proposed by psychologist Charles Spearman in 1904. It is a method to describe the relationships among several observable random variables by a few unobservable latent variables (factors) and measuring abstract factors by specific indicators (Liu and Lan, 2008). The main idea of factor analysis is to classify and group observational variables consistent with specific correlation values of variables; and variables highly correlated with each other are classified into the same group (Wang and Shu, 2000). The variables in different groups are less correlated; the highly correlated variables together form a 'basic structure' and many 'basic structures' together in the study form common factors (Liu and Lan, 2008).

Factor Analysis includes two categories: exploratory factor analysis and confirmatory factor analysis (Liu and Lan, 2008). Exploratory factor analysis is mainly used in the initial stage of data analysis, and confirmatory factor analysis is further carried out based on exploratory factor analysis. Confirmatory factor analysis is a key step in structural equation model analysis, and it is a 'special application' of Structural Equation Model (SEM) and a 'submodel' of the structural equation. The mathematical expression for factor analysis can be written as follows:

**Y1=b11X1+b12X2+⋯+b1mXm**

**Y2=b21X1+b22X2+⋯+b2mXm**

**…**

**Yp=bp1X1+bp2X2+⋯+bpmXm**

Y1, Y2, ⋯, Yp are original variables ($n$ = p), which are standard variables with a standard deviation of 1/ mean of 0. X1，X2，⋯, Xm represents factor variables ($n$=m), where m<p. During factor analysis, it is important to pay attention to the key indicators, such as factor loading, communalities, and variance contribution of common factors.

There are two main purposes of factor analysis: 'How to name and explain factor variables' and 'how to construct factor variables' (Ma et al., 2018). Directed by both purposes, the main steps for performing factor analysis include: ① Judgment and assessment. All variables to be analysed should be judged and assessed to determine whether each variable is suitable for factor analysis. ② Construction. The factor variables can be further constructed based on determining the variables to be tested for factor analysis. ③ Interpretable optimisation. Factor rotation is used to make the factor more interpretable; ④ Based on the previous analysis, the score of each factor is further calculated. Considering the construction of a performance assessment indicator system for the quality underground public space, it is also a process of gradually constructing factors and continuously optimising the indicator system. The questionnaire survey is designed and distributed in combination with factor analysis here.

In this study, two surveys are conducted on the importance of underground public space quality assessment indicators. Exploratory factor analysis is carried out using the first survey data to form a complete closed-loop research programme. Furthermore, confirmatory factor analysis is also carried out by using the data of the second survey.

1) The Analysis Process of Exploratory Factor Analysis

The exploratory factor analysis is mainly used to separate or extract common factors. The common factor plays a role in dividing the observable variables in the scale into several groups according to specific rules by a complicated mathematical method. Moreover, observable variables in each group are strongly correlated to such a common factor. In other words, the absolute value of the 'carrying capacity' is relatively high as far as this common factor is concerned. Therefore, the common factor is different from the general observable variable, which is latent and unobservable. However, the relationship between common factors and observable variables can be calculated and studied. The common factors extracted through exploratory factor analysis can be regarded as a systematic classification of observable variables in the measurement scale and represent the basic structure of the measurement scale.

2) Confirmatory Factor Analysis Steps

Confirmatory factor analysis includes the following six steps: ① A factor model is defined, including determining the number of factors and the factor loading. As for factor loading, it can be previously set as '0', or any other freely varying constant, or a number that varies under certain constraints (for example, equal to another factor loading). ② Observed values are collected according to the research purpose. ③ A correlation coefficient matrix is acquired. In this step, a covariance matrix of variables is obtained based on source data. ④ Model fitting is carried out. Here, a method (such as Maximum Likelihood Estimation, Progressive Distribution Free Estimation) needs to be selected to estimate a freely varying factor loading. ⑤ The model is evaluated. When the factor model complies with the data, the factor loading should be selected on the premise of minimizing the difference between the implicit correlation matrix and the actual observability matrix. The commonly used statistical parameters include: chi-square fit index (x2), comparative fit index (CFI), goodness of fit index (GFI) and root mean square error (RMSEA). According to the standard suggested by Bentler (1990), if x2/DF⩽3.0, CFI⩾0.90, GFI⩾0.85 and RMSE⩽0.05, the fitting degree of the model is acceptable. ⑥ The model is modified. If the fitting effect of the model is poor, corresponding constraint relations should be improved or redefined through theoretical analysis to modify the model. In this way, an optimal model can be generated.

### 4.4.3 Questionnaires

The questionnaire survey in the study contains two parts. In the first part, 30 questionnaires have been distributed as planned to the underground space design experts to test the questionnaires' feasibility for underground public space quality assessment system indicators (UPSQASI) and put forward suggestions for the questionnaire. In the second part, a formal questionnaire survey is conducted among users of Beijing Metro. The questionnaire consists of two sections. While one section targets the impressions made by the underground space in Beijing, the other section targets the importance of the UPSQASI.

Based on planning, design, and construction status of underground public space in Beijing CBD area, experts in underground space design and commissioners participating in planning and construction of underground public space in Beijing CBD are interviewed specifically about system indicator of the UPSQAIS. The questionnaire is designed for the residents in Beijing to score the importance of each indicator according to their experience of using underground public space.

To comprehensively analyse and investigate factors affecting the underground public space, SPSS is adopted to make factor analysis on design and assessment indicators of aboveground and underground public space proposed in the existing literature. The combined analysis is used to sort the relevant information and determine strongly correlated classifications and factors. All kinds of factors affecting the underground public space quality around the urban metro should be covered as much as possible in the questionnaire design. Finally, assessment factors and weight distribution are summarised in a table.

Questionnaires are distributed in the present study to ensure scientific and accuracy of assessment results. People of different occupations, genders and ages are interviewed and surveyed to modify relevant assessment results and weight. As the questionnaire is professional, and the assessment case is underground public space in Beijing, interviewees selected for the questionnaire survey should have certain professional knowledge, such as teachers, graduate students, and designers. Moreover, these interviewees must have been living in Beijing for at least three years, who are familiar with Beijing and gained certain insights into it as well.

### 4.4.4 Weight calculation of evaluation

Due to uncertainty, randomness and correlation of underground public space quality assessment factors, the urban underground public space quality assessment is a complex multi-criteria and multi-objective problem. Hierarchical factors affecting the urban underground public space quality are achieved through exploratory factor analysis and confirmatory factor analysis. A multi-layered analytical structure model is formed according to the interrelated influence and affiliation of factors, and values are assigned to assessment indicators. Since the assessment indicator system is divided into three levels, the corresponding weights are also classified into three levels. The sum of the weights of indicators at all levels is 1, where individual indicators at levels 2 and 3 are relative to the total target rather than the indicators at the upper level.

### 4.4.5 Assessment grading criteria

According to the Del Phi method, in this paper, the quality of underground space design is assessed in three grades: excellent, good, and general. Excellent means the underground public space design has taken into account the influencing factor and achieved good results, so 5 points are assigned. Good means the green design of underground public space has taken into account the influencing factor and achieved certain results, but there are still some defects, so 3 points are assigned. General means the green design of underground public space has rarely taken into account or have no regard for the influencing factor, or achieved no good effects in this aspect, 1 point is assigned to this grade. During the assessment, each factor is scored according to the grade. The weighted average score of each indicator is then calculated. The sum of this weighted average score is the final comprehensive score of the project.

## 4.5 Limitations

There are also challenges and concerns for the research project, as well as some limitations. In the preliminary framework of UPSQAIS, classifications and indicators are formed by collecting literature and expert opinions. It is representative because the sources of data in the literature are rich. However, the expert interview section is limited because user participation is limited in the initial period of framework formation. Experts also have the attributes of users, but their starting points of thinking are different. In particular, it can be seen as a complex problem when determining indicators related to user behaviour and preferences. As emphasised by Harling (2012), more variables and factors must be investigated to address the problem, especially when it comes to humans. Another limitation of this study is the depth and time limitation of the author's doctoral studies. The author focuses on quality assessment system formation and verification, while the existing research results dominate the quantification of indicators. There is not enough in-depth research on quantification criteria for indicators, which can be further optimised in the future.

As mentioned above, the process of establishing and verifying UPSQAIS is critical. However, the research method about establishing and verifying an indicator system is not highlighted in previous studies. Therefore, it is essential to use an assessment criterion to evaluate a different subject using fuzzy analysis method and analytic hierarchy process. Nevertheless, they fail to profoundly investigate how to get the weight of an assessment indicator itself. In 2000, Wang and Shu scientifically analysed the factors affecting the underground space environment through factor analysis to determine the principle and draw more comprehensive and profound conclusions. On this basis, factors affecting the urban underground space environment were investigated by questionnaire survey. Furthermore, the relevant factors were analysed. 12 main adverse factors affecting the urban underground space environment were obtained. Therefore, the author tried to apply factor analysis to quantitatively analyse establishment and verification of the quality assessment system. It provided an important way to confirm the effectiveness of assessment system indicators. The survey results collected by the mixed design method helped to reduce the impact. In addition, the impacts of different questionnaire contents on the weight of quality assessment criteria were comparatively analysed. The research structure should be a more precise and more satisfactory one.

The case selected in this study is the Guomao Station, the most complex metro station in Beijing (Wang, 2006). The advantage of this selection is that it is rather typical in testing based on assessment indicators due to its complexity. Whether such comprehensive assessments apply to other ordinary-sized metro stations in Beijing or other Chinese cities with a population of less than 3 million, remains a question. Without a doubt, this is also a limitation of this study. To reduce limitation, data are collected from 6 stations in Beijing CBD area for testing. In the end, the most complex and comprehensive Guomao Station is selected as the case study.

Given the value of underground public space in the academic environment, more empirical research, especially comparative research, is needed. In this way, it would enable the covering of more academic institutions and understand users' opinions and behaviour in underground public space. Space design strategies should be studied in many case studies to evaluate better the design quality provided by a space organisation of underground public space. Space design would significantly affect the user experience; therefore, it requires further examinations of the generated analytical framework's effectiveness. Doctoral research is like a project, which should take the limited time and the accessibility of cases into account. More exceptional cases differ from each other can be selected as the main case. However, the accessibility of time and learning settings imposes restrictions over the choice. The author learned from this process to learn how to balance research ambitions with real-world decisions. Even if there are better research options in the future, it is crucial to consider making the best choice.

# 5. The Quality Assessment System of Underground Public Space and discussion

This chapter introduces building an evaluation indicator system, including systematic, scientific, feasible and hierarchical principles. It builds a logic framework for evaluating urban underground public space based on these principles. It establishes the evaluation indicator system based on expert investigation and visit analysis. This chapter has used exploratory and confirmatory factor analysis for systematic indicators with quality design and evaluation indicators for urban underground public space. It built a quality evaluation indicator system for urban underground public space. Towards the end, it described evaluation standards and definitions of each indicator in subsystems.

## 5.1 Determination of evaluation indicator system

As above discussed, the evaluation indicator system mentioned in previous studies generally focuses on underground space and exterior connections, spatial structure, interior design, lighting, safety, comfort level, social functions, activities, characteristics, and management. It is almost impossible to find an available indicator system to assess the design quality of underground public space. However, as mentioned in Chapter 3, the quality evaluation indicator system for urban underground public space has been built preliminarily depending on users' functional and mental demands for underground space facilities. It is also based on the existing design and evaluation indicators for underground and aboveground public space. Based on the influences and features of urban underground space, this paper proposes that the design of the quality evaluation indicator system for urban underground public space should follow principles as below:

- Systematic principle

Designing a comprehensive and complete indicator system and avoid complexity and repetitiveness is required. Urban underground space should be considered a system; each influencing factor should be understood and reflected comprehensively. It is also required to focus on the structure of the indicator system and understand the relationships among influencing factors. The indicator system should comprehensively reflect the overall conditions of the evaluated objects and grasp major factors. It should reflect direct and indirect effects, in order to guarantee completeness and reliability of the comprehensive evaluation.

- Scientific principle

Under the scientific principle, selected indicators should be objective and reasonable; the evaluated objects should be thoroughly understood, and professional knowledge is required. The evaluation indicator system should have a scientific and theoretical foundation. The selection of indicators, determination of weight coefficients, and the selection, calculation and synthesis of data should be based on scientific theories to ensure authentic and objective assessment results.

- Feasibility

The indicators should be designed to meet theoretical requirements and for practical operation. The indicator system should be simple, definite, easily understood, and feasible in practice for data availability. If the evaluation system is simple and straightforward and highly operational, evaluators can easily accept and apply it to the practical evaluation domain. At the same time, it can avoid inconsistent understanding in indicators that free of ambiguous indicator setting.

- Purpose

The definite targets, including the final and staged targets, are required before determining the indicator system, and each indicator should reflect the targets. Only in this way can the indicators selected be more scientific and reasonable. The targets designed for the indicator system should be consistent with those for safety evaluation, as the indicator system is built for the final safety evaluation.

- Objectivity

Most of the indicator systems are highly subjective due to their nature being based on others' practical experience or achievements. Although some mathematical methods can be applied to filter indicators, subjectivity still exists. Therefore, evaluators should be objective and fair and try to avoid subjectivity when determining the indicator system. Both quantitative and qualitative indicators must be expressed quantitatively in evaluation methods. As a result, the evaluation indicator system should be measurable and available for practical data collection.

The above content has summarised the designing principles of the evaluation indicator system for urban underground public space, of which each is representative. Based on the above principles, the established evaluation indicator system should be studied repeatedly to determine the most suitable safety evaluation indicator system for urban underground space.

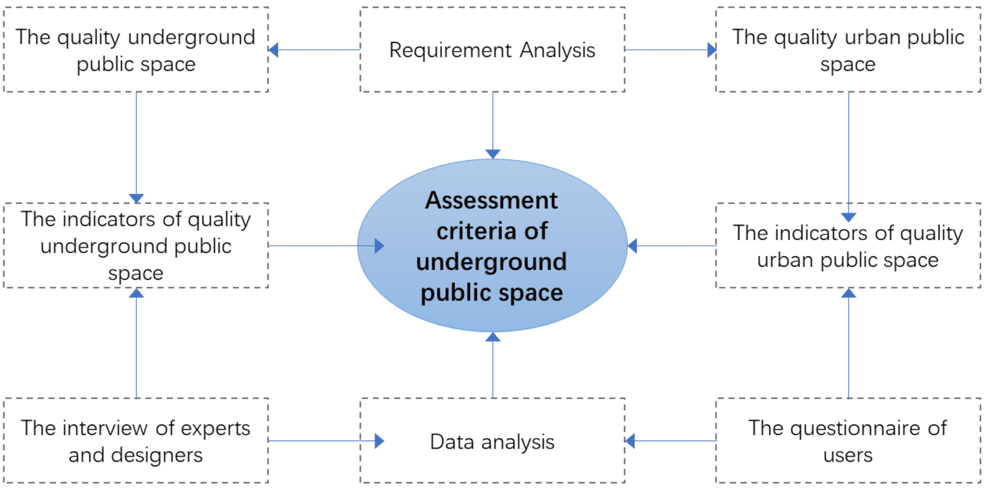



Figure 5-1 Views on Quality Evaluation Factors of Underground Public Space

## 5.2 Primary selection of indicator system

Whether the indicator system can genuinely and accurately describe and reflect overall urban public space conditions depends on the selected urban underground space indicators. After dividing the general objective into detailed criterion layers, the next step is to select specific indicators related to each criterion layer.

### 5.2.1 Steps of selection

According to the above analysis, the structure and elements of the urban underground space system have been defined. Based on urban underground space characteristics, frequency and theoretical analysis have been used to select high-frequency indicators from the underground space's safety evaluation system. A pre-selected indicator set is formed, and the final indicator set is determined. Although there are some similarities between underground and aboveground public space, underground space functions and problems are more complex and challenging due to its characteristics. Therefore, it must implement quality evaluation for urban underground public space, starting from its spatial characteristics. Depending on the design indicator system for underground space and aboveground public space, a suitable quality evaluation indicator system for urban underground public space should be built.

Table 5-1 References from literatures (Carmody and Sterling, 1993, Durmisevic and Sariyildiz, 2001, Zhao, 2009a)

| Dimension | Attributes | Indicator | References |
|---|---|---|---|
| Form aspects / Psychological aspects / Functionality of the space (Durmisevic and Sariyildiz, 2001) Physiological environment / Psychological environment / Affection requirement (Zhao, 2009b) Safety / Legibility / A sequential principle/ Comfort / Integrity (Che, 2012a) Masterplan / Sustainability / Interior environment (Hong, 2018) Sociability / Uses & Activities / Access & Linkages / Comfort & Image (Crabill, 2009) Cognition / Perception (Relph, 1997) Morphological / Functional / Visual; Morphological / Perceptual (Sholihah, 2016) | Exterior and entrance design / Layout and spatial configuration / Interior elements and systems / Lighting / Life safety patterns / (Carmody and Sterling, 1993) Safety / Comfort (Durmisevic and Sariyildiz, 2001) Air quality/ Auditory / Sense of smell / Lighting / Disaster prevention / Barrier-free design / Legibility /Proportion and scale /Art environment / Land scape (Zhao,2009) Evacuation of pulp /Barrier-free design /Leading / Efficiency/ Spatial perception / Spatial sequence / Interior design / Art environment / Spatial integration (Che, 2012a) Service facility / Ecological design (landscape) / Barrier-free design / Safety design / Internal dimensions/ Internal legibility / Art / Culture (Cao, 2015) Land use / Terrain using / The structure of defence / Lighting/ Air condition system/ Energy use / humidity and temperature / Light environment / Sound environment /Air quality / Psychological environment(Hong, 2018) Sociability / Uses & Activities/ Access & | Effective fire suppression | (Carmody and Sterling, 1993) |
| | | Clear signs and emergency lighting | (Carmody and Sterling, 1993) |
| | | İndirect lighting of ceilings and walls | (Carmody and Sterling, 1993) |
| | | Artificial light with natural characteristics | (Carmody and Sterling, 1993) |
| | | Natural lighting through window and skylights | (Carmody and Sterling, 1993) |
| | | Natural elements and materials | (Carmody and Sterling, 1993) |
| | | Colourful, warm, and spacious environment | (Carmody and Sterling, 1993) |
| | | Zones of distinct character | (Carmody and Sterling, 1993) |
| | | Sunken exterior courtyard | (Carmody and Sterling, 1993) |
| | | A system of path, activity nodes, and landmarks | (Carmody and Sterling, 1993) |
| | | Escape | (Durmisevic and Sariyildiz, 2001) |
| | | Visibility / light | (Durmisevic and Sariyildiz, 2001) |
| | | Surveillance / presence of people | (Durmisevic and Sariyildiz, 2001) |
| | | legibility | (Zhao, 2009) |
| | | Coherence | (Durmisevic and Sariyildiz, 2001) |
| | | Layout / connectivity patterns | (Durmisevic and Sariyildiz, 2001) |
| | | Adjacency | (Durmisevic and Sariyildiz, 2001) |
| | | Accessibility | (Durmisevic and Sariyildiz, 2001) |
| | | Light | (Durmisevic and Sariyildiz, 2001) |
| | | Temperature / draft | (Durmisevic and Sariyildiz, 2001) (Zhao, 2009b) |
| | | Air quality / air quality standards | (Durmisevic and Sariyildiz, 2001) (Zhao, 2009b) (WELL Building 2014) |
| | | Disaster prevention | (Zhao, 2009b) |
| | | Crime statistics | (Crabill, 2009) PPS |
| | | Evening use | (Crabill, 2009) PPS |
| | | Spaces for events | (Place Collective, 2010) |
| | | Symbols and icons | (Relph, 1997) |
| | | Landmarks | (Relph, 1997) |
| | | Local identity | BREEAM Communities |

| | | | |
|---|---|---|---|
| | Linkages / Comfort & Image (Crabill, 2009) Symbols & icons / Imageability & Identity / Clarity / Legibility / Sensorial Experience / Characteristics & features (Relph, 1997) | Wayfinding | (Durmisevic and Sariyildiz, 2001) |
| | | Attractiveness / maintenance | (Durmisevic and Sariyildiz, 2001) |
| | | Physiological comfort | (Durmisevic and Sariyildiz, 2001) |
| | | Nature light | (Zhao, 2009b) |
| | | Interior design | (Zhao, 2009b) |
| | | Art environment | (Zhao, 2009b) |
| | | Auditory | (Zhao, 2009b) |
| | | Sense of smell | (Zhao, 2009b) |
| | | Clean | (Crabill, 2009) PPS |
| | | Attractive | (Crabill, 2009) PPS |
| | | Walkable (distance) | (Crabill, 2009) PPS |
| | | Sittable (furniture) | (Crabill, 2009) PPS |
| | | Sunlight and nature light | (Place Collective, 2010) |
| | | Variation of levels | (Place Collective, 2010) |
| | | Distance | (Place Collective, 2010) |
| | | Size | (Che, 2012a) |
| | | Shape | (Che, 2012a) |
| | | Types of public space | (Che, 2012a) |
| | | Squares | (Bobylev, 2009) |
| | | green spaces | (Zhao, 2009) |
| | | Linked spaces | (Che, 2012a) |
| | | Material / colour | (Durmisevic and Sariyildiz, 2001) |
| | | Transit usage | (Crabill, 2009) PPS |
| | | Parking usage pattern | (Crabill, 2009) PPS |
| | | Pedestrian activity | (Crabill, 2009) PPS |
| | | Activities, markets, culture | (Crabill, 2009) PPS |
| | | Variation of levels | (Place Collective, 2010) |
| | | Contemplative resting places | (Place Collective, 2010) |
| | | Central meeting place | (Place Collective, 2010) |
| | | Construction and separation walls | (Durmisevic and Sariyildiz, 2001) |
| | | Dimensions | (Durmisevic and Sariyildiz, 2001) |
| | | Furniture positioning and design | (Durmisevic and Sariyildiz, 2001) |
| | | Signing system | (Durmisevic and Sariyildiz, 2001) |
| | | Create a theme | (Xing, 2015) |
| | | Outstanding theme | (Xing, 2015) |
| | | Uniform colour | (Xing, 2015) |
| | | Space conditions | (Xing, 2015) |
| | | Spatial density | (Che, 2012) |
| | | Rest facilities | (Che, 2012) |
| | | Aesthetic | (Che, 2012) |
| | | Retail sales | (Crabill, 2009) PPS |
| | | Land use pattern | (Crabill, 2009) PPS |
| | | Shared spaces | BREEAM Communities |

| | | | |
|---|---|---|---|
| | | Proximity to buildings | BREEAM Communities |
| | | Exterior noise intrusion | (WELL Building 2014) |
| | | Noise control and optimisation | (Cho et al., 2015) |

Table 5-1 shows all reviewed dimensions, attributes, and indicators in the literature. The characteristics of pre-selected indicators are analysed. A small number of most important indicators to represent the influence on urban underground space safety have been selected. The indicator system consists of their frequencies of occurrence and influence on urban underground public space safety. The availability of indicator data is analysed to substitute some unavailable indicators. The importance of indicators is analysed to retain important indicators while removing insignificant ones. The completeness of indicators is analysed to comprehensively reflect the indicator system's influence on the quality of urban underground public space. The independence of indicators is analysed to maintain relative independence among selected indicators and avoid overlaps.

### 5.2.2. Selection of indicators

The evaluation indicator system for underground public space quality is constructed by integrating definitions of underground and aboveground low-carbon design and quality public space (Yu, 2015). The indicator system of urban underground and aboveground space after analysis and summary consists of space functions, site safety, interior environment comfort, and operation & management (Hong, 2018). This section will combine the user needs mentioned in Chapter 3 to keep indicators.

#### 5.2.2.1 Selection of exterior connection indicators:

**Legibility**: The exterior extension of underground public space should highlight the degree of legibility as it shows the direct connection between underground space and the exterior environment (Carmody and Sterling, 1993, Durmisevic and Sariyildiz, 2001, Wu, 2006).

**Spatial accessibility**: The underground public space also has attributes of the aboveground public space; therefore, accessibility is one element activating the underground public space (Wu, 2006).

**Connectivity**: The problems resulting from traffic jams should be alleviated through transport facilities in underground public space (Durmisevic and Sariyildiz, 2001).

**Activity**: More public attributes of space and activities should be included in urban attributes of public space(Carmona et al., 2012, Jiang, 2014).

#### 5.2.2.2 Selection of space safety indicators:

**Disaster avoidance**: Underground public space needs to provide sites for avoiding disasters for users under special circumstances, such as extreme weather and unexpected terrorism (Yang, 2009).

**Disaster prevention**: Underground space needs to guarantee the safety of users and prevent fire, waterlogging (Hong, 2018), earthquake and other disasters when it is used as urban public space due to its architectural features (Yuan, 2009, Lu, 2015, Hong, 2018).

**Appropriate body perception**: It includes a control for thermal environments like interior temperatures and humidity. It is necessary to provide a comfortable underground interior environment(Cao, 2009).

**Air quality**: It includes adequate ventilation and control for air pollution. The natural wind is required for achieving adequate ventilation. It is also necessary to control pollutant concentration in outdoor air(Yu, 2015).

5.2.2.3 Selection of interior environment indicators:

**Interior design**: It includes spatial dimensions, colours, materials, furniture and layout. Providing appropriate and humanised design can improve users' satisfaction (Shu, 2015a).

**Combination of functional spaces**: It provides more functional contents and combination modes (Shu, 2015b).

**Art control**: When basic demands are satisfied, art modes should be used to improve spatial quality and increase users' psychological satisfaction (Phoenix room, 2014, Lu, 2015).

#### 5.2.2.4 Selection of operational indicators:

**Information monitoring**: The operation of underground public space should be monitored, and real-time feedback and information sharing should be conducted (Zhang, 2013).

**Intelligent management**: A management system for space should be formulated and implemented. Measures should be taken to keeping order during operation, including control for carbon emission in space (Lu, 2014, Shu, 2015b).

**Maintenance**: Public facilities should be offered and maintained during the operation (Zhang, 2013).

The selected indicators are classified again according to the exterior connection, space safety, interior environment, and underground public space operation in the first level. It also includes life safety, exterior and entrance friendly design, user comfort, spatial configuration, Friendly interior design, management, identity, sociability, and activity space in the second level. In the process of indicator screening, the author found that the index content in the nine classifications overlaps with the indexes of the four major classifications in multiple directions, as shown in Figure 5-2.

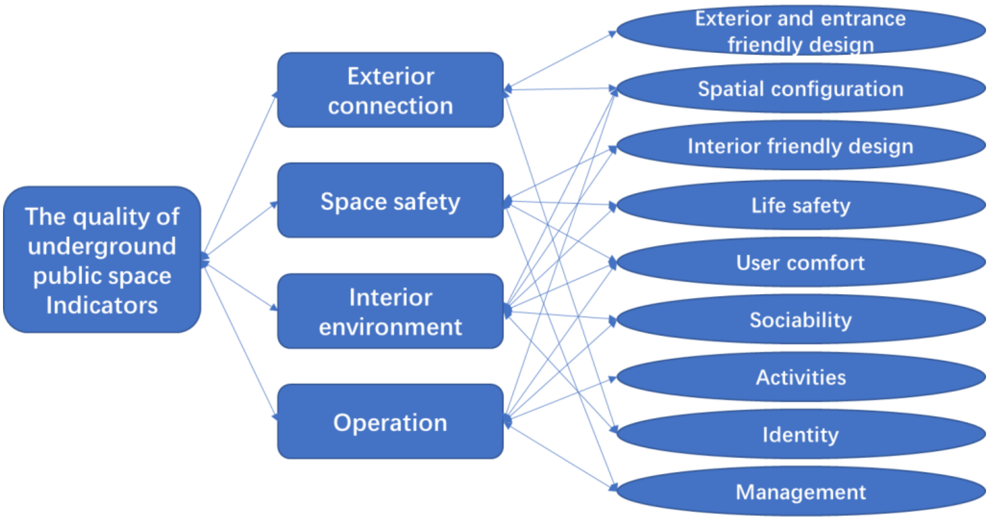



Figure 5-2 The structure of indicator system

*Figure source: by author*

The evaluation system is based on analysing the factors affecting the quality of underground public space and the guidelines for the quality design of above and underground public spaces and evaluation standards. This section will revise, delete and supplement the factors affecting the quality evaluation of underground public space. The factors are compared with the factors affecting aboveground public space design. These are based on the analysis of the factors affecting the underground public space design in Chapter 3, putting forward the quality evaluation factor of underground public space.

Through the analysis of factors affecting the aboveground public space design and the study of underground public space in Chapter 3, the article has taken out the relevant evaluation factors that affect the underground public space design. They have four attributes of underground public space, which can be classified into nine categories. See Table 5-2 for details. The categories of quality evaluation indicators for underground public space are described as below:

1) Exterior and entrance friendly design

It includes indicators which are accessibility, legibility, sunken courtyard, sunken open space, vertical entrance, and diversity integrations.

2) Spatial configuration

It includes indicators: a system of paths, activities nodes, landmarks, connectivity, distinct zones, overlooking activity, hierarchy privacy, interconnected space, and high ceilings.

3) Friendly interior design

It includes colour, size, nature elements, materials, furnishings, signs and maps, and ventilated.

4) Life safety

It includes escape, air quality, disaster prevention, wayfinding, fire suppression, and ventilated.

5) User comfort

It includes temperature, variety of shade, art control, lighting, and noise control.

6) Sociability

It includes cooperative, social services, diverse uses and interactive.

7) Activities

It includes events and theme sales.

8) Identity

It includes imageability, history and symbolic, culture, and unique nature.

9) Management

It includes informational facilities, hygiene services, rules and regulations, and affordability.

Table 5-2 Indicator screening (by author)

| Dimensions | Attributes | Indicators |
|---|---|---|
| Exterior connection<br>Space safety<br>Interior environment<br>Operation | Exterior and entrance friendly design | Accessibility |
| | | Legibility |
| | | Sunken courtyard |
| | | Sunken open space |
| | | Vertical entrance |
| | | Diversity integrations |
| | Spatial configuration | A system of paths |
| | | Activities nodes |
| | | Landmarks |
| | | Connectivity |
| | | Distinct zones |
| | | Overlooking activity |

| | | |
|---|---|---|
| | | Hierarchy privacy |
| | | Interconnected space |
| | | High ceilings |
| | Friendly interior design | Colour |
| | | Size |
| | | Nature elements |
| | | Materials |
| | | Furnishings |
| | | Signs and maps |
| | Life safety | Escape |
| | | Air quality |
| | | Disaster prevention |
| | | Wayfinding |
| | | Fire suppression |
| | | Ventilated |
| | User comfort | Lighting |
| | | Temperature |
| | | Variety of shade |
| | | Art control |
| | | Noise control |
| | Sociability | Cooperative |
| | | Social services |
| | | Diverse uses |
| | | Interactive |
| | Activities | Events |
| | | Theme sales |
| | Identity | Imageability |
| | | History and symbolic |
| | | Culture |
| | | Unique nature |
| | Management | Informational facilities |
| | | Hygiene services |
| | | Rules and regulations |
| | | Affordability |

### 5.2.3 Expert interview, questionnaire, and data analysis

After the first round of indicator selection, the author has further selected and adjusted the quality evaluation system for underground public space in this section. In this section, interviewees are divided into two groups for filling in questionnaires and attending interviews. The indicator system is then determined through the factor analysis. The designing experts and related staff of underground space first proposed optimisation opinions for the first round of indicators through questionnaires and interviews and provided suggestions for the feasibility of quality evaluation for underground public space. This section investigates the importance of indicators from the quality evaluation system for users of underground public space around the metro. The EFA (exploratory factor analysis) and the CFA (confirmatory factor analysis) are conducted for data and finally determines the evaluation indicator system.

The author has consulted 34 experts and designers in terms of the design and evaluation of underground space. The experts provided suggestions on the indicator system and completed questionnaires (see Appendix - questionnaire 2) related to the degree of importance of the above indicators. The author also interviewed experts on the feasibility of quality evaluation for underground public space and collected 34 valid questionnaires. These experts are from universities and designing institutions that once hosted or participated in underground space and civil defence planning, and underground space design in many cities, including Beijing, Tianjin, Hangzhou, Haikou, Jinan, Nanning, Qingdao, Yantai, Xi'an, and Chongqing China.

The Table of Consultation for Expert Opinions (see Appendix questionnaire 2) includes two parts. One uses five rating scales to classify indicators from above into five levels: 'very important', 'important', 'slightly important', 'not very important' and 'not important'; respectively they are valued at 5, 4, 3, 2, and 1. The other requests experts to quantitatively rate the importance of indicators (Xu et al., 2007).

In professional opinions, 'Life safety' is the most important in quality evaluation for underground public space among the existing nine indicators, with a proportion of 70%. 'User comfort' and 'Exterior and entrance friendly design' followed, with the proportion of 58.2% and 52.94%. 'Spatial configuration', 'Management' and 'Friendly interior design' occupied 41.18%, 38.24% and 26.47% respectively. 'Sociability', 'Identity' and 'Activities' were the least important - only 17.65% of participants rated them 'very important'. 47.06%, 35.29% and 23.53% of participants rated them 'important' respectively. Therefore, the indicator framework is modified as follow (see Table 5-3 below).

Table 5-3. The data of Q1

| No. | Attributes | Mini. | Max. | Expected value | Standard deviation | Variance | Samples |
|---|---|---|---|---|---|---|---|
| 1 | Exterior and entrance friendly design | 3.0 | 5.0 | 4.41 | 0.7 | 0.49 | 34 |
| 2 | Spatial configuration | 3.0 | 5.0 | 4.24 | 0.74 | 0.55 | 34 |
| 3 | Friendly interior design | 2.0 | 5.0 | 4.0 | 0.78 | 0.61 | 34 |
| 4 | Life safety | 3.0 | 5.0 | 4.68 | 0.53 | 0.29 | 34 |
| 5 | User comfort | 3.0 | 5.0 | 4.47 | 0.71 | 0.5 | 34 |
| 6 | Sociability | 2.0 | 5.0 | 3.74 | 0.86 | 0.75 | 34 |
| 7 | Activities | 2.0 | 5.0 | 3.44 | 0.96 | 0.92 | 34 |
| 8 | Identity | 2.0 | 5.0 | 3.68 | 0.81 | 0.65 | 34 |
| 9 | Management | 2.0 | 5.0 | 4.06 | 0.92 | 0.84 | 34 |

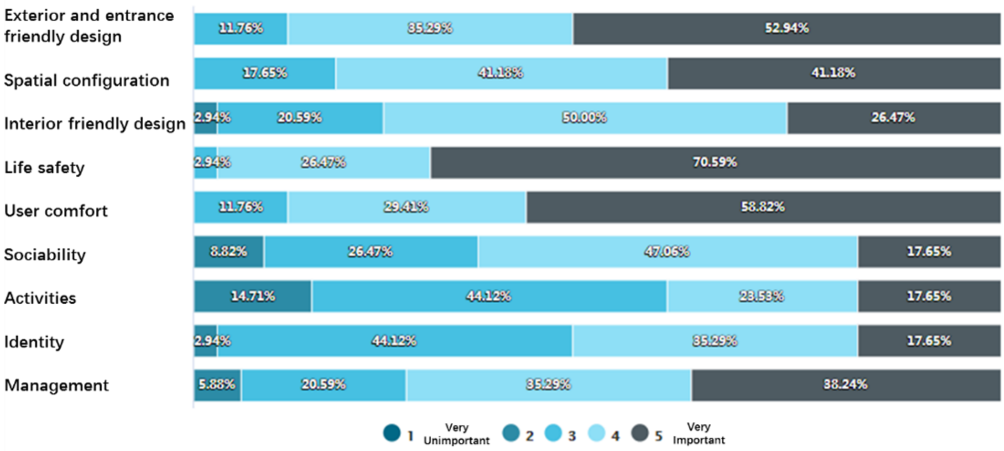



Figure 5-3. Q1 the most important item in quality evaluation for underground public space

In the second question of the original questionnaires, the experts consider that the fundamental indicators of exterior and entrance friendly design in underground public space quality are the vertical entrance, legibility, accessibility, sunken open space, sunken courtyard, and diversity integrations (in order). Vertical entrance is considered a very important indicator from professional practitioners' interviews, and it contains crucial functions that are barrier-free.

Table 5-4. The data of Q2

| No. | Attributes | Mini. | Max. | Expected value | Standard deviation | Variance | Samples |
|---|---|---|---|---|---|---|---|
| 1 | Accessibility | 2.0 | 5.0 | 4.12 | 0.84 | 0.71 | 34 |
| 2 | Legibility | 2.0 | 5.0 | 4.03 | 0.94 | 0.88 | 34 |
| 3 | Sunken courtyard | 2.0 | 5.0 | 3.71 | 0.87 | 0.76 | 34 |
| 4 | Sunken open space | 2.0 | 5.0 | 3.82 | 0.97 | 0.94 | 34 |
| 5 | Vertical entrance | 2.0 | 5.0 | 4.41 | 0.89 | 0.8 | 34 |
| 6 | Diversity integrations | 2.0 | 5.0 | 3.47 | 0.86 | 0.74 | 34 |

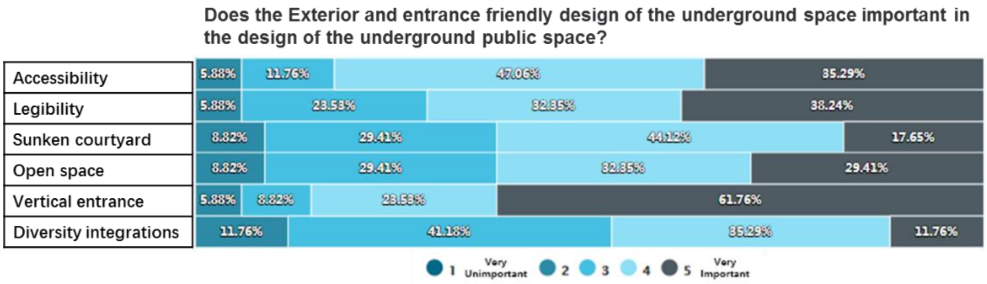



Figure 5-4. Q2 the very important indicators of exterior and entrance friendly design

According to underground space design experts, 67.65% of experts consider 'a system of paths' is very important among indicators of 'Spatial configuration'. 44.12% believe that 'connectivity' is very important, and 41.18% think that 'connectivity' is important. Meanwhile, 50% of experts consider that 'activities nodes' is important, and 23.53% of experts take it as the most important indicator.

Table 5-5 The data of Q3

| No. | Attributes | Mini. | Max. | Expected value | Standard deviation | Variance | Samples |
|---|---|---|---|---|---|---|---|
| 1 | A system of paths | 2.0 | 5.0 | 4.44 | 0.89 | 0.8 | 34 |
| 2 | Activities nodes | 2.0 | 5.0 | 3.88 | 0.88 | 0.77 | 34 |
| 3 | Landmarks | 2.0 | 5.0 | 3.82 | 0.9 | 0.82 | 34 |
| 4 | Connectivity | 3.0 | 5.0 | 4.29 | 0.72 | 0.52 | 34 |
| 5 | Distinct zones | 1.0 | 5.0 | 3.53 | 0.99 | 0.98 | 34 |
| 6 | Overlooking activity | 1.0 | 5.0 | 3.12 | 1.04 | 1.08 | 34 |
| 7 | Hierarchy privacy | 2.0 | 5.0 | 3.56 | 0.99 | 0.98 | 34 |
| 8 | Interconnected space | 1.0 | 5.0 | 3.65 | 1.04 | 1.08 | 34 |
| 9 | High of ceilings | 1.0 | 5.0 | 3.12 | 1.23 | 1.5 | 34 |

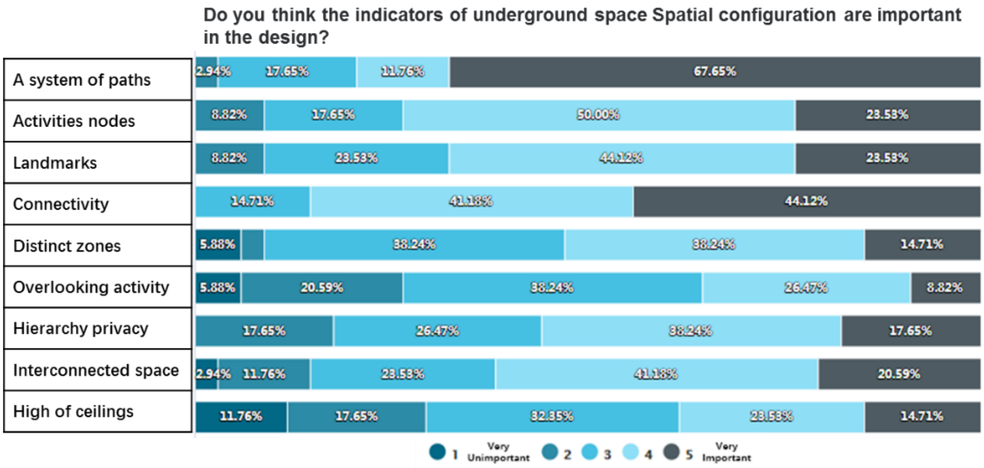



Figure 5-5. Q3 the very important indicators of spatial configuration

Among indicators of 'interior design', 70.59% experts consider 'signs and maps' the most important under the 'very important' item; followed by 'size', and 44.12% experts consider it important. In the interior design for underground public space, whether colours, materials, natural elements, and interior layout have a comfortable or uncomfortable influence on users are less recognisable by others. Therefore, the questionnaire implies that even professional designers may consider these elements 'not very important' in the overall interior design.

Table 5-6 The data of Q4

| No. | Attributes | Mini. | Max. | Expected value | Standard deviation | Variance | Samples |
|---|---|---|---|---|---|---|---|
| 1 | Colour | 2.0 | 5.0 | 3.41 | 0.74 | 0.55 | 34 |
| 2 | Size | 2.0 | 5.0 | 4.06 | 0.92 | 0.84 | 34 |
| 3 | Nature elements | 2.0 | 5.0 | 3.38 | 0.99 | 0.97 | 34 |
| 4 | Materials | 1.0 | 5.0 | 3.5 | 0.93 | 0.86 | 34 |
| 5 | Furnishings | 1.0 | 5.0 | 3.62 | 0.99 | 0.97 | 34 |
| 6 | Signs and maps | 2.0 | 5.0 | 4.5 | 0.9 | 0.8 | 34 |

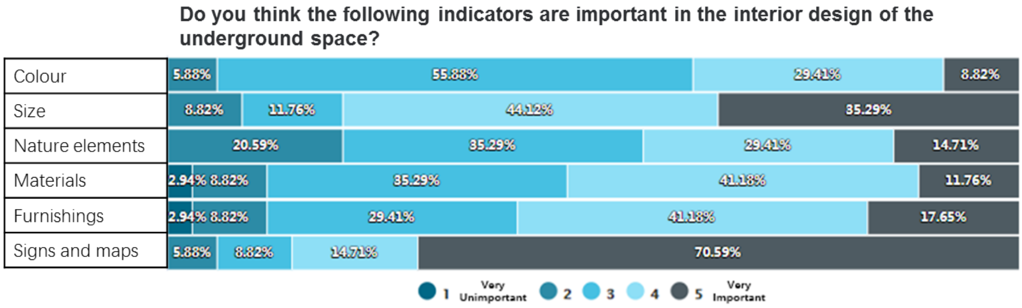



Figure 5-6. Q4 the very important indicators of interior design

However, among safety indicators, a high proportion of experts rates 'very important' for six attributes, in which 'fire' and 'escape' are considered 'very important', with the proportion up to 70.34%.

Table 5-7. The data of Q5

| No. | Attributes | Mini. | Max. | Expected value | Standard deviation | Variance | Samples |
|---|---|---|---|---|---|---|---|
| 1 | Escape | 2.0 | 5.0 | 4.56 | 0.82 | 0.68 | 34 |
| 2 | Air quality | 3.0 | 5.0 | 4.47 | 0.71 | 0.5 | 34 |
| 3 | Disaster prevention | 2.0 | 5.0 | 4.35 | 0.92 | 0.84 | 34 |
| 4 | Wayfinding | 2.0 | 5.0 | 4.26 | 0.83 | 0.69 | 34 |
| 5 | Fire suppression | 2.0 | 5.0 | 4.56 | 0.79 | 0.62 | 34 |
| 6 | Ventilated | 2.0 | 5.0 | 4.38 | 0.82 | 0.67 | 34 |

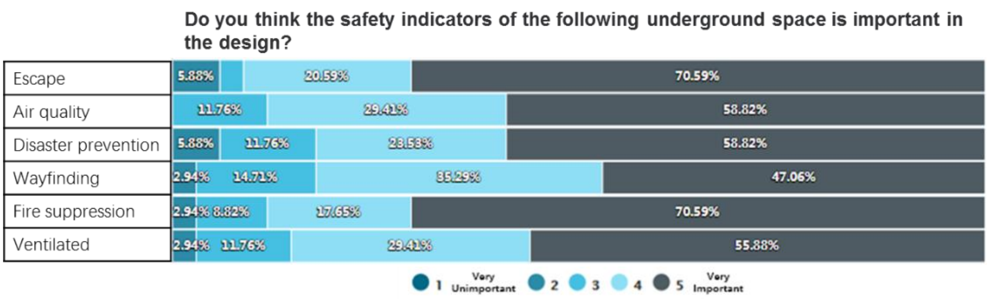



Figure 5-7 Q5 the very important indicators of safety

Among indicators of 'user comfort', most experts take 'lighting' as 'very important', followed by 'temperature'. Besides, most professionals rate 'art control' as 'important'.

Table 5-8. The data of Q6

| No. | Attributes | Mini. | Max. | Expected value | Standard deviation | Variance | Samples |
|---|---|---|---|---|---|---|---|
| 1 | Lighting | 2.0 | 5.0 | 4.47 | 0.79 | 0.62 | 34 |
| 2 | Temperature | 2.0 | 5.0 | 4.26 | 0.86 | 0.75 | 34 |
| 3 | Variety of shade | 2.0 | 5.0 | 4.15 | 0.86 | 0.74 | 34 |
| 4 | Art control | 2.0 | 5.0 | 3.74 | 0.86 | 0.75 | 34 |
| 5 | Noise control | 1.0 | 5.0 | 3.56 | 1.05 | 1.1 | 34 |

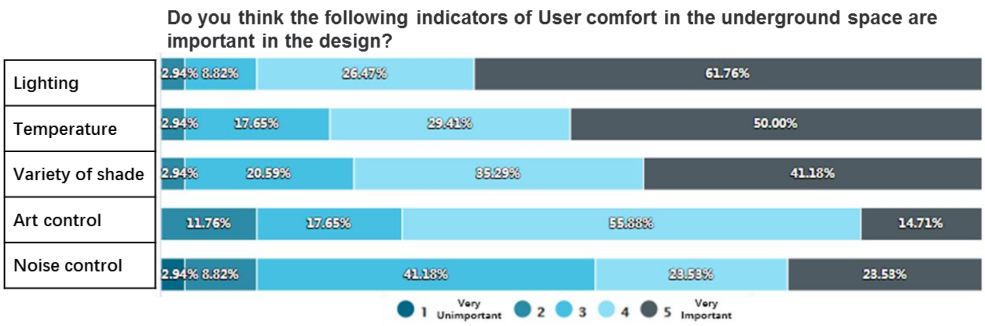



Figure 5-8. Q6 the very important indicators of 'user comfort'

Among indicators of 'social function', over half of participants think 'social service' and 'diverse uses' are 'very important' and 'important' respectively. Furthermore, most participants believe 'cooperative' and 'interactive' are 'slightly important'.

Table 5-9. The data of Q7

| No. | Attributes | Mini. | Max. | Expected value | Standard deviation | Variance | Samples |
|---|---|---|---|---|---|---|---|
| 1 | Cooperative | 1.0 | 5.0 | 3.38 | 1.04 | 1.09 | 34 |
| 2 | Social services | 2.0 | 5.0 | 3.79 | 0.88 | 0.77 | 34 |
| 3 | Diverse uses | 1.0 | 5.0 | 3.62 | 1.02 | 1.03 | 34 |
| 4 | Interactive | 1.0 | 5.0 | 3.44 | 0.93 | 0.86 | 34 |

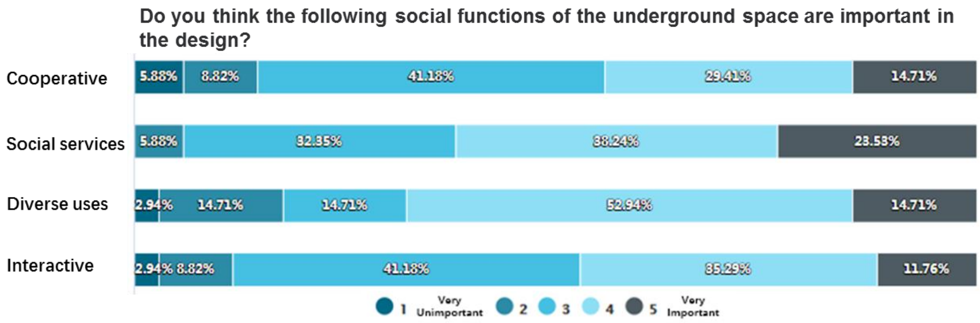



Figure 5-9. Q7 the very important indicators of 'social function'

Many professionals rate the 'very important' activities in aboveground public space as 'slightly important' for underground public space; most professionals prefer the middle position. From the activity type, they prefer to develop more marketing activities in underground public space.

Table 5-10 the data of Q8

| No. | Attributes | Mini. | Max. | Expected value | Standard deviation | Variance | Samples |
|---|---|---|---|---|---|---|---|
| 1 | Events | 1.0 | 5.0 | 3.38 | 1.04 | 1.09 | 34 |
| 2 | Theme sales | 1.0 | 5.0 | 3.53 | 1.11 | 1.23 | 34 |

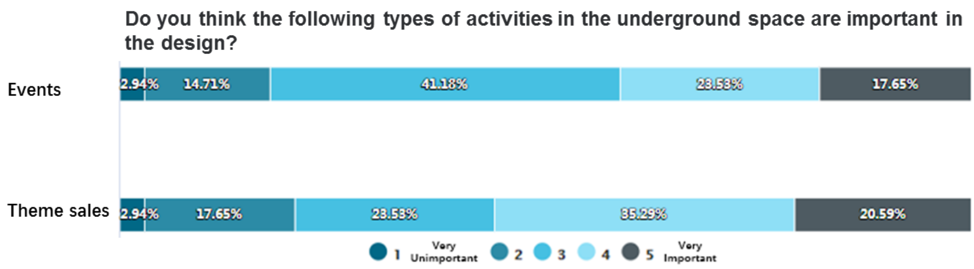



Figure 5-10. Q8 the very important indicators of activities

'Identity' is also an 'important' factor for aboveground public space, and over half of professionals consider that all items in this category are 'important' or 'very important'.

Table 5-11. the data of Q9

| No. | Attributes | Mini. | Max. | Expected value | Standard deviation | Variance | Samples |
|---|---|---|---|---|---|---|---|
| 1 | Imageability | 2.0 | 5.0 | 3.94 | 1.07 | 1.15 | 34 |
| 2 | History symbolic | 1.0 | 5.0 | 3.59 | 1.05 | 1.1 | 34 |
| 3 | Culture | 1.0 | 5.0 | 3.5 | 1.05 | 1.11 | 34 |
| 4 | Unique nature | 1.0 | 5.0 | 3.53 | 1.24 | 1.53 | 34 |

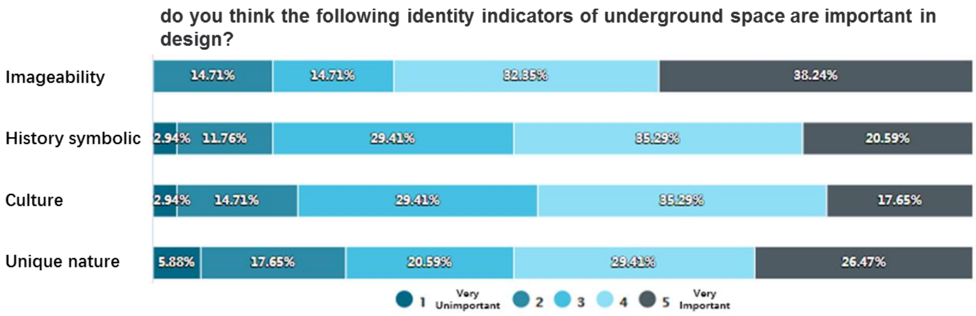



Figure 5-11. Q9 the very important indicators of 'Identity'

Among indicators of 'management', 94.12% of professionals consider that 'hygiene services' is 'important' or 'very important'. The lowest score for 'information facilities' and 'hygiene services' is 3, while the lowest score for 'rules & regulation' and 'affordability' is 2.

Table 5-12 the data of Q10

| No. | Attributes | Mini. | Max. | Expected value | Standard deviation | Variance | Samples |
|---|---|---|---|---|---|---|---|
| 1 | Informational facilities | 3.0 | 5.0 | 3.85 | 0.78 | 0.61 | 34 |
| 2 | Hygiene services | 3.0 | 5.0 | 4.5 | 0.62 | 0.38 | 34 |
| 3 | Rules & regulations | 2.0 | 5.0 | 3.91 | 0.79 | 0.63 | 34 |
| 4 | Affordability | 2.0 | 5.0 | 3.53 | 1.08 | 1.17 | 34 |

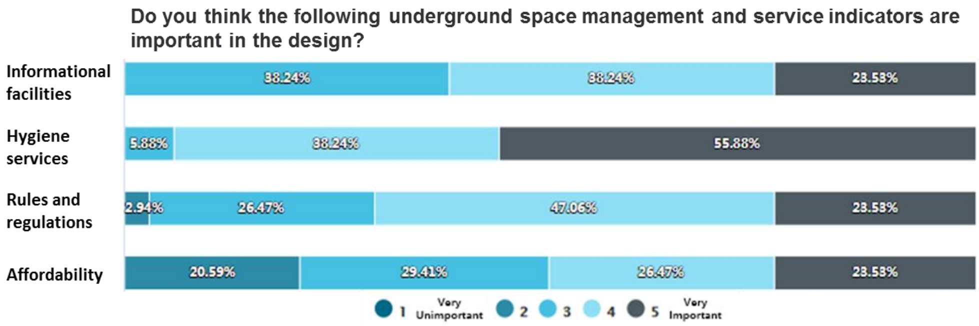



Figure 5-12. Q10 the very important indicators of 'management'

The last part of the questionnaires is an open-ended question. Among 34 questionnaires, 11 proposed modifying the questionnaire, covering three main problems: (1) ordinary users may have problems understanding the contents, and therefore, detailed descriptions should be added; (2) there are overlaps for existing indicators. For example, the sunken courtyard belongs to sunken open space, and the two can be combined. The fire prevention has overlaps with 'fire', which should be defined first; (3) suggestions from experts should be added to each indicator. For example, 'Lighting' includes natural light, artificial light source, and indirect light source. Hence, it should be considered as an independent category to look into the three lighting indicators.

Expert questionnaires are mainly used for modifying the indicator system (see Table 5-13 below). Moreover, for the questionnaires' improvement, the analysis results are obtained with statistical methods, but data analysis is relatively limited. The following chapter will discuss the questionnaires for users with modified indicators. Meanwhile, the Exploratory Factor Analysis

(EFA) for indicators of the quality evaluation system for underground public space with the SPSS was conducted, followed by the weight calculation of analysis results.

Table 5-13 Indicator screening

| Objective | Attributes | | Indicator | |
|---|---|---|---|---|
| The indicators of quality underground public space | 1 | Exterior and entrance friendly design | 1 | Accessibility |
| | | | 2 | Sunken open space |
| | | | 3 | Vertical entrance |
| | | | 4 | Legibility |
| | | | 5 | Diversity integrations |
| | 2 | Spatial configuration | 6 | A system of paths |
| | | | 7 | Activities nodes |
| | | | 8 | Landmarks |
| | | | 9 | Interconnected space |
| | | | 10 | Distinct zones |
| | | | 11 | Height variation |
| | | | 12 | Hierarchy |
| | | | 13 | privacy |
| | | | 14 | Overlooking activity |
| | 3 | Friendly interior design | 15 | Colour |
| | | | 16 | Size |
| | | | 17 | Nature elements |
| | | | 18 | Materials |
| | | | 19 | Furnishings |
| | | | 20 | Signs and maps |
| | | | 21 | Art control |
| | 4 | Lighting | 22 | Nature light |
| | | | 23 | Artificial lighting |
| | 5 | Life safety | 24 | Escape |
| | | | 25 | Disaster prevention |
| | | | 26 | Surveillance |
| | | | 27 | Alarm |
| | | | 28 | Fire suppression |
| | 6 | User comfort | 29 | Air quality |
| | | | 30 | Temperature |
| | | | 31 | Noise control |
| | 7 | Sociability | 32 | Social services |
| | | | 33 | Cooperative |
| | | | 34 | Diverse uses |
| | | | 35 | Interactive |
| | 8 | Activities | 36 | Events |
| | | | 37 | Theme sales |
| | 9 | Identity | 38 | Imageability |
| | | | 39 | History and symbolic |

| | | | | |
|---|---|---|---|---|
| | | | 40 | Culture |
| | | | 41 | Unique nature |
| | 10 | Management | 42 | Informational facilities |
| | | | 43 | Hygiene services |
| | | | 44 | Rules and regulations |
| | | | 45 | Affordability |

### 5.2.4 Questionnaire and analysis for user experience

For the initial indicator system in the previous section, the author has made a new questionnaire (see Appendix Questionnaire 2 form) about user experience and analysed the importance and frequency of selecting each category and indicator.

Table 5-14. The statistical result of Q1 in questionnaire

| Options | Conditions | Rate |
|---|---|---|
| Exterior and entrance friendly design | 167 | 65.23% |
| Spatial configuration | 107 | 41.80% |
| Friendly interior design | 102 | 39.84% |
| Lighting | 132 | 51.56% |
| Life safety | 172 | 67.19% |
| User comfort | 117 | 45.70% |
| Sociability | 55 | 21.48% |
| Activities | 11 | 4.30% |
| Identity | 56 | 21.88% |
| Management | 85 | 33.20% |

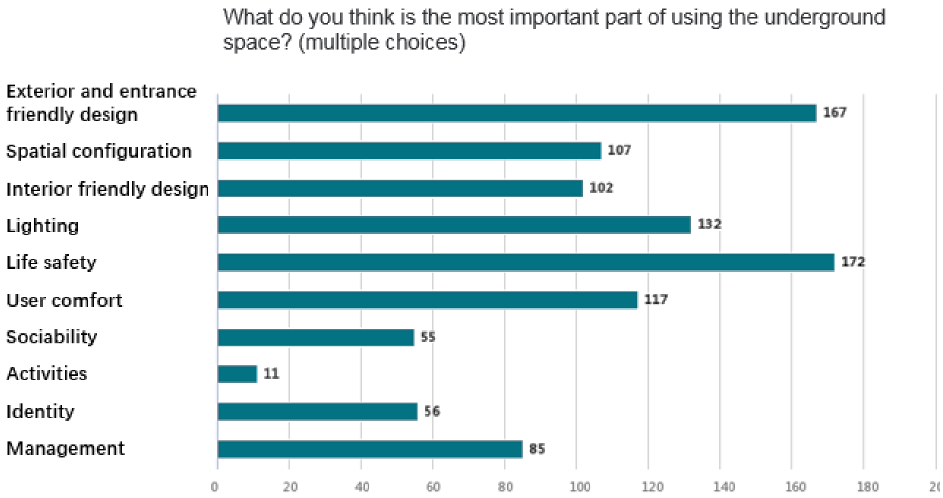



Figure 5-13. The result of Q1 in questionnaire

Question 1 is a multiple-choice question, which investigates the importance of modified indicator classification. It requires interviewees to select the most important one or more from 10 options. Questionnaires from 256 interviewees were collected, and the importance rank of indicators is: life safety, exterior and entrance friendly design, lighting, user comfort, spatial configuration, Friendly interior design, management, identity, sociability, and activity space.

Table 5-15. The statistical result of Q2 in questionnaire

| Options | Conditions | Rate |
|---|---|---|
| Accessibility | 207 | 80.86% |
| Sunken open space | 56 | 44.53% |
| Vertical entrance | 92 | 35.94% |
| Legibility | 114 | 26.17% |
| Diversity integrations | 67 | 21.88% |

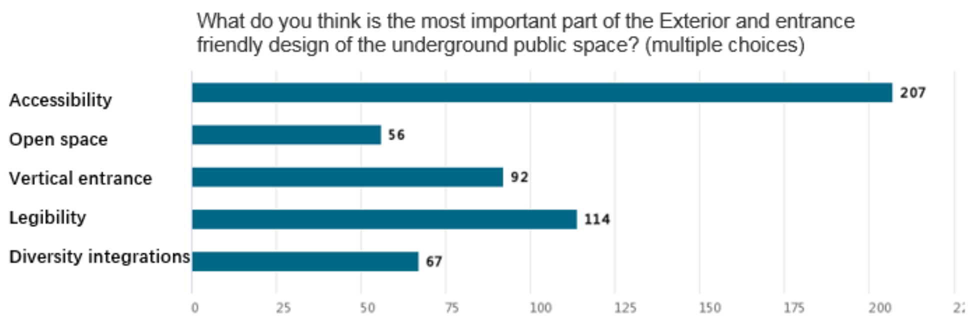



Figure 5-14. The result of Q2 in questionnaire

Question 2 is a multiple-choice question, which looks into the importance of modified indicator classification and requires interviewees to select the most important one or more from 5 options. The replies from 256 interviewees were collected, and the importance rank of indicators is: accessibility, disabled facilities, vertical entrance, diversity integrations, and sunken open space.

Table 5-16. The statistical result of Q3 in questionnaire

| Options | Conditions | Rate |
|---|---|---|
| A system of paths | 191 | 74.61% |
| Activities nodes | 61 | 23.83% |
| Landmarks | 94 | 36.72% |
| Interconnected space | 147 | 57.42% |
| Distinct zones | 85 | 33.20% |
| Height variation | 32 | 12.50% |
| Hierarchy | 44 | 17.19% |
| privacy | 18 | 7.03% |
| Overlooking activity | 25 | 9.77% |

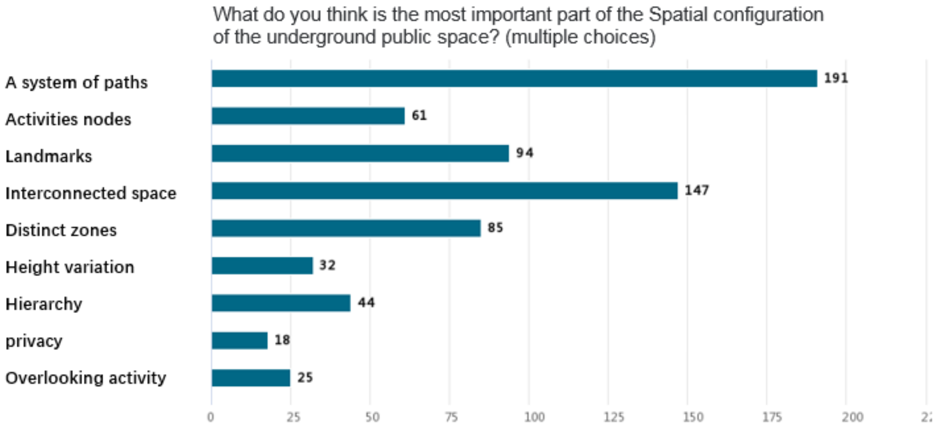



Figure 5-15. The result of Q3 in questionnaire

Question 3 is a multiple-choice question, which investigates the importance of modified indicator classification and requires interviewees to select the most important one or more from 9 options. The author collected questionnaires from 256 interviewees and the importance rank is: A system of paths, Activities nodes, Landmarks, Interconnected space, Distinct zones, Height variation, Hierarchy, privacy, and Overlooking activity.

Table 5-17. The statistical result of Q4 in questionnaire

| Options | Conditions | Rate |
|---|---|---|
| A system of paths | 91 | 35.55% |
| Activities nodes | 135 | 52.73% |
| Landmarks | 63 | 24.61% |
| Interconnected space | 77 | 30.08% |
| Distinct zones | 70 | 27.34% |
| Height variation | 162 | 63.28% |
| Hierarchy | 59 | 23.05% |
| privacy | 91 | 35.55% |
| Overlooking activity | 135 | 52.73% |

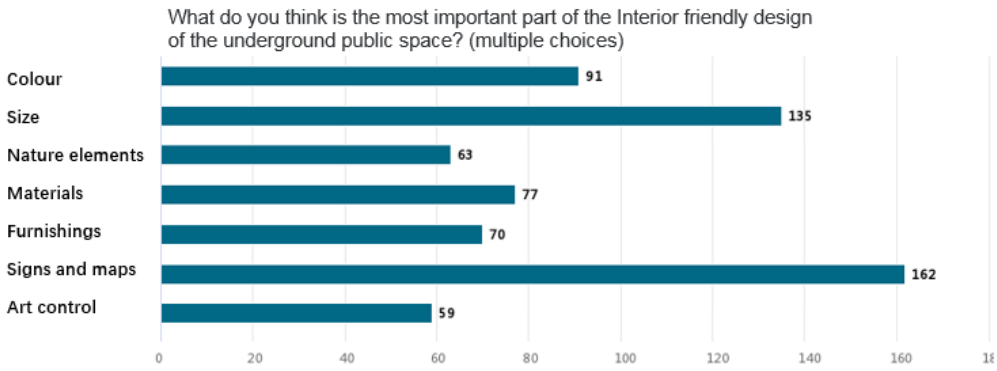



Figure 5-16. The result of Q4 in questionnaire

Question 4 is a multiple-choice question, which looks into the importance of modified indicator classification and requires interviewees to select the most important one or more from 7 options. The replies from 256 interviewees were collected, and the importance rank of indicators is: signs and maps, size, colour, materials, furnishings, nature elements, and ventilated.

Table 5-18 The statistical result of Q5 in questionnaire

| Options | Conditions | Rate |
|---|---|---|
| Nature light | 74 | 28.91% |
| Artificial lighting | 19 | 7.42% |
| It doesn't matter, as long as it's bright | 128 | 57.92% |

Question 5 is a multiple-choice question, which investigates the importance of modified indicator classification and requires interviewees to select the most important one or more from 2 options. Among 256 interviewees, 50% of users pay more attention to enough luminance in terms of natural light and artificial light.

Table 5-19. The statistical result of Q6 in questionnaire

| Options | Conditions | Rate |
|---|---|---|
| Escape | 216 | 84.38% |
| Disaster prevention | 157 | 61.33% |
| Surveillance | 176 | 68.75% |
| Alarm | 138 | 53.91% |
| Fire suppression | 186 | 72.66% |

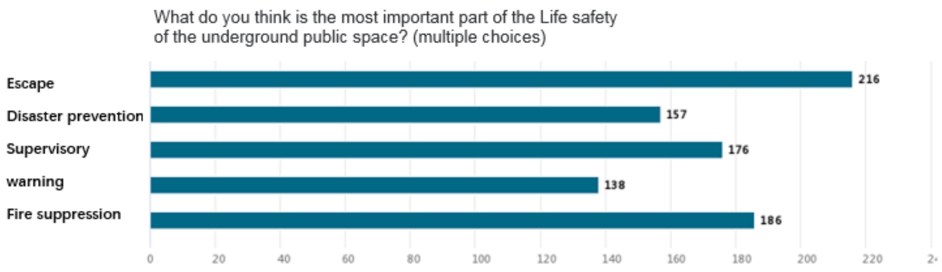



Figure 5-17. The result of Q6 in questionnaire

Question 6 is a multiple-choice question, which looks into the importance of modified indicator classification and requires interviewees to select the most important one or more from 5 options. The author collected replies from 256 interviewees, and the importance rank of indicators is: escape, fire, monitoring, disaster, avoidance, and alarm.

Table 5-20. The statistical result of Q7 in questionnaire

| Options | Conditions | Rate |
|---|---|---|
| Air quality | 243 | 94.92% |
| Temperature | 141 | 55.08% |
| Noise control | 162 | 63.28% |

Question 7 is a multiple-choice question, looking into the importance of modified indicator classification and requires interviewees to select the most important one or more from 3 options. Among 256 interviewees, 94.92% users consider that the most important factor among underground public space comfort indicators is air quality; 63.28% users take noise control as important and 55.08% users consider temperature important.

Table 5-21. The statistical result of Q8 in questionnaire

| Options | Conditions | Rate |
|---|---|---|
| Social services | 164 | 64.06% |
| Cooperative | 174 | 67.97% |
| Diverse uses | 134 | 52.34% |
| Interactive | 50 | 19.53% |

Question 8 is a multiple-choice question, looking into the importance of modified indicator classification and requires interviewees to select the most important one or more from 4 options. The replies from 256 interviewees were collected, and the importance rank of indicators is: social services, cooperative, diverse uses, and interactive.

Table 5-22. The statistical result of Q9 in questionnaire

| Options | Conditions | Rate |
|---|---|---|
| Social services | 164 | 64.06% |
| Cooperative | 174 | 67.97% |

Question 9 is a multiple-choice question, which investigates the importance of modified indicator classification and requires interviewees to select the most important one or more from 2 options. Among the 256 questionnaires, the selection rates for two underground public spaces are 64.06% and 67.97% respectively. Some users do not want to attract people with any underground public space activity because it has been extremely crowded in Beijing's metro stations.

Table 5-23. The statistical result of Q10 in questionnaire

| Options | Conditions | Rate |
|---|---|---|
| Imageability | 192 | 75.00% |
| History and symbolic | 84 | 32.81% |
| Culture | 131 | 51.17% |
| Unique nature | 115 | 44.92% |

Question 10 is a multiple-choice question, investigating the importance of modified indicator classification and requires interviewees to select the most important one or more from 4 options. 192 out of 256 interviewees (i.e. 75%) hope that underground public space will be an architectural space leaving a deep impression, and other options are ranked in turn: culture, unique nature, history and symbolic.

Table 5-24 The statistical result of Q11 in questionnaire

| Options | Conditions | Rate |
|---|---|---|
| Informational facilities | 193 | 75.39% |
| Hygiene services | 225 | 87.89% |
| Rules and regulations | 91 | 35.55% |
| Affordability | 144 | 56.25% |

Question 11 is a multiple-choice question, which investigates the importance of modified indicator classification and requires interviewees to select the most important one or more from 4 options. 225 out of 256 interviewees (87.89%) consider that 'health facility' is the most important among underground public facilities, and other options are ranked in turn, being informational facilities, affordability, and rules and regulations.

As concluded, the statistical results of the questionnaires on user experience have been shown in the following table, which ranks indicators again and calculates the weight (see Table 5-25 below). It can be seen from the table that the attribute weights according to questionnaire results of user experience are ranked: life safety, exterior and entrance friendly design, lighting, user comfort, spatial configuration, Friendly interior design, management, identity, sociability, and activity space.

Table 5-25. The weight for quality of underground public space indicators by users' experiences.

| Objective | categories | | Indicator | |
|---|---|---|---|---|
| The indicators of quality underground public space | 1 | Life safety | 1 | Escape |
| | | | 2 | Fire |
| | | | 3 | Monitoring |
| | | | 4 | Disaster avoidance |
| | | | 5 | Alarm |
| | 2 | Exterior and entrance friendly design | 6 | Accessibility |
| | | | 7 | Disabled facilities |
| | | | 8 | Vertical entrance |
| | | | 9 | Diversity integrations |
| | | | 10 | Sunken open space |
| | 3 | Lighting | 11 | Nature light |
| | | | 12 | Artificial lighting |
| | | | 13 | Indirect lighting |
| | 4 | User comfort | 14 | Air quality |
| | | | 15 | Noise control |
| | | | 16 | Temperature |
| | 5 | Spatial configuration | 17 | A system of paths |
| | | | 18 | Connectivity |
| | | | 19 | Landmarks |
| | | | 20 | Distinct zones |
| | | | 21 | Activities nodes |
| | | | 22 | Spatial stratification |
| | | | 23 | Layer height change |
| | | | 24 | Overlooking activity |
| | | | 25 | Hierarchy privacy |
| | 6 | Friendly interior design | 26 | Signs and maps |
| | | | 27 | Size |
| | | | 28 | Colour |
| | | | 29 | Materials |
| | | | 30 | Furnishings |
| | | | 31 | Nature elements |
| | | | 32 | Ventilated |
| | 7 | Management | 33 | Hygiene services |
| | | | 34 | Informational facilities |
| | | | 35 | Affordability |
| | | | 36 | Rules and regulations |
| | 8 | Identity | 37 | Imageability |
| | | | 38 | Culture |
| | | | 39 | Unique nature |
| | | | 40 | History and symbolic |
| | 9 | Sociability | 41 | Cooperative |

| | | | | |
|---|---|---|---|---|
| | | | 42 | Social services |
| | | | 43 | Diverse uses |
| | | | 44 | Interactive |
| | 10 | Activity space | 45 | Theme sales |
| | | | 46 | Events |

### 5.2.5 Factor analysis

#### 5.2.5.1 Exploratory factor analysis

In this section, the author filters, conducts dimensionality reduction and classified indicators that influence underground public space quality using exploratory factor analysis. In addition, the section names latent variables verify the factor model, modifies the model structure, and sorts the above indicators as per importance. As a result, the analysis process is more scientific and appropriate. Based on actual users' experience for underground public space in Beijing, 46 factors (see Table 5-26) that influence the underground public space quality have been selected initially. Besides, the exploratory factor analysis is a technique used for finding structural relationships among multivariant observable variables to achieve dimensionality reduction.

Table 5-26. Initial indicators affecting quality of underground public space in Beijing.

| **Indicators** | | **Indicators** | | **Indicators** | |
|---|---|---|---|---|---|
| Accessibility | $x_1$ | Nature elements | $x_{17}$ | Social services | $x_{33}$ |
| Sunken open space | $x_2$ | Materials | $x_{18}$ | Cooperative | $x_{34}$ |
| Vertical entrance | $x_3$ | Furnishings | $x_{19}$ | Diverse uses | $x_{35}$ |
| Legibility | $x_4$ | Signs and maps | $x_{20}$ | Interactive | $x_{36}$ |
| Diversity integrations | $x_5$ | Art control | $x_{21}$ | Events | $x_{37}$ |
| A system of paths | $x_6$ | Nature light | $x_{22}$ | Theme sales | $x_{38}$ |
| Activities nodes | $x_7$ | Artificial lighting | $x_{23}$ | Imageability | $x_{39}$ |
| Landmarks | $x_8$ | Indirect lighting | $x_{24}$ | History and symbolic | $x_{40}$ |
| Interconnected space | $x_9$ | Escape | $x_{25}$ | Culture | $x_{41}$ |
| Distinct zones | $x_{10}$ | Disaster prevention | $x_{26}$ | Unique nature | $x_{42}$ |
| Height variation | $x_{11}$ | Surveillance | $x_{27}$ | Informational facilities | $x_{43}$ |

| | | | | | |
|---|---|---|---|---|---|
| Hierarchy | $x_{12}$ | Alarm | $x_{28}$ | Hygiene services | $x_{44}$ |
| privacy | $x_{13}$ | Fire suppression | $x_{29}$ | Rules and regulations | $x_{45}$ |
| Overlooking activity | $x_{14}$ | Air quality | $x_{30}$ | Affordability | $x_{46}$ |
| Colour | $x_{15}$ | Temperature | $x_{31}$ | | |
| Size | $x_{16}$ | Noise control | $x_{32}$ | | |

1) Determine possibility of factor analysis

The factor analysis is not applicable to all multivariable data in practice. The SPSS provides four statistical data pieces to determine whether the factor analysis applies to observable data. Those meeting the screening standards include the KOM (kaiser-meyer-olkin) measure of sampling adequacy, Bartlett test of sphericity, anti-image correlation matrix, and communalities. Based on the above determination and filtration standards, 294 pieces of data covering 46 filtration questions have been imported into the SPSS for the EFA. Meanwhile, the principal component analysis (PCA) is implemented for extracting common factors. For results see Table 5-27.

Table 5-27. Summary of factor analysis results

| Indicators | | Factor a1 | Factor a2 | Factor a3 | Factor a4 | Factor a5 | Factor a6 | Factor a7 | Factor a8 | Factor a9 | Factor a10 | Communalities c=a12+a22+…+a102 | Special factor | MSA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Landmarks | $x_{8}$ | 0.833 | -0.143 | 0.109 | 0.123 | -0.279 | -0.008 | -0.046 | -0.072 | 0.035 | -0.050 | 0.830278 | 0.17 | 0.830 |
| Height variation | $x_{11}$ | 0.832 | -0.126 | 0.115 | 0.148 | -0.307 | -0.054 | -0.042 | -0.072 | 0.004 | -0.028 | 0.848142 | 0.15 | 0.849 |
| Hierarchy | $x_{12}$ | 0.811 | -0.191 | 0.152 | 0.088 | -0.256 | -0.093 | 0.044 | 0.068 | -0.023 | -0.042 | 0.808088 | 0.19 | 0.808 |
| Overlooking activity | $x_{14}$ | 0.804 | -0.250 | 0.037 | 0.088 | -0.192 | -0.041 | -0.093 | -0.043 | -0.059 | 0.001 | 0.770554 | 0.23 | 0.771 |
| Colour | $x_{15}$ | 0.802 | -0.091 | -0.260 | -0.025 | 0.094 | -0.149 | 0.102 | -0.122 | 0.091 | 0.135 | 0.802541 | 0.20 | 0.802 |
| Art control | $x_{21}$ | 0.785 | -0.146 | -0.285 | 0.029 | 0.161 | -0.035 | 0.000 | -0.134 | -0.062 | -0.014 | 0.768749 | 0.23 | 0.768 |
| Nature elements | $x_{17}$ | 0.779 | -0.139 | -0.293 | -0.001 | 0.231 | -0.131 | 0.134 | -0.080 | -0.072 | -0.005 | 0.812099 | 0.19 | 0.812 |
| Distinct zones | $x_{10}$ | 0.776 | -0.133 | 0.161 | 0.095 | -0.287 | -0.036 | 0.045 | 0.032 | -0.024 | -0.047 | 0.74431 | 0.26 | 0.745 |
| Activities nodes | $x_{7}$ | 0.775 | -0.204 | 0.063 | 0.155 | -0.251 | 0.022 | 0.001 | -0.134 | -0.044 | 0.017 | 0.753902 | 0.25 | 0.753 |
| Hierarchy | $x_{13}$ | 0.762 | -0.218 | 0.136 | 0.066 | -0.327 | -0.061 | 0.023 | 0.094 | -0.039 | -0.121 | 0.787197 | 0.21 | 0.788 |
| History and symbolic | $x_{40}$ | 0.758 | -0.148 | 0.048 | 0.003 | 0.209 | 0.076 | -0.011 | -0.175 | -0.026 | -0.407 | 0.845309 | 0.15 | 0.845 |
| Materials | $x_{18}$ | 0.758 | -0.122 | -0.308 | -0.076 | 0.161 | -0.136 | 0.122 | -0.080 | -0.020 | 0.141 | 0.77607 | 0.22 | 0.776 |
| Culture | $x_{41}$ | 0.747 | -0.172 | 0.038 | 0.120 | 0.201 | 0.209 | -0.184 | -0.169 | -0.036 | -0.329 | 0.859473 | 0.14 | 0.860 |
| Fire suppression | $x_{39}$ | 0.746 | -0.170 | -0.038 | 0.113 | 0.217 | 0.104 | -0.140 | -0.181 | -0.044 | -0.276 | 0.788007 | 0.21 | 0.788 |
| Cooperative | $x_{34}$ | 0.744 | 0.044 | 0.074 | -0.089 | -0.002 | 0.140 | -0.261 | -0.100 | 0.191 | 0.287 | 0.785444 | 0.21 | 0.786 |
| Unique nature | $x_{42}$ | 0.736 | -0.144 | -0.026 | 0.016 | 0.306 | 0.151 | -0.191 | -0.066 | -0.117 | -0.311 | 0.831048 | 0.17 | 0.832 |
| Interactive | $x_{36}$ | 0.736 | -0.073 | 0.033 | -0.023 | 0.103 | 0.091 | -0.429 | -0.061 | 0.012 | 0.293 | 0.841288 | 0.16 | 0.842 |
| Furnishings | $x_{19}$ | 0.725 | -0.130 | -0.332 | -0.039 | 0.162 | -0.142 | 0.281 | -0.103 | -0.042 | 0.053 | 0.794821 | 0.21 | 0.795 |
| Social services | $x_{33}$ | 0.698 | 0.044 | 0.077 | -0.057 | 0.048 | 0.092 | -0.289 | -0.164 | 0.212 | 0.218 | 0.711971 | 0.29 | 0.712 |
| Diverse uses | $x_{35}$ | 0.674 | -0.052 | -0.096 | 0.004 | 0.110 | 0.113 | -0.463 | -0.049 | -0.010 | 0.314 | 0.806547 | 0.19 | 0.807 |
| Indirect lighting | $x_{24}$ | 0.662 | 0.019 | -0.148 | 0.154 | -0.017 | -0.093 | -0.160 | 0.316 | -0.354 | 0.102 | 0.754339 | 0.25 | 0.754 |
| Temperature | $x_{31}$ | 0.655 | 0.292 | -0.086 | -0.345 | -0.042 | -0.028 | -0.076 | 0.241 | 0.311 | -0.123 | 0.818965 | 0.18 | 0.820 |
| Interconnected space | $x_{9}$ | 0.652 | -0.221 | 0.154 | 0.147 | -0.346 | -0.142 | 0.128 | -0.084 | 0.238 | 0.085 | 0.746459 | 0.25 | 0.746 |
| Nature light | $x_{22}$ | 0.627 | 0.087 | -0.167 | 0.037 | -0.231 | -0.071 | -0.127 | 0.362 | -0.225 | -0.020 | 0.686556 | 0.31 | 0.687 |
| Signs and maps | $x_{20}$ | 0.613 | -0.002 | -0.387 | -0.023 | 0.186 | -0.210 | 0.327 | -0.025 | 0.075 | 0.085 | 0.725171 | 0.27 | 0.726 |
| A system of paths | $x_{6}$ | 0.607 | -0.201 | 0.292 | 0.021 | -0.314 | -0.093 | 0.305 | 0.064 | 0.288 | -0.064 | 0.785961 | 0.21 | 0.786 |
| Size | $x_{16}$ | 0.606 | -0.042 | -0.397 | -0.086 | 0.069 | -0.303 | 0.342 | -0.151 | 0.037 | 0.086 | 0.779105 | 0.22 | 0.779 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Diversity integrations | $x_{5}$ | 0.604 | -0.001 | 0.398 | 0.135 | 0.239 | 0.002 | 0.051 | 0.220 | -0.004 | 0.075 | 0.655213 | 0.34 | 0.655 |
| Noise control | $x_{32}$ | 0.600 | 0.291 | -0.162 | -0.275 | 0.102 | -0.129 | -0.188 | 0.357 | 0.230 | -0.139 | 0.808609 | 0.19 | 0.809 |
| Affordability | $x_{46}$ | 0.561 | 0.353 | 0.250 | -0.513 | -0.109 | 0.154 | 0.112 | -0.081 | -0.117 | -0.007 | 0.833439 | 0.17 | 0.834 |
| Rules and regulations | $x_{45}$ | 0.546 | 0.324 | 0.121 | -0.505 | -0.125 | 0.162 | 0.143 | -0.065 | -0.171 | 0.022 | 0.769026 | 0.23 | 0.846 |
| Sunken open space | $x_{2}$ | 0.543 | 0.012 | 0.406 | 0.060 | 0.351 | -0.023 | 0.027 | 0.183 | -0.090 | 0.069 | 0.634238 | 0.37 | 0.635 |
| Artificial lighting | $x_{23}$ | 0.532 | 0.033 | -0.248 | 0.095 | -0.170 | -0.106 | -0.036 | 0.409 | -0.353 | 0.000 | 0.687964 | 0.31 | 0.689 |
| Air quality | $x_{30}$ | 0.490 | 0.297 | -0.103 | -0.278 | 0.142 | -0.149 | -0.146 | 0.353 | 0.427 | -0.209 | 0.830502 | 0.17 | 0.830 |
| Accessibility | $x_{1}$ | 0.483 | 0.072 | 0.439 | 0.317 | 0.271 | -0.036 | 0.187 | 0.143 | -0.026 | 0.143 | 0.682963 | 0.32 | 0.683 |
| Alarm | $x_{28}$ | 0.314 | 0.790 | -0.145 | 0.232 | 0.020 | -0.042 | 0.041 | -0.008 | -0.075 | 0.025 | 0.807704 | 0.19 | 0.808 |
| Fire suppression | $x_{29}$ | 0.183 | 0.762 | -0.059 | 0.338 | -0.103 | -0.009 | -0.009 | -0.078 | -0.022 | -0.119 | 0.763358 | 0.24 | 0.764 |
| Escape | $x_{25}$ | 0.192 | 0.753 | -0.009 | 0.390 | -0.051 | -0.025 | 0.029 | -0.152 | 0.016 | -0.130 | 0.800381 | 0.20 | 0.800 |
| Surveillance | $x_{27}$ | 0.286 | 0.713 | -0.081 | 0.272 | 0.031 | 0.036 | 0.045 | 0.034 | -0.021 | 0.079 | 0.68283 | 0.32 | 0.683 |
| Disaster prevention | $x_{26}$ | 0.217 | 0.654 | -0.028 | 0.432 | -0.139 | -0.025 | -0.102 | -0.261 | 0.158 | 0.026 | 0.786324 | 0.21 | 0.786 |
| Hygiene services | $x_{44}$ | 0.428 | 0.516 | 0.074 | -0.512 | -0.130 | 0.134 | 0.089 | -0.199 | -0.214 | 0.008 | 0.845298 | 0.15 | 0.808 |
| Vertical entrance | $x_{3}$ | 0.465 | 0.003 | 0.581 | 0.020 | 0.239 | 0.103 | 0.182 | 0.024 | -0.028 | 0.035 | 0.657634 | 0.34 | 0.657 |
| Legibility | $x_{4}$ | 0.388 | 0.178 | 0.491 | 0.117 | 0.398 | -0.117 | 0.286 | 0.088 | 0.018 | 0.091 | 0.707236 | 0.29 | 0.707 |
| Informational facilities | $x_{43}$ | 0.546 | 0.281 | 0.156 | -0.582 | -0.103 | 0.108 | 0.097 | -0.126 | -0.137 | 0.038 | 0.807908 | 0.19 | 0.770 |
| Theme sales | $x_{38}$ | 0.307 | -0.105 | -0.309 | 0.138 | -0.026 | 0.770 | 0.310 | 0.174 | 0.110 | 0.049 | 0.954252 | 0.05 | 0.954 |
| Events | $x_{37}$ | 0.348 | -0.062 | -0.300 | 0.201 | -0.048 | 0.756 | 0.250 | 0.196 | 0.111 | 0.069 | 0.947187 | 0.05 | 0.947 |
| Cronbach's α | | 0.952 | 0.939 | 0.883 | 0.915 | 0.841 | 0.854 | 0.899 | 0.812 | 0.871 | 0.953 | 0.8919 | | |
| Combined reliability (CR) | | 0.9126 | 0.889 | 0.92 | 0.8974 | 0.8442 | 0.8055 | 0.7897 | 0.719 | 0.7989 | 0.9435 | 0.8519 | | |
| Average Variance Extracted, AVE | | 0.5378 | 0.5356 | 0.6974 | 0.6864 | 0.5209 | 0.5089 | 0.4858 | 0.4611 | 0.5714 | 0.8931 | 0.5898 | | |
| Characteristic value d = x12+x22 +…+x462 | | 4.839 | 3.747 | 3.488 | 2.007 | 2.605 | 2.035 | 1.945 | 1.383 | 1.715 | 1.787 | 25.551 | | |
| Variance contribution rate | | 14.847 | 11.326 | 8.360 | 7.814 | 7.491 | 7.100 | 6.848 | 5.022 | 4.966 | 4.339 | 78.112 | | |

Table 5-28. KMO and Bartlett sphericity test

| KMO Statistics | | 0.927452 |
|---|---|---|
| Bartlett Test of Sphericity | $x^2$ | 12475.001 |
| | df | 1035 |
| | Sig. | .000 |

Table 5-28 has shown that the KMO Statistics is 0.927 (the closer to 1 the better), reaching the 'Middling' level. Besides, the Barlett Test of Sphericity Sig. is 0.00 (﹤0.05). Therefore, the factor analysis is applicable to selected 46 questions in this research and the factor model can be built. MSA values of variables shown in Table 5-28 reach the adaptation determination standard (﹥0.50) so that all indicators can be retained. The intercommunity value of some questions shown in Table 3 does not reach the filtration threshold (﹤0.20), and the above indicators meet the requirements completely so that all 46 factor questions can be retained.

2) Determine the number of factors

In the exploratory factor analysis process, the predetermination criterion has been used in questionnaire design. Variables are selected as per the pre-proposed structure of factor model. Scree Plot (Figure 5-18) has shown the turning point between the 10th and 11th eigenvalues, above which the factor number represents the quantity of factors. Based on the principle that the Kaiser eigenvalue is larger than 1, there are a total of 10 factor eigenvalues in Figure 5-18 that are larger than 1. The accumulative contribution rate of variables is calculated with the formula (2). The results indicate that the accumulative contribution rate of variance reaches 78.112% when 10 factors are extracted. Hence, the factor model used for extracting 10 common factors is reliable. Based on the above four methods, the final number of common factors is determined to be 10.

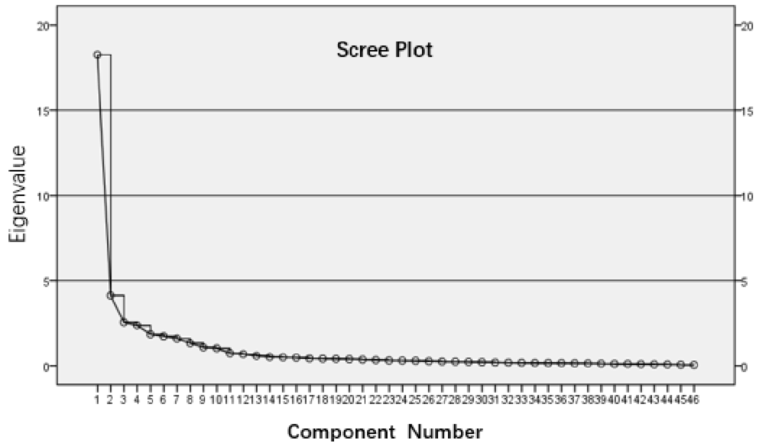



Figure 5-18. Scree Plot

3) Explanation of factor structure

Table 5-28 has shown that a load of selected factors is larger than 0.50 so that the variance of explaining indicator variables with common factors reaches over 25%. The intercommunity value of the selected 32 questions reaches over 0.20, meeting the requirements. The Cronbach's α coefficient is 0.854 for 46 questions, reaching an ideal level, and Cronbach's α coefficient for each dimension reaches over 0.60 (＞0.50), indicating high interior stability and consistency of each factor dimension, and stable factor structure. The combined reliability value is larger than 0.7, indicating stable measurement for scale reliability; and the average variance is close to the standard value 0.5, showing good explanation for corresponding latent variables with each observable variable. In summary, each common factor can be named according to included common features.

The first common factor explains 14.847% of the total variance. It is ranked as per the contribution rate of variance: interconnected space ＞ a system of paths ＞ height variation ＞ privacy ＞ landmarks ＞ hierarchy ＞ distinct zones ＞ activities nodes ＞ overlooking activity. This explains the influence of 'spatial configuration' on the quality of underground public space. Therefore, it is named as 'spatial configuration attribute'.

The second common factor explains 11.326% of the total variance. It is ranked: size ＞ signs and maps ＞ furnishings ＞ materials ＞ nature elements ＞ colour ＞ art control. This explains the influence of 'Friendly interior design' on the quality of underground public space. Therefore, it is named as 'Friendly interior design attribute'.

The third common factor explains 8.360% of the total variance. It is ranked to be: escape ＞ fire suppression ＞ disaster prevention ＞ alarm ＞ surveillance. This explains the influence of 'life safety' on the quality of underground public space. Therefore, it is named as 'life safety attribute'.

The fourth common factor explains 7.814% of the total variance. It is ranked: hygiene services > informational facilities > affordability > rules and regulations. This explains the influence of 'management' on the quality of underground public space. Therefore, it is named as 'management attribute'.

The fifth common factor explains 7.491% of the total variance. It is ranked to be legibility > accessibility > vertical entrance > sunken open space > diversity integrations, which explains the influence of 'exterior and entrance friendly design' on the quality of underground public space. Therefore, it is named as 'exterior and entrance friendly design attribute'.

The sixth common factor explains 7.100% of the total variance. It is ranked to be culture > unique nature > history and symbolic >imageability, which explains the influence of 'identity' on the quality of underground public space. Therefore, it is named as 'identity attribute'.

The seventh common factor explains 6.848% of the total variance. It is ranked to be diverse uses > interactive > cooperative > social services. This explains the influence of 'sociability' on the quality of underground public space. Therefore, it is named as 'sociability attribute'.

The eighth common factor explains 5.022% of the total variance. It is ranked to be artificial lighting > indirect lighting > nature light, which explains the influence of 'lighting' on the quality of underground public space. Therefore, it is named as 'lighting attribute'.

The ninth common factor explains 4.966% of the total variance. It is ranked: air quality ＞ noise control ＞ temperature. This explains the influence of 'comfort' on the underground public space quality. Therefore, it is named as 'comfort attribute'.

The tenth common factor explains 4.339% of the total variance. It is ranked to be theme sales ＞ events, which explains the influence of 'activity type' on the quality of underground public space. Therefore, it is named as 'activities attribute'.

The above named 10 common factors are ranked as per the average score (see Table 5-29), being spatial configuration ＞ Friendly interior design ＞ life safety ＞ management ＞ exterior and entrance friendly design ＞ identity ＞ sociability ＞ lighting ＞ user comfort ＞ activities. It can be considered as the order of the influence of quality system indicators for underground public space around Beijing's metro stations.

Table 5-29. Ranking of the influence degree of underground public space quality system indicators

| Objective | Attributes | | Indicator | |
|---|---|---|---|---|
| The indicators of underground public space quality | 1 | Spatial configuration | 1 | Interconnected space |
| | | | 2 | A system of paths |
| | | | 3 | Height variation |
| | | | 4 | privacy |
| | | | 5 | Landmarks |

| | | | | |
|---|---|---|---|---|
| | | | 6 | Hierarchy |
| | | | 7 | Distinct zones |
| | | | 8 | Activities nodes |
| | | | 9 | Overlooking activity |
| | 2 | Friendly interior design | 10 | Size |
| | | | 11 | Signs and maps |
| | | | 12 | Furnishings |
| | | | 13 | Materials |
| | | | 14 | Nature elements |
| | | | 15 | Colour |
| | | | 16 | Art control |
| | 3 | Life safety | 17 | Escape |
| | | | 18 | Fire suppression |
| | | | 19 | Disaster prevention |
| | | | 20 | Alarm |
| | | | 21 | Surveillance |
| | 4 | Management | 22 | Hygiene services |
| | | | 23 | Informational facilities |
| | | | 24 | Affordability |
| | | | 25 | Rules and regulations |
| | 5 | Exterior and entrance friendly design | 26 | Legibility |
| | | | 27 | Accessibility |
| | | | 28 | Vertical entrance |
| | | | 29 | Sunken open space |
| | | | 30 | Diversity integrations |
| | 6 | Identity | 31 | Culture |
| | | | 32 | Unique nature |
| | | | 33 | History and symbolic |
| | | | 34 | Imageability |
| | 7 | Sociability | 35 | Diverse uses |
| | | | 36 | Interactive |
| | | | 37 | Cooperative |
| | | | 38 | Social services |
| | 8 | Lighting | 39 | Artificial lighting |
| | | | 40 | Indirect lighting |
| | | | 41 | Nature light |
| | 9 | User comfort | 42 | Air quality |
| | | | 43 | Noise control |
| | | | 44 | Temperature |
| | 10 | Activities | 45 | Theme sales |
| | | | 46 | Events |

#### 5.2.5.2 Confirmatory factor analysis

The confirmatory factor analysis (CFA) is used to verify whether the known specific structure plays its role in the expected mode. According to CFA results, there are 10 ($\xi 1$ — $\xi 10$) latent variables that influence the quality of underground public space and consist of 46 tested questions. As a result, the theoretical quality evaluation model for underground public space is built. The 294 pieces of data are used as test samples and imported in the AMOS to build the structural equation modelling (SEM). Figure 5-19 has shown the calculation results. Each fitting indicator can reach the threshold by continuously modifying the structure of the factor model.

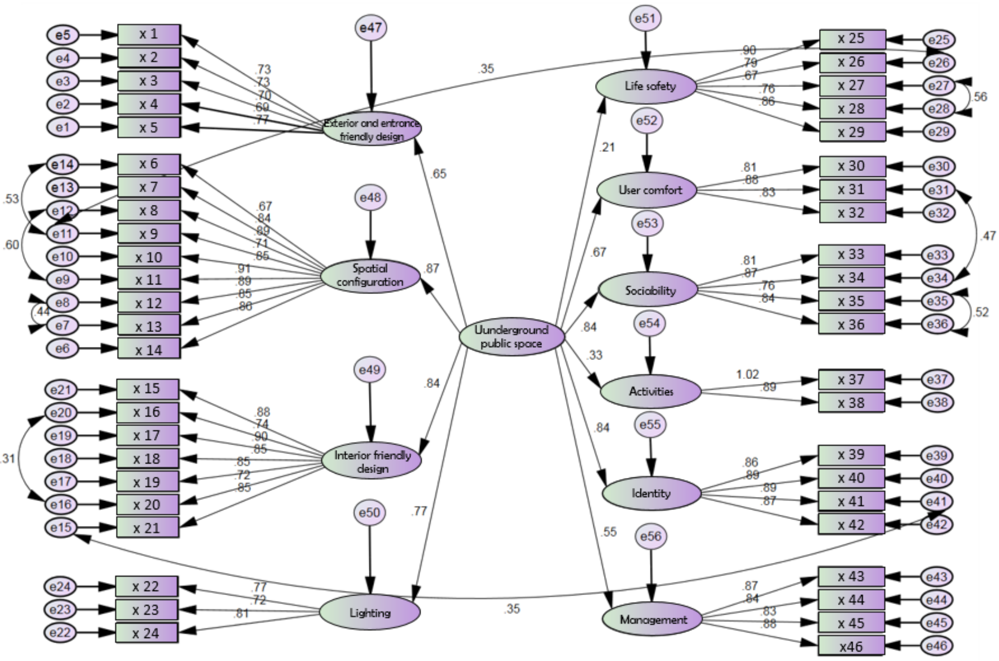



Figure 5-19. Parameter estimation of the process model

Table 5-30. SEM global fitting index

| Fit indices | Absolute fit index | | | comparative fit index | | | Simplify the fitting index | | |
|---|---|---|---|---|---|---|---|---|---|
| | x2/df | GFI | RMSEA | IFI | CFI | RFI | NFI | PNFI | PGFI |
| Ideal value | 1～ 3 | ＞0.90 | ＜0.06 | ＞ 0.90 | ＞ 0.90 | ＞ 0.90 | ＞ 0.90 | ＞0.50 | ＞0.50 |
| Presumptive models | 2.718 | 0.711 | 0.077 | 0.862 | 0.862 | 0.787 | 0.798 | 0.755 | 0.644 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Modified model | 1.859 | 0.807 | 0.54 | 0.934 | 0.934 | 0.854 | 0.868 | 0.786 | 0.7 |
| 0.7 is an acceptable threshold (Hair, 1997) and its proposed value is over 0.6 (Fornell and Larcker, 1981). However, most of scholars have used following classification method (Kline, 1998), where it is optimal when the reliability coefficient is over 0.9; it is great when the reliability coefficient is about 0.8; it is appropriate when the reliability coefficient is about 0.7; and the minimum acceptable value is above 0.5. If the reliability value is lower than 0.5, over a half of observable variations result from random error. | | | | | | | | | |

Comparing the ideal value and the hypothesis model in table 4 shows that the original model still has room for correction. The fine-tuning of the original model based on the rationality of interpretation. It has mainly reflected the correlation between the measurement error I of the observation index of an exogenous latent variable. The overall SEM fitting index has further improved (Figure 5-19), and then basically reached the threshold of each index. The value in figure 2 is the path coefficient, which is used to measure the correlation between variables or the effect value between variables. Indirect effect divided into direct effect, indirect effect and total effect. The weight of system indicators has calculated through the analysis of the data results (see Table 5-31 below).

Table 5-31. The weighting for quality of underground public space Indicators by CFA

| Objective | Attributes | | Weight | Indicator | | Weight |
|---|---|---|---|---|---|---|
| The indicators of quality underground public space | 1 | Spatial configuration | 0.2 | 1 | Interconnected space | 0.025 |
| | | | | 2 | A system of paths | 0.022 |
| | | | | 3 | Height variation | 0.013 |
| | | | | 4 | privacy | 0.023 |
| | | | | 5 | Landmarks | 0.024 |
| | | | | 6 | Hierarchy | 0.025 |
| | | | | 7 | Distinct zones | 0.025 |
| | | | | 8 | Activities nodes | 0.023 |
| | | | | 9 | Overlooking activity | 0.02 |
| | 2 | Friendly interior design | 0.222 | 10 | Size | 0.025 |
| | | | | 11 | Signs and maps | 0.036 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | | 12 | Furnishings | 0.037 |
| | | | | 13 | Materials | 0.034 |
| | | | | 14 | Nature elements | 0.034 |
| | | | | 15 | Colour | 0.015 |
| | | | | 16 | Art control | 0.041 |
| | 3 | Life safety | 0.124 | 17 | Escape | 0.028 |
| | | | | 18 | Fire suppression | 0.019 |
| | | | | 19 | Disaster prevention | 0.028 |
| | | | | 20 | Alarm | 0.019 |
| | | | | 21 | Surveillance | 0.03 |
| | 4 | Management | 0.115 | 22 | Hygiene services | 0.018 |
| | | | | 23 | Informational facilities | 0.015 |
| | | | | 24 | Affordability | 0.038 |
| | | | | 25 | Rules and regulations | 0.044 |
| | 5 | Exterior and entrance friendly design | 0.084 | 26 | Legibility | 0.012 |
| | | | | 27 | Accessibility | 0.009 |
| | | | | 28 | Vertical entrance | 0.021 |
| | | | | 29 | Sunken open space | 0.021 |
| | | | | 30 | Diversity integrations | 0.021 |
| | 6 | Identity | 0.057 | 31 | Culture | 0.02 |
| | | | | 32 | Unique nature | 0.002 |
| | | | | 33 | History and symbolic | 0.02 |
| | | | | 34 | Imageability | 0.015 |
| | 7 | Sociability | 0.007 | 35 | Diverse uses | 0.002 |
| | | | | 36 | Interactive | 0.002 |
| | | | | 37 | Cooperative | 0.001 |
| | | | | 38 | Social services | 0.002 |
| | 8 | Lighting | 0.101 | 39 | Artificial lighting | 0.044 |
| | | | | 40 | Indirect lighting | 0.025 |
| | | | | 41 | Nature light | 0.032 |
| | 9 | User comfort | 0.054 | 42 | Air quality | 0.019 |
| | | | | 43 | Noise control | 0.022 |
| | | | | 44 | Temperature | 0.013 |
| | 10 | Activities | 0.037 | 45 | Theme sales | 0.019 |
| | | | | 46 | Events | 0.018 |

## 5.3 Evaluation indicator framework

An original and holistic conceptual underground public space framework has been proposed based on extensive literature review and the perceived spatial space, functional and operational complexity, and hybrid characteristics of emerging urban spatial types. Through the expert interview, user experience, and exploratory factor analysis, the author could filter and supplement the index, combining with urban underground space and public space characteristics. The research framework has been established to include exterior connection, space safety, interior environment, and operation. In total, the quality evaluation indicator system of city underground public space has 10 attributes and 46 secondary indicators (See Table 5-32).

Table 5-32. Underground public space quality system indicators

| Objective | Attributes | | Indicator | |
|---|---|---|---|---|
| The indicators of underground public space quality | 1 | Friendly interior design | 1 | Size |
| | | | 2 | Signs and maps |
| | | | 3 | Furnishings |
| | | | 4 | Materials |
| | | | 5 | Nature elements |
| | | | 6 | Colour |
| | | | 7 | Art control |
| | 2 | Spatial configuration | 8 | Interconnected space |
| | | | 9 | A system of paths |
| | | | 10 | Height variation |
| | | | 11 | privacy |
| | | | 12 | Landmarks |
| | | | 13 | Hierarchy |
| | | | 14 | Distinct zones |
| | | | 15 | Activities nodes |
| | | | 16 | Overlooking activity |
| | 3 | Life safety | 17 | Escape |
| | | | 18 | Fire suppression |
| | | | 19 | Disaster prevention |
| | | | 20 | Alarm |
| | | | 21 | Surveillance |
| | 4 | Management | 22 | Hygiene services |
| | | | 23 | Informational facilities |
| | | | 24 | Affordability |
| | | | 25 | Rules and regulations |
| | 5 | Lighting | 26 | Artificial lighting |
| | | | 27 | Indirect lighting |
| | | | 28 | Nature light |
| | 6 | Exterior and entrance friendly design | 29 | Legibility |
| | | | 30 | Accessibility |
| | | | 31 | Vertical entrance |
| | | | 32 | Sunken open space |
| | | | 33 | Diversity integrations |
| | 7 | Identity | 34 | Culture |
| | | | 35 | Unique nature |
| | | | 36 | History and symbolic |
| | | | 37 | Imageability |
| | 8 | User comfort | 38 | Air quality |

| | | | | |
|---|---|---|---|---|
| | | | 39 | Noise control |
| | | | 40 | Temperature |
| | 9 | Activities | 41 | Theme sales |
| | | | 42 | Events |
| | 10 | Sociability | 43 | Diverse uses |
| | | | 44 | Interactive |
| | | | 45 | Cooperative |
| | | | 46 | Social services |

## 5.4 Indicators of underground public space quality

This section will explain the content of the assessment indicators. The potential benefits of the implementation of the elements have summarised from relevant literature reviews and research results. The author selected design specifications from this research survey and developed specific evaluation criteria and precautions. Indicators should not be interpreted in isolation but should be understood as intertwined elements that constitute urban space quality. Most urban underground public space quality and design principles are particularly relevant to design practitioners, and urban designers directly influence few principles.

A. Friendly interior design

1) Size

- Reasons and considerations:

With no other influencing factors, people prefer broad roads (Zacharias, 2002).

The broad roads can be viewed as the road signs, helping people locate themselves (Xing, 2015b).

The narrow space at the metro station, particularly the narrow stairway and passages, hinders emergency evacuation and indirectly increases fire casualty (Zhang, 2013).

The plane dimensions of the public space include the width and length. For the linear space, width is more important than length, and for the dotted space, width and length are equally important.

The dimensions refer to not only the measurements of the space but also the ratio between them. There are both horizontal and vertical space dimensions. Different measurements bring about a different effect on the underground public space. It is noteworthy that the dimensions include the measurements of the space and the ratio between them. Similar to absolute measurements, the relative measurements are crucial to the public space (Tang, 2013). The low storey height in the underground space can be depressing. However, it can be costly if the storey height is too large. A proper height should be decided based on the actual needs, striking a balance between the underground space effect and the investment.

- Evaluation indicators and measures:

a. Provide adequate underground space dimensions that meet the traffic needs based on space types.

b. Provide proper height-width ratios.

c. Linear space

For the passages with stores on both sides, a 2.5m width can accommodate 4 to 5 streams of people if each stream is 500mm to 600mm wide. During the workdays, the width can accommodate shoppers' traffic, but on the weekends when there are more shoppers, it can be crowded. For the passages with counters on both sides and the passing shoppers, the 2.5m width should accommodate the consumers buying items in front of the counters as well. If the distance between the consumers and the counters is 450mm, then the 2.5m-wide passage can accommodate three streams only, which is far behind the needs during the peak hours on the weekends, or even during the weekdays with the regular consumer size.

For the passages with counters on both sides, if the distance between the consumers and the counter is 450mm, the width of the passing consumer stream is 600mm, and the number of the passing stream is represented by n, then the width of the passage should be W=2*450+60*n; and for the passages with stores on both sides, W=600*n. Therefore, the design should be based on the accurate prediction of the consumer size. Space can be crowded or unsafe if the passages are not wide enough. An extra amount of space should be reserved based on the formula to create a pleasant shopping environment.

d. Dotted or plane space

The dotted space exits as nodes in the underground public space. Functions are the major determinants of the dimensions of the dotted space. If the courtyard serves the ornamental purposes only (i.e., there are only fountains, sculptures and stairways), the dimensions are usually small. The dotted space that accommodates a spiral stair in some shopping malls often has a semi-diameter of 9m. The overall semi-diameter of the stair is often about 5m. The designers leave a passing space of 4m surrounding the stair, making the space less crowded. If the courtyard needs to accommodate exhibitions, stages, or the resting space, the nodes' dimensions should be larger. For instance, the Nanjing Aqua City courtyard includes an aqua stage, an audience area, and the passing space. The semi-diameter of the courtyard is about 15m, and the aqua stage is about 4.5m. The widths of the audience area and the passing space is 6m and 4.5m respectively. The zones are divided naturally with proper dimensions.

e. Height-width ratio and space enclosure

According to Spreiregen and Ashihara Yoshinobu (2001), the space enclosure is strong when the ratio between the height of the objects and the viewing distance is 1:1, i.e. the height-width ratio is 1:2, and the angle between the horizontal sight and the top edge is 45°. The space enclosure is weaker when the ratio between the height of the objects and the viewing distance is 1:2, i.e. the height-width ratio is 1:4, and the angle between the horizontal sight and the top edge is 30°. The space enclosure is the weakest when the ratio between the height of the objects and the viewing distance is 1:3, i.e. the height-width ratio is 1:6, and the angle between the horizontal sight and the top edge is 18°. The space enclosure is at a minimum when the ratio between the objects' height and the viewing distance is 1:4 or less.

Vertically, the sight range of human eyes is 130°, 55° upwards and 75° downwards. In other words, the comfortable vertical sight range is limited. In the shopping space, useful information should be displayed within this range to attract the shoppers' attention.

Table 5-33. Size evaluation measures scoring

| Level | Score | Explanation |
|---|---|---|
| Good | 5 | Comfortable width and height, and the aspect ratio gives a feeling of safety. |
| Satisfactory | 3 | Meet underground building design requirements |
| Need Improvement | 1 | No conditions available |

2) Signs and maps

- Reasons and considerations:

The signage system in the underground public space can be classified into the traffic signs and ad signs, with the former being particularly important (Liu, 2006).

With the 'signage system', we can learn about the information on the site and the directions. There are also space reminders, which guide the directions or provide the information on a site's location.

Graphic guide: The graphics are a symbol system that conveys accurate information. There are different types of signage graphics in the economic and cultural sectors, such as prohibition, restriction and direction. The graphics are often creative, clear, recognisable, simple and appropriately coloured. The graphic guides can be found at the horizontal and vertical evacuation sites, the emergency exits and the special space. The legal and habitual use of the signs must be followed.

- Evaluation indicators and measures:

Unlike the traditional maps, the guide maps are neither portable nor suitable for a long time studying. They provide the surrounding information. The contents of the guide maps for different sites vary. The guide maps for the underground space are distinctive in the following ways.

Directions: The directions in the guide maps are consistent with reality. The direction that the users face is the right above direction in the maps.

Contents: The guide maps are often on the information signboards at the entrance of the underground space. The destination is often marked, telling the user his or her location.

The guide maps are often based on space's general layout, marking the entrance and exits, the facilities inside (such as the washing rooms and the emergency facilities), the landmarks, and the public transportation system nearby. Before entering the underground space, the user would obtain a basic idea about the space, and the turns and intersections they will encounter, thus avoiding getting lost in the underground passages.

The vertical passages are also marked on the map, including the stairways, the lifts, and the escalators. This information is crucial for the senior or the disabled because not every entrance & exit has barrier-free facilities.

Representation: In the multi-floor underground space, the 3D maps are replacing the traditional 2D guide maps. For example, some metro stations are the intersections of several lines. Some metro lines run below the newly built large traffic hubs. Multi-floor underground traffic space can be found in these areas. At the Xi'an North Railway Station, the passengers can access the metro station directly after getting out from the railway station, achieving the seamless connection between the railways and the urban rail system.

In all underground public facilities, provide a clear, complete system of signs and maps (Arthur and Passini, 1992).

a. The signs pertaining to wayfinding must be visually accessible from relevant circulation routes.

b. The signs must have consistent design features can be easily recognised, particularly in complex sites.

c. Maps must be visually accessible from relevant circulation routes.

d. Well-known terms should be used.

e. Maps must be aligned with the surroundings, so people do not have to make complicated mental rotations to orient themselves.

f. The information must be packaged according to content.

g. Maps should not be overly complicated.

Maps should emphasise the key recognisable elements that contribute to forming a strong image of the facility: key paths, activity nodes, landmarks, zones, and the overall boundaries of the building.

Table 5-34. Signs and maps Evaluation measures scoring

| Level | Score | Explanation |
|---|---|---|
| Good | 5 | Meet all requirements |
| Satisfactory | 3 | Meet a,b,c,d,e, requirements |
| Need Improvement | 1 | Meet some requirements but have defects |

3) Furnishings

Reasons and considerations: In this study, the furnishings refer to all objects that serve one or other functions at the metro station. The study focuses on the location of the furnishings: would they hinder escape, sight or monitoring. The objects that are larger than the human body can be used as a shelter. The furnishings discussed in this section include the seats, trash cans, information boards and phone charging facilities, etc.

The furnishings' arrangement and design quality decide the appeal and comfort (Wang, 2008a). The furnishings can create a special space or atmosphere attractive to the customers (Xing, 2015b). The shoppers would then get interested in the courtyard. Many people chat, rest or take photos here when it is not raining.

- Evaluation indicators and measures:

Select furnishings that are not massive in design with materials and colours that provide warmth, texture, a sense of quality, and association with nature (Carmody and Sterling, 1993).

a. Provide sufficient formal seating amenities.

b. Provide sufficient informal seating amenities.

c. Provide a rubbish bin of sufficient density (according to each rubbish bin's service radius is about 10m~20m, equivalent to the set interval of about 20m~40m).

d. Furniture with other service features added as appropriate.

The furnishings in the underground public space should be reasonably designed, functional and user-friendly. They should be reasonable in use, style, price and technology. The furnishings should serve the public. Also, cultural backgrounds should be taken into consideration when the public resting facilities are designed. Users should always be put first.

Table 5-35. Furnishings evaluation measures scoring

| Level | Score | Explanation |
|---|---|---|
| Good | 5 | Meet all requirements<br>a. Provide sufficient formal seating amenities.<br>b. Provide sufficient informal seating amenities.<br>c. Provide a bin of sufficient density which setting interval of about 20m~40m.<br>d. Furniture with other service features added as appropriate. |
| Satisfactory | 3 | Provide sufficient formal seating amenities and it provided bins |
| Need Improvement | 1 | Meet some requirements but have defects |

4) Materials

- Reasons and considerations:

According to Carmody (1993), natural materials help create a positive underground environment. Nevertheless, few natural materials are used in the underground stations in the Netherlands. Colours, space rations and measurements affect space evaluation. Colours are meaningless in themselves, but they play a significant role when being applied in the space. The light colours make the space look spacious, and warm colours help people forget coldness and humidity (Carmody, 1993).

Brightness is not the sole determinant of the visibility, which largely depends on the material's properties and colours on the surface. The reflective materials, such as tiles and stainless steel, make the space brighter. It is not sufficient to provide the designers with the illuminance information only. The general perception about the space depends on other factors such as the materials' properties and colours on the surface.

- Evaluation indicators and measures:

a. Provide the materials with better fire-resistant performance

b. Provide the skid-proof flooring

c. Provide the water, damp and mildew proof materials

d. Provide sound isolation and absorption materials

e. Provide the natural materials that are in harmony with the overall hue of the space.

The local materials should be used to enclose the underground public space, meet the functional, aesthetic, and cultural needs. The materials used are a key component of the interior environment. An optimal decision should be made based on the overall conditions.

Table 5-36. Materials evaluation measures scoring

| Level | Score | Explanation |
|---|---|---|
| Good | 5 | Meet all requirements |
| Satisfactory | 3 | Meet a,b,c requirements |
| Need Improvement | 1 | Meet some requirements but have defects |

5) Nature elements

- Reasons and considerations:

One study concludes that plants made a significant contribution to the perceived quality of space (Laviana et al., 1983). While they had a positive influence on people's evaluation of the interior environment, they did not appear to affect the perception of spaciousness, nor did they affect thermal comfort (Greenhall, 1982).

The introduction of the landscapes on the ground is another way to overcome the fear for the underground public space. Human beings have been symbiotic with nature since ancient times (Zhang, 2013). They are willing to approach nature in physically and psychologically. This suggests that the appropriate introduction of some ecological landscape design would help design the underground space environment. Such an approach would allow a closer relationship between people and underground space, eliminate the sense of rigidity, and create an underground public space that is closer to nature and suitable for people to stay.

Green plants not only beautify the environment but also eliminate tension and depression. Moreover, green plants can also produce oxygen under photosynthesis, which has a certain mitigation effect on the unfavourable gases generated by the underground space we mentioned earlier. At the same time, green plants can also absorb harmful substances in the air, such as building materials, smoke from smoking, air conditioners. Due to underground space limitations, we should try to choose plants adaptive to partial or full shades and easy cultivation. The green plants can be combined with underground light sources to achieve better environmental effects.

- Evaluation indicators and measures:

a. Introduce plants to the underground public space

b. Introduce natural elements, such as water, stones and wood, into the node space

c. Introduce natural materials, such as stones and wood

Use natural elements and materials in underground spaces to create visual stimulation, warmth, and a feeling of quality and evoke associations with the natural world. Green plants, pools and fountains of water and materials such as wood or stone are effective.

Table 5-37. Nature elements evaluation measures scoring

| Level | Score | Explanation |
|---|---|---|
| Good | 5 | Meet all requirements |
| Satisfactory | 3 | Meet a or b or c requirements |
| Need Improvement | 1 | No conditions available |

6) Colour

- Reasons and considerations:

Colour is a powerful element in interior design that can affect the overall attractiveness and acceptability of an environment (Carmody and Sterling, 1993) Colours are the most direct visual elements to perceive the world, much more direct than graphics, texts and numbers (Zhang, 2013). The proper colour matching makes one feel pleasant, warm, cosy, safe and less confining (Shu, 2015a). The colours in the space give people the sense about the volume, temperature, weight and distance. Therefore, the proper colour matching helps create an underground public space that serves different purposes (Xing, 2015b).

In the underground space where the colour is natural and harmonious, it is more likely to make people feel the environment's elegance (Shu, 2015a). Some underground space places present people with negative impressions such as narrowness, darkness, occlusion, and unsanitariness. This view was reconfirmed in the author's survey of users. Therefore, the design should be based on warm colours, bringing people a feeling of being warm and arid. For example, the dark and light colour contrasts can highlight the shape and outline of the underground space. The impression of the space can be heightened through the contrast in lights. It can also use coloured lights to distinguish different underground areas, which increases its interest, and alleviate the unfavourable conditions of the underground space.

- Evaluation indicators and measures:

Use colour to provide visual stimulation, warmth, and to enhance spaciousness in the underground environment. Each project architectural type has a family of colours, materials, and special features that should be used to create nagging atmospheres and elevate everyone's experience.

a. The colour match of the underground public space should be in line with the general hue's requirements.

b. The colour combination should be appropriate and pleasant.

Table 5-38. Colour evaluation measures scoring

| Level | Score | Explanation |
| --- | --- | --- |
| Good | 5 | Meet all requirements |
| Satisfactory | 3 | Meet a requirements |
| Need Improvement | 1 | Meet some requirements but have defects |

7) Art control

- Reasons and considerations:

The art elements should be introduced to the underground space, changing the cold and dull atmosphere and improving the space quality (Su, 2008b).

The underground public space with a wealth of art and cultural programmes can transform the underground space's ambience. Such space can also improve people's impression of the underground space, and contribute to the network's design legacy.

The decoration of the metros and metro stations in Stockholm is world-renowned, known as the world's longest art corridor. The metro line is 108km long, the longest metro network in the world. One can find the sculptures, murals, oil paintings, installation arts, inscriptions, and reliefs from the 1950s to the 21st Century in the network. The colours of the caves at each station are different. The passengers can enjoy the works by different artists at over 100 stations (Shangguan, 2017).

- Evaluation indicators and measures:

a. Introduce the unique artworks in the design

b. Artworks should be an integral part of the public space design

Table 5-39. Art control evaluation measures scoring

| Level | Score | Explanation |
|---|---|---|
| Good | 5 | Meet all requirements |
| Satisfactory | 3 | Meet some requirements but have defects |
| Need Improvement | 1 | No conditions available |

B. Spatial configuration

The spatial configuration is a critical component in the underground public space's quality assessment system and one of the key areas that the users care the most. It addressed the overall facility plan, the circulation system, the arrangement, connectivity, and shape of spaces within the facility. Interconnected space, a system of paths, height variation, privacy, landmarks, hierarchy, distinct zones, activities nodes, and overlooking activity are all included(van der Hoeven and Juchnevic, 2016).

8) Interconnected space

Reasons and considerations:

The connection between the underground traffic system and the commercial space facilitates the movement among different destinations (Xing, 2015b). The Xujiahui Station on Shanghai Metro Line 1 is connected to the shopping malls nearby, better guiding the population flow between the shopping malls and the metro stations. The connection between the underground space and the metro stations in Hong Kong is excellent. The underground transit stations and traffic hubs improve accessibility (Jiang, 2014).

Evaluation indicators:

**Connection** can be established in 4 ways.

a. Passages: connect the underground space with the metro stations with one or more underground passages, including the pedestrian passages and commercial facilities on both sides.

b. Shared walls: connect the underground space with the metro stations with the doors on the shared underground enclosure walls.

c. Sunken open space.

d. Lifts, escalators, stairways and slopes.

Connect the underground public space with the metro stations and other public traffic facilities nearby, including the large-and-medium public transportation hubs, ferry stations, long-distance passenger stations, railway stations and airports. Connect the underground public space with the parking space and shopping malls nearby. Connect the underground public space with the nearby cultural and entertainment facilities, such as the underground gyms, exhibition halls, and libraries. Connect the underground public space with the civil air defence facilities nearby(van der Hoeven and van Nes, 2014).

Table 5-40. Interconnected space evaluation measures scoring

| Level | Score | Explanation |
|---|---|---|
| Good | 5 | Contains more than one connection methods and is active |
| Satisfactory | 3 | One connection method and is active |
| Need Improvement | 1 | Possibility of not having any connections |

9) A system of paths

- Reasons and considerations:

The connection with the external space perfects the urban network and enlivens the city (Jacobs, 1992; Carmona, 2012). Connections increase the chance of accidental encounters and social interactions (Carmona, 2010; Jacobs, 1961). Connect people with the destinations with proper time and energy cost and arouse the visual interest in the whole network; no barriers;

safe; and pleasant for pedestrians with the pedestrian facilities being readily available (Forsyth and Southworth, 2008).

- Evaluation indicators:

a. No crossings among the metro station paths.

b. The walking distance should be as short as possible in the passages that serve one function only.

c. Get direct and safe connections to the exits and buildings aboveground.

d. Connect the internal space underground.

e. The underground public space should not be isolated but connected into a bigger network by the space nodes, thus encouraging the pedestrians to use the underground space and serve key purposes.

f. The direct connection to the most important route in the space aboveground should be established, avoiding winding and complicated passages. A sound network should be established within the underground public space.

g. The walking distance between the metro station and the next destination should be no more than 400m.

h. Provide functions such as retailing, service and entertainment within walking distance.

Table 5-41. A system of paths evaluation measures scoring

| Level | Score | Explanation |
|---|---|---|
| Good | 5 | The distance to the next destination from the metro station should not exceed 400m, and there are mixed functions within the walking distance of the station, including retail, service and entertainment. |
| Satisfactory | 3 | The distance to the next destination from the metro station should not exceed 400m |
| Need Improvement | 1 | The distance from the metro station to the next destination is more than 400m, and there is no other function within the walking distance of the station. |

10) Height variation

- Reasons and considerations:

Increased ceiling height is sometimes utilised to enhance feelings of spaciousness in an underground facility (Carmody and Sterling, 1993). Changing floor levels can differentiate interior space much like changing ceiling height, resulting in a more complex and more spacious environment.

Height dimensions are more often overestimated than horizontal dimensions, which implies that increasing the ceiling height in a room will impact perceived spaciousness that is greater than a similar increase in other room dimensions (Menchikoff, 1975).

Savinar has found that increased ceiling height reduced crowding feelings even though floor space remained constant (Savinar, 1975).

- Evaluation indicators:

a. Increase the indoor space height by changing the shapes of the ceilings in the underground space

b. Lower the ground to increase the indoor space height of the underground space

c. The space height has a significant impact on user experience. On the one hand, the absolute height can be depressing if it is too small, or unfriendly if too large. On the other hand, the attraction between the ceilings and the ground is smaller if the room height ratio and the room area are larger; vice versa

d. The minimal absolute indoor height should be no less than 2.2m.

e. There should be height variations in some parts.

Table 5-42. Height variation evaluation measures scoring

| Level | Score | Explanation |
|---|---|---|
| Good | 5 | The shortest space in the room should be suitable for people to lift their hands without touching the ceiling. It should be no less than 2.2m, and there is a height change in the local space. |
| Satisfactory | 3 | The shortest space in the room should be suitable for people to lift their hands without touching the ceiling. It should be no less than 2.2m |
| Need Improvement | 1 | The shortest space in the room is less than 2.2m |

11) Privacy

Reasons and considerations:

Lining public corridors and lobbies with windows looking into more private spaces will result in unacceptable visual exposure (Heerwagen and Orians, 1990).

The open seats encourage social interactions while the inward space protects privacy (Cho et al., 2015).

The semi-transparent and / or movable filters, such as the low-and-medium plants, semi-transparent walls and fences, rocks and fountains protect privacy on the one hand and encourages social interactions on the other.

Evaluation indicators:

a. Provide open and inward seats.

b. Provide movable filters to create physical or visual barriers.

c. The seat arrangements should encourage social interactions at different levels (Carr et al., 1992)

d. Provide inward and outward seats at different locations; introduce movable filters to the centres or private spaces (Marcus & Francis, 1997). Connect the seats, plants, building facades and the scalable facilities (such as the window blinds or curtains).

e. Provide movable filters to create physical or visual barriers, such as window blinds, low-and-medium plants, semi-transparent walls and fences, rocks and fountains.

f. Provide open and inward seats.

Table 5-43. Privacy evaluation measures scoring

| Level | Score | Explanation |
|---|---|---|
| Good | 5 | Provides an adjustable filter to create physical or visual obstacles and provides an exposed seating arrangement for people to view and an inward-looking layout. |
| Satisfactory | 3 | Provides an adjustable filter to create physical or visual obstacles |
| Need Improvement | 1 | Adjustable filters are not available to create physical or visual impairments. |

12) Landmarks

- Reasons and considerations:

Landmarks serve as a point of reference to orientate in space and thus enhance legibility (Hirtle, 2008; Lynch, 1960).

Landmarks contribute to the aesthetic quality and identity of urban space (Lynch, 1960).

- Evaluation indicators:

a. Introduce landmarks to the node space.

b. Provide diverse landmarks.

The visual landmarks can be any physical nodes, objects or structures that are significantly different from the rest of the space, helping navigate the users with the distinctive visual features. They can be the monuments, sculptures, fountains, trees, signs or visual displays distinctive in appearances, shapes, materials, colours and proportions. For the entire environment, the development itself can be counted as a landmark.

Table 5-44. Landmarks evaluation measures scoring

| Level | | Score | Explanation |
|---|---|---|---|
| Good | | 5 | Provides landmarks that are identifiable at the spatial node, and more than one form |
| Satisfactory | | 3 | Provides landmarks that are identifiable at the spatial node |
| Need Improvement | | 1 | There are no landmarks in the space that can form an impression. |

13) Hierarchy

- Reasons and considerations:

The underground space can be as deep as 50m. Hierarchical development thus becomes a plan requirement (Kong, 2006).

Underground space utilisation should focus on comprehensive development, hierarchical development and functional facility improvement (Ni, 2006).

Communities are no longer confined to shapes. They are a multi-layered zone that overlaps the walking area (Wu, 2014).

Hierarchical development is the reflection of sustainable development of the underground space. The underground space is layered by functions; development needs at different stages should be taken into consideration, achieving the coordination between the existing facilities and the newly built ones (Zhang, 2006).

- Evaluation indicators:

a. Separate people from goods

b. Separate the functions

Table 5-45. Hierarchy evaluation measures scoring

| Level | Score | Explanation |
|---|---|---|
| Good | 5 | The hierarchical design of underground public space should be separated from people and goods. And it should be differentiated. |
| Satisfactory | 3 | The hierarchical design of underground public space should be separated from people and good. |
| Need Improvement | 1 | There is no layered design in the underground public space, and it is impossible to separate people and goods. |

14) Distinct zones

Reasons and considerations:

Districts as one of the key elements that enhance the ability to form mental images and thus improve orientation and wayfinding (Lynch, 1960).

Within large underground facilities, create zones of distinct character to enhance orientation and provide a more stimulating interior environment (Carmody and Sterling, 1993).

Make reasonable use of the underground space, coordinate with the existing buildings nearby, define the function division, and implement efficient management (Li, 2012).

Evaluation indicators:

a. The zones should have meaningful names and clear boundaries with identifiable gateways or entrance transitions.

b. Separate different function zones with diverse design approaches, such as the height variation, plants, or the natural boundaries.

Table 5-46. Distinct zones evaluation measures scoring

| Level | Score | Explanation |
|---|---|---|
| Good | 5 | Zones have meaningful names and clear boundaries with identifiable gateways or entrance transitions. İn addition, possibility of providing a variety of design techniques to achieve the definition and separation between different functional partitions in the underground public space |
| Satisfactory | 3 | Zones have meaningful names and clear boundaries with identifiable gateways or entrance transitions. |
| Need Improvement | 1 | Cannot provide any space partitioning possibilities |

15) Activities nodes

Reasons and considerations:

The activity nodes enhance self-supervision and safety, deterring criminal intentions (Carmody and Sterling, 1993).

Different activities cater to the varied interests of the users and create attractive environments. The activity nodes encourage spontaneous activities and interactions.

The visibility of the activity nodes encourages the users to join in or exit the activities (Cho et al., 2015).

Evaluation indicators and measures:

a. Provide diverse activity nodes

b. Make the activity nodes visible

c. Make the major activity nodes recognisable

The largest distance between the activity nodes is 300m (Alexander and colleagues, 1987). The activity nodes should be established in the underground public space. The hierarchy and structure of the nodes are important. They should allow the users to view the activities in the space directly.

Table 5-47. Activities nodes evaluation measures scoring

| Level | Score | Explanation |
|---|---|---|

| | | |
|---|---|---|
| Good | 5 | At the same time, the diversity of the active nodes is provided, the active nodes are visible, and the main active nodes can be easily identified. |
| Satisfactory | 3 | Can provide at least 1 condition from above |
| Need Improvement | 1 | No conditions available |

16) Overlooking activity

- Reasons and considerations:

Good visibility attracts more attention and encourages natural supervision (Jacobs, 1961; Shaftoe, 2008).

The vigour in the space improves the visual quality and makes walking more pleasant (Carmona et al., 2010; Gehl, 1996; Hong Kong Planning Department, 2006).

- Evaluation indicators and measures:

a. Establish sound visual and physical connections with the surroundings. The porosity and transparency of the ceilings of the walking space ensures safety, and encourage the interactions between the internal space and the external space, and between the public areas and the private areas.

b. Overlook at the activity area through the windows and create a long indoor landscape (John Carmody, 1993).

Table 5-48. Overlooking activity evaluation measures scoring

| Level | Score | Explanation |
|---|---|---|

| | | |
|---|---|---|
| Good | 5 | Establish a good visual and physical relationship with the surrounding environment, and provide internal windows overlooking the active area |
| Satisfactory | 3 | Establish a good visual and physical relationship with the surrounding environment |
| Need Improvement | 1 | No conditions available |

C. Life safety

17) Escape

The escape here is the escape from damages caused by human behaviours, such as criminal acts, urban riots, wars(Beroggi, 2000).

- Reasons and considerations:

One may be threatened by the existence of another person and want to escape. He or she may feel terrified if there are obstacles that prevent them from escaping (Korz, 1998; Fisher and Nasar, 1992).

Fisher and Nasar (1992:40) defined the chances of escape as 'the paths to exit from the potential threats or the contact in response to the possible attack'.

- Evaluation indicators and measures:

Based on the definition, the following spatial aspects can have a role in determining the degree for escape possibilities:

a. All elements that may hinder escape

b. Clarity/spatial continuity

c. Accessibility: whether the escape paths are readily accessible or not. In other words, there should be sufficient escape paths.

Table 5-49. Escape evaluation measures scoring

| Level | Score | Explanation |
|---|---|---|
| Good | 5 | Meet all requirements |
| Satisfactory | 3 | Meet some requirements but have defects |
| Need Improvement | 1 | No conditions available |

18) Fire suppression

- Reasons and considerations:

Statistics on underground space disasters worldwide from 1987 to 2012 suggests that fire is the most frequent disaster, accounting for 31% (ref). It is followed by floods (17%), explosions (12%), traffic accidents (6%), institutional destruction and construction accidents (3%), and others (2%) (Fei et al., 2012). Large-scale disasters in the underground public space often have grave consequences because the evacuation and rescue is challenging. In addition, the large population flow may result in the stampede, worsening the conditions (Jia, 2015). The reasonable evacuation time is within 3 minutes; otherwise, it would be dangerous (Su, 2008b).

- Evaluation indicators and measures:

a. Provide the fire and smog prevention design and the fire isolation installations

b. Install the monitoring system to monitor the temperature and toxic gases in the sites with large population flow

c. Introduce the fire alarm and extinguishing facilities (Shu, 2015b)

d. Put in place the fire lighting facilities and evacuation lighting signs

e. Prepare the escape outfit (such as the gas-proof masks) (Su, 2008b)

Table 5-50. Fire suppression evaluation measures scoring

| Level | Score | Explanation |
|---|---|---|
| Good | 5 | Meet all requirements |
| Satisfactory | 3 | Meet some requirements but have defects |
| Need Improvement | 1 | No conditions available |

19) Disaster prevention

The underground space is more resistant to disasters (excluding fire and floods) than the ground buildings. Nevertheless, during the 1995 Hyogoken-Nanbu Earthquake, the underground structures were destroyed. Earthquakes are therefore taken as the third major disaster to the underground space.

- Reasons and considerations:

It is more difficult to ask questions about underground public space in terms of disaster prevention than to ask questions on the ground. Therefore, we should deal with the problem of evacuation, rescue and smoke evacuation in underground space. All underground public spaces must be equipped with safety measures and monitoring systems that can be used for emergency treatment in emergencies. This can reduce the occurrence of disasters and reduce the loss to a small degree in a disaster.

- Evaluation indicators and measures:

1) Floods

a. The entrances & exits, ventilation doors and smoke outlets of the underground space should be located at the high-lying sites.

b. Pump stations and sumps should be set up.

c. The jacketed walls should be built.

d. Built large-scale underground water storage system.

e. Predict the floods and prepare the emergency plans.

Flood control has long been the challenge for the underground space. Floods are mostly seasonal and local. They seldom claim lives but could cause substantial economic losses, ground depression and ground facility destruction.

2) Earthquakes

The buildings' performance target should be set based on the purpose of the structures and the requirements of the proprietors and users. The target can be individualized (higher than the requirements).

Adopt proper structure system, building materials and design methods (not limited to the required ones).

Conduct building performance assessment. If the performance is satisfactory, then inform the proprietors and users of the actual performance data; otherwise, adjust the performance target or redesign the buildings.

Table 5-51. Disaster prevention evaluation measures scoring

| Level | Score | Explanation |
|---|---|---|
| Good | 5 | Meet all requirements |
| Satisfactory | 3 | Meet some requirements but have defects |
| Need Improvement | 1 | No conditions available |

20) Alarm

- Reasons and considerations:

The researcher who has tested the effectiveness of several approaches to communication in a metro emergency which includes alarm only, two officers directing people out plus a non-directive public address announcement, a non-directive public address announcement from the control centre, a directive public address announcement from the control centre, and a directive public address announcement from the control centre plus two officers directing people out (Sime et al., 1990, Proulx and Sime, 1991)

Safety management is conducive to preventing accidents. The underground space is often closed with narrow sight, making escape and rescue difficult. The accident prevention mechanism is particularly important. Safety management aims to prevent unknown accidents or the accidents that have not occurred before (Lu, 2014).

- Evaluation indicators and measures:

a. Voice fire alarm system panels and controls.

b. Lift floor location and operation annunciators.

c. Sprinkler valve and water flow annunciators.

d. Emergency generator status indicators.

In underground public facilities, provide effective detection, alarm, and two-way voice communication systems. Safety management quantises the severity of the unsafe factors based on the evaluation results.

Table 5-52. Alarm evaluation measures scoring

| Level | Score | Explanation |
|---|---|---|
| Good | 5 | Meet all requirements |
| Satisfactory | 3 | Meet some requirements but have defects |
| Need Improvement | 1 | No conditions available |

21) Surveillance

- Reasons and considerations:

The safety issues should be taken into consideration during the planning stage. The prevention facilities should be installed at the sites with height variations. Regular maintenance and upgrade should be made to the monitoring and safety check facilities (Li, 2012).

The visualisation of underground safety surveillance is the basis and core of visualised management. It covers the surveillance of the population flow, traffic flow, voltage, current, temperature, humidity, the concentration of toxic gases, and pressures of all areas, systems, disasters and emergencies. The data is visualised in the space simulation graph and system operation graph. The surveillance data can be stored in real-time and used for a higher safety visualisation management level.

There are security personnel at the entrance. The development process is under surveillance. However, the emergency exits, security personnel and CCTV surveillance are radical measures and may put the space under over control.

- Evaluation indicators and measures:

a. Provide the surveillance system over the emergencies in the public space

b. Provide intelligent surveillance systems over the population flow, traffic flow, voltage, current, temperature, humidity, the concentration of toxic gases, and pressures.

Table 5-53. Surveillance evaluation measures scoring

| Level | Score | Explanation |
|---|---|---|
| Good | 5 | Meet all requirements |
| Satisfactory | 3 | Meet some requirements but have defects |
| Need Improvement | 1 | No conditions available |

D. Management

22) Hygiene services

- Reasons and considerations:

According to the International Tunnelling Association study, the modern underground space should be hygiene, comfortable and safe. Factors such as the physical and mental health of human beings should be considered when the underground space is developed. The next goal is to leverage the underground space fully (Godard, 2004).

Regular maintenance makes the urban space more resilient and hygiene, which is beneficial for the physical and mental health of the users (CABE, 2010). Sound space encourages positive social behaviours and reduces crimes and violence (Wilson, 1961). Convenient facilities increase the use frequency and duration of the public space (Muller et al., 2010).

- Evaluation indicators and measures:

a. Keep the space hygiene and sound

b. Provide sufficient and diverse hygiene facilities

Sufficient well-maintained hygiene facilities, such as public washing rooms, trash cans and waterers make the space more comfortable and convenient. The users will stay a longer time in such space. In the regularly maintained space, the users care more about the environment (Cooper and Francis, 1998).

Table 5-54. Hygiene services evaluation measures scoring

| Level | Score | Explanation |
|---|---|---|
| Good | 5 | Meet all requirements |
| Satisfactory | 3 | Meet some requirements but have defects |
| Need Improvement | 1 | No conditions available |

23) Informational facilities

- Reasons and considerations:

The convenient information facilities encourage the users to make better use space and to locate themselves. Such space is more convenient and inclusive (Organization, 2017).

Communication facilities encourage social interactions (Cho et al., 2015).

- Evaluation indicators and measures:

a. Provide public communication facilities (phones, mobile signals and Wi-Fi)

b. Provide barrier-free, well-located and user-friendly communication and information facilities, such as public phones, notice boards and poster boards, Wi-Fi and information centre. Free Wi-Fi helps attract more user groups and serve more purposes.

Table 5-55. Informational facilities evaluation measures scoring

| Level | Score | Explanation |
| --- | --- | --- |
| Good | 5 | Meet all requirements |
| Satisfactory | 3 | Meet some requirements but have defects |
| Need Improvement | 1 | No conditions available |

24) Affordability

- Reasons and considerations:

Affordable or free cultural and entertainment programs encourage people to visit, use and linger in urban spaces (Carmona et al., 2012).

The inclusive environment is more resilient, diverse and vigorous (CABE, 2004).

- Evaluation indicators and measures:

a. Provide public services and facilities for free

The events in the public space should be held for public goods rather than for private gains. All users should be provided with access to the programs, services, and facilities for free or affordable. Free seats, public washing rooms, parking space, Wi-Fi, and access to space and events should be provided.

Table 5-56 Affordability evaluation measures scoring

| Level | Score | Explanation |
|---|---|---|
| Good | 5 | Meet all requirements |
| Satisfactory | 3 | Meet some requirements but have defects |
| Need Improvement | 1 | No conditions available |

25) Rules and regulations

- Reasons and considerations:

Laws, regulations and corresponding policies and management systems ensure that the project serves the public goods (Huang, 2009).

- Evaluation indicators and measures:

a. Adopt inclusive and preventative regulations and laws.

b. Engage the users in space management.

The sound public space should be inclusive and preventative. The laws and regulations should not restrict the humans, animals and events unless they are potentially risky.

Table 5-57. Rules and regulations evaluation measures scoring

| Level | Score | Explanation |
|---|---|---|
| Good | 5 | Meet all requirements |
| Satisfactory | 3 | Meet some requirements but have defects |
| Need Improvement | 1 | No conditions available |

E. Lighting

26) Artificial lighting

- Reasons and considerations:

The lighting facilities can change people's perception of public space. Sufficient lighting attracts the users to use the space and prolong the urban life and activities in the buildings nearby (Cooper and Francis, 1998).

Adjustable lighting helps foster the sense of belonging, interactions and privacy and reduce energy consumption. Buildings, fountains, sculptures and evening signs with sufficient illumination helps guide the users (Levine, 2003).

- Evaluation indicators and measures:

a. Provide sufficient lighting for the main paths and event nodes.

b. Provide environment and /or adjustable light.

Appropriate lighting makes the space safer. Nevertheless, excessive or insufficient lighting is not acceptable. Innovative use of the lighting facilities makes the space more aesthetically pleasant and charming, contributing to building a unique city. Landscapes, retailing activities, building details, signs and formal/informal furnishings (such as benches, handrails and stairways) should be employed to create different lighting strategies and effects. The bus stations, entrances, edges, main sidewalks and events are key space nodes.

The lighting of the investigation spot was measured manually. There could be errors. According to the results, the underground space's indoor illuminance is between 200 and 300LUX (not directly under the light). The illuminance of the metro hall is slightly brighter than that of the metro station. The observation spot's illuminance was about 300LUX, and that of the metro station and the supporting commercial space is about 200LUX. The illuminance under the skylight of Tai Koo Li was between 900 (morning during the weekdays) and 1200LUX (afternoon on the weekends). The illuminance is much brighter than that of the indoor space. The illuminance is brighter on the sunny days (than the rainy days) and in the afternoon (than in the morning).

Table 5-58. Artificial lighting evaluation measures scoring

| Level | Score | Explanation |
|---|---|---|
| Good | 5 | Meet all requirements |
| Satisfactory | 3 | Meet some requirements but have defects |
| Need Improvement | 1 | No conditions available |

27) Indirect lighting

- Reasons and considerations:

Space's quality does not rely on the lines and the background but the fine curves. The soft light from the indirect lighting in the curve space makes space gentler (Li, 2012).

- Evaluation indicators and measures:

a. Achieve indirect lighting with the interior decorative materials

Soften the light by leveraging the diffuse reflection of the internal structures

b. Use the photovoltaic effect to get indirect light.

The materials affect the lighting design. The colours and the reflectance of the materials have much to do with the light environment. The same light gets different reflections when casting on the surfaces in different colours. The light reflection and absorption properties of the materials decides the overall illuminance and range of the space. We can highlight or hide the building structures with light. The indirect lighting based on the photovoltaic effect converts the light into electricity and then converts the electricity back to light for illuminance.

Table 5-59. Indirect lighting evaluation measures scoring

| Level | Score | Explanation |
|---|---|---|
| Good | 5 | Meet all requirements |
| Satisfactory | 3 | Meet some requirements but have defects |
| Need Improvement | 1 | No conditions available |

28) Nature light

- Reasons and considerations:

The shadow and light encourage different activities during different hours in a day. This helps adjust the microclimate, improve the comfort and bring about positive mental benefits.

Artificial lighting could improve the dark underground environment but cannot replace the natural light. The natural light requires no energy consumption. It includes the direct light from the sun and the scattered beams from the sky. It is of great significance to introduce natural light into the underground space. On the one hand, artificial lighting has the same frequency and can make the users fatigue, while the frequency of the natural light changes as the time passes by, and the weather changes. Such changes connect people to the external environment, reduce the terror for the underground space, and makes the underground space full of changes. On the other hand, natural light is less dazzling. Its broad-spectrum is beneficial to human health. Exposure to the sun helps human bodies better absorb the beneficial elements. Therefore, the introduction of natural light is essential.

- Evaluation indicators and measures:

a. Introduce the natural light to weaken the isolation between the indoor and outdoor space

b. Introduce the natural light via the light wells, courtyards, skylights and sunken open space, saving energies

c. Introduce the natural light to help develop the sense of directions

d. Create areas with shadows and sunlight

The shadow is designed based on the contexts. Direct light is not ideal for the tropical environment but is encourages for other climate conditions. In both scenarios, excessive light or shadow makes the space less comfortable and functional.

Table 5-60. Nature light evaluation measures scoring

| Level | Score | Explanation |
|---|---|---|
| Good | 5 | Meet all requirements |
| Satisfactory | 3 | Meet some requirements but have defects |
| Need Improvement | 1 | No conditions available |

F. Exterior and entrance friendly design

29) Legibility

- Reasons and considerations:

The legible environment helps the users to develop accurate images out of it. The images are then used to respond to the environment. Legibility is a key indicator to assess the quality of a city (Lynch, 1960).

Good legibility attracts the users and makes the space safer (Jacobs, Jacobs, 1961).

In essence, legibility measures the physical and spatial quality of the surroundings (Ramadier and Moser, 1998).

The environment experience is kinaesthetic (Carmody and Sterling, 1993). It involves movements and time. To support such activities, the information in the space should be legible and clear. Legibility is the balance between the contents and the accessibility of the space (Sholihah, 2016). It is crucial for navigation and space understanding.

Legibility is a key indicator of the quality of underground space (Cho et al., 2015). People can easily get lost in the underground space. Hence, legibility is important. There should be good legibility at the entrances and exits of the underground space to attract users.

- Evaluation indicators and measures:

a. Provide good legibility at the entrances and exits

b. Provide horizontal and vertical legibility

In a well-connected space, one can see all nodes in the space from any node. The more nodes one can see, the better connected space is. The users are more likely to move around (Hillier et al., 1976).

Table 5-61. Legibility evaluation measures scoring

| Level | Score | Explanation |
|---|---|---|
| Good | 5 | Meet all requirements |
| Satisfactory | 3 | Meet some requirements but have defects |
| Need Improvement | 1 | No conditions available |

30) Accessibility

- Reasons and considerations:

The pedestrian space is the core of the public space (Salingaros, 1999).

The barrier-free facilities show the care for the residents. They reflect social progress and urban civilisation (Kong, 2007).

Good pedestrians make the urban space more inclusive and equal (Carmona et al., 2012).

Good accessibility makes spontaneous and regular events possible (Gehl, 2011).

People should use the superficial zones in the underground space. Safety should be stressed. The barrier-free facilities are the supporting facilities along the roads or public and residential buildings that offer convenience and safety to the disabled, the senior, the injured, and the young and other social members.

- Evaluation indicators and measures:

a. Provide barrier-free facilities.

b. Provide safe walkways.

The barrier-free Lifts and wider gates are designed for the senior or the passengers with large luggage or baby strollers. There are often two types of handrails with different heights and diameters on the Lifts at the foreign metro stations. The wider handrails are for the adults, and the narrower ones are for the children (Li, 2012).

Table 5-62. Accessibility evaluation measures scoring

| Level | Score | Explanation |
|---|---|---|
| Good | 5 | Meet all requirements |
| Satisfactory | 3 | Meet some requirements but have defects |
| Need Improvement | 1 | No conditions available |

31) Vertical entrance

- Reasons and considerations:

While ramps, escalators, and stairways can provide open, graceful transitions into underground facilities, Lifts are likely to be present in all buildings and may be the primary means of vertical circulation in many deep multistore structures (Carmody and Sterling, 1993).

- Evaluation indicators and measures:

a. The Lifts should be the barrier-free passages.

b. The glass-enclosed Lifts are recommended.

Place glass-enclosed Lifts in multistore Sunken open spaces to enhance orientation and relieve feelings of confinement. Use glass-enclosed inclined Lifts alongside escalators to improve accessibility, orientation, and security.

Table 5-63. Vertical entrance evaluation measures scoring

| Level | Score | Explanation |
|---|---|---|
| Good | 5 | Meet all requirements |
| Satisfactory | 3 | Meet some requirements but have defects |
| Need Improvement | 1 | No conditions available |

32) Sunken open space

- Reasons and considerations:

The sunken open space connects the space underground and aboveground, serving as the switch space for public events, entertainments and transportation (Ming et al., 2007)

The underground public space is integral to the urban public space system and plays its role in collaboration with the public space aboveground. The media that connect the public space underground and aboveground is key in the urban public space design. Such media can be the sunken open space, the sunken courtyard, and the sunken streets.

By leveraging opportunities such as metro construction, commercial activities, old town protection, and public space construction, we combine the underground space development with the construction of urban squares, commercial space, and traffic facilities to increase the urbanisation rate space and create a charming urban environment.

The sunken open space introduces natural light, air and ground landscapes to the underground space, making the space less confined. The horizontal access to the underground space makes it more acceptable. The natural ventilation and light make disaster evacuation easier. Simultaneously, the sunken open space as the urban public space creates a pleasant site and provides more access to the underground space. The enclosed space formed based on the height variation, helps prevent noise and coldness, making the space quiet.

- Evaluation indicators and measures:

a. Combine the urban metro station with the sunken open space

b. Take the sunken open space as the additional access to the underground space of the buildings

c. Ensure that there are no more than three storeys of sunken open space and the height is similar to that of the surrounding traditional buildings

The dimensions of the sunken open space should be controlled within a reasonable range. According to Camillo Sitte (2013), the urban square cannot be too large. The length-width ratio of the traditional urban open space is between 1:1 and 1:3. There should be a balance between the enclosure and the openness. Enclosure keeps people's attention within the space and openness connects the space with the urban environment. The largest angle of human's vertical sight range is 30°. When the length-width ratio is 1:2, the horizontal line's angle and the upper interface are 45° with a great enclosure. When the length-width ratio is 1:3.4, the angle between the horizontal line and the upper interface is 30° with enclosure being broken and people's attention being distracted. When the length-width ratio is smaller than 1:3.4, the angle between the horizontal line and the upper interface is less than 30° with great openness and no sense of boundaries. Therefore, the enclosure and openness are ideal when the length-width ratio is between 1:2 and 1:3.4.

Table 5-64. Sunken open space evaluation measures scoring

| Level | Score | Explanation |
|---|---|---|
| Good | 5 | Meet all requirements |
| Satisfactory | 3 | Meet some requirements but have defects |
| Need Improvement | 1 | No conditions available |

33) Diversity integration

- Reasons and considerations:

The underground public space as an integral part of the urban public space system combines the urban public space with the natural environment, extending the natural touch into the underground space and expanding the urban green ecological space (Lu, 2015).

Element integration helps promote urban underground space. The introduction of light, landscapes and activities to underground space relies on the space aboveground and the integrated design of the underground-aboveground space. As a component of the urban public space, the underground space requires an integrated design of the urban elements.

- There are two types of integration:

a. Build the underground public space system among urban parks, squares and roads above the ground, connect the space under the private lots nearby, and ensure the good connectivity between public and private spaces.

b. Built the underground public space under the private lots and connected the underground space across blocks to form an underground network. The underground space formed in this way is of good quality but requires coordination among the proprietors.

- Evaluation indicators and measures:

a. Combine the urban greenbelts with the underground traffic space

b. Develop the greenbelts, underground rails and underground parking space together

The accessibility and public nature of the space should be considered when the space underground and aboveground are developed together.

Table 5-65. Diversity integration evaluation measures scoring

| Level | Score | Explanation |
|---|---|---|
| Good | 5 | Meet all requirements |
| Satisfactory | 3 | Meet some requirements but have defects |
| Need Improvement | 1 | No conditions available |

G. Identity

34) Culture

- Reasons and considerations:

The cultural promotion and renewal strategies are closely related to the economy and environment of the city (Jenks and Dempsey, 2005).

The street activities should be organised or be performed at the designated areas, thus well managing the spaces (Shaftoe, 2008).

The cultural environment at the entrances to the underground space is a part of the local urban art and cultural environment. It is shaped by indoor and outdoor decoration themes under different subjects, such as sculptures, murals, and lighting facilities that showcase different styles of local cultures (Liu, 2006).

- Evaluation indicators and measures:

a. Launch art and culture programs

b. Cater to local culture

Regionalism involves the environmental boundaries (focuses) that represent the group boundaries (focuses). It has the sub-cultural values. Sub-culture is not only a lifestyle and collective behaviour but a way to get integrated into the community.

Table 5-66. Identity evaluation measures scoring

| Level | Score | Explanation |
|---|---|---|
| Good | 5 | Meet all requirements |
| Satisfactory | 3 | Meet some requirements but have defects |
| Need Improvement | 1 | No conditions available |

35) Unique nature

- Reasons and considerations:

The unique natural characteristics enrich the aesthetic and symbolic values of the urban space. The natural elements enhance the sense of locality and belonging. The lower density and play a crucial role to protect biodiversity (Stone Jr and Rodgers, 2001).

Unique natural features contribute to the visual identity of public space. Apart from visual character, preserving nature with strong links to history or religion (Cho et al., 2015).

There cannot be large natural space underground, but we can extend the natural characteristics aboveground to the underground space, impressing people with a specific natural pattern.

- Evaluation indicators and measures:

a. Preserve natural elements with strong links to preservation, history or religion (Cho et al., 2015).

b. The continuity of the urban narration can be related to the following factors:

I). Outdated: the urban structures and locations cannot adapt to changes.

II). Changing time framework: the things that do not changes with the time

Resilience and robustness: the ability to resist or adapt to changes (Carmona et al., 2012).

Table 5-67. Unique nature evaluation measures scoring

| Level | Score | Explanation |
| --- | --- | --- |
| Good | 5 | Meet all requirements |
| Satisfactory | 3 | Meet some requirements but have defects |
| Need Improvement | 1 | No conditions available |

36) History and symbolic

- Reasons and considerations:

The cultural heritages arouse the locality and sense of belonging and cater to the specific user groups from related history, cultural and religious backgrounds.

By relocating the functions and facilities on the ground to the underground space, we relieve the land shortage, avoid destroying the historical and cultural blocks aboveground, and protect the city's original landscapes (Hong, 2018).

- Evaluation indicators and measures:

a. Provide the traces of historical and cultural heritage protection

b. Provide the evidence on historical and cultural heritage protection and development

When developing the underground space in the historical areas, we should adopt different development approaches based on the nature of the historical protection zone and land usage. For instance, the space under the historical residential areas (such as quadrangle courtyards and hutongs) should provide the supporting services, such as determining the parking space based on the areas' resident population and introducing the natural light by building the sunken open space. The space under the downtown protection areas should be developed into rail lines, parking spaces, and commercial spaces. No space should be developed under the areas that forbid or limit constructions (such as the relic sites and the palaces). If necessary, the development depth and scale should be strictly controlled (Hong, 2018).

Table 5-68. History and symbolic evaluation measures scoring

| Level | Score | Explanation |
|---|---|---|
| Good | 5 | Meet all requirements |
| Satisfactory | 3 | Meet some requirements but have defects |
| Need Improvement | 1 | No conditions available |

37) Imageability

- Reasons and considerations:

The unique space is memorable and attractive (Shaftoe, 2012).

The recognisable space elements create strong psychological images and better guide the users (Lynch, 1960).

- Evaluation indicators and measures:

a. Provide unique and memorable space features.

b. Retain or add more well-known features.

c. Adopt unique forms, colours, proportions, green elements, artworks and other design approaches to build a memorable image.

The urban planner should focus not only on the differences in location but also on making the space more unique, requiring keen observation of the space potentials.

Table 5-69. Imageability evaluation measures scoring

| Level | Score | Explanation |
|---|---|---|
| Good | 5 | Meet all requirements |
| Satisfactory | 3 | Meet some requirements but have defects |
| Need Improvement | 1 | No conditions available |

H. User comfort

38) Air quality

- Reasons and considerations:

Good ventilation improves the urban space experience and is conducive to the mental and physical health of the users (McIndoe et al., 2005).

The temperature, humidity and air quality within the buildings affect people's physiological feelings. When these conditions are ideal, people can live and move around in the buildings (Wang and Shu, 2000, Hong, 2018)

The indoor air quality is closely related to people's health. The underground space's ventilation is poor and often gathers toxic gases, thus harming people's health. The indoor air quality is subject to the wind speed, air purification system and fresh air volume. A healthy underground space can be provided only by improving air quality (Hong, 2018).

- Evaluation indicators and measures:

a. The ratio between the size of the ventilation outlets and the ground area, or the air change rate

b. Monitor and regulating the areas with large population density and flow rate

The Ventilation Requirements on Acceptable Indoor Air Quality (ASHRAE 62-2001 is the most influential indoor air quality standards. There are three ways to control indoor air quality: (1) provide sufficient ventilation facilities with good quality; (2) control the pollution source and reduce the possibility of pollution; and (3) filter and disinfect the indoor air. In practice, we mostly focus on the relative humidity, CO1, CO2, total bacterial count, TVOC content and concentration of radon (Huang and Wang, 2006).

Table 5-70. Air quality evaluation measures scoring

| Level | Score | Explanation |
|---|---|---|
| Good | 5 | Meet all requirements |
| Satisfactory | 3 | Meet some requirements but have defects |
| Need Improvement | 1 | No conditions available |

39) Noise control

- Reasons and considerations:

Good auditory quality makes the users pleasant and enrich the perceptions about the happy space (McIndoe et al., 2005, Shaftoe, 2008).

The underground public space is subject to serious noise. The metro operation can cause these noises (because it is close to the metro facilities), the air-conditioning and ventilation systems, or the intense noises from outer operating machines. Noise is disturbing and stressful. It may hinder communications (Cao, 2009).

- Evaluation indicators and measures:

a. Protect the environment from noise pollution

b. Improve the auditory quality

c. The underground space is mostly used during the day for shopping and transportation purposes. According to the National Noise Standards, the commercial areas' noise should be controlled within 50 DB and that of the traffic space within 60 DB (Zheng, 2012). Good auditory quality is as important as air quality. The urban space can be protected from the noise (caused by transportation or devices) when measures related to the spatial arrangement, the building layout, and the barriers and enclosures are taken.

Table 5-71. Noise control evaluation measures scoring

| Level | Score | Explanation |
|---|---|---|
| Good | 5 | Meet all requirements |
| Satisfactory | 3 | Meet some requirements but have defects |
| Need Improvement | 1 | No conditions available |

40) Temperature

- Reasons and considerations:

The heat transmission of the underground enclosures is decided by the air temperature and the periodical changes in the surface temperature. When the underground space enclosures are 6-7m thick, the periodical changes in the surface temperature have no impact on the heat transmission of the underground enclosures (Hu et al., 1983).

The underground buildings have low permeability and stable temperature. Their enclosures seldom gain or lose any heat. The deeper the underground buildings are, the more energy will be saved (Wu, 2006).

The comfortable temperature is related to the air humidity. When the air is humid, the sweat on human bodies cannot evaporate, and the body temperature would be unpleasantly high. The air humidity varies between summer and winter. The pleasant temperature during the two seasons is not the same as well. In most regions of China, the air is humid in summer and dry in winter. At the same wind speed, the pleasant temperature in summer would be lower than that in winter (Hong, 2018).

- Evaluation indicators and measures:

a. Control the air temperature and humidity of the air supply outlet with the heat regulation facilities and the steam humidification equipment

b. The pleasant underground temperature is between 18 and 26°

The underground space with a depth between 0m and 30m can be connected to the ground via the sunken open space and the skylights, and there is barely the sense of confinement. Compared to the superficial underground space, the underground space's temperature with a depth between 30m and 100m is relatively constant. The underground with a depth of over 100m has a constant temperature (Su, 2008b).

ASHRAE 62-2001 stated three ways to control the indoor air quality: (1) provide sufficient ventilation facilities with good quality; (2) control the pollution source and reduce the possibility of pollution; and (3) filter and disinfect the indoor air (Wan, 2013).

Table 5-72. Temperature evaluation measures scoring

| Level | Score | Explanation |
|---|---|---|
| Good | 5 | Meet all requirements |
| Satisfactory | 3 | Meet some requirements but have defects |
| Need Improvement | 1 | No conditions available |

I. Activities

41) Theme sales

- Reasons and considerations:

The underground sales space can be integrated with the metro space, turning the metro station's passive space into a part of the underground sales space (Liu, 2010). Theme fairs are more attractive for passengers. According to a questionnaire survey, over 79% of the respondents find the theme fairs appealing.

The metro stations' entrances and exits lead the passengers directly to the underground shopping malls (Liu, 2010). Almost all metro stations in Hong Kong connect to key landmarks in the city, serving as road signs and a component of the pedestrian system. People can move among different shopping malls, without worrying about the weather conditions.

- Evaluation indicators and measures:

a. Organise theme fairs in the underground public space

b. Integration

The underground sales space can be integrated with the metro space, making full use of the passenger flow and turning the passive space in the metro station into a part of the underground sales space using the advantage of the shopping mall, creating a win-win situation (Liu, 2010).

Table 5-73. Theme sales evaluation measures scoring

| Level | Score | Explanation |
|---|---|---|
| Good | 5 | Meet all requirements |

| | | |
|---|---|---|
| Satisfactory | 3 | Meet some requirements but have defects |
| Need Improvement | 1 | No conditions available |

42) Events

- Reasons and considerations:

Retailing, commercial, cultural and community events help increase the user size of the urban space and provide the users with senses of closeness, privacy and direction. Different events can be held in public space throughout the day (Cho et al., 2015).

- Evaluation indicators and measures:

a. Hold collaborative events at the intersection of the underground public space and the ground space.

b. Design the underground public space that accommodates different events.

Quality urban space is never a separate or independent entity. The events, design and management of the marginal urban space is important as well. The vigour of the marginal space is triggered by the collaborative effect of the events nearby, which attract the users to access and use the urban space (Gehl, 2011).

Table 5-74. Events evaluation measures scoring

| Level | Score | Explanation |
|---|---|---|
| Good | 5 | Meet all requirements |

| | | |
|---|---|---|
| Satisfactory | 3 | Meet some requirements but have defects |
| Need Improvement | 1 | No conditions available |

J. Sociability

43) Diverse uses

- Reasons and considerations:

The underground public space is the open space for public activities underground. It includes the commercial, cultural, entertaining, educational and office space (Shao, 2016).

Most researchers believe the multi-functional development mode brings about diversity to a region (Hillier, 1996).

The mixed use of space promotes the sustainable development of a city (Hong, 2018).

The multi-functional resting and communication space underground attracts the consumers to stay in the underground space, fostering more consumption nodes (Su, 2008b).

- Evaluation indicators and measures:

a. Provide shopping, entertaining, recreational and transportation functions.

b. Mixed use and Multi-use

The underground multi-use architecture refers to underground buildings and complexes that serve multiple purposes. Its urban feature distinguishes it from other underground multi-use architecture. The underground complex represents the interactions between the architecture and the urban environment. It combines multiple functions and overcomes the limits of single functions. The underground complex carries extensive integrated functions by combining the interdependent single functions. In contrast, the underground multi-function architecture is merely the accumulation of the buildings in terms of amount and type. It does not interact with the urban environment or creates new systems. The local adjustment has no impact on the overall conditions.

Table 5-75. Diverse uses evaluation measures scoring

| Level | Score | Explanation |
|---|---|---|
| Good | 5 | Meet all requirements |
| Satisfactory | 3 | Meet some requirements but have defects |
| Need Improvement | 1 | No conditions available |

44) Interactive

- Reasons and considerations:

The upper floors of the sunken open space provide the exchange venues for the pedestrian space.

The interactive elements offer opportunities for contact and deviation, encouraging involuntary social interactions (Carmona et al., 2012).

- Evaluation indicators and measures:

a. Provide the interactive elements in the urban space

Many latest urban design reviews and guidelines suggest using movable chairs and interactive elements, such as sculptures, installations, fountains, interactive displays, swings and game facilities (chess, hopscotch and mini-golf, etc.).

The moveable seats improve the space's adaptability and flexibility and offer more choices and greater comfort. The seats would also encourage social interactions and enhance the sense of control and ownership. The interactive elements make the space vigorous and serve as the landmarks, bring unique qualities to the urban space.

Table 5-76. Interactive evaluation measures scoring

| Level | Score | Explanation |
|---|---|---|
| Good | 5 | Meet all requirements |
| Satisfactory | 3 | Meet some requirements but have defects |
| Need Improvement | 1 | No conditions available |

45) Cooperative

- Reasons and considerations:

The government-led public development model provides a material basis (metro lines and municipal facilities) for underground space development. Such a model reflects government development intentions, guides social investment, and decides the city's underground space structures (Lu, 2015). It provides possibilities for non-public development projects on the one hand and the constraints on the other.

- Evaluation indicators and measures:

a. Provide four cooperative development modes of the underground public space

b. Public-sector development led by the government for public interests

c. Private-sector development led by investors such as real estate developers and financial institutions

d. Build-Operate-Transfer development

e. Public-Private Partnerships development

Table 5-77. Cooperative evaluation measures scoring

| Level | Score | Explanation |
|---|---|---|
| Good | 5 | Meet all requirements |
| Satisfactory | 3 | Meet some requirements but have defects |
| Need Improvement | 1 | No conditions available |

46) Social services

- Reasons and considerations:

The health care facilities are conducive to keep all people healthy and provide supports for the aging trend (CABE, 2010)

Include the integrating and balanced communities, build community bonds, and promote social inclusiveness and equality.

- Evaluation indicators and measures:

a. Provide affordable social services for vulnerable group users.

b. Provide health care services and other social services for the vulnerable groups, including the senior, the young and the disabled. These services can be provided by the consulting centres, the day-care centres and families. This area does not belong to the work scope of urban designers. But we need to address the health and equality challenges with diverse designs.

Table 5-78. Social services evaluation measures scoring

| Level | Score | Explanation |
|---|---|---|
| Good | 5 | Meet all requirements |
| Satisfactory | 3 | Meet some requirements but have defects |
| Need Improvement | 1 | No conditions available |

## 5.5 Discussion

The development of underground space has been mainly designed by civic engineers for a long time (Besner, 2017). The underground public space should play a more important role in the city and contribute to people's living environment (Admiraal and Cornaro, 2018). In the previous chapters, the author analysed the importance of the quality assessment indicators of underground public space by interviewing experts and three questionnaires of different user groups and used data statistics and SPSS statistical calculation software to analyse the questionnaires. Each method has its own advantages and disadvantages. Three different results are discussed below.

### 5.5.1 The differences between designers and users

The existing literature of underground public space design could be summarised into two categories: guidance for planning and design, and the analysis of design examples. For the underground public space design quality assessment system studied in this thesis, only a few studies provided empirical evidence that could be tested. Many literatures suggested that underground space design should consider the human-centred design concept. For example, John and Raymond (1993) put forward the idea of the people-orientated design for underground space, also suggested six aspects for the qualitative research in underground space design, including exterior and entrance design, layout and spatial configuration, interior elements and systems, lighting, and life safety pattern. There are five factors in the human-centred design of underground space, including safety, legibility, a sequential principle, comfort, and integrity. However, underground public space has not received the same attention as the surface level public space due to its spatial characteristics. The researches on underground public space design and assessment are relatively insufficient. Therefore, this thesis has made documentary research on the aboveground public space while studying the public space design quality assessment system. There are great differences between the aboveground public space and the underground public space regarding the physical conditions. However, the underground public space still could learn the experiences from the aboveground public space design and practices.

According to the results of the interview of underground space design experts and scholars, and the questionnaire investigation results of the underground space designers in the previous chapters, the author has investigated and reconstructed the underground public space quality assessment system, including 46 indicators of 4 attributes and 10 categories with a sequential order. Although the systematic indicators' framework in the literature did not specify how the sequence was ranked, people would subconsciously believe that the leading indicator is more important according to the rule of thumb. From the designer's perspective, the assessment indicators of underground public space design quality should focus more on the design of space. Therefore, **exterior and entrance friendly design**, **spatial configuration** and **Friendly interior design** were the three most important indicators considered by experts and designers of underground space. Safety is also a crucial indicator, but there are already corresponding design standards, so it was not the most concerning design indicator. However, activities, identity, and management were the least important indicators from experts and designers' perspective. The result here did not mean that experts and designers believe that safety, comfort, or sociality is not important. It just shows that they are more aware of the effects of the quality of space design itself on people physically and psychologically. Therefore, from a professional perspective, the importance of classification indicators was different from the users' intuition.

The second questionnaire was designed for the users of the underground public space around the subway. The investigation questions were all multiple-choice questions, and the respondents could tick the important options as many as possible if they want. As a result, 259 valid respondents expressed their options regarding important indicators, which differed from the result of the first constructed framework indicator (see Table 5-79). The users interviewed rated **life safety**, **exterior and entrance**

**friendly design** and **lighting** as the three most important indicators, followed by user comfort, while identity, sociability, and activity space as the least important indicators. Under various categories, the importance ranking of indicators also changed. The investigation result of this questionnaire had obvious advantages, and respondents can quickly check out their answers. However, the investigation result of this questionnaire was relatively limited, and it was difficult to make a step-by-step analysis and calculate the weight of the indicators. It intends to provide designers with a design focus and reminds the designer to emphasise the problems valued by users in the construction of underground public space.

Table 5-79. The differences between designers and users

↑rise ↓decline — invariant or improvement

| Result of designers' investigation | | | | Result of users' investigation | |
|---|---|---|---|---|---|
| Categories | | Indicator | | Categories | Indicator |
| Exterior and entrance friendly design | ↓ | Accessibility | — | Life safety | Escape |
| | | Legibility | — | | Fire |
| | | Sunken courtyard | — | | Monitoring |
| | | Sunken open space | ↓ | | Disaster avoidance |
| | | Vertical entrance | ↑ | | Alarm |
| | | Diversity integrations | ↓ | Exterior and entrance friendly design | Accessibility |
| Spatial configure-tion | ↓ | A system of paths | — | | Disabled facilities |
| | | Activities nodes | ↓ | | Vertical entrance |
| | | Landmarks | — | | Diversity integrations |
| | | Connectivity | ↑ | | Sunken open space |
| | | Distinct zones | ↓ | Lighting | Indirect lighting |
| | | Overlooking activity | ↑ | | Nature |
| | | Hierarchy privacy | ↓ | User comfort | Air quality |
| | | Interconnected space | — | | Noise control |
| | | High of ceilings | ↑ | | Temperature |
| Friendly interior design | ↓ | Colour | ↓ | Spatial configuration | A system of paths |
| | | Size | — | | Connectivity |
| | | Nature elements | ↓ | | Landmarks |
| | | Materials | — | | Distinct zones |
| | | Furnishings | — | | Activities nodes |
| | | Signs and maps | ↑ | | Spatial stratification |

| | | | | | |
|---|---|---|---|---|---|
| Life safety | ↑ | Escape | — | | Layer height change |
| | | Air quality | — | | Overlooking activity |
| | | Disaster prevention | — | | Hierarchy privacy |
| | | Wayfinding | — | Friendly interior design | Signs and maps |
| | | Fire suppression | ↑ | | Size |
| | | Ventilated | — | | Colour |
| User comfort | ↑ | Lighting | — | | Materials |
| | | Temperature | — | | Furnishings |
| | | Variety of shade | — | | Nature elements |
| | | Art control | — | | Ventilated |
| | | Noise control | ↑ | Management | Hygiene services |
| Sociability | ↓ | Cooperative | — | | Informational facilities |
| | | Social services | — | | Affordability |
| | | Diverse uses | — | | Rules and regulations |
| | | Interactive | — | Identity | Imageability |
| Activities | ↓ | Events | ↓ | | Culture |
| | | Theme sales | ↑ | | Unique nature |
| Identity | ↑ | Imageability | — | | History and symbolic |
| | | History and symbolic | ↓ | Sociability | Cooperative |
| | | Culture | ↑ | | Social services |
| | | Unique nature | ↑ | | Diverse uses |
| Manageme nt | ↑ | Informational facilities | ↓ | | Interactive |
| | | Hygiene services | ↑ | Activity space | Theme sales |
| | | Rules and regulations | ↓ | | Events |
| | | Affordability | ↑ | | |
| ↑rise ↓decline —invariant or improvement | | | | | |

### 5.5.2 The differences between designers and computer calculation

After the previous two investigations, we can notice the differences between the investigation results of designers and users. Meanwhile, this paper continued to use the third questionnaire to compensate for the failure to get the objective ranking and weight calculation of the system indicators in the previous two investigations by changing the form of the questionnaire. The third questionnaire aimed to score the importance of the quality assessment system indicators for underground public space design obtained. The questionnaire set 5 levels of score for each category from 'least important', 'less important', 'moderately important', and 'important' to 'very important'. The sociological statistical analysis software was then used to conduct an exploratory factor analysis and confirmatory factor analysis on the investigation results. Finally, the sequence of the assessment framework system indicators and the weight allocation of the indicators of the underground public space design quality were obtained.

For exploratory factor analysis, the results of 296 questionnaires have been collected and analysed by the sociological statistics software of SPSS. The result reordered the system framework sequence, including the sequence of categories and the sequence of each indicator. For exploratory factor analysis, the results showed that the first three questions (including the respondent's gender, age, and occupation) could not be classified as any factor in the analysis, so they were deleted upon screening. Other indicators were aggregated by category, and a new sequence was generated. However, the results of exploratory factor analysis cannot be used to calculate the indicator weight directly. After the exploratory factor analysis, to calculate the indicator weight, AMOS software was used to conduct confirmatory factor analysis over 296 questionnaires with the first three questions deleted to plot the potential variables and corresponding questions into a measurement model. The model's fitting quality was then checked through data fitting, and the model was modified to improve its quality. Lastly, the modified model data was calculated to obtain the system indicators' weight values, which will affect the scores in the later assessment. The final indicator sequence of the quality assessment system for underground public space design was determined through the above analysis. According to the weight calculation result, the sequence of the importance of each category was **Friendly interior design**, **spatial configuration**, **life safety**, **management, lighting, exterior and entrance friendly design, identity, user comfort, activities**, and **sociability**.

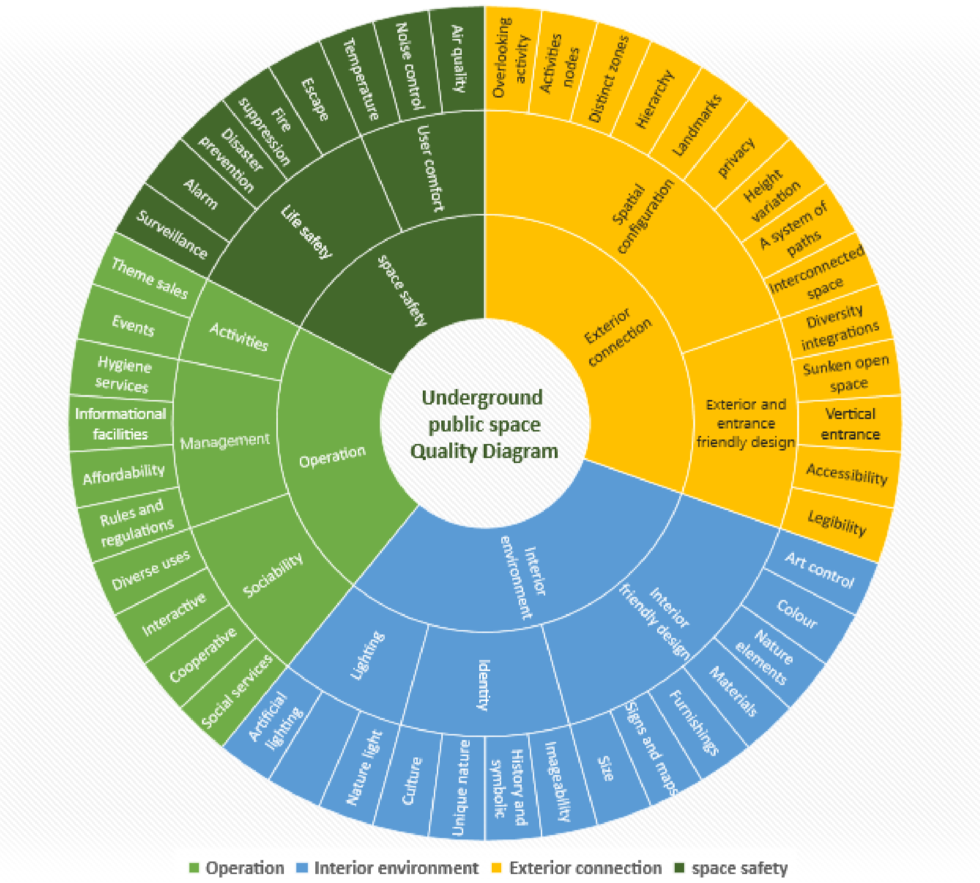



Figure 5-20. Underground public space quality diagram

The underground public space quality diagram covered all indicators, which serves as the guideline for underground public space design and the systematic indicator of assessment. The diagram cannot reflect the sequence, because all indicators are important from the perspective of design, and they will be the factor affecting the underground space quality (Carmody and Sterling, 1993). On the other hand, from the perspective of assessment, it is necessary to rank and calculate the weighting of the indicators, which can calculate the scoring results more objective.

As the diagram shows that there is still a difference between the result of the indicator framework and the user experience and feelings through factor analysis (as shown in Table 5-80). In the assessment indicators of underground public space design quality, the importance of the interior design and spatial structure of underground public space still ranked at the forefront, followed by the safety and management of underground public space. Of course, the results calculated by software will be affected by the indicator framework, such as the number of indicators per category in the framework will affect the quality of the model.

Table 5-80. The differences between designers and computer calculation

↑rise ↓decline —invariant or improvement

| Result of users' investigation | | | | Result of factors analysis | |
|---|---|---|---|---|---|
| Categories | | Indicator | | Categories | Indicator |
| Life safety | ↓ | Escape | — | Spatial configuration | Interconnected space |
| | | | | | A system of paths |
| | | Fire | — | | Height variation |
| | | Monitoring | ↓ | | privacy |
| | | Disaster avoidance | ↑ | | Landmarks |

| | | | | | |
|---|---|---|---|---|---|
| | | Alarm | ↑ | | Hierarchy |
| Exterior and entrance friendly design | ↓ | Accessibility | ↓ | | Distinct zones |
| | | Disabled facilities | ↑ | | Activities nodes |
| | | Vertical entrance | — | | Overlooking activity |
| | | Diversity integrations | ↓ | Friendly interior design | Size |
| | | Sunken open space | ↑ | | Signs and maps |
| Lighting | ↓ | Indirect lighting | — | | Furnishings |
| | | Nature | — | | Materials |
| User comfort | ↓ | Air quality | — | | Nature elements |
| | | Noise control | — | | Colour |
| | | Temperature | — | | Art control |
| Spatial configuration | ↑ | A system of paths | ↓ | Life safety | Escape |
| | | Connectivity | — | | Fire suppression |
| | | Landmarks | ↓ | | Disaster prevention |
| | | Distinct zones | ↓ | | Alarm |
| | | Activities nodes | ↓ | | Surveillance |
| | | Spatial stratification | — | Management | Hygiene services |
| | | Layer height change | ↑ | | Informational facilities |
| | | Overlooking activity | ↓ | | Affordability |
| | | Hierarchy privacy | ↑ | | Rules and regulations |
| Friendly interior design | ↑ | Signs and maps | ↓ | Exterior and entrance friendly design | Legibility |
| | | Size | ↑ | | Accessibility |
| | | Colour | ↓ | | Vertical entrance |
| | | Materials | — | | Sunken open space |
| | | Furnishings | ↑ | | Diversity integrations |
| | | Nature elements | ↓ | Identity | Culture |
| | | Ventilated | — | | Unique nature |
| Management | ↑ | Hygiene services | — | | History and symbolic |
| | | Informational facilities | — | | Imageability |
| | | Affordability | — | Sociability | Diverse uses |
| | | Rules and regulations | — | | Interactive |
| Identity | ↑ | Imageability | ↓ | | Cooperative |
| | | Culture | ↑ | | Social services |
| | | Unique nature | ↑ | Lighting | Artificial lighting |
| | | History and symbolic | ↑ | | Indirect lighting |
| Sociability | ↑ | Cooperative | ↓ | | Nature light |
| | | Social services | ↓ | User comfort | Air quality |
| | | Diverse uses | ↑ | | Noise control |
| | | Interactive | ↑ | | Temperature |
| Activity space | — | Theme sales | — | Activities | Theme sales |
| | | Events | — | | Events |
| | | | | | |
| ↑rise ↓decline —invariant or improvement | | | | | |

### 5.5.3 The differences with other studies

As specified in the literature review, the underground space design and assessment research were summarised into two categories: the output of exploratory or suggestive indicators without a complete framework. The indicators of this type are presented through a combination of the nature of qualitative indicators with cases. It is easy to understand, but difficult to use in specific designs and assessments. The other is the indicators with a relatively complete system framework. It is mostly constructed by deriving from the literature review method, and the research method of the process is relatively simple. The assessment methods of each indicator factor after forming the assessment system are expert interview, analytic hierarchy process (expert scoring) and fuzzy analytical method (questionnaire scoring) (Hong, 2018). The indicators are mainly qualitative. From the perspective of design, designers can implement the requirements of indicators in the design through understanding. However, it is not easy to apply the unquantified indicators in the assessment from the assessment perspective. This study reviewed a wide range of design guidelines and energy-saving assessment criteria for underground space, underground public space, and urban public space. The findings confirmed the four attributes of underground public space most concerned by the users: exterior connection, space safety, interior environment, and operation. The exterior connection includes spatial configuration, exterior and entrance friendly design; the space safety includes life safety and user comfort; the interior environment includes Friendly interior design, lighting, and identity; the operation includes management, activities, and sociability.

In this study, the author used various methods to deduce and verify the design quality assessment system indicators of underground public space and quantified all indicators according to the requirements to make the assessment indicators easier to be used in the assessment of space design. In the literature, Baoyong Wang (2000) used the statistical analysis software of SPSS to analyse the factors affecting the underground space environment. More and more attention has been paid to the development and utilisation of urban underground space. People tend to compare the ground environment with the underground environment, but they are obviously different. Therefore, to create a better urban underground space environment, it is necessary to conduct a scientific analysis of the factors affecting the urban underground space environment. This paper investigated the factors affecting the urban underground space environment through questionnaires and used SPSS to analyse these factors to get 12 main adverse factors affecting the urban underground space environment (Wang and Shu, 2000). After obtaining the underground public space framework indicator system through literature review, professional interviews, and questionnaires, this research used SPSS software to conduct factor analysis and got the 46 most important indicator factors. According to the quality assessment indicator system obtained, AMOS software was used to conduct confirmatory factor analysis over questionnaire results to calculate the indicator weight.

## 5.6 Chapter conclusion

This sector comes up with the evaluation system on the quality design of the underground public space. With the documentary research, the expert interview and the questionnaire survey, this chapter screens and sequences the influencing factors of underground and ground public space design. The evaluation indicators of the underground public space are classified into ten categories based on literature review. The second questionnaire survey investigates the user experience. The quality assessment factor system is adjusted based on the survey results. The third questionnaire survey invites users to score the importance of the evaluation indicators. EFA and CFA are then employed to sequence and weight the indicators.

# 6 Case Study: Guomao Metro Station in Beijing CBD

This section will evaluate the underground public space's planning and design near the Guomao metro station in Beijing’s Central Business District, and the quality of the underground public space built. The evaluation will be divided into two parts. The first part is a three-person team led by the author to measure evaluation and scoring. According to the evaluation results, the three will discuss and score. The second part is to randomly score the satisfaction of users in the metro station area. Because there is no instrument data, the users' scoring is based on subjective feelings. In the following discussion section, the two evaluation results will be compared and analysed.

## 6.1 Historical Evolution of Beijing Underground Public Space

The evolution of the underground space in modern Beijing can be divided into three phases (Zhang, 2015).

1). **Civil air defence facility and public works construction**. When China was under the rule of the Kuomintang and the Reorganised National Government led by Wangjingwei, a 2,460 square metres air defence project was built along the Shibei Hutong and the Tieshizi Hutong. More air defence facilities were built from 1950 to 1978. Later, the country had progressed into the Peace and War stage from 1978 to 1986 and then into the Civil Air

Defence and Urban Construction stage since 1986. Meanwhile, the underground water supply and sewage pipes were built in Beijing and the power, gas and heating systems were further constructed. To conclude, the underground space in Beijing was mostly utilised for the municipal infrastructure at the early stage.

2). **Underground rail transit**. In 1956, Beijing Metro Line 1 was put into operation. The original intention of the construction of underground railway is to evacuate the crowds during the war and lay foundations for the future underground transportation system. Later, the metro transportation in Beijing gradually witnesses a scale development. Base on the metro planning that by late April in 2015, 17 metro lines with a total length of 660km had been built and put into operation (Zhang, 2015), representing a relatively mature underground transit network.

3). **Underground commercial space development**. Over the past two decades, the traditional commercial districts in Beijing have been revitalised through renovation, and traditional business has embraced unprecedentedly fast development(Wang, 2006). The urban planners design a variety of underground commercial spaces, such as underground business streets, metros, underground facilities, and underground transit facilities (such as passages, tunnels and corridors). The underground public space in Beijing is currently developed under either the public greenbelts or the downtown roads. According to the Underground Space Development and Utilisation Plan for Central Areas in Downtown Beijing (2004), the underground development under the public greenbelts should be held in tight control. Detailed plans should be devised based on the local conditions. The surroundings, types, locations and sizes of the public greenbelts should be taken into consideration in the planning of underground space. On top of that, the multi-functional space that meets the landscaping and technical specifications can be developed under the public greenbelts. In recent years, an increasing number of projects have been developed under the public greenbelts in Beijing, all being close to the metros in the commercial business districts or the core areas of the science parks. Typical cases include the Xidan Culture Square (Completed), the Beijing Exhibition Centre Square (Completed), the Zhongguancun Square (Completed), the Olympic Park Centre Area (Completed), the National Olympic Sports Centre South (To be completed in 2020), the CBD greenbelts and underground public facilities (To be completed in 2018), the underground project in the Lize Business District (To be completed in 2020 ) and the underground cultural and entertainment Centre in Beijing International Sculpture Park (To be completed in 2020).

In addition, the underground space planning of the Tongzhou Canal Core Area and the Advanced Business Park (Fengtai) are formulated, which covers the downtown squares, the squares in front of the large public buildings, the greenbelts in the central business districts, and the greenbelts in the new downtowns. This paper conducts case analyses of the Xidan Culture Square (Completed), the Beijing Exhibition Centre Square (Completed), the Zhongguancun Square (Completed), the Olympic Park Centre Area (Completed), and the National Olympic Sports Centre South (To be completed).

Table 6-1 The examined typologies of cases in Beijing

| Name \ Typologies | | Xidan Culture Square ( | Beijing Exhibition Centre Square | the Zhongguancun Square | the Olympic Park Centre Area | National Olympic Sports Centre South |
|---|---|---|---|---|---|---|
| Mono-function | Commercial | | ○ | | | ○ |
| | Transportation | | | | | |
| | Leisure | | | | | |
| | Disaster prevention | | | | | |
| Multi-function | Commercial | ○ | | ○ | ○ | |
| | Transportation | | | ○ | | |
| | Leisure | | | | ○ | |
| | Disaster prevention | ○ | | ○ | | |

The projects developed under the downtown roads in Beijing, such as the municipal pipelines, the rail transit facilities, and the underground passages and interchanges, are crucial to the city development. Nowadays, those underground pipelines constructed at different times are intersected under the downtown roads. As the city expands and people's living standards improve, more underground pipelines of different kinds are built.

## 6.2 Project description

The core area of the Central Business District (CBD) in Beijing is about 5.5km away from the Imperial Palace and the Tian'anmen Square. Within the area stand the CCTV Tower, the China World Trade Centre and the Yintai Centre. Covering a land of 7km, the double-cross area mostly serves the office purposes. Facing the Jianguomen Outer Street and neighbouring the East Third Ring Road in the west, the Zhenzhi Road in the east, the Guanghua Road in the north and the Jianguo Road in the south, the CBD fully showcases its functions.

The Beijing CBD has witnessed rapid development since the release of the Comprehensive Planning of Beijing Central Business District in 2001. Later, the competent departments and units worked together to formulate the Opinions on Greenbelt Planning and Management in Beijing Central Business District, which covers systematic studies of topics such as public greenbelt use and greening rates based on the construction characteristics of CBD.

In 2004, the Beijing Municipal Institute of City Planning & Design worked with the Pei Cobb Freed & Partners to compile the Regulatory Detailed Plan for Beijing Central Business District. Focusing on the city design, the Plan sets out the detailed planning requirements and further improves the function of the CBD, aiming to build it into the epitome of urban spatial form of Beijing as an international metropolis. The Underground Space Planning for Beijing Central Business District was completed in the same year. The Plan provides a '1-axis, 1-zone, 2-point and 3-line' underground space framework (Wang, 2006), which elaborates on the specific technical requirements of development and utilization of the underground space and plays a guiding role in CBD development.

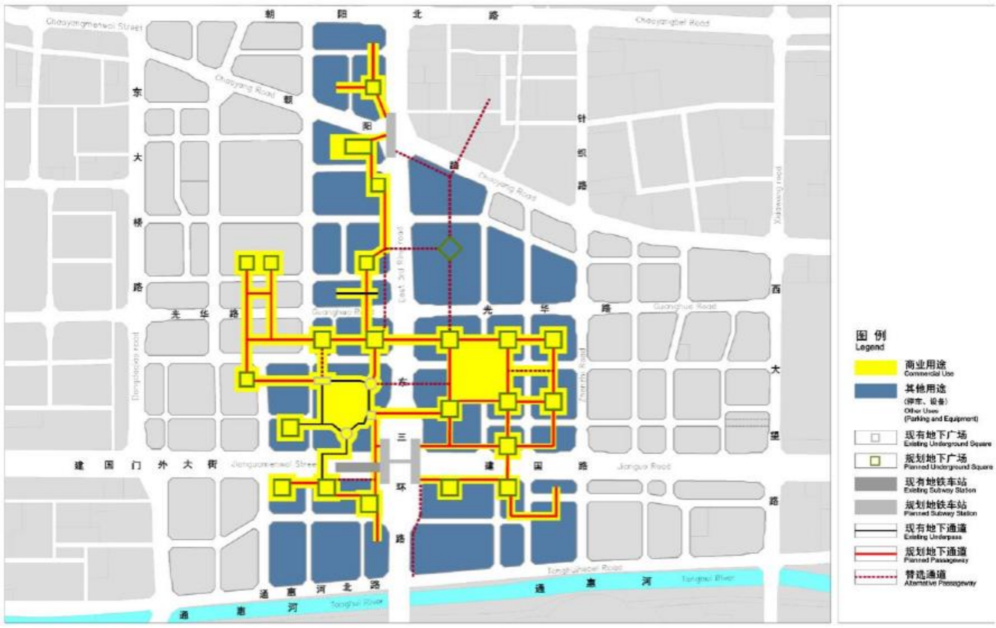



Figure 6-1 The connectivity of underground space in Beijing CBD

*Figure source: Detailed planning for the core area of Beijing Central Business District*

The Canadian model (Huang and Shi, 2004) was adopted in the CBD underground space planning(Zhang, 2015). The underground space within the lot is connected to form a continuous underground pedestrian network, which includes:

1) Underground passages within the lot, referring to public passages in the project.

2) Underground passages of the public land

- Underground passages among the lots that vertically cross the secondary trunk roads, access roads and public greenbelts of the city.

- Underground passages that cross the arterial roads

- Underground passages of the free area in the metro that connect the metro stations with the neighbouring area.

3) Overall planning of the underground space

Build underground streets and squares, such as the CBD Core Area under the roads and public greenbelts.

Figure 6-2 the master plan of underground space in Beijing CBD

*Figure source: Detailed planning of underground space for Beijing Central Business District, project designed by Beijing Institute of Urban Planning and Design*

By 2018, the planned length of the underground passages in CBD totalled about 6,000m. The length of the underground public passages within the lot is about 4,000m (67%), and that of underground passages is 1,000m (16%) under the public land (7.7% among the lots and 8.3% under the arterial roads), and 1,000m (17%) for the overall planning of the underground space (Phase I of CBD Core Area). 97% of the planned passages within the lot were built and 30% under the public land. 51% of the planned underground passages are connected with each other. In addition to China World Trade Centre, Yintai Centre, CBD Core Area and their neighbouring areas, most underground projects were completed within the individual lots and did not achieve effective connectivity.

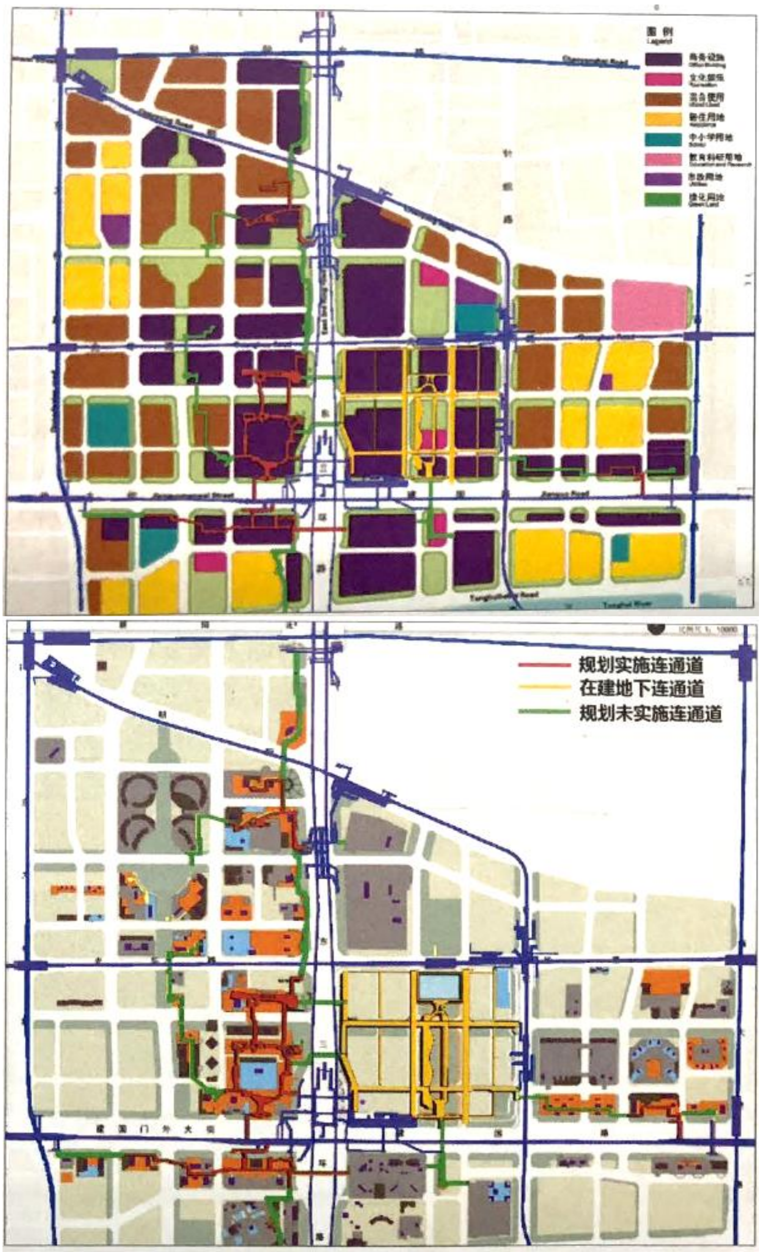



Figure 6-3 The land use of Beijing CBD (top) and the existing underground connectivity of Beijing CBD (down)

*Figure source: Detailed planning of underground space for Beijing Central Business District, project designed by Beijing Institute of Urban Planning and Design*

The underground passages (both completed and to be completed) are built under the commercial space, which requires efficient underground connectivity. In contrast, with the neighbouring areas being mostly occupied by the residential and office buildings due to more developed rail transit, the needs for underground connectivity are declining. The underground commercial areas within the reach of 500m around Guomao Metro Station and 300m around Jintai Xizhao Metro Station and Dawanglu Metro Station have achieved connectivity, improving the accessibility and economic performance of the underground space. For instance, the north-south underground passage at the Guomao Metro Station connects the China World Trade Centre with the Yintai Centre; the Jintai Xizhao Metro Station is connected to the ground floor of the Fortune Plaza; and the Dawanglu Metro Station is connected to the ground floor of the Gemdale Plaza.

## 6.3 Implementation of the Underground Public Space Planning in CBD Core Area

This section will evaluate the implementation of underground space planning in Beijing CBD area. Including the analysis of the overall implementation and spatial distribution of the underground pedestrian system, the analysis of the implementation of different types of underground connecting passages, and the analysis of the main factors affecting the implementation of the plan combined with implementation cases.

### 6.3.1 Evaluation Scope

The evaluation scope covers an area of about 4 square kilometres, 2.21 square kilometres of which is the core area. It neighbours the Chaoyang North Road and Chaoyang Road in the north, Tonghui River in the south, West Dawanglu Road in the east and Dongdaqiao Road in the west. The evaluation focuses on the implementation of the underground pedestrian system planning in the underground public space of CBD. The underground driving systems and the special public facilities such as utility tunnels are not evaluated. The Canadian model was adopted in the CBD underground space planning. The underground space within the lot is connected to form a continuous underground pedestrian network, which includes

#### 6.3.1.1 Underground passages within the site blocks

Public passages within CBD

#### 6.3.1.2 Underground passages in the public land

(1) Underground passages between the sites that cross the secondary trunk roads, access roads and public greenbelts of the city.

(2) Underground passages that cross the arterial roads.

(3) Underground passages of the free area in the metro that connect the metro stations with the neighbouring area.

#### 6.3.1.3 Overall Planning of the Underground Space

Build underground streets and squares, such as the CBD Core Area under the roads and public greenbelts.

### 6.3.2 Evaluation Contents

The planning evaluation can be divided into general implementation, categorised implementation, and influencing factors, and development mode see Table 6-2.

Table 6-2 The planning evaluation

| **General implementation** | **Categorised implementation and influencing factors** | **Development mode** |
|---|---|---|
| General implementation and space division of the underground pedestrian systems are analysed. | Implementation of different types of underground passages and the major factors that influence the implementation of specific cases are analysed. | Development mode of the underground public space in CBD. |

### 6.3.3 **Planning evaluation**

#### 6.3.3.1 General implementation

Evaluate the underground space in the CBD lot. The planned length of the underground passages in CBD totalled about 6,000m: about 4,000m (67%) within the corridor, 1,000m (16%) under the public land (7.7% among the lots and 8.3% under the arterial roads), and 1,000m (17%) for the overall planning of the underground space (Phase I of CBD Core Area).

97% (4,180m) of the planned passages within the lot were built and 30% under the public land. The underground space of CBD Core Area (Phase I) is under construction.

Table 6-3 Connectivity of the pedestrian passages within the site

| Type | Name | Planned length | Progress |
|---|---|---|---|
| Within the site | Yintai Centre | 450 | Completed |
| | Jianwai SOHO | 373 | Completed |
| | Central International Trade Centre | 160 | Completed |
| | Full Tower | 78 | Completed |
| | Central Park | 182 | Completed |
| | Guanghua International | 110 | Completed |
| | Gemdale Plaza | 260 | Completed |
| | Gemdale-Metro Station | 85 | Completed |
| | Wanda Plaza | 345 | Completed |
| | IFC | 162 | Completed |
| | China World Trade Centre (Phase III) | 245 | Completed |
| | China World Trade Centre (Phase III)-Metro Station | 23 | Completed |
| | Zhonghai Plaza | 225 | Completed |
| | Fortune Plaza | 710 | Completed |
| | Fortune Plaza-Metro Station | 60 | Completed |
| | Jing'ao Plaza | 110 | Completed |
| | Aether Square | 70 | Completed |
| | BTV | 120 | Completed |
| | Kerry Centre | 115 | Completed |
| | Core Area (Phase I) | 1000 | To be completed |
| | Core Area (Phase II) | 1500 | To be launched |

| | Sub-total | 3860 | |
|---|---|---|---|

Table 6-4 Connectivity across the secondary trunk roads under the public land

| Type | Name | Planned length | Progress |
|---|---|---|---|
| Across the secondary trunk roads | Jing'ao Plaza-Fortune Plaza | 25 | Completed |
| | Central Park-Fortune Plaza | 40 | To be launched |
| | Fortune Plaza-Full Tower | 43 | To be launched |
| | Full Tower-Kerry Centre | 25 | To be launched |
| | China World Trade Centre (Phase III)-Kerry Centre | 40 | To be launched |
| | China World Trade Centre-Zhonghai Plaza | 15 | To be launched |
| | IFC-Central International Trade Centre | 20 | Completed |
| | Central International Trade Yantai Centre | 25 | Completed |
| | Jianwai SOHO-Yintai Centre | 30 | To be launched |
| | Yintai Centre-Third Ring Road | 30 | To be launched |
| | CCTV Tower-Core Area | 40 | To be launched |
| | Core Area-Wanda Plaza | 40 | To be launched |
| | China World Trade Centre (Phase II & III) | 30 | Completed |
| | China World Trade Centre | 25 | Completed |
| | Huajun International Centre | 25 | Completed |
| | Wanda Plaza-Jindi Plaza | 40 | To be launched |
| | Subtotal | 150 | |

Table 6-5 Connectivity across the arterial roads

| Type | Name | Planned length | Progress |
|---|---|---|---|
| Connectivity across the arterial roads | Jing'ao Plaza-Jingguang Plaza | 60 | To be launched |
| | Hanghua Plaza-Metro Line 10 | 120 | To be launched |
| | Yintai Centre-Hanghua Plaza | 170 | Completed |
| | China World Trade Centre (Phase III)-CBD Core Area | 90 | To be launched |
| | China World Trade Centre (Phase II)-CBD Core Area (Phase I) | 100 | To be launched |
| | Subtotal | 170 | |

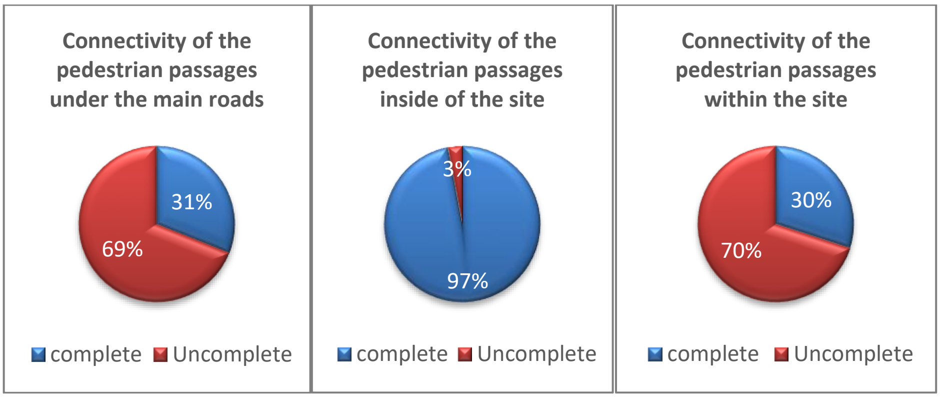



Figure 6-4 Connectivity of the pedestrian passages

The lagged implementation of the underground public space planning undermines the connectivity. About 51% of the planned underground passages are connected with each other. In addition to China World Trade Centre, Yintai Centre, CBD Core Area and their surroundings, most underground projects were constructed within the individual lots and did not achieve effective connectivity.

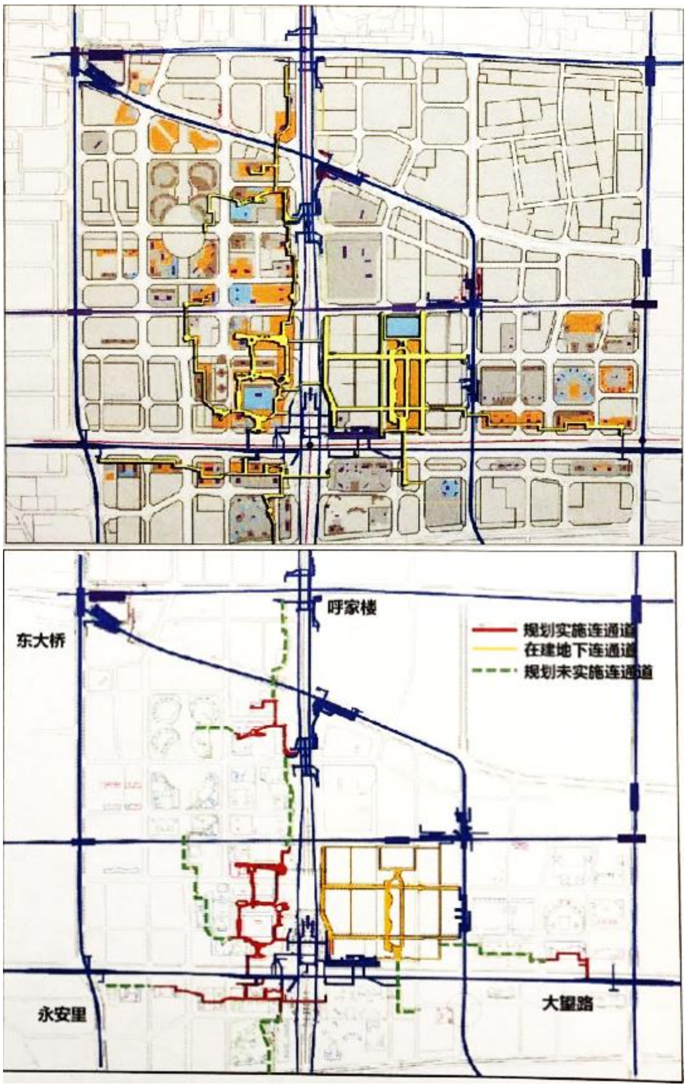



Figure 6-5 The master plan of Beijing CBD (top) and the existing underground connectivity of Beijing CBD (down)

*Figure source: Detailed planning of underground space for Beijing Central Business District, project designed by Beijing Institute of Urban Planning and Design*

The connectivity under the commercial areas crowded with business facilities is excellent. The underground business cluster of China World Trade Centre-Yintai Centre has initially taken shape. The connectivity under the commercial areas crowded with business facilities along the East Third Ring and Jianguo Road is being enhanced.

The connectivity under the commercial areas crowded with business facilities is excellent. The space under the residential and office areas mostly serve the non-commercial purposes, with relatively insufficient demand for underground passages construction. The areas from Zhonghai Plaza to Central Park and from Hanghua Plaza to BTV serve the residential and office purposes, the underground space of which provides the non-commercial supporting services. More needs should be identified and satisfied progressively.

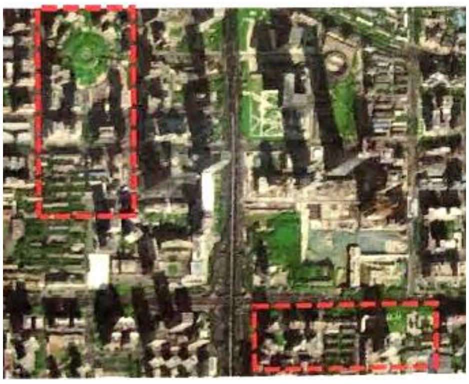


Figure 6-6 The site of Beijing CBD (left) and the existing underground function of Beijing CBD (right)

*Figure source: Detailed planning of underground space for Beijing Central Business District*

The metro station helps improve the underground space connectivity. The underground commercial areas within the reach of 500m around China World Trade Centre Metro Station and 300m around Jintai Xizhao Metro Station and Dawanglu Metro Station have achieved connectivity, improving the accessibility and economic performance of the underground space. For instance, the north-south underground passage at the China World Trade Centre Metro Station connects the World Trade Centre with the Yintai Centre; the Jintai Xizhao Metro Station is connected to the ground floor of the Fortune Plaza; and the Dawanglu Metro Station is connected to the ground floor of the Gemdale Plaza.

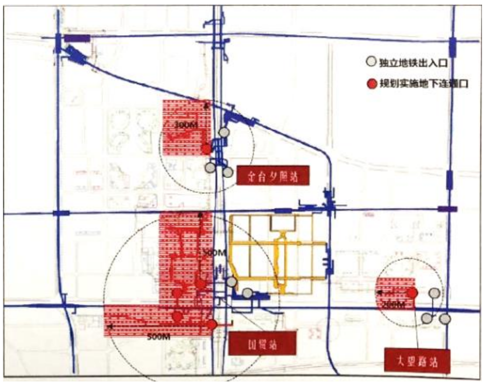



Figure 6-7 The photo of Beijing CBD (left) and the existing metro station of Beijing CBD (right)

*Figure source: By author (lift) and Detailed planning of underground space for Beijing Central Business District*

#### 6.3.3.2 Analysis of categorised implementation

(1) Insufficient underground connectivity

The underground passages among the lots include the north-south underground pedestrian system along the East Third Ring and the west-east pedestrian system in the south of the Jianguo Road. Among the 12 underground passages, 4 have been completed, with the planning-implementation ratio being 25%. One of the 4 completed underground passages has not been put into use yet.

Table 6-6 Implemented connection corridors usage

| No. | Project | In service/Not in service |
|---|---|---|
| 1 | Jing'ao Plaza-Fortune Plaza | Not in service |
| 2 | China World Trade Centre (Phase III)- China World Trade Centre (Phase II) | In service |
| 3 | Yintai Centre- Central International Trade Centre | In service |
| 4 | Central International Trade Centre-IFC | In service |

Most completed underground passages are near China World Trade Centre-Yintai Centre, forming a local underground pedestrian network. But the underground connectivity in other areas lags far behind.

The underground connectivity network of China World Trade Centre-Yintai Centre is built based on the general project planning. The underground space is connected via the metro. The project-based passages improve the overall connectivity of the underground space within the project and boost the economy. The underground passages as part of the project relieve the fund pressure. The underground commercial facilities along the passages are highly concentrated. The underground passages enhance the continuity of the commercial space and contribute to the underground business clusters. These passages are about 25-50m wide. The business space is about 9-12m wide on each side, leaving a passage width of 8-10m. The underground passages require less construction and are technically less challenging. The project is connected to the metro line. The transit platform is built under the project area, improving the connectivity of the underground space, attracting more passengers and unleashing the economic potential of the commercial facilities.

The underground connectivity of Kerry Centre-China World Trade Centre is restricted by the regulations on public land and the subsidy policies. The constructors are not willing to build the passages. The underground connectivity depends on the investment from the constructors of neighbouring projects. The constructors cannot get the property right over the underground passages due to the lack of public roads and the legal basis for underground space layering. There is no guarantee over related ownership. The construction cost of the underground passages is high and existing facilities require renovation. Currently, no regulation or subsidy policy on the commercial use of the passages under the public land is in place, resulting in payment imbalance. Social subjects' willingness to invest in the project construction is weak. The needs and willingness of different shareholders vary. The rights and obligations on passages are not well-defined. No coordination mechanism is in place, which makes it difficult to implement the passage construction plans. Local connectivity is not as effective when the overall underground connectivity is not achieved. In light of the revenue and expenditure and their demands, the related construction subjects' willingness to implement the projects is not strong enough.

(2) Passages that cross the arterial roads are mostly located in the free areas of metro stations. Few independent underground passages are built.

Underground passages that cross the arterial roads: A total of 11 underground passages that cross the arterial roads are planned, 5 of which are built in the free areas of metro stations. Only 2 independent underground passages are built. The independent passages that cross the arterial roads are difficult to build and the construction cost is high. Only the underground passage between Yintai Centre and Hanghua Plaza is built.

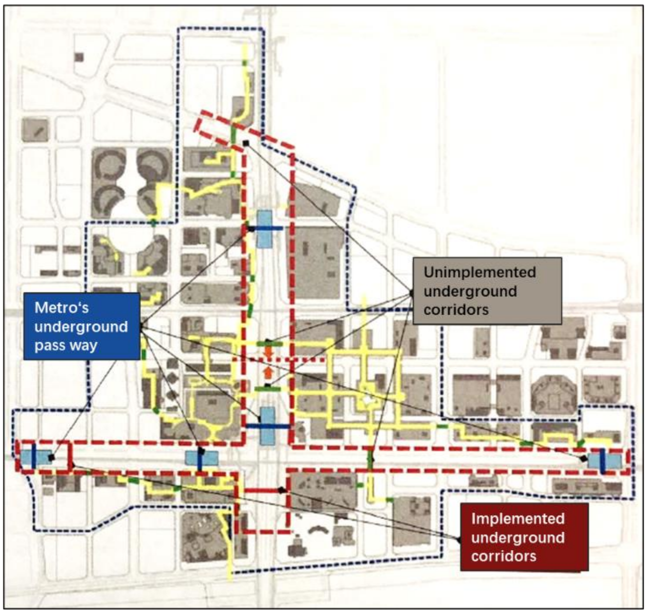



Figure 6-8 The underground pass way of Beijing CBD

*Figure source: Detailed planning of underground space for Beijing Central Business District*

The Yintai-Hanghua passage is sponsored and managed by the CBD Management Committee and has been put into service. Sponsored by the government, the passage improves the local connectivity with remarkable indirect benefits, though the project is costly and technically challenging. There are no supporting facilities along the passage, with the space patterns being single. As a local public transit passage, it is sponsored by the government. The Yintai Centre is responsible for the section within its project scope. The Investment and Service Centre under the CBD Management Committee is responsible for the operation of the passage. The passage connects 32 pipelines in 6 categories under the East Third Ring Road, part of Metro Line 10 aboveground, and 32 bridge piers at 8 sites near the Guomao Bridge and the Dabeiyao Bridge. The total construction cost is RMB 150 million, and the annual maintenance cost is about RMB 1.5 million. It connects several lots, metro stations and bus stations, remarkably improving the connectivity of the underground space in the south of the Guomao Bridge and relieving the traffic pressure. The main passage is about 165m and 9.4m. No supporting facilities are built along the passage. The underground space is mostly linear and the general environment is dull.

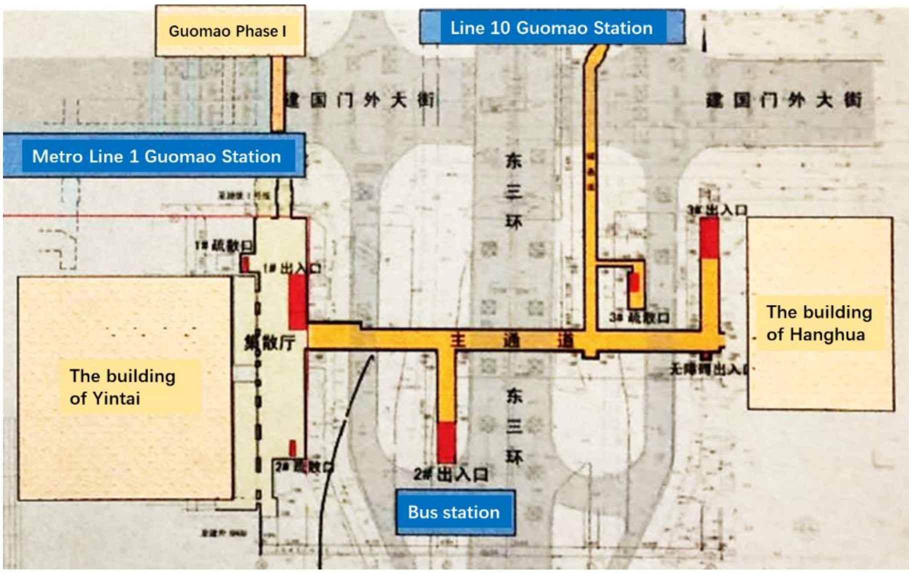



Figure 6-9 The Yintai-Hanghua underground pass way of Beijing CBD

*Figure source: Detailed planning of underground space for Beijing Central Business District*

The independent underground passage helps guide the non-motorised traffic flow during peak hours. But the utility ratio is low during the off-peak hours. The Yintai-Hanghua underground passage connects the metro station to the commercial buildings and bus stations nearby, relieving the traffic pressure during the peak hours. With the pipelines and bridge piers under the Third Ring Road taken into consideration, the passage is located deep and loosely connected to the ground space, thus failing to attract part of the non-motorised traffic flow aboveground. During the off-peak hours, the underground passage is particularly deserted.

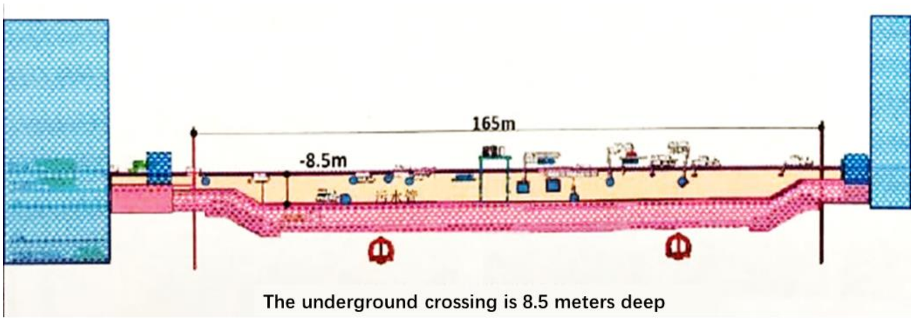



Figure 6-10 Depth of crossing way of Beijing CBD

*Figure source: Detailed planning of underground space for Beijing Central Business District*

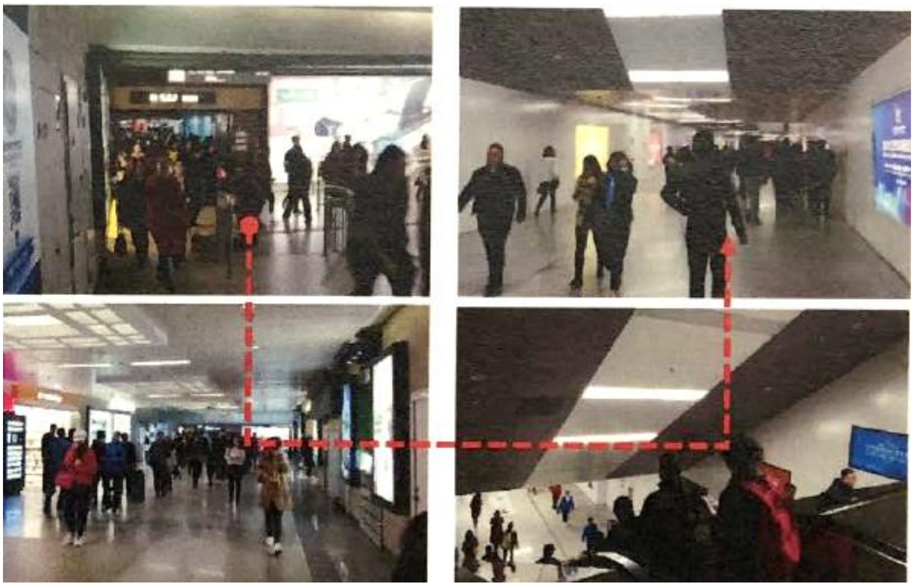


Figure 6-11 People flow in Guomao metro stations and underground crossings during morning rush hour

*Figure source: photo by author (10.20 am, 10/2017)*

Figure 6-12 People flow in Guomao metro stations and underground crossings during non-morning rush hour

*Figure source: photo by author (10.20 am, 10/2017)*

(3) Under-developed connectivity between the metro station and the underground space and small amount of metro entrances & exits (mostly independent)

A total of 20 metro passages are planned in the core area (Figure 6-13), with 9 metro entrances & exits leading to the ground directly and 7 underground connection passages (4 at Guomao Station). Four planned underground connection passages are built into the entrances & exits leading to the ground directly. The metro connection passages account for 35%, connecting 5 lots only. The connectivity between the metro stations and the underground space in the CBD requires improvement. There are 18 entrances at the People's Square Metro Station in Shanghai, directly connecting 9 lots nearby. The amount of the metro entrances & exits and the underground space connection at the People's Square Metro Station outperform the metro stations in the CBD area.

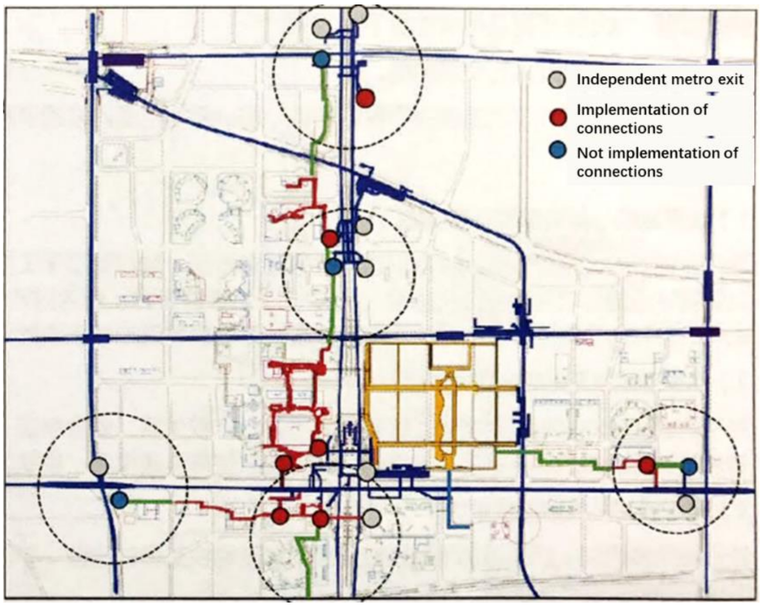



Figure 6-13 Implementation and not Implementation of the underground connection

*Figure source: Detailed planning of underground space for Beijing Central Business District, project designed by Beijing Institute of Urban Planning and Design*

The metro transit platform is built on the project lot, achieving seamless connection between the metro station and the underground space and promoting the underground business. A new transit platform will be built at the intersection of Line 1 and Line 2 at the Guomao Station. Seven transit passages will be built and renewed, connecting the Guomao Stations on Line 1 and Line 10 to the new transit platform. The passengers can transfer between Line 1 and Line 10, enter the Guomao station, or arrive at the World Trade Centre.

The new transit platform has four floors underground, 3,000sqm on each floor. Floor 3 and Floor 4 are used for transit and equipment storage purposes. Floor 1 and Floor 2 are used to accommodate the commercial facilities. The platform connects Line 1 in the south and Line 10 in the east, and the underground commercial area of the World Trade Centre in the north. There are 8 escalators, 1 stairway, and 1 barrier-free elevator in the hall, leading the passengers to access the metro station and the commercial areas or to transfer between Line 1 and Line 10. A 3D underground pedestrian system is thus built.

The exchange platform and integrated implementation mechanism between the metro stations and the nearby areas are not in place. The metro company takes charge of the part under the roads and the lot owner is responsible for the part within the project scope. The property right of the passages under the roads belongs to the metro company and the passages, and that of the passages within the project scope belongs to the lot owner. There is no plan to connect the metro station with the neighbouring lots. It is costly to build the connection passages at a later stage. When the metro station is built earlier, restricted by the tight schedule and budget, the integrated development with the neighbouring area is not taken into consideration. When the lot is developed earlier, no explicit metro connection plan is in place. There are no clear implementation mechanisms on metro connection, property ownership, fund sources, function design and use requirements, making it challenging to connect the metro station to the lots. The connection passage built at a later stage can be costly and undermine the metro operations.

The facilities along the metro connection passages require improvement. There are security checks at both ends of the underground passages at the metro station, slowing down the passenger flow. And these passages are often deep underground. There are no barrier-free elevators at some exists, making it inconvenient to move up and down.

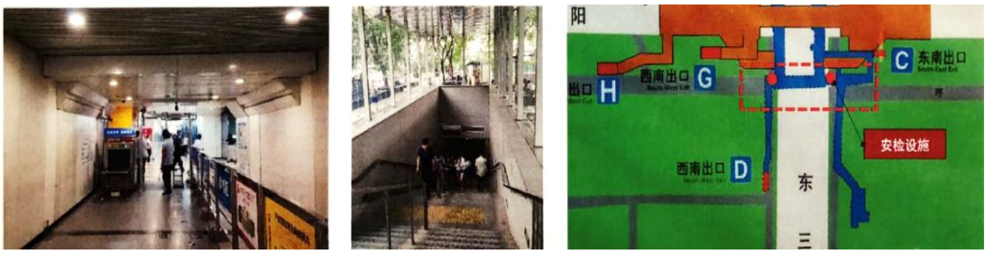



Figure 6-14 Security inspection facilities at the end of the passage (left)

Entrance and exit of the passage (middle)

Master plan of Hujialou metro station (right)

*Figure source: photo by author (11/10/2017)*

The development of the space under the roads and public greenbelts in CBD Core Area is led, planned and coordinated by the government. There are two types of underground space: the complex under the public greenbelts, and the commercial streets and traffic corridors under the roads.

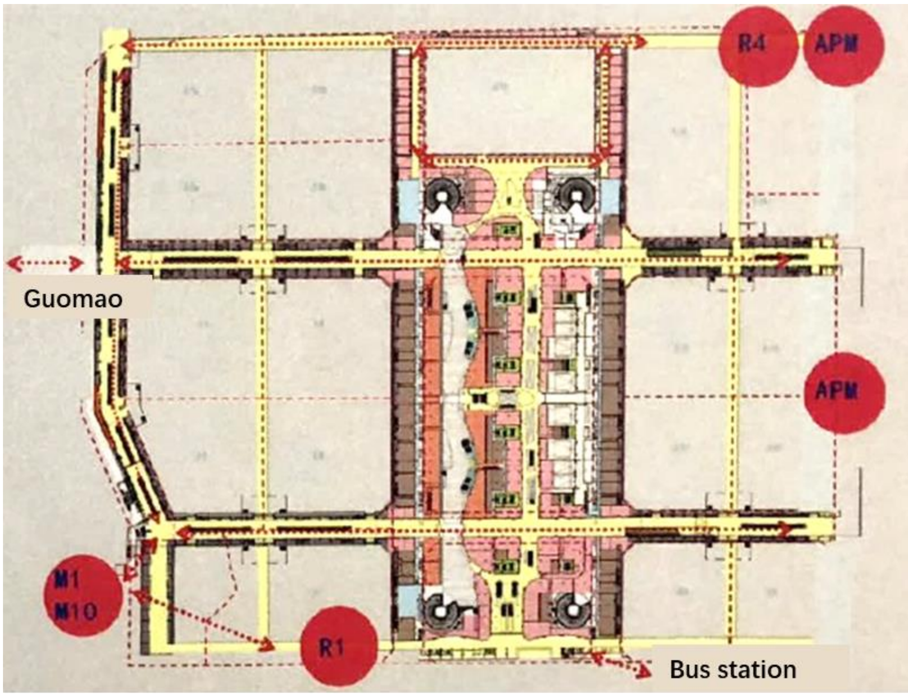



Figure 6-15 Master plan of Beijing CBD core area

*Figure source: Detailed planning of underground space for Beijing Central Business District, project designed by Beijing Institute of Urban Planning and Design*

The government-led space development projects under the public greenbelts and roads are suitable for newly built areas. These projects help improve the overall use efficiency of the underground public space. The underground space development in the CBD Core Area is led by the CBD Management Committee. The project involves 4 roads and greenbelts. As a newly developed project, the construction is less challenging, and the coordination is easier. In addition, as a government-led project, the underground space belongs to the government. Also, by combining the public passages with the supporting buildings, and the utility tunnels with the traffic passages, the space is intensively utilised, bringing about both environmental and economic benefits. Last but not least, the space under the public greenbelts covers an area of nearly 120,000 sqm on five floors, serving a wide range of functions and bringing about scale benefits.

### 6.3.4 Influencing factors

The major influencing factor in the implementation of the underground public space plan lies in the metro station, the public land and the business clusters. The metro station should strengthen the coordinated development of the rail system and the underground space and build a rail system that Centres on the metro station, realise the connectivity via the underground pedestrian system and foster the underground businesses.

## 6.4 Data analysis

This sub-section evaluates and scores three types of underground public space near the Guomao Station, namely the dotted space, the linear space and the planar space.

### 6.4.1 Friendly interior design

- Size

The Guomao underground public space provides a wide range of space with the ideal widths and height-width ratios.

Figure 6-16 The Friendly interior design of Guomao underground public space.
*Figure source: Photo by author (11/2017)*

- Signs and maps

The signs and maps along the flow routes in the Guomao underground public space are conspicuous, recognisable, and readable. They are in harmony with the surroundings. The key recognizable elements are thus created. There are signs and maps for key paths, event venues, landmarks, and regions.

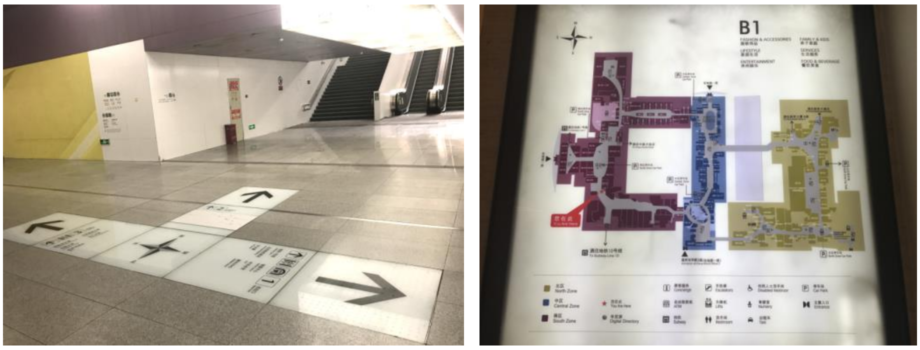



Figure 6-17 The signs and maps of Guomao underground public space.
*Figure source: Photo by author (11/10/2017)*

- Furnishings

Little furnishing is provided in the Guomao underground public space, including the public channels and the pedestrian streets. There are chairs, trash cans and information display boards within the service scope of the commercial tenants.

Figure 6-18 The furnishings of Guomao underground public space.
*Figure source: Photo by author (11/10/2017)*

- Materials

The interior materials are mostly stoning with excellent fire-resistance. Stones are also skid and waterproof. The materials go harmony with the general hue of the space. The materials of the public areas are also natural stones. The choice and collocation of the materials are natural and harmonious.

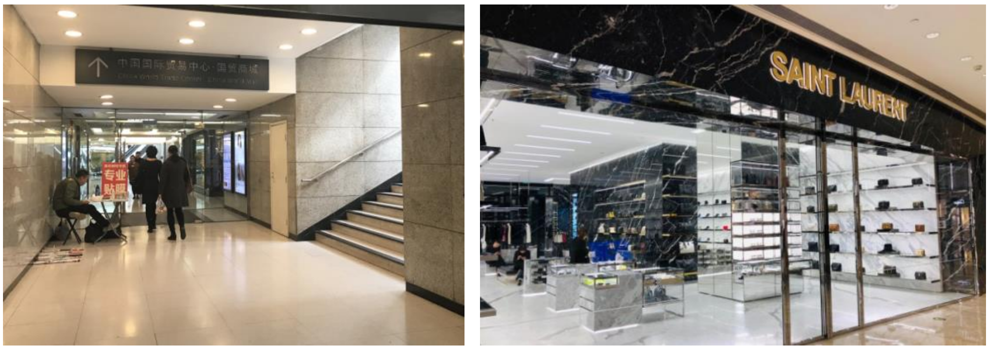



Figure 6-19 The materials of Guomao underground public space.
*Figure source: Photo by author (15/10/2017)*

- Nature elements

Many plants are introduced to the public space and the node space, which are supplemented by the natural materials.


Figure 6-20 The nature elements of Guomao underground public space.
*Figure source: Photo by author (10/2017)*

- Colour

The general hue is in line with the hue requirements for the metro stations and the interior design of the underground buildings. The colour combination is proper and pleasant. Local parts are decorated with the bright colours to create the nodes.

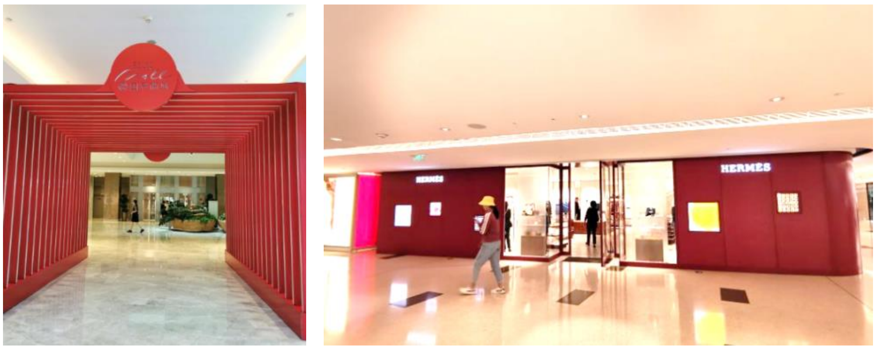



Figure 6-21 The colour of Guomao underground public space.
*Figure source: Photo by author (10/2017)*

- Art control

No unique artworks are included in the original plan. The space is simple and elegant overall. Several artworks are introduced later.

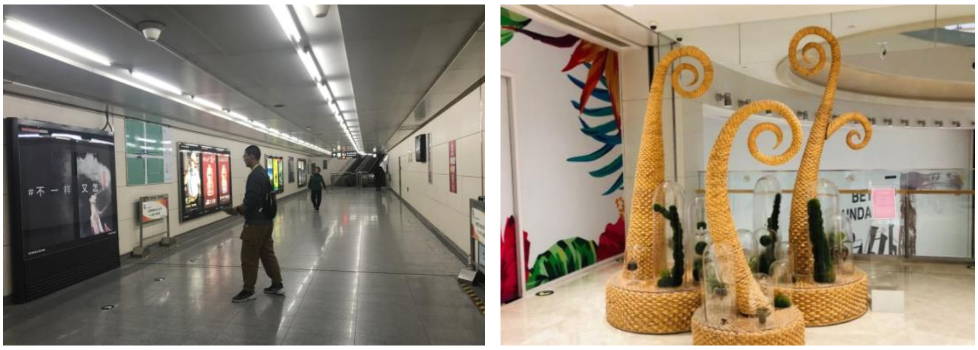


Figure 6-22 The art control of Guomao underground public space.
*Figure source: Photo by author (10/2017)*

Table 6-7 Friendly interior design score statistics by author

| Indicators | Good | Satisfactory | Need Improvement |
|---|---|---|---|
| **Size** | | 3 | |

| | | | |
|---|---|---|---|
| **Signs and maps** | 5 | | |
| **Furnishings** | | 3 | |
| **Materials** | 5 | | |
| **Nature elements** | 5 | | |
| **Colour** | | 3 | |
| **Art control** | | | 1 |
| **Spatial configuration** | 3.57 | | |

Table 6-8 Friendly interior design score statistics by users

| Indicators | Highest score | Lowest score | Average score |
|---|---|---|---|
| **Size** | 5 | 3 | 3.9 |
| **Signs and maps** | 5 | 2 | 3.73 |
| **Furnishings** | 5 | 3 | 3.91 |
| **Materials** | 5 | 2 | 3.8 |
| **Nature elements** | 5 | 2 | 3.75 |
| **Colour** | 5 | 3 | 4.01 |
| **Art control** | 5 | 1 | 3.81 |
| **Spatial configuration** | 3.84 | | |

### 6.4.2 Spatial configuration

The spatial configuration evaluation involves interconnected space, system of paths, height variation, privacy, landmarks, hierarchy, distinct zones, activity nodes, and overlooking activity.

- Interconnected space

The Guomao Station is well connected to the nearby office buildings and commercial facilities via the underground public space, achieving the internal connectivity of the underground space. The corridor under the Exit D of Guomao Station directly leads to the Yintai Centre.

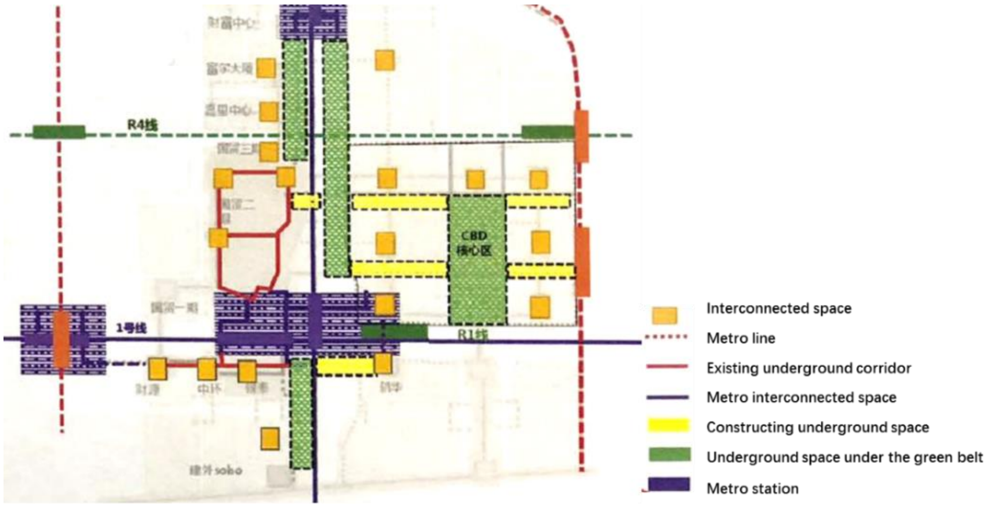



Figure 6-23 Interconnected space in Guomao metro station

*Figure source: drawing by author.*

- A system of paths

The lots surrounding the Guomao Station are not completely connected. The lots in the west of the East 3rd Ring Road have been connected; and those in the south of the Jianguo Road are connected via the metro station. The lots in the northeast, northwest and southwest of the metro station will get connected. But the connection between the underground public space of the southeast lots and the underground buildings relies on the Guomao Station on Line R1. By then, all space surrounding the Guomao Station will get connected.

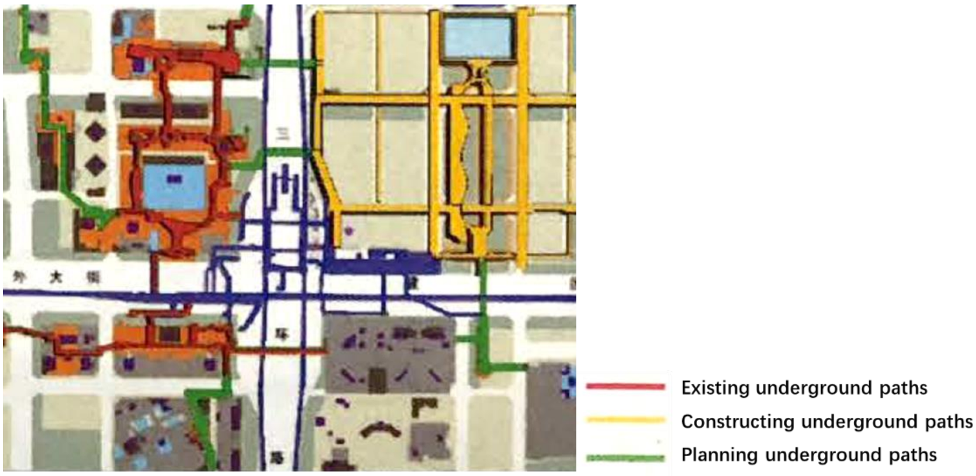



Figure 6-24 A system of paths for underground public space in Guomao metro station

*Figure source: drawing by author, project designed by Beijing Institute of Urban Planning and Design*

- Height variation

The height variation of the ceilings in the underground passage, from 3.3m to 4.5m. In the south of Jianguo Road makes the space more flexible and less restricted.

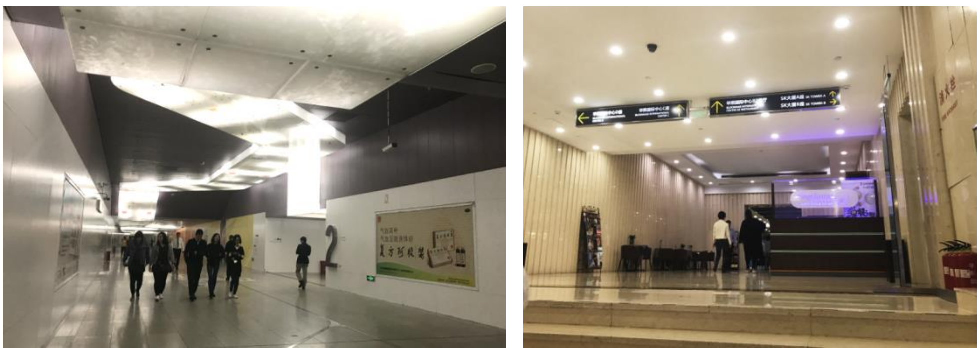


Figure 6-25 The spatial configuration of Guomao underground public space.

*Figure source: Photo by author (10/2017)*

- Privacy

Different seats are provided in the Guomao underground public space. Movable visual obstacles are offered, such as the plants of low and medium heights and the semi-transparent walls as fences.


Figure 6-26 The spatial configuration of Guomao underground public space.
*Figure source: Photo by author (10/2017)*

- Landmarks

There are diverse eye-attracting landmarks in the node space of the Guomao underground public space, such as the caisson ceilings.


Figure 6-27 Landmarks in underground public space.
*Figure source: Photo by author (10/2017)*

- Hierarchy

The hierarchy design separates the goods and the visitors with the paths.

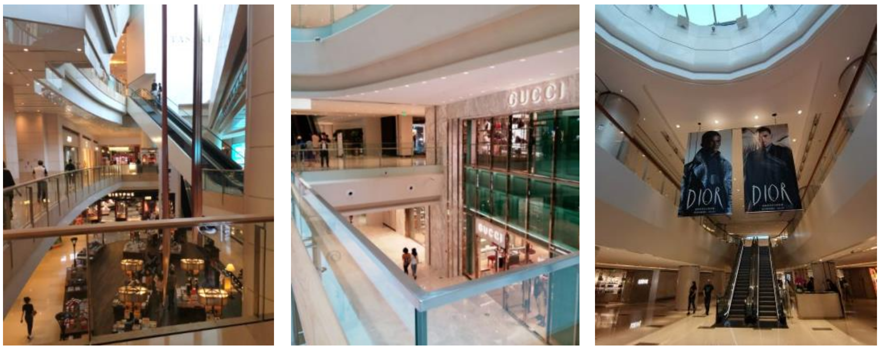



Figure 6-28 The spatial configuration of Guomao underground public space.
*Figure source: Photo by author (10/2017)*

- Distinct zones

The Guomao underground public space has meaningful names and clear boundaries with identifiable gateways or entrance transitions. It divides different function zones with various design approaches.


Figure 6-29 The spatial configuration of Guomao underground public space.
*Figure source: Photo by author (10/2017)*

- Activities nodes

The underground space provides diverse activity nodes that are readily recognisable in the functional zones. The hierarchy is important and should allow the user to see the activities in the space directly.

Figure 6-30 The spatial configuration of Guomao underground public space.
*Figure source: Photo by author (10/2017)*

- Overlooking activity

Sound visual and physical relations are established between the Guomao underground public space and the surroundings. The ceiling of the main pedestrian floor is transparent and safe, encouraging the interactions between the inside space and outside space, and between the public areas and the private areas. The users can overlook the activity areas through the windows and enjoy the indoor views. But the underground intersection between the metro and the buildings needs improvement.

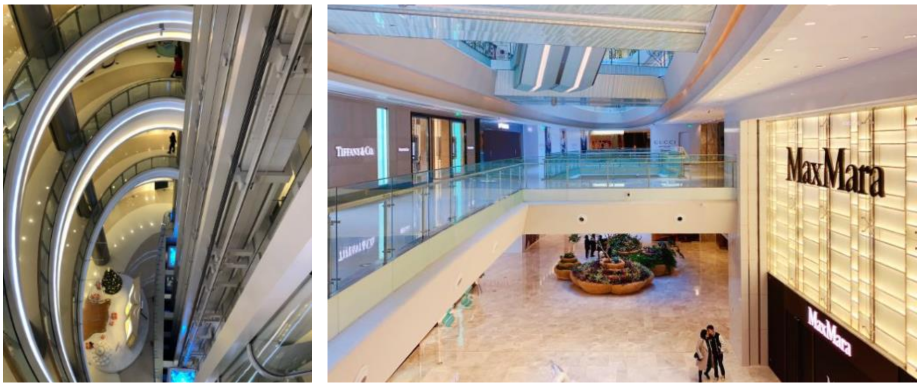


Figure 6-31 The spatial configuration of Guomao underground public space.

*Figure source: Photo by author (10/2017)*

Table 6-9 Spatial configuration score statistics by author

| Indicators | Good | Satisfactory | Need Improvement |
|---|---|---|---|
| **Interconnected space** | 5 | | |
| **A system of paths** | | 3 | |
| **Height variation** | 5 | | |
| **Privacy** | | 3 | |
| **Landmarks** | | 3 | |
| **Hierarchy** | 5 | | |
| **Distinct zones** | | 3 | |
| **Activities nodes** | | 3 | |
| **Overlooking activity** | | 3 | |
| **Spatial configuration** | 3.67 | | |

Table 6-10 Spatial configuration score statistics by users

| Indicators | Highest score | Lowest score | Average score |
|---|---|---|---|
| **Interconnected space** | 5 | 2 | 3.89 |
| **A system of paths** | 5 | 2 | 3.85 |
| **Height variation** | 5 | 2 | 4.09 |
| **Privacy** | 5 | 2 | 3.78 |
| **Landmarks** | 5 | 2 | 3.88 |
| **Hierarchy** | 5 | 3 | 3.92 |
| **Distinct zones** | 5 | 2 | 3.76 |
| **Activities nodes** | 5 | 2 | 3.99 |
| **Overlooking activity** | 5 | 2 | 3.89 |
| **Spatial configuration** | 3.88 | | |

### 6.4.3 Life safety

- Escape

The Guomao underground public space is well organized, providing clear road signs and information on the exits. There are sufficient escapes inside.

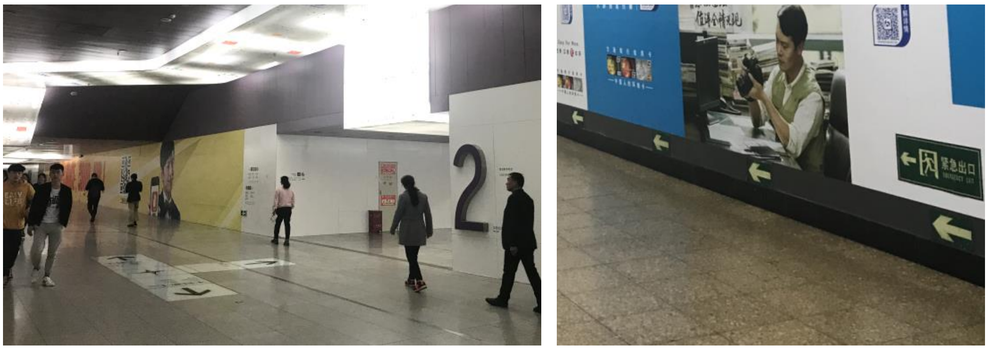


Figure 6-32 The escape of Guomao underground public space.
*Figure source: Photo by author (10/2017)*

- Fire suppression

The fire alarm and extinguishing facilities are installed. The monitoring system should be introduced to the sites with large passenger flow, monitoring the temperature and harmful gases.

Figure 6-33 Fire protection system and fire alarm and fire extinguishing facilities.
*Figure source: Photo by author (10/2017)*

- Disaster prevention

The flood and earthquake prevention functions are also taken into consideration. The entrances and exits at the low-lying places are elevated.

Figure 6-34 The disaster prevention of Guomao underground public space.

*Figure source: Photo by author (10/2017)*

- Alarm

According to the CBD Management Committee, the safety accident prevention mechanism is set up to prevent the unknown accidents or the accidents that have not occurred before.

Figure 6-35 The alarms of Guomao underground public space.

*Figure source: Photo by author (10/2017)*

- Supervisory

The closed-circuit digital video monitoring system of Guomao (Phase III) monitors the hotels, office buildings and shopping malls with thousands of cameras. The data is transmitted with the high-definition standard (2Mb/s) continuously. The monitoring data should be viewed only and re-played. All monitoring data would be kept for 30 days.

The largest concurrent traffic in the monitoring system is 5150Mb/S (2513.3Mb/s in the hotel and 2636.9Mb/s in the property management office). Most storage system can hardly deal with such a large data traffic. In addition, the project could be expanded in future, leading to a sharp increase in the needs for the storage space. As the monitoring cameras and control servers grow, the storage system should be scaled flexibly.

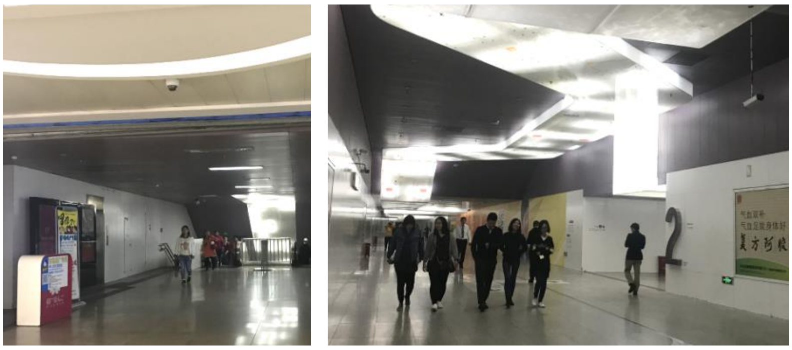


Figure 6-36 The supervisory of Guomao underground public space.

*Figure source: Photo by author (10/2017)*

Table 6-11 Life safety score statistics by author

| Indicators | Good | Satisfactory | Need Improvement |
|---|---|---|---|
| **Escape** | 5 | | |
| **Fire suppression** | 5 | | |
| **Disaster prevention** | 5 | | |
| **Warning** | 5 | | |
| **Supervisory** | 5 | | |

| | |
|---|---|
| **Spatial configuration** | 5 |

Table 6-12 Life safety score statistics by users

| Indicators | **Highest score** | **Lowest score** | **Average score** |
|---|---|---|---|
| Escape | 5 | 2 | 3.92 |
| Fire suppression | 5 | 2 | 3.99 |
| Disaster prevention | 5 | 2 | 4.01 |
| Warning | 5 | 2 | 3.94 |
| Supervisory | 5 | 2 | 3.88 |
| Spatial configuration | 3.94 | | |

### 6.4.4 Management

- Hygiene services

Maintained by the CBD Management Committee, the Guomao underground public space is clean and in good shape. Working with the neighbouring office buildings and commercial space, the Committee provides sufficient sanitary facilities in the public space, such as public chairs, restrooms, and trash cans.


Figure 6-37 The hygiene services of Guomao underground public space.

*Figure source: Photo by author (10/2017)*

- Informational facilities

There are public communication and information facilities and poster boards in the space.


Figure 6-38 Informational facilities of Guomao underground public space.
*Figure source: Photo by author (10/2017)*

- Affordability

The Guomao underground public space provides passage services and related facilities for free on a limited basis. It offers catering and entertainment services for the users of the office buildings nearby. Being connected with the square on the ground, it encourages excellent underground-aboveground interactions.

Figure 6-39 Affordability of Guomao underground public space.

*Figure source: Photo by author (10/2017)*

- Rules and regulations

The construction and operation of the Guomao underground public space are contracted to companies. The CBD Management Committee coordinates the property right and deals with the planning, application, and supervision. Therefore, the Committee sets lack rules or regulations on the users, animals, or activities, unless they are risky and dangerous.

Figure 6-40 Guomao underground public space.

*Figure source: Photo by author (10/2017)*

Table 6-13 Management score statistics by author

| Indicators | Good | Satisfactory | Need Improvement |
|---|---|---|---|
| **Hygiene services** | 5 | | |
| **Informational facilities** | 5 | | |
| **Affordability** | 5 | | |
| **Rules and regulations** | 5 | | |
| **Spatial configuration** | | 5 | |

Table 6-14 Management score statistics by users

| Indicators | Highest score | Lowest score | Average score |
|---|---|---|---|
| **Hygiene services** | 5 | 2 | 3.93 |
| **Informational facilities** | 5 | 3 | 3.95 |
| **Affordability** | 5 | 3 | 4.11 |

| | | | |
|---|---|---|---|
| **Rules and regulations** | 5 | 2 | 3.97 |
| **Spatial configuration** | 3.99 | | |

### 6.4.5 Lighting

- Artificial lighting

There is sufficient lighting along the main paths and activity nodes. The innovative application of the lighting facilities creates the charming atmosphere.

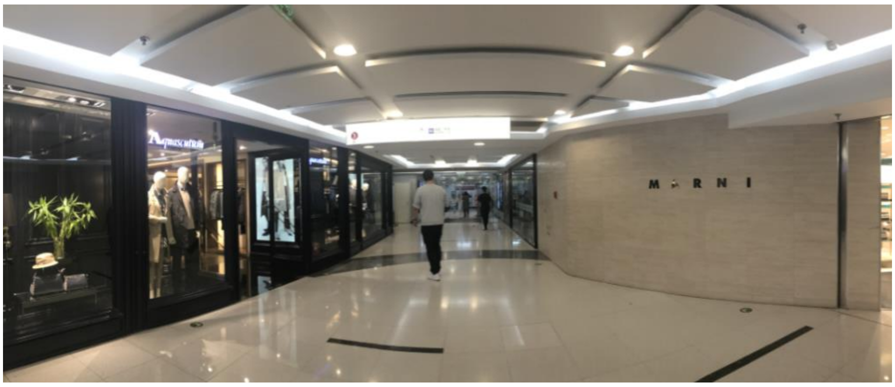


Figure 6-41 Artificial lighting of Guomao underground public space.

*Figure source: Photo by author (10/2017)*

- Indirect lighting

The indirect lighting is provided with the interior decorative materials, fully leveraging the diffuse reflection of the internal structures to soften the light.

Figure 6-42 Indirect lighting of Guomao underground public space.

*Figure source: Photo by author (10/2017)*

- Nature light

The light wells and skylights are built in part of the underground buildings to bring in the natural light, which, however, only accounts for a small share in the whole underground public space, especially in that connected to the metro stations.

Figure 6-43 Nature light of Guomao underground public space.

*Figure source: Photo by author (10/2017)*

Table 6-15 Lighting score statistics by author

| Indicators | Good | Satisfactory | Need Improvement |
|---|---|---|---|
| **Artificial lighting** | **5** | | |
| **Indirect lighting** | **5** | | |

| | | | |
|---|---|---|---|
| **Nature light** | | **3** | |
| **Spatial configuration** | **4.3** | | |

Table 6-16 Lighting score statistics by users

| Indicators | Highest score | Lowest score | Average score |
|---|---|---|---|
| **Artificial lighting** | 5 | 2 | 3.81 |
| **Indirect lighting** | 5 | 3 | 3.99 |
| **Nature light** | 5 | 3 | 4.01 |
| **Spatial configuration** | 3.94 | | |

### 6.4.6 Exterior and entrance friendly design

- Legibility

The Guomao underground public space is well connected to the Guomao Station. The users could access the underground space via the metro entrances & exits and the buildings. Therefore, the access to the Guomao underground space is readily recognisable horizontally and vertically.

Figure 6-44 Legibility of Guomao underground public space.

*Figure source: Photo by author*

- Accessibility

But the barrier-free facilities lag far behind. For example, there are facilities that help the disabled to access the metro at Exit D, but no slope is provided at the steps of the entrance, preventing the disabled to use the facilities independently. There are only 2 entrances & exits at the Guomao Station with the barrier-free facilities, one of which is the vertical exit. The vertical exit is not friendly for wheelchair users or passengers with carts or luggage.

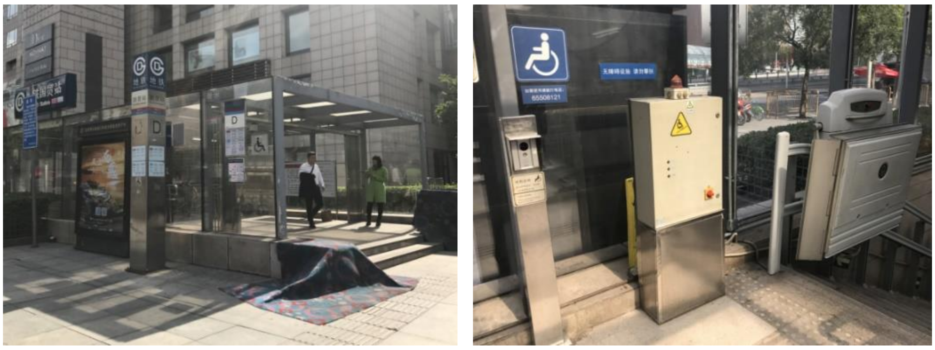


Figure 6-45 Accessibility of Guomao underground public space.
*Figure source: Photo by author*

- Vertical entrance

Only 2 of the independent exits & entrances of the underground space have elevators, 1 is the exit of the metro station and 1 is the access to the courtyard of SK Plaza.

Figure 6-46 Vertical entrance of Guomao underground public space.

*Figure source: Photo by author*

- Sunken open space

The sunken open space is a common form of the underground public space. But there is no such exit & entrance to the Guomao underground public space.

- Diversity integration

In the under-construction space under the CBD Core Area, the greenbelts are combined with the underground transportation facilities (including the underground rails and garages).

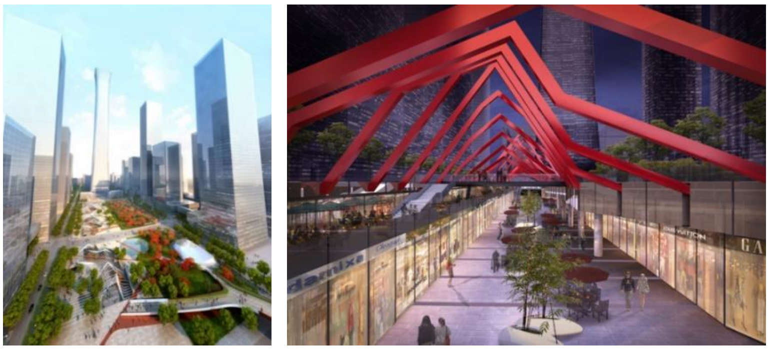


Figure 6-47 Computer rendering of CBD Core Area underground space

*Figure source: masterplan of CBD area*

Table 6-17 Exterior and entrance friendly design score statistics by author

| Indicators | Good | Satisfactory | Need Improvement |
|---|---|---|---|
| **Legibility** | **5** | | |
| **Accessibility** | | **3** | |
| **Vertical entrance** | | | **1** |
| **Sunken open space** | | | **1** |
| **Diversity integrations** | | | **1** |
| **Spatial configuration** | **2.2** | | |

Table 6-18 Exterior and entrance friendly design score statistics by users

| Indicators | Highest score | Lowest score | Average score |
|---|---|---|---|
| **Legibility** | 5 | 2 | 3.84 |
| **Accessibility** | 5 | 2 | 3.86 |
| **Vertical entrance** | 5 | 2 | 3.98 |
| **Sunken open space** | 5 | 2 | 3.8 |
| **Diversity integrations** | 5 | 2 | 3.95 |
| **Spatial configuration** | 3.886 | | |

### 6.4.7 Identity

- Culture

There are art walls that exhibit the traditional Chinese culture in the Guomao underground public space. But this is a short-time event that takes place during the Spring Festival.

Figure 6-48 Culture wall of Guomao underground public space.

*Figure source: Photo by author*

- Unique nature

Beijing Metro Line 1 is the first metro line in Beijing and China. But there is no unique nature about it. The Line 10 launched in 2008 does not include this element either.

- History and symbol

Not historical and symbolic elements are found in the Guomao underground public space.

- Imageability

The Guomao underground public space fails to impress the users with imageability, though it is located at one of the busiest metro stations in the busy CBD area.

Table 6-19 Identity core statistics by author

| Indicators | Good | Satisfactory | Need Improvement |
|---|---|---|---|
| Culture | | 3 | |
| Unique nature | | | 1 |
| History and symbolic | | | 1 |
| Imageability | | 3 | |
| Spatial configuration | 2 | | |

Table 6-20 Identity core statistics by users

| Indicators | Highest score | Lowest score | Average score |
|---|---|---|---|
| Culture | 5 | 2 | 3.83 |
| Unique nature | 5 | 2 | 3.91 |
| History and symbolic | 5 | 1 | 3.77 |
| Imageability | 5 | 1 | 3.82 |

| | |
|---|---|
| **Spatial configuration** | 3.83 |

### 6.4.8 User comfort

- Air quality

The ventilation and air purification system are introduced to monitor and regulate the air quality of the regions with large population density and flow. When the air quality is good aboveground, the underground air quality is good too; and when the air quality is poor aboveground, the underground air quality is better than that above the ground.

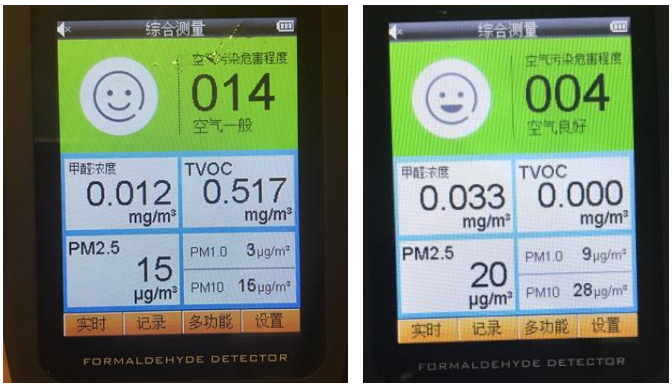



Figure 6-49 Air quality of Guomao underground public space.

*Figure source: Photo by author*

- Noise control

The Guomao Station is built under the roads, protecting the underground public space from noise pollution. The music is played indoors to improve the auditory experience.



Figure 6-50 Noise control of Guomao underground public space.

Figure source: Photo by author

- Temperature

In November 2017, the temperature aboveground was between -4° and 4°, while that of the underground space was between 12° and 15°. Although the underground temperature is pleasant, it is below the national standard for the indoor temperature 18℃-26℃.



Figure 6-51 Temperature of Guomao underground public space.

*Figure source: Photo by author*

Table 6-21 User comfort score statistics by author

| Indicators | Good | Satisfactory | Need Improvement |
|---|---|---|---|
| **Air quality** | 5 | | |
| **Noise control** | 5 | | |

| | | | |
|---|---|---|---|
| **Temperature** | | 3 | |
| **Spatial configuration** | 4.3 | | |

Table 6-22 User comfort score statistics by users

| Indicators | Highest score | Lowest score | Average score |
|---|---|---|---|
| **Air quality** | 5 | 3 | 4.08 |
| **Noise control** | 5 | 2 | 3.91 |
| **Temperature** | 5 | 3 | 3.95 |
| **Spatial configuration** | 3.98 | | |

### 6.4.9 Activities

- Theme sales

During the evaluation period, there were no themed sales activities held in the Guomao underground public space. But the space conditions at Guomao are ideal for such activities.

- Events

Theme entertainment programs can be launched in the underground skating rink and the space aboveground. The underground public space can be used to hold large-scale theme events such as ice-skating.

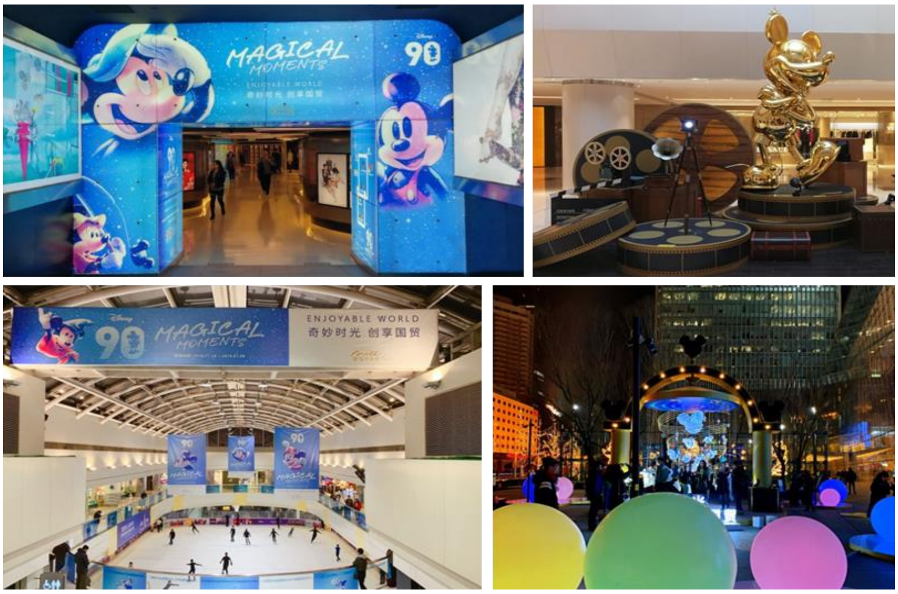



Figure 6-52 Event of Guomao underground public space.

*Figure source: Photo by author*

Table 6-23 Activities score statistics by author

| Indicators | Good | Satisfactory | Need Improvement |
|---|---|---|---|
| **Theme sales** | | **3** | |
| **Events** | **5** | | |
| **Spatial configuration** | **4** | | |

Table 6-24 Activities score statistics by users

| Indicators | Highest score | Lowest score | Average score |
|---|---|---|---|
| **Theme sales** | 5 | 2 | 3.77 |
| **Events** | 5 | 2 | 3.99 |
| **Spatial configuration** | 3.88 | | |

### 6.4.10 Sociability

- Diverse uses

The underground public space serves the shopping, entertainment, recreation, and pedestrian purposes. The vast space allows for greater possibilities.

Figure 6-53 Diverse uses of Guomao underground public space.

*Figure source: Photo by author*

- Interactive

The skating rink in the Guomao underground public space attracts many users. The open space design encourages underground-aboveground interactions. In many sites, the ground floors are used as the aboveground space, guiding the passengers into the underground public space.

Figure 6-54 Interactive of Guomao underground public space.

*Figure source: Photo by author*

- Cooperative

The Public-Private Partnerships mode is introduced in the development of the Guomao underground public space. The construction and operation are contracted to the developers. The government owns the property right and handles the planning and supervision tasks. The planning department plans and approves the development of the underground space; the landscape department is responsible for environment evaluation; the housing and construction committee takes charge of construction management; the civil air defence department examines the civil air defence facilities; the traffic committee handles the connections; and the metro company builds the metros.

Social services

The Guomao underground public space provides no service facilities for the special groups.

Table 6-25 Sociability score statistics by author

| Indicators | Good | Satisfactory | Need Improvement |
|---|---|---|---|
| **Diverse uses** | **5** | | |
| **Interactive** | **5** | | |
| **Cooperative** | **5** | | |
| **Social services** | | | **1** |
| **Spatial configuration** | **4** | | |

Table 6-26 Sociability score statistics by users

| Indicators | Highest score | Lowest score | Average score |
|---|---|---|---|
| **Diverse uses** | **5** | **2** | 3.93 |
| **Interactive** | **5** | **2** | 3.83 |
| **Cooperative** | **5** | **2** | 3.85 |
| **Social services** | **5** | **2** | 3.95 |
| **Spatial configuration** | **3.89** | | |

### 6.5 Evaluation results

The influencing factors were plotted, tabled, and weighted. Then the field investigations were made to score the factors (Good, Satisfactory and Need Improvement). The weighted mean scores of each factor were then summed up as below (see Table 6-25 and 6-26).

The overall score of the Guomao underground public space is 3.715 (5 for Good, 3 for Satisfactory and 1 for Need Improvement). The mean scores of each factor are shown in Figure 6-53. The spatial configuration, Friendly interior design and life safety are rated high; and the sociability, identity, activities, and exterior and entrance friendly design are rated low.

Table 6-27 Score statistics by author

| Attributes | Indicators | Good | Satisfactory | Need Improvement |
|---|---|---|---|---|
| **Friendly interior design** | Size | | 3 | |
| | Signs and maps | 5 | | |
| | Furnishings | | 3 | |
| | Materials | 5 | | |
| | Nature elements | 5 | | |
| | Colour | | 3 | |
| | Art control | | | 1 |
| | Spatial configuration | 3.57 | | |
| **Spatial configuration** | Interconnected space | 5 | | |
| | A system of paths | | 3 | |
| | Height variation | 5 | | |
| | Privacy | | 3 | |
| | Landmarks | | 3 | |
| | Hierarchy | 5 | | |
| | Distinct zones | | 3 | |
| | Activities nodes | | 3 | |
| | Overlooking activity | | 3 | |
| | Spatial configuration | 3.67 | | |
| **Life safety** | Escape | 5 | | |
| | Fire suppression | 5 | | |
| | Disaster prevention | 5 | | |
| | Warning | 5 | | |
| | Supervisory | 5 | | |
| | Spatial configuration | 5 | | |

| | | | | |
|---|---|---|---|---|
| **Management** | Hygiene services | 5 | | |
| | Informational facilities | 5 | | |
| | Affordability | 5 | | |
| | Rules and regulations | 5 | | |
| | Spatial configuration | 5 | | |
| **Lighting** | Artificial lighting | 5 | | |
| | Indirect lighting | 5 | | |
| | Nature light | | 3 | |
| | Spatial configuration | 4.3 | | |
| **Exterior and entrance friendly design** | Legibility | 5 | | |
| | Accessibility | | 3 | |
| | Vertical entrance | | | 1 |
| | Sunken open space | | | 1 |
| | Diversity integrations | | | 1 |
| | Spatial configuration | 2.2 | | |
| **Identity** | Culture | | 3 | |
| | Unique nature | | | 1 |
| | History and symbolic | | | 1 |
| | Imageability | | 3 | |
| | Spatial configuration | 2 | | |
| **User comfort** | Air quality | 5 | | |
| | Noise control | 5 | | |
| | Temperature | | 3 | |
| | Spatial configuration | 4.3 | | |
| **Activities** | Theme sales | | 3 | |
| | Events | 5 | | |
| | Spatial configuration | 4 | | |
| **Sociability** | Diverse uses | 5 | | |
| | Interactive | 5 | | |
| | Cooperative | 5 | | |
| | Social services | | | 1 |
| | Spatial configuration | 4 | | |
| | overall score | 3.715 | | |

Table 6-28 Score is calculated by weight

| No. | Categories | Average score | Weight score | No. | Indicators | Score | Weight score |
|---|---|---|---|---|---|---|---|
| 1 | Friendly interior design | 3.57 | 0.76 | 1 | Size | 3 | 0.075 |
| | | | | 2 | Signs and maps | 5 | 0.18 |
| | | | | 3 | Furnishings | 3 | 0.111 |
| | | | | 4 | Materials | 5 | 0.17 |
| | | | | 5 | Nature elements | 5 | 0.17 |
| | | | | 6 | Colour | 3 | 0.045 |
| | | | | 7 | Art control | 1 | 0.041 |
| 2 | Spatial configuration | 3.67 | 0.71 | 8 | Interconnected space | 5 | 0.125 |
| | | | | 9 | A system of paths | 3 | 0.066 |
| | | | | 10 | Height variation | 5 | 0.065 |
| | | | | 11 | privacy | 3 | 0.069 |
| | | | | 12 | Landmarks | 3 | 0.072 |
| | | | | 13 | Hierarchy | 5 | 0.125 |
| | | | | 14 | Distinct zones | 3 | 0.075 |
| | | | | 15 | Activities nodes | 3 | 0.069 |
| | | | | 16 | Overlooking activity | 3 | 0.06 |
| 3 | Life safety | 5 | 0.62 | 17 | Escape | 5 | 0.14 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | 18 | Fire suppression | 5 | 0.095 |
| | | | | 19 | Disaster prevention | 5 | 0.14 |
| | | | | 20 | Alarm | 5 | 0.095 |
| | | | | 21 | Surveillance | 5 | 0.15 |
| 4 | Management | 5 | 0.54 | 22 | Hygiene services | 5 | 0.09 |
| | | | | 23 | Informational facilities | 5 | 0.075 |
| | | | | 24 | Affordability | 5 | 0.19 |
| | | | | 25 | Rules and regulations | 5 | 0.044 |
| 5 | Lighting | 5 | 0.44 | 26 | Artificial lighting | 5 | 0.22 |
| | | | | 27 | Indirect lighting | 5 | 0.125 |
| | | | | 28 | Nature light | 5 | 0.16 |
| 6 | Exterior and entrance friendly design | 2.2 | 0.15 | 29 | Legibility | 5 | 0.06 |
| | | | | 30 | Accessibility | 3 | 0.027 |
| | | | | 31 | Vertical entrance | 1 | 0.021 |
| | | | | 32 | Sunken open space | 1 | 0.021 |
| | | | | 33 | Diversity integrations | 1 | 0.021 |
| 7 | Identity | 1.5 | 0.09 | 34 | Culture | 3 | 0.06 |
| | | | | 35 | Unique nature | 1 | 0.002 |
| | | | | 36 | History and symbolic | 1 | 0.02 |
| | | | | 37 | Imageability | 1 | 0.015 |
| 8 | User comfort | 4.3 | 0.21 | 38 | Air quality | 5 | 0.095 |
| | | | | 39 | Noise control | 5 | 0.11 |
| | | | | 40 | Temperature | 3 | 0.039 |
| 9 | Activities | 4 | 0.15 | 41 | Theme sales | 3 | 0.057 |
| | | | | 42 | Events | 5 | 0.09 |
| 10 | Sociability | 4 | 0.03 | 43 | Diverse uses | 5 | 0.01 |
| | | | | 44 | Interactive | 5 | 0.01 |
| | | | | 45 | Cooperative | 5 | 0.005 |
| | | | | 46 | Social services | 1 | 0.01 |

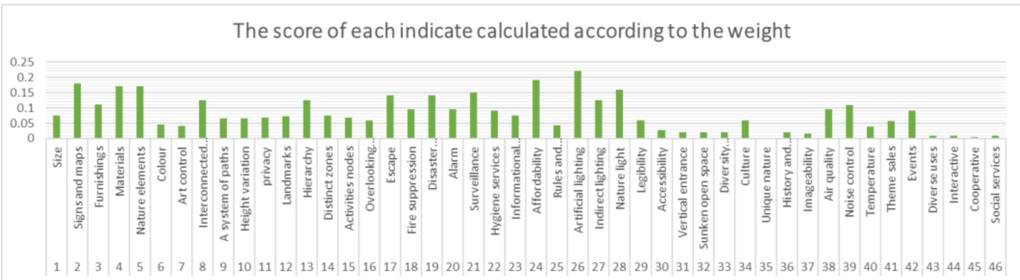



Figure 6-55 The score of each indicates calculated according to the weight

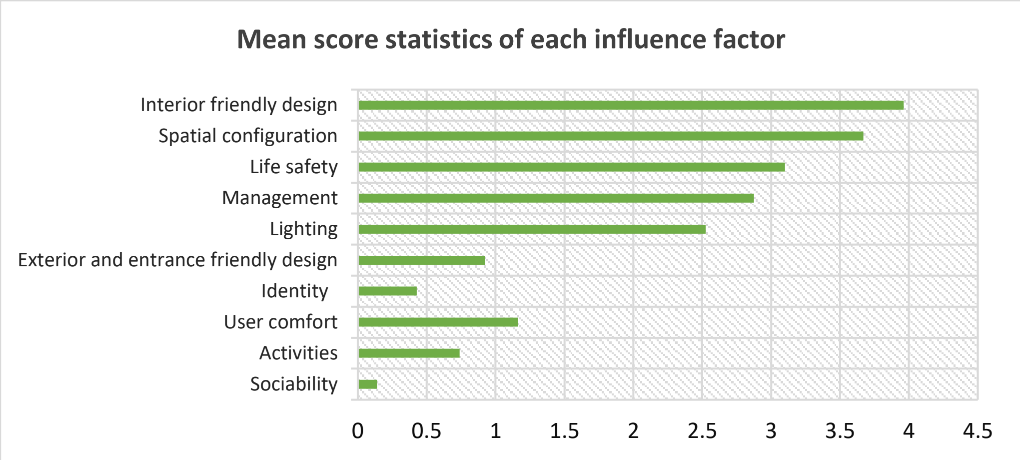
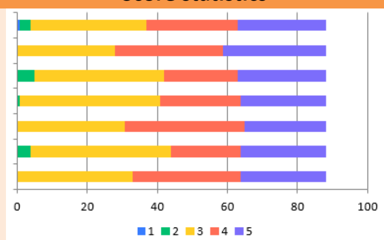
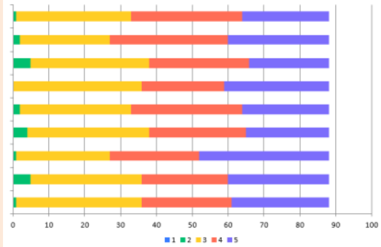
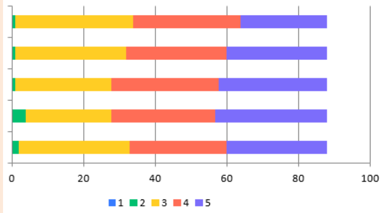
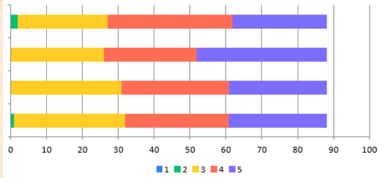
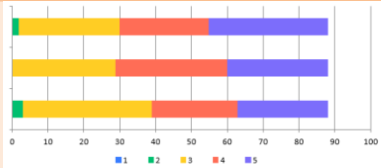
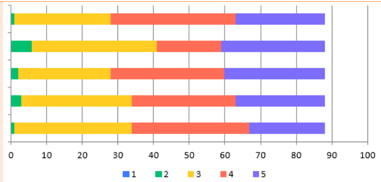
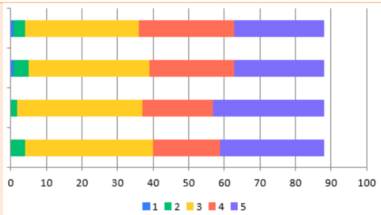
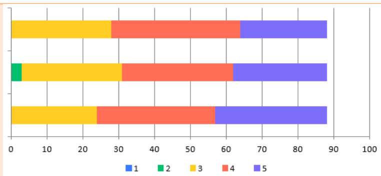


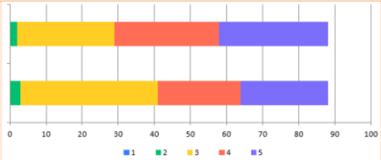
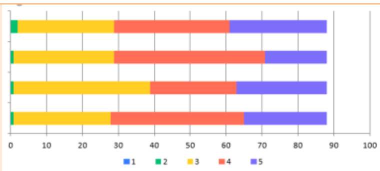

Figure 6-56 Mean score statistics of each influence factor

Randomly conduct on-site surveys of users to score factors, ranging from the most dissatisfied 1 score to the most satisfactory 5 score. The overall score of the underground public space of China World Trade Centre is 3.905 (good represents 5 points, satisfactory represents 3 points, and needs improvement score 1 point), which is higher than the author's standard score (assessment score 3.715). The average score for each factor is shown in table 6-27. According to the user's subjective feelings, the average score of each indicator is not big.

Table 6-29 Score statistics by users

| **Attributes** | Indicators | **Score statistics** | Average score |
|---|---|---|---|
| **Friendly interior design** | Size |  | 3.9 |
| | Signs and maps | | 3.73 |
| | Furnishings | | 3.91 |
| | Materials | | 3.8 |
| | Nature elements | | 3.75 |
| | Colour | | 4.01 |
| | Art control | | 3.81 |
| | Spatial configuration | 3.84 | |
| **Spatial configuration** | Interconnected space | | 3.89 |
| | A system of paths | | 3.85 |

| | | | |
|---|---|---|---|
| | Height variation |  | 4.09 |
| | Privacy | | 3.78 |
| | Landmarks | | 3.88 |
| | Hierarchy | | 3.92 |
| | Distinct zones | | 3.76 |
| | Activities nodes | | 3.99 |
| | Overlooking activity | | 3.89 |
| | Spatial configuration | 3.88 | |
| **Life safety** | Escape |  | 3.92 |
| | Fire suppression | | 3.99 |
| | Disaster prevention | | 4.01 |
| | Warning | | 3.94 |
| | Supervisory | | 3.88 |
| | Spatial configuration | 3.94 | |
| **Management** | Hygiene services |  | 3.93 |
| | Informational facilities | | 3.95 |
| | Affordability | | 4.11 |
| | Rules and regulations | | 3.97 |
| | Spatial configuration | 3.99 | |
| **Lighting** | Artificial lighting |  | 3.81 |
| | Indirect lighting | | 3.99 |
| | Nature light | | 4.01 |
| | Spatial configuration | 3.94 | |
| **Exterior and entrance friendly design** | Legibility |  | 3.84 |
| | Accessibility | | 3.86 |
| | Vertical entrance | | 3.98 |
| | Sunken open space | | 3.8 |
| | Diversity integrations | | 3.95 |
| | Spatial configuration | 3.88 | |
| **Identity** | Culture |  | 3.83 |
| | Unique nature | | 3.91 |
| | History and symbolic | | 3.77 |
| | Imageability | | 3.82 |
| | Spatial configuration | 3.83 | |
| **User comfort** | Air quality |  | 4.08 |
| | Noise control | | 3.91 |
| | Temperature | | 3.95 |
| | Spatial configuration | 3.98 | |
| **Activities** | Theme sales | | 3.77 |

| | | | |
|---|---|---|---|
| | Events |  | 3.99 |
| | Spatial configuration | 3.88 | |
| **Sociability** | Diverse uses |  | 3.93 |
| | Interactive | | 3.83 |
| | Cooperative | | 3.85 |
| | Social services | | 3.95 |
| | Spatial configuration | 3.89 | |
| | overall score | 3.905 | |

This section studies the quality evaluation indicator system of the underground public space and makes a case analysis of the Guomao underground space in the CBD. The first part evaluates the planning and construction of the underground space, and the second part scores the spatial design. There are differences between the evaluation of the plan and that of the design. The constructed space is not necessarily satisfactory even though the plan is evaluated to be good. The issues with the planning are not consistent with the indicators for space quality improvement. The design quality of the Guomao underground public space is evaluated based on the quality evaluation system of the public space. The weighted sum of all factors is 3.715 (Satisfactory), indicating that the quality of the Guomao underground public space meets the design requirements. But improvements should be made to the sociability, identity, activities, and exterior and entrance friendly design of the space. The scores of all indicators on the exterior and entrance friendly design suggest that improvement in this aspect is particularly needed. The user comfort and lighting also require improvement.

### 6.6 Discussion

The CBD area will be built into the largest underground public space in Beijing. The project is in the northeast corner of the Guomao Station and will be connected with the Guomao Station. In Guomao Station, there are both the Metro Line 1, first metro opened in Beijing, and the Metro Line R1, planned and not yet completed. As the capital of China, Beijing's planning and design have been imitated and studied by other cities in China. And the underground space design of Guomao Station in CBD area of Beijing is very famous as it is connected to the China World Trade Centre, a very high-end building. Therefore, under the impetus of many reasons, this paper chose the Guomao Station as a case of assessment and test. In this paper, Chapter 6 was divided into two parts. Part 1 was to evaluate the implementation of underground space planning and design in CBD area, from the assessment of the implementation and planning of Part 1, it can be seen that the actual construction of underground space was not completely implemented in accordance with the planning and design due to many affecting factors. The second part is to evaluate the quality of underground public space. Evaluation and scoring will be divided into two parts. The first part is a three-person team led by the author who will use instruments to measure and score the site，the second part of on-site user scores in the random questionnaire.

### 6.6.1 Evaluate the implementation of underground space planning and design in CBD area

In terms of planning and layout, there are three main factors affecting the implementation of underground space.

A. **the layout patterns are mostly monotonous**: the utilisation mode of underground space, road and green space of the existing project plot is monotonous, with the linear channel as the main mode, which can only satisfy the traffic demands;

B. **Weak land use integration**: the whole channel of underground connection of commercial clusters and public facilities should be strengthened;

C. **Insufficient corridor function**: metro connection is the main driving force for the development of underground space, but the connectivity between the metro station and the surrounding underground space is insufficient, so the integrated construction of metro and the surrounding underground space should be strengthened.

In terms planning and implementation, the factors affecting the implementation of underground space were analysed.

A. **Department management coordination**: as the planning and management review of underground space implementation process is a tedious process in Beijing, it is necessary to strengthen the overall coordination of relevant management departments such as land use, rail, road, green space, municipal pipeline and civil air defence, and streamline the planning management approval mechanism;

B. **Construction sequence coordination**: at present, most of the underground channel construction lags behind the project construction, which increases costs for later transformation and difficulty for implementation. Therefore, it is necessary to further coordinate the planning and construction sequence of the road, the project and the underground connection channel, and promote the synchronous application and construction;

C. **Implementation subject coordination**: at present, the subject of underground channel construction is composed of many different owners who have different demands, so it is difficult to coordinate. Therefore, the subject of the construction should be further coordinated to ensure the overall implementation of underground space.

In terms of policy guarantee, the factors affecting the implementation of underground space were analysed and summarised.

A. **Ownership of underground space**: it is necessary to define the scope of the property right of the underground space of public land, clarify the subject of the relevant property right, and take into account the interests of the public welfare and investment subjects;

B. **Land transfer policy**: if the operational functions are added on both sides of the underground channel of public land, it will involve the problem of separate land transfer. It is suggested that the commercial auxiliary facilities of the underground channel can be transferred by agreement with the channel project;

C. **Subsidy policy and operation managemen**t: the fund subsidy for the construction of underground channel should be properly introduced to raise the enthusiasm of social investment. The opening time and operation management requirements of underground channel should be clarified to ensure the use efficiency of the public.

### 6.6.2 Evaluate the quality of completed underground public space

Urban underground public space is an essential fundamental part of a city, and it plays a vital role in the liveability, vitality and inclusivity of the city. Therefore, evaluating the quality of underground public spaces is critical to the success of urbanisation. However, the extensive use of underground space in mods may be considered to have constituted underground public space (Horvat et al., 1998; Monnikhof et al., 1998; Chow et al., 2002; Evans et al., 2009). However, the fundamental difficulty in achieving proper organised planning and development of underground public space seems to lie in the “business as usual” approach demonstrated for hundreds of years. Under normal circumstances, planners, policymakers, and the public seem to be invisible to see (Sterling et al., 2012). When essential humans become humans, increasing the use of underground public space becomes more and more critical. The needs of big cities must be met so that they can not only live but be both liveable and prosperous.

In the second part of the assessment, this research conducted evaluation and example test in the underground public space around Guomao Station in Beijing according to the system indicators of this study. In the second part of the assessment, this research conducted evaluation and example test in the underground public space around Guomao Station in Beijing according to the system indicators of this study. The test is divided into two parts. In the first part, the author uses the underground public space quality evaluation standard from the designer's perspective and combines the instrument's on-site measurement to score the case. The evaluation result is 3.715 points. In the second part, users are required to evaluate the satisfaction of the underground public space based on their subjective feelings. The evaluation result is 3.905 points.

The professional final assessment result was 3.715 points, indicating an underground public space with qualified quality. It can be seen from the chart of scores Figure 6-57 that although the final score was up to the standard after weight calculation, the score of some indicators was still lower than three. Therefore, it is recommended that the indicators with a score of lower than three should be improved. In the process of assessment, it can be found that there were significant differences in the quality of underground public space between the new part and the old part in this mixed metro station. On one hand, the quality of the new part of the underground space was satisfactory, but on the other hand, the connection between the old station and the surrounding area was also obviously weakened, so the quality of underground public space should be improved. Based on the quality chart of underground public space, the scores of 10 categories were summarised and discussed by four attributes: exterior connection, space safety, interior environment, and operation.

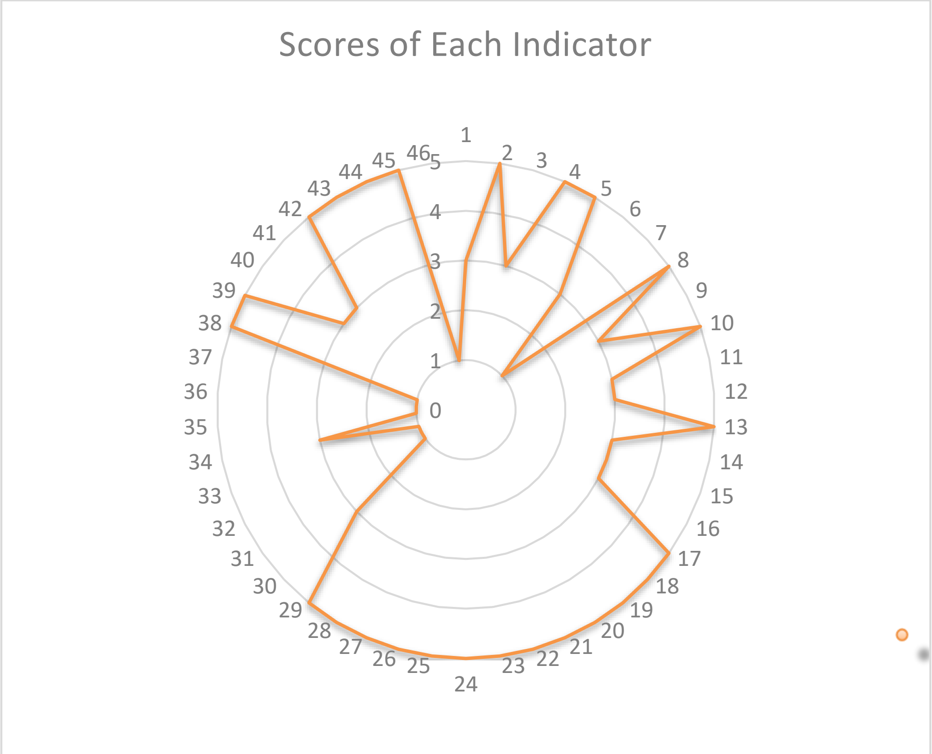



Figure 6-57 The chart of Scores for Each Indicator

The evaluation result by users is 3.905 points, the evaluation result and the professional score are in the same interval. Because the scoring of users is subjectively oriented, even scores are mainly concentrated in the 2-4 points range. The index evaluation results cannot effectively the difference see Figure 6-58, and it is not easy to guide the improvement of space quality. However, its results still have reference significance for later upgrading and transformation.

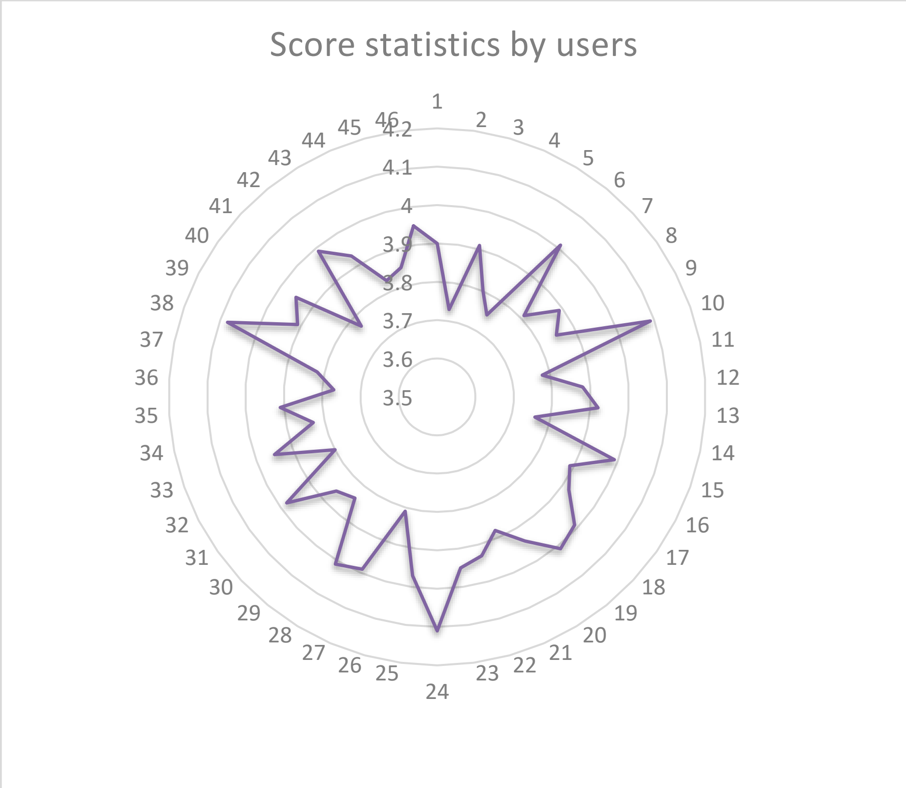



Figure 6-58 The chart of Scores for Each Indicator by users

#### 6.6.2.1 Exterior connection

From the perspective of urban design, the underground public space system is an integral part of urban public space system, which must cooperate with urban ground public space system to give the value of the into full play (Lu, 2015). Therefore, the medium connecting the underground public space with the ground becomes the key of the whole urban public space system. Compared with the traditional aboveground buildings, it is necessary to adopt totally different design methods to design the spatial layout for the underground space facilities. Simply applying a well-known aboveground layout and spatial configuration pattern to an underground building will likely to result in a defective environment, so this kind of underground environment will not be considered as equivalent as the ground environment (Carmody and Sterling, 1993, Alexander, 1977). In this research, exterior connection includes spatial configuration, exterior and entrance friendly design. The indicators of these two categories belong to the connection between the underground space and the external environment. The key design problem in this attribute lies in the quality and structure of the underground public space as a whole. Besides, there should be no lack of external reference points and spatial positioning (Carmody and Sterling, 1993). The indicators referred in the spatial configuration are the external connection between the underground public space and other underground buildings. While the indicators of the exterior and entrance friendly design part are the direct external connection between the underground public space and the ground.

The score for the assessment of the exterior connection with the underground public space around the Guomao Station was 3.14. The average score for the assessment of external connection with the underground parts of other buildings was 3.67. For the nine assessment indicators under this category, 3 of them scored five points, and the other six scored three points. The results of the test were consistent with that of the user experience. The importance of spatial configuration ranked second out of 10 categories in the questionnaire of user experience. From the results of the assessment and the questionnaire, it can be seen that spatial configuration ranked at the forefront in the design and user experience of underground public space. However, its score in the assessment of the connection between underground public space and the outside in another category was only 2.2, lower than three. Among the five indicators, legibility made the highest score of five points, accessibility three points, and only one point for the other three indicators of vertical entrance, sunken open space, and diversity integrations. The reason for the low score was related to the high-density environment on the ground, because the existing underground public space was not connected with the green space square of the ground, so a lot of opportunities for connection with the exterior are lost. But in the northeast corner of the Guomao Station, the core area of CBD, the ground central square was connected with the underground public space, and the green space were used to design the sunken plaza and roof light (Qi et al., 2015).


Figure 6-59 The core area of CBD relates to the green space to design the sunken open space and the underground space lighting skylight

*Figure source: (Qi et al., 2015)*

Table 6-30 Underground public space quality assessment 'Exterior connection' score

| Attributes | Categories | Indicators | Good | Satisfactory | Need Improvement |
|---|---|---|---|---|---|
| **Exterior connection** | Spatial configuration | Interconnected space | 5 | | |
| | | A system of paths | | 3 | |
| | | Height variation | 5 | | |
| | | privacy | | 3 | |
| | | Landmarks | | 3 | |
| | | Hierarchy | 5 | | |
| | | Distinct zones | | 3 | |
| | | Activities nodes | | 3 | |
| | | Overlooking activity | | 3 | |
| | Exterior and entrance friendly design | Legibility | 5 | | |
| | | Accessibility | | 3 | |
| | | Vertical entrance | | | 1 |
| | | Sunken open space | | | 1 |
| | | Diversity integrations | | | 1 |
| **average score** | | 3.14 | | | |

#### 6.6.2.2 Space safety

As part of urban space, underground space can absorb and accommodate a considerable portion of kinetic energy and vitality. In addition to underground public space, it can also serve as residential space, office space, commercial space, cultural activity space, transportation space and other various use space to coordinate and cooperate with the ground space, to give greater vitality and potential to urban development and further realize the strategy of sustainable development (Yang, 2009). Life safety is often considered as an important design issue. On one hand, most underground buildings are subject to certain physical constraints, special design features are required to ensure basic safety under emergency situations. On the other hand, underground space is easily trapped by fire, urban waterlogging, and other natural disasters, which is also the reason why people often hold negative feelings about underground space. Therefore, the perception of safety is important to ensure the well-being of the users of underground public space and the overall acceptance of the underground facilities (Carmody and Sterling, 1993).

In this study, space safety includes life safety and user comfort, in which life safety refers to the monitoring and prevention of some man-made disasters in underground space. The underground public space around the Guomao Station is very prominent in the first part of disaster prevention and control category, with each indicator scoring five. The reason for such a good performance is that on one hand, the building standards of CBD area buildings adopt the building standards of high-level buildings, so that the quality of the underground space under integrated construction is also high. Meanwhile, the public space around the metro is constructed in strict accordance with the safety standards of the metro, so the overall safety quality reaches a high standard. However, on the other hand, in order to ensure the safe operation of underground space and for safety reasons, many economic benefits and high-quality environmental construction are abandoned for some underground public service facilities.

The second part related to space security is user comfort. These indicators are more closely related to the physical safety factors of people during activities in the underground public space, including air quality, noise control and temperature control. In the actual assessment, two indicators scored five, rated as good, and temperature indicator scored three, a satisfaction level. In the previous attribute assessment, it has been clarified that the underground public space around the Guomao Station is not sufficiently connected with the exterior, and that the underground space is relatively closed. But on the other hand, the difficulty of the air quality control was also reduced because of the relatively closed space. The metros are mostly constructed in Beijing by using the underground space under the road, and the Guomao Station is also constructed in this way. Therefore, the interior of underground public space where users gather is basically not influenced by metro noise. Temperature control only scored three points in the assessment. Although the temperature in the underground public space was between 13° and 15° (the outdoor temperature in Beijing reached about 10° during the investigation in the mid-November), the standard for indoor temperature in Beijing is 18°-25°. Therefore, even if users can obviously feel warm when entering the underground space from the outside, there is still room for improvement.

Table 6-31 underground public space quality assessment 'pace safety' score

| Attributes | Categories | Indicators | Good | Satisfactory | Need Improvement |
|---|---|---|---|---|---|

| | | | | | |
|---|---|---|---|---|---|
| **Space safety** | Life safety | Escape | 5 | | |
| | | Fire suppression | 5 | | |
| | | Disaster prevention | 5 | | |
| | | warning | 5 | | |
| | | Supervisory | 5 | | |
| | | average score | 5 | | |
| | User comfort | Air quality | 5 | | |
| | | Noise control | 5 | | |
| | | Temperature | | 3 | |
| | | average score | 4.3 | | |
| **average score** | | 4.65 | | | |

### 6.6.2.3 Interior environment

Interior design cover almost every aspect of the interior environment of the building in the broadest sense (Carmody and Sterling, 1993), and in this study, the focus was on the visual design of the interior environment. In addition to the factors related to the form of the interior space, some interior decoration factors of the underground building will also influence the interior environment of the underground building, such as furniture, furnishings, lamps, greening and landscape pieces, which are all within the scope of building inclusions. The interior environment of the building will affect people's sense of comfort and mood in the building to a certain extent. A comfortable interior building environment can make people feel happy, so it is very important to create a comfortable interior environment (Hong, 2018). In the questionnaire of metro users, lighting factor was considered as one of the three most important indicators. When further asked in the questionnaire about which is the most important among natural light, artificial light, or illuminance (regardless of light source), users chose illuminance as the most important factor. It can also be seen from the result of the questionnaire that users have a clear negative or stereotyped impression of the underground space, but they do not understand that the approach used in the design is the way to reduce the negative feelings caused by underground space. Therefore, it may not be possible to create a more comfortable and satisfactory space by simply adopting the views of users in the design or assessment of the underground space. Another category under this attribute is spatial identity. This factor is not easy to realise for underground space, but it is of great significance for urban space. Even in the design of aboveground space, which is not restricted by physical conditions, identity is an important factor but difficult to realise.

The attribute of interior environment includes Friendly interior design, lighting, and identity, with an average assessment score of 3.29. The result of the category assessment showed that designers and developers has attached great importance to the Friendly interior design and lighting parts, with the average score of three. As for the Friendly interior design, three indicators scored five, three scored three, and only art control failed to meet the standard. The art control here is not the decorative art in the later stage, but the art design that combines the building itself in the early stage of construction. As for the lighting, artificial lighting and indirect lighting scored five, and the indicators of natural light also met the standard. Although natural light was less used in the underground public space around the Guomao Station at present, which was mostly caused by the fact that the metro station was built earlier and out of touch with the design of ground green space, so there lost a great number of opportunities to introduce the natural light into the underground. Lastly, in the classification indicator assessment of identity, culture and imageability scored three, while unique nature and history and symbolic only scored one. The score of identity in the assessment failed to meet the standard. This showed that although the underground public space was recognized as good in Beijing, there is a weak link in this part of the assessment. When users were asked about the quality and the most impressive part of the underground public space of Guomao Station in the interview, most people had a positive impression on the underground public space around the Station, but not everyone had a deep impression on a specific area or part.

Table 6-32 Underground public space quality assessment 'Interior environment' score

| Attributes | Categories | Indicators | Good | Satisfactory | Need Improvement |
|---|---|---|---|---|---|
| Interior environment | Friendly interior design | Size | | 3 | |
| | | Signs and maps | 5 | | |
| | | Furnishings | | 3 | |
| | | Materials | 5 | | |
| | | Nature elements | 5 | | |
| | | Colour | | 3 | |
| | | Art control | | | 1 |
| | | average score | 3.57 | | |
| | Lighting | Artificial lighting | 5 | | |
| | | Indirect lighting | 5 | | |
| | | Nature light | | 3 | |
| | | average score | 4.3 | | |
| | Identity | Culture | | 3 | |
| | | Unique nature | | | 1 |
| | | History and symbolic | | | 1 |
| | | Imageability | | 3 | |

| | | | |
|---|---|---|---|
| | | average score | 2 |
| **average score** | | 3.29 | |

#### 6.6.2.4 Operation

The quality of underground space management will also directly affect the quality of urban underground space. Management is a part difficult to quantify in the design assessment, and the content of management should be updated with the development of city and technology. Even though the management rules have been made for underground public space, it is difficult to control the implementation of management as a result of the ownership of underground space. The underground space around Guomao Station is managed by CBD Management Committee System. The Management Committee puts forward specific design management and control conditions, and then the developer is responsible for the construction, and continues to participate in the coordination and management of underground public space in the later stage. Moreover, the quality of the buildings connected with the Guomao Station are also high. Therefore, in the assessment of management classification indicators of underground public space in this region, it achieved a good score. When the relevant indicators of urban public space obtained in the literature were used in underground space, some contents showed that the indicators of urban aboveground public space may not be taken seriously in the underground space. However, the projects with outstanding performance in the management of underground public space also won good impression and reputation in the actual assessment.

In the assessment of operation attribute, the total average score was 4.3, and the classification indicators include management, activities, and sociality, with the total assessment score of four. In the category of management, all four indicators scored five points. In the category of activities, one indicator scored five and another indicator scored three. Among the four indicators of sociability, only the social services scored one, and the other indicators all scored five. In the actual investigation and assessment of the underground public space of the project, the most impressive part was the cleanliness, tidiness, and vitality of the space. Of course, this was also directly related to the owners around the Guomao Station. The quality of the underground space here were also improved overall due to CBD's special geographical location. Furthermore, the developers of China World Trade Centre integrated the design of underground space into the design of aboveground buildings, so the underground space was designed and constructed adopting a high standard from the beginning. Due to its huge volume, China World Trade Centre had a great influence on the underground space of this region. When users mentioned about the Guomao Station and CBD area, the first thing that came to their mind was China World Trade Centre, thus the impression of underground public space will also be improved.

Table 6-33 Underground public space quality assessment 'Operation' score

| Attributes | Categories | Indicators | Good | Satisfactory | Need Improvement |
|---|---|---|---|---|---|
| **Operation** | Management | Hygiene services | 5 | | |
| | | Informational facilities | 5 | | |
| | | Affordability | 5 | | |
| | | Rules and regulations | 5 | | |
| | | average score | 5 | | |
| | Activities | Theme sales | | 3 | |
| | | Events | 5 | | |
| | | average score | 4 | | |
| | Sociability | Diverse uses | 5 | | |
| | | Interactive | 5 | | |
| | | Cooperative | 5 | | |
| | | Social services | | | 1 |
| | | average score | 4 | | |
| **average score** | | 4.3 | | | |

## 6.7 Chapter Conclusion

The result of the investigation and assessment in the previous section clearly showed that the quality of underground public space varies from case to case. There were also clear indications that the overall finding showed that some classification indicators are very important to users, and also play an important role in the underground space and the whole city. The result also showed that the quality assessment of underground public space was not dependent on a single indicator. These indicators were linked together and elaborated as a whole, so one indicator may not dominate the others. The finding also indicated that the identity of the underground public space design, even if it failed to meet the requirements of this category, will become the identity of underground space for the outstanding performance of each or several categories. Therefore, it can be said that it is the overall complexity of underground public space that contributes to its unique characteristics, and finally forms the impression and feeling of users.

The initial framework of the underground public space quality introduced in Chapter 5 is helpful to qualitatively measure the underground public space quality indicators in 10 categories provided in the urban design discourse. The following figure showed the final diagram/framework, which can be recommended as a tool for assessing the quality of underground public space, as follows:

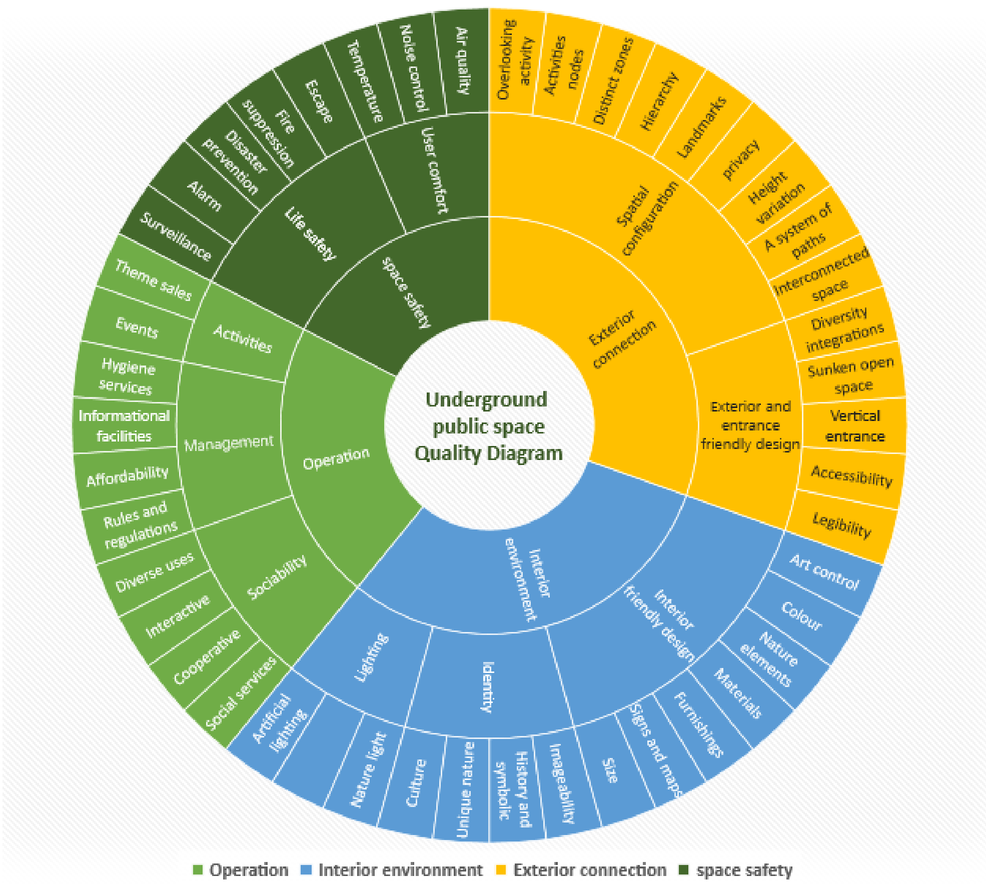



Figure 6-60 Underground public space Quality Diagram

The next chapter (Chapter 7) presented the main research conclusions, research contributions and research significance, and proposed further study on this specific topic.

# 7 Conclusion and Future Work

This thesis summarised the relevant theories of underground space and urban public space design and evaluation, and then screened, analysed, and then applied in the underground public space. Secondly, a set of indicators of the quality evaluation system for underground public space are constructed, and the underground public space quality evaluation framework is proposed by analysing the design elements that affect the quality of underground space. Finally, the underground public space quality evaluation system is applied and verified by taking the underground public space in the CBD area of Beijing as an example.

In this paper, Chapter 2 and Chapter 3 reviewed the current status of published design and quality assessment approaches for underground and aboveground public space. The author initially did not discuss the quality of underground public spaces in Chapter 3 because the spatial forms of underground public spaces are more diverse than ground public spaces, including open or semi-open spaces and more enclosed spaces. It also has more connections with surrounding buildings. It is usually connected with rail transit, connected with the underground parts of surrounding buildings, and may connect with public spaces on the ground. The nature of its land-use includes public land and private land, so the underground public space has its own complex characteristics. Therefore, before discussing quality, the author first sorted out the development route of underground public space in the second chapter, explaining the potential and importance of underground public space. Redefine the concept of underground public space, and look for the development momentum and trend of underground public space in the development of urban design theory. Finally, in the following chapters, the classification of underground public space is used as the basis for the quality evaluation index of underground public space.

Compared with those for aboveground public space, the design and quality assessment approaches for underground public space still have great room for improvement. However, the existing quality assessment approaches for aboveground public space cannot be directly applied to underground public space. Some research achievements have been made on the design approaches for underground public space in terms of urban design and human centred design, but they cannot be directly applied as the quality assessment approaches for the underground public space design. The assessment results for the assessment indicators proposed in the assessment system of green building design in underground public space should be obtained through analytic hierarchy process and fuzzy analytical method by scoring questionnaires, but it is not easy to evaluate qualitative indicators in the assessment.

In Chapter 5, EFA and CFA were used to rank and weight the indicators of the underground public space quality assessment system framework through literature review, professional interviews and three questionnaires. Firstly, an underground public space quality assessment system indicator framework was presented by means of documentary research, expert interviews and questionnaires to experts and practitioners in the field of underground space. The second questionnaire was an investigation of the user experience, and the results were different from the original framework, indicating that the most concerned indicator of underground public space by users is space safety. The third questionnaire was designed to score the importance of the user's quality assessment indicators for underground public space. Fourthly, EFA and CFA were used to rank and weight the indicator framework system, thereby establishing an underground public space design quality assessment indicator system. In Chapter 6, the analysis results of Chapter 5 were used to evaluate and score the design quality of underground public space around Guomao Station in CBD area of Beijing.

This chapter further discussed the implications of the key findings, that is, to analyse three different results obtained by three methods and discuss the case results evaluated by the existing indicator system. These three results showed that the ranking of quality assessment indicators for underground public space obtained through documentary research by professional researchers was different from the ranking of the indicators obtained through results of user experience research, the scoring of indicator importance by users and the analysis results with professional software. The final assessment results of the case also indicated that people generally believe that high-quality places still have room for updates and improvements in the assessment.

## 7.1 Contribution of the Study

### 7.1.1 Main Conclusions and Contributions

(1) A quality evaluation system for underground public space was built and a theoretical basis for the design of underground public space was provided.

This research defined the concept of underground public space, and studied the formation and development of urban design theory from architecture, psychology, and urban planning theories such as building space combination, human demand, and resilient city. At the same time, the thesis also defined the quality of space, and what is the quality of underground public space, and how to measure and quantify it. Finally, the quality evaluation system for underground public space was constructed from the aspects of exterior connection, space safety, interior environment, and operation.

(2) Quantitative indicators for underground public space quality evaluation was proposed by analysing the factors that affect the quality of urban underground public space.

Through analysing factors at the site affecting the quality design quality of underground space, this research proposed a method for the quality evaluation of underground public space from four aspects of exterior connection, space safety, interior environment, and operation.

As for exterior connection, the exterior extension of the underground public space should be highly recognisable; the underground public space should have the attributes of the aboveground public space at the same time, so accessibility is one of the factors to activate the underground public space. The traffic facilities in the underground public space should be connected to reduce the problems caused by traffic congestion; more activities should be integrated into the underground public space to reflect the public attribute function of the space.

As for space safety, underground public space should be considered as a place for users to avoid disasters under special conditions, such as extreme weather, emergent terrorist acts. Based on the architectural characteristics of underground space, when it is used as urban public space, the safety of users should be considered as top priority to protect them from hazards such as fire, waterlogging, earthquakes, etc.; appropriate apparent temperature should be maintained, including the control of indoor temperature, humidity and other thermal environment, to create a comfortable underground environment; good ventilation and air pollution control should be maintained, with natural wind being introduced, but at the same time, the pollutant concentration of outdoor air should also be controlled.

As for interior environment, a reasonable and human-centred interior design should be provided, including spatial scale, colour, material, furniture, and furnishing; richer functional content and more combination modes should be available; the quality of space should be improved by artistic means while meeting the basic demands, so as to increase users' psychological satisfaction.

As for operation, underground public space should conduct monitoring over its operation, and feedback and share relevant information in real time; intelligent management system shall be developed and implemented for the space, and measures shall be taken to maintain order during operation, including the control of space energy consumption; public service facilities should be provided and maintained during operation.

(3) A quality evaluation system for underground public space was built based on the investigation and analysis of professionals and users over the

importance of the quality evaluation indicators of underground public space.

This thesis, based on the questionnaire survey and interview of designers and users on the importance of the quality evaluation indicators of underground public space, analysed and determined the weight of each influence indicator from the perspectives of 10 categories such as life safety, exterior and entrance friendly design, lighting, user comfort, spatial configuration, Friendly interior design, management, identity, sociability, activity space by exploratory factor analysis and confirmatory factor analysis, built an evaluation system for underground public space quality evaluation and carried out quantitative output for 46 indicators in these 10 categories.

(4) Empirical Test

The evaluation was carried out on the planning and design of the underground space in CBD areas of Beijing as well as the quality of underground public space around the Guomao Metro Station. First, the author evaluated the implementation of the planning and design of the underground space in CBD areas of Beijing, and analysed the development and utilization of underground space in the whole CBD area by visiting CBD Management Committee and field investigation. Finally, the author selected the underground public space around Guomao Metro Station as the evaluation object to verify and evaluate the evaluation system of the case. Based on the investigation and analysis, this research found that the quality of underground public space around Guomao Metro Station is up to the standard at present, but there is still room for improvement. Relevant suggestions were therefore put forward on this basis.

(5) Quantitative Research

Quantitative analysis as adopted in the construction of evaluation indicator system for underground public space. Firstly, the quantitative analysis software SPSS was used to perform EFA (exploratory factor analysis) over 296 users on the importance of underground public space quality evaluation indicators, and then CFA (confirmatory factor analysis) was performed on the determined evaluation system to get the weight value of underground public space quality evaluation indicators. Finally, a quantitative research was conducted on the evaluation indicators of underground public space. This paper took the underground public space around Guomao Metro Station in the CBD area as the example and carried out on-site measurement and analysis of its internal environment.

### 7.1.2 The Main Innovation

(1) In view of the particularity of underground space, and with reference to the quantitative research methods of relevant underground and

aboveground public space design and evaluation standards, the quantitative research methods used in the literature were converted into the quantitative methods suitable for underground space. For example, the aboveground public space is a completely open environment, while the underground space is mainly closed and enclosed space, so there will be great differences in vision and psychology. Therefore, the thesis suggested that some relatively private enclosed or semi-enclosed space should be provided for the open space in ground public space, while underground public space should give more consideration to a more open and flexible space by means of design.

(2) By analysing the factors that affect the quality of underground public space, this research proposed a quality evaluation method for underground public space from four aspects of exterior connection, space safety, interior environment, and operation. Traditional researches on underground space usually focused on a certain method and level. The construction of the quality evaluation system framework for underground space was not complete, and the particularity of underground space was often ignored. It analysed the factors affecting the quality of underground space, and proposed methods for the design of underground public space from the aspects of life safety, exterior and entrance friendly design, lighting, user comfort, spatial configuration, Friendly interior design, etc. It had taken the differences between influence factors for underground and aboveground

space into full considered, and proposed corresponding design methods and strategies for the particularity of underground space.

(3) A green design evaluation system for underground public space was built with factor analysis. As can be seen from the documentary research, the architectural design standard of WELL Building in the United States is a set of architectural evaluation systems jointly built by dozens of doctors, with its foundation of LEED's green building standard. As for the underground space, some related researches on the design and evaluation system of green buildings have been carried out, but there is currently no underground public space design standard or quality evaluation system. Therefore, the author summarised a large number of documents, and built a quality evaluation system for underground public space, which had been applied and verified in actual projects.

## 7.2 Implication of the Study

On the one hand, the establishment of underground space quality evaluation system indicators has the following theoretical significance:

(1) Based on the relevant basic theory, the indicator system for underground public space quality evaluation was deduced to provide theoretical basis for the design of underground public space.

As seen from the above-mentioned international research situation that the current researches on underground space mainly focus on methodology research, and the research on basic theory is relatively weak, resulting in the lack of theoretical foundation and support for the underground space quality evaluation method. Based on the basic theories of architecture, planning, psychology and other related disciplines, this paper built the theoretical foundation for the underground public space quality evaluation from the perspectives of design for people and places making, and provided theoretical support provided for the quality design of underground public space, which is of great theoretical significance.

(2) Based on the design method and quantitative research method of underground space and aboveground public space, and in consideration of the particularity of underground space, a more comprehensive quality evaluation system for underground public space was proposed, providing methodology basis for the design of underground public space.

The research on underground space design in academic community mostly focus on two aspects: on the one hand, macro research on related strategies and suggestions, and on the other hand, some specific technical researches. The shortcomings in these researches are as follows: Firstly, most of these researches are based on the aboveground architectural design methods, lacking consideration for the particularity of underground space. Secondly, these researches are usually carried out on some popular aspects without forming a set of multilevel and comprehensive design methods and evaluation system. Finally, the lack of in-depth and quantitative researches limits people's views on the application of human-centred design and sustainable development of underground space in underground space to a qualitative level, and there is no unified theoretical guidance in actual construction, resulting in the non-universal application of people-oriented underground public space design in practice.

This paper took the underground public space as the research object and applied the method of the aboveground urban design into the underground urban design. It studied and summarised the human-centred evaluation indicators of the underground public space design from multiple perspectives, and proposed a quality evaluation system for the underground public space, providing a methodological guidance for the application of people-oriented design in underground space.

On the other hand, the establishment of underground space quality evaluation system indicators has the following practical significance:

(1) The construction of underground public space quality design system is conducive to improving the overall quality of urban public space

With the continuous deterioration of human living environment, the harmonious development between man and nature has become the focus of people all over the world. Because of the particularity of underground space, it will consume many resources in construction and operation management. If it is not properly managed, it will also cause damage to the surrounding environment. China is now one of the countries with the largest volume of underground space construction in the world. Therefore, the application of people-oriented and green concept in the design of underground public space meets the demands of urban development, saving resources and protecting the environment, which is in line with the trend and requirements for the development of flexible, liveable, and inclusive cities in the future.

(2) The construction of the quality design system for underground public space is conducive to solving urban problems

With the continuous development of cities, urban land is approaching saturation, traffic congestion, land shortage, environmental damage and other urban problems are rising, so it is an inevitable development trend to expand the space underground. The development and construction of underground space, as well as the application of quality design concept in the design of underground public space, can not only raise land utilization rate, and mitigate the land shortage, but also improve resource utilization rate and environmental protection.

(3) The construction of high-quality underground public space is conducive to providing a healthy and comfortable environment for people

Applying the concept of quality to the design of underground space is also conducive to providing people with a more comfortable and healthy underground living environment. Compared with aboveground space, the underground space will give people a certain degree of discomfort both physically and psychologically due to its humidity, closeness, and gloom. A comfortable, bright, and green underground environment will make people feel relaxed and safe, thus attracting more people using the underground **space.**

## 7.3 Limitation of the Study

The practical and theoretical summaries of underground space development are still in the process of developing and improving. Many cities, core areas of cities and high-density development areas are in urgent need of underground space, while its development value remains to be explored, development mode needs to be improved, and development philosophy continues to change. The opportunities and problems facing urban underground space in the new century leave the research of this paper room for future improvement, and the paper is still insufficient in the following aspects:

(1) The quality evaluation indicators of underground public space are from the perspective of urban design, but the indicators involve human-centred design and sustainable development and other perspectives. The construction of the system framework may be limited by the author's professional background, and more people with professional background, such as architects, underground space engineering technicians, and related personnel in psychology and other disciplines should be invited to cooperate in the construction of the existing framework.

(2) In the construction of indicators for underground public space quality evaluation system, the model-fitting data did not reach the optimal state when conducting CFA exploratory factor analysis on the indicator factors by AMOS, which was related to the framework structure of the indicator factors. There was a big gap in the number of indicators distributed in the current framework. For example, there are 9 indicators in the classification of spatial configuration, while only 2 indicators in the classification of activities. Such a distribution caused the fitting state of the model fail to reach the ideal state during analysis, so the current frame structure can be further optimised.

(3) The specific parameters of quality evaluation indicators of underground public space in the research still have room for improvement, and further in-depth quantitative research can be conducted for each indicator. At the same time, indicators can be combined with qualitative analysis to determine changes of environmental conditions.

## 7.4 Recommendation for Further Research Work

The development of underground space has received much attention due to the construction of metros and high-rise buildings, but with the development of urban theory, the functions of underground space are also changing. Its role is not only to provide a single function for the city, such as transportation, or municipal facilities, but also to make more contributions to the development of flexible, liveable, and inclusive city. The main reasons for the formation of underground public space are the construction of urban rail transit and the development of high-rise buildings in urban central areas. These two conditions are the necessary conditions for its formation and are indispensable. Since there are few researches on the design and evaluation of underground public space, the author had done a great number of researches on the design and evaluation of urban public space. As a determiner for space, the word 'quality' is not a single direction, but a comprehensive concept including the human Centred design of underground space, site construction, green building of underground space, etc. This research was based on the perspective of urban design, so the quality evaluation system framework indicator constructed in this paper was targeting at the planning of underground public space and the design quality of the completed underground public space.

The application of underground public space design and evaluation still faces many problems and challenges. Firstly, urban designers may pay more attention to the design of ground public space, while ignore the underground public space. With the connection between metro station and underground space of buildings becoming a routine operation, more attention should be paid to the design of underground public space by the designer in the future, and a good connection with the ground public space should be made, because the two are interdependent. Secondly, some functions of the aboveground public space should be considered to be integrated into underground public space. Underground public space should have the necessary attributes of public space, such as social function and identity. Thirdly, underground space is different from aboveground buildings for its own particularity. For example, underground space has the natural advantage of saving land, and this evaluation factor is not as important as in the design of aboveground buildings, so the evaluation criteria for underground buildings and aboveground buildings should also be different. However, the design and evaluation of urban public space are now mainly for aboveground buildings, and there are no special evaluation criteria for the design of underground space.

A variety of problems and challenges are still found in the application of underground public space design and evaluation, but there also present many opportunities and advantages. International research development on urban public space, human Centred design and green building provides good environment and technical support for the application of urban underground space quality evaluation. In addition, the introduction of relevant incentive policies also provides guarantee for the use of quality space in the design of underground space, such as China's subsidies for projects that meet the three-star standard on green building, Montreal's subsidies of free commercial space for owners who take the initiative to build connection with underground cities and metros, etc (Anderson, 1976, Zacharias, 2000). These measures have greatly stirred up the enthusiasm of developers and designers.

In recent years, the emphasis on interdisciplinary requires that the application in underground space design should not only continue to develop and improve traditional design methods, but also absorb and introduce methods and technologies from other disciplines that can be used for reference. In addition, the design of underground space should not only consider and use one or several design methods but make a comprehensive consideration and the use of multiple technologies in order to achieve the diversified development of quality design concepts.

This thesis is mainly a systematic research on the indicators of the quality evaluation system for underground public space. Due to the limitations of many factors such as time, personal capability and objective conditions, there are inevitably some omissions in the research of some aspects of related fields and the contents that need to be further explored. Therefore, more in-depth researches in this field should be carried out from the following aspects in the future:

(1) Improvement of the quality evaluation system for underground public space.

The improvement of the evaluation system can be made from two aspects: firstly, to improve and update the impact indicators of the evaluation system. The design method of underground public space is constantly improving and updating, so the evaluation indicators should also be continuously supplemented and updated; secondly, the weight of the evaluation system was mainly calculated by professional questionnaires. Although this paper took average value through multiple questionnaires in order to reduce the subjective influence, certain subjectivity will inevitably exist. It is, therefore, our goal in the future research to establish a more objective evaluation system.

(2) Strengthening of the content and scope of quantitative research coverage

This paper only conducted preliminary quantitative research on the quality evaluation indicators of underground public space. Some of the indicators were relatively complete, such as the illuminance range, appropriate temperature, and humidity of underground space. However, the quantitative content of other indicators was relatively simple. For example, for the interior design of underground public space, what scale of underground public space should the one with the highest quality score? This still needs further proof. Whether public furniture can still be quantified to the distance, type, and number? In conclusion, our aim is to make the quality evaluation system for underground public space more scientific and manageable.

(3) Potential application model

At present, China's metro construction is developing rapidly, and the underground public space connected with the metro and the underground public space under the urban public space is also developing rapidly. As more enter underground space, new and reconstructed projects also need an evaluation standard to evaluate their quality. The initial target template for the results of the study was the evaluation criteria for BREEAM (Building Research Establishment Environmental Assessment Method) communities and the WELL Building Standard. In the future, it is hoped that the quality evaluation standard of underground public space can also become an independent special evaluation.

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# APPENDIX

This research is about improving the quality of the underground public space around the metros, so that is necessary to investigate the space users and space designers. The survey included questionnaires and interviews. The survey focused on the user's perception of the underground public space, and the target population was random and anonymous. The interview was conducted by the planning and design staff of the underground public space.

1 The aims of the project is that to deal with linguistic features in the humanized design of underground public space in the Beijing CBD area, and to recognise the role of such features in the support of design for people, including tangible and intangible factors, around metro stations.

2 Each respondent has one questionnaire, they will finish 18 questions. 10 questions and about 1 hour for each interviewee.

3 The participants and interviewee would be confidentiality and anonymity. All information will be used by this research. They would not be potentially identifiable in any published material.

4 All participation in the research is completely voluntary, that participants are at liberty to withdraw at any time without prejudice or

negative consequences, that non-participation will not affect an individual rights/access to other services/care.

5 There is no any potential risks, harms and benefits to participants in this research.

6 The contact details of the investigators: Jie Zhou, jie.zhou@nottingham.ac.uk

7 The following attachment is that the content of the research survey that needs to be informed by the interviewee.

**APPENDIX – Rviewee consent form**

Hello! I am a Ph.D. student at the University of Nottingham, UK.

Please confirm the following terms and conditions before accepting the interview:

1. Respondents voluntarily agreed to participate in the interview.

2. During the interview, the respondent agreed to accept the recording, and knew that the recording would be converted into a textual draft for the interviewer to organise the analysis.

3. In the process of data collation, the interviewer will properly keep the recordings; the above documents will be used as research and research and future publication materials.

4. The interviewer of the identity of the respondent will be kept strictly confidential.

5. The respondent agreed to check the verification content together with the interviewer and correct it in time for the misunderstanding.

Respondents: Interviewer:

Date

## APPENDIX – Questionnaire 1 form

### Investigation on the importance of environmental quality index of Beijing metro and surrounding underground public space

Hello! I am a doctoral candidate at the University of Nottingham in the UK. I am investigating the environmental comfort level of underground space around Beijing metro.Please fill in according to your real situation, your answer will affect the authenticity and accuracy of the research results. Your information will be kept strictly confidential. Thank you again for your support and participation.

1. What's your gender? (Single choice * to be answered)

"Male

A. female

2. How old are you? (Single choice * to be answered)

○ Under 18 years old

18 to 22 years old

23 ~ 40 years old

41 ~ 60 years old

○ Aged 60 and above

3. What is your occupation? (Single choice * to be answered)

○ Government departments

○ Professional and technical personnel (architectural designers, urban planners, engineers and other related professionals)

○ Staff (office workers)

○ Freelancing (a job that does not require a regular job)

A. students

The following questions are graded, with 1 being the least important, 5 being the most important, and from 1 to 5 increasing in degree

4. Do you think the following options are important when using underground space? (Please fill in 1 to 5 digits for marking questions. * Must be answered)

Underground space and external connection (entrance and exit design, orientation, etc.) _____

Spatial structure (path design, spatial connectivity, etc.) _____

Interior design (color, scale, materials, ventilation, signage, etc.) _____

Lighting (natural light, artificial lighting, etc.) _____

Safety (escape, air quality, disaster prevention, etc.) _____

Comfort (temperature, noise, etc.) _____

Social (free service facilities, multi-functions, etc.) _____

Events (performances, themed markets, etc.) _____

Features (special landmarks, culture, etc.) _____

Management (supporting services, information facilities, etc.) _____

5. Do you think the following options are important in the outdoor and entrance design of underground space? (Please fill in 1 to 5 digits for marking questions. * Must be answered)

Easy to get to _____

Open space (sunken plaza) _____

Vertical space (elevator or staircase) _____

Accessibility _____

A combination of forms _____

6. Do you think the structural design options of underground space are important? (Please fill in 1 to 5 digits for marking questions. * Must be answered)

Path design (the connecting road between destinations) _____

Spatial nodes (artwork, placement of plants, or spatial variations such as indoor squares) _____

Landmark design (lighting well, sculpture, artwork or plant) _____

Spatial connectivity (interior space or connection between metro station and underground passage) _____

Zoning (e.g. separation between retail and dining and cultural facilities) _____

Floor height changes (changes in interior space height) _____

Spatial layering (two or more floors underground) _____

Privacy (layer to layer privacy protection) _____

Overlook activities (from above can see activities below) _____

7. Do you think the following options are important in the interior design of underground space? (Please fill in 1 to 5 digits for marking questions. * Must be answered)

Color _____

Size (spacious or narrow) _____

Plant landscape _____

Material (metal or wood, etc.) _____

Furniture (seating) _____

Signs and maps _____

Art Elements (Gallery) _____

8. Do you think the following types of underground space lighting are important? (Please fill in 1 to 5 digits for marking questions. * Must be answered)

Natural light _____

Artificial lighting _____

Indirect lighting (e.g. material reflection) _____

9. Do you think the following underground space safety facilities are important? (Please fill in 1 to 5 digits for marking questions. * Must be answered)

Escape _____

To avoid disaster _____

To monitor the _____

Warning (Alert) _____

The fire _____

10. Do you think the following indexes of comfort level of underground space are important? (Please fill in 1 to 5 digits for marking questions. * Must be answered)

Air quality _____

Indoor temperature and humidity _____

Noise control _____

11. Do you think the following social functions of underground space are important? (Please fill in 1 to 5 digits for marking questions. * Must be answered)

Social service facilities (free service facilities) _____

Complementary with the aboveground space function (as the vacancy of the aboveground space function complement) _____

Multifunctional use (can carry out many kinds of activities, function conversion) _____

Interactive Spaces (facilities or spatial extensions) _____

12. Do you think the following types of activities in underground space are important? (Please fill in 1 to 5 digits for marking questions. * Must be answered)

Recreational activities (performances, performances) _____

Theme Market _____

13. Do you think the following characteristics of underground space are important? (Please fill in 1 to 5 digits for marking questions. * Must be answered)

Characteristic architectural design _____

History or Symbol _____

Special cultural events (such as galleries) _____

Unique natural features _____

14. Do you think the following management and service options for underground space are important? (Please fill in 1 to 5 digits for marking questions. * Must be answered)

Information facilities _____

Health facilities _____

Administrative Regulations _____

Service staff _____

## APPENDIX – Questionnaire 2 form

Investigation on the importance of environmental quality index of Beijing metro and surrounding underground public space

Hello! I am a doctoral candidate at the University of Nottingham in the UK. I am investigating the environmental comfort level of underground space around Beijing metro. Please fill in according to your real situation, your answer will affect the authenticity and accuracy of the research results. Your information will be kept strictly confidential. Thank you again for your support and participation.

1. What's your gender? (Single choice * to be answered)

"Male

A. female

2. How old are you? (Single choice * to be answered)

○ Under 18 years old

18 to 22 years old

23 ~ 40 years old

41 ~ 60 years old

○ Aged 60 and above

3. What is your occupation? (Single choice * to be answered)

○ Government departments

○ Professional and technical personnel (architectural designers, urban planners, engineers and other related professionals)

○ Staff (office workers)

○ Freelancing (a job that does not require a regular job)

A. students

The following questions are graded, with 1 being the least important, 5 being the most important, and from 1 to 5 increasing in degree

4. Do you think the following options are important when using underground space? (Please fill in 1 to 5 digits for marking questions. * Must be answered)

Underground space and external connection (entrance and exit design, orientation, etc.) _____

Spatial structure (path design, spatial connectivity, etc.) _____

Interior design (color, scale, materials, ventilation, signage, etc.) _____

Lighting (natural light, artificial lighting, etc.) _____

Safety (escape, air quality, disaster prevention, etc.) _____

Comfort (temperature, noise, etc.) _____

Social (free service facilities, multi-functions, etc.) _____

Events (performances, themed markets, etc.) _____

Features (special landmarks, culture, etc.) _____

Management (supporting services, information facilities, etc.) _____

5. Do you think the following options are important in the outdoor and entrance design of underground space? (Please fill in 1 to 5 digits for marking questions. * Must be answered)

Easy to get to _____

Open space (sunken plaza) _____

Vertical space (elevator or staircase) _____

Accessibility _____

A combination of forms _____

6. Do you think the structural design options of underground space are important? (Please fill in 1 to 5 digits for marking questions. * Must be answered)

Path design (the connecting road between destinations) _____

Spatial nodes (artwork, placement of plants, or spatial variations such as indoor squares) _____

Landmark design (lighting well, sculpture, artwork or plant) _____

Spatial connectivity (interior space or connection between metro station and underground passage) _____

Zoning (e.g. separation between retail and dining and cultural facilities) _____

Floor height changes (changes in interior space height) _____

Spatial layering (two or more floors underground) _____

Privacy (layer to layer privacy protection) _____

Overlook activities (from above can see activities below) _____

7. Do you think the following options are important in the interior design of underground space? (Please fill in 1 to 5 digits for marking questions. * Must be answered)

Color _____

Size (spacious or narrow) _____

Plant landscape _____

Material (metal or wood, etc.) _____

Furniture (seating) _____

Signs and maps _____

Art Elements (Gallery) _____

8. Do you think the following types of underground space lighting are important? (Please fill in 1 to 5 digits for marking questions. * Must be answered)

Natural light _____

Artificial lighting _____

Indirect lighting (e.g. material reflection) _____

9. Do you think the following underground space safety facilities are important? (Please fill in 1 to 5 digits for marking questions. * Must be answered)

Escape _____

To avoid disaster _____

To monitor the _____

Warning (Alert) _____

The fire _____

10. Do you think the following indexes of comfort level of underground space are important? (Please fill in 1 to 5 digits for marking questions. * Must be answered)

Air quality _____

Indoor temperature and humidity _____

Noise control _____

11. Do you think the following social functions of underground space are important? (Please fill in 1 to 5 digits for marking questions. * Must be answered)

Social service facilities (free service facilities) _____

Complementary with the aboveground space function (as the vacancy of the aboveground space function complement) _____

Multifunctional use (can carry out many kinds of activities, function conversion) _____

Interactive Spaces (facilities or spatial extensions) _____

12. Do you think the following types of activities in underground space are important? (Please fill in 1 to 5 digits for marking questions. * Must be answered)

Recreational activities (performances, performances) _____

Theme Market _____

13. Do you think the following characteristics of underground space are important? (Please fill in 1 to 5 digits for marking questions. * Must be answered)

Characteristic architectural design _____

History or Symbol _____

Special cultural events (such as galleries) _____

Unique natural features _____

14. Do you think the following management and service options for underground space are important? (Please fill in 1 to 5 digits for marking questions. * Must be answered)

Information facilities _____

Health facilities _____

Administrative Regulations _____

Service staff _____