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Building three-dimensional pedestrian networks in cities

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Abstract

With the rapid growth of automobile transport over the last century, conflicts between automobile and pedestrian transport have been viewed as a major concern in urban and transport planning. Elevated and underground pedestrian networks, which compensate for sidewalks at the street level and provide alternative options for pedestrians, have been developed in many cities. Elevated and underground pedestrian networks offer pedestrian–car separation in a vertical dimension and efficient connections between transit services and cities for subway passengers. This study aims to provide a balanced understanding of the development of underground pedestrian networks and propose supportive strategies for decision makers, planners, and designers concerned with the future implementation of underground pedestrian networks and the building of three-dimensional pedestrian networks in cities. The study applied textual analysis to examine the topic. The study indicated that three-dimensional pedestrian systems were developed based on historical precedents. It highlighted important considerations (such as dense cities, disaster mitigation and protection, and urban functions) in developing underground pedestrian networks in cities. Furthermore, it discussed significant aspects in planning and designing such networks, including safety, ease of orientation, and convenience. The paper also discussed policy implications in developing underground pedestrian networks and the building of three-dimensional pedestrian networks in cities.

Keywords: Pedestrian planning; Compact city; Underground transport

1 Introduction

With the rapid growth of automobile transport over the last century, conflicts between automobile and pedestrian transport have been viewed as a major concern in urban and transport planning. Globally, researchers, planners, and decision makers have employed various techniques and strategies to reinstate the role of walking as a critical element in urban accessibility at the local level, such as pedestrianisation (Hussein, 2017; Özdemir & Selçuk, 2017), segregation of pedestrians from cars horizontally (Koglin, 2015) and vertically (Cui et al., 2013b), and integration of traffic with pedestrians (Nalmpantis, Lampou, & Naniopoulos, 2017). Elevated and underground pedestrian networks that segregate pedestrian and vehicle traffic, as well as compensate for sidewalks at the street level and provide alternative options for pedestrians, have been developed in many cities. Underground pedestrian networks typically appear well developed in cities with dense urban settings, extreme weather conditions, and well-developed underground railway systems (Cui et al., 2013a). The issue of planning and designing sidewalks at the street level has long been discussed in studies concerning pedestrian networks (Guo & Loo, 2013; Kelly, Hodgson & Page, 2011; Mokitimi & Vanderschuren, 2017); however, there is very scarce evidence on elevated and underground pedestrian networks, particularly underground pedestrian networks.

The development of underground pedestrian networks is a profound urban phenomenon, characterised by dense central area urban settings. For example, Chicago, with its dense central business district core of tall, primarily commercial skyscrapers, began underground pedestrian network construction in the 1960s (Wang & Liang, 2010). In many cities experiencing rapid urbanisation and motori-

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sation and the associated urban problems, sustainable urban development is challenging. To achieve more effective utilisation of urban infrastructure and resources to build compact cities, the key is to solve the contradiction between the demand and supply of urban spaces, in other words, to achieve the efficient use of urban spaces. However, the high density of land use creates transport congestion and thereby adversely affect economic activities. Efficient use of urban spaces in three dimensions would increase the potential of land use and the land value, thereby increasing urban capacity for compact city development (Broere, 2016; Bobylev, 2016; He, Song, Dai, & Durbak, 2012).

Underground pedestrian networks have been developed not only because they provide an additional layer of pedestrian networks, but they also allow pedestrian–car separation in a vertical dimension and efficient connections between transit services and cities for subway passengers. They provide a weather-protected and air-conditioned pedestrian environment, which is a significant benefit for pedestrians in cities with severe weather conditions, such as Toronto and Sapporo (Belanger, 2007; Sakakura, Shimizu, & Itabashi, 2007). In addition, with isolation from automobiles as well as electronic surveillance and patrolling, underground pedestrian networks ensure safe movement for pedestrians (Boisvert, 2007; Boivin, 1991; Robertson, 1993). Moreover, with integration into public transport, underground car parks, underground shopping malls and streets, underground pedestrian networks provide convenient transport options and combine commuting, shopping, and entertainment for an enhanced travel experience for pedestrians (Dillon, 1985; Robertson, 1987; Zacharias, Zhang, & Nakajima, 2011). Furthermore, the aggregation of pedestrian flows and activities in underground pedestrian networks can be commercially exploited, which yields economic benefits (Maitland, 1992). Accordingly, underground pedestrian networks serve the requirements of subway transport, commercial activity, pedestrians, and automobiles and help to facilitate urban vitality.

This research aims to provide a balanced understanding of how to build underground pedestrian networks and propose supportive strategies for decision makers, planners, and designers concerned with the future implementation of underground pedestrian networks for building three-dimensional pedestrian networks in cities. The research applied textual analysis to examine the object. Textual analysis was determined to be an appropriate method for organising the discussion of how to build underground pedestrian networks. The textual analysis of examples of underground pedestrian networks globally, which provides empirical evidence, can complement the theories on such networks for a more balanced understanding. Therefore, publications, websites, and reports with information on the development, planning, and design of underground pedestrian networks were analysed.

Combining arguments and discussion presented by a textual analysis of documents associated with the development, planning, and design underground pedestrian networks, this research developed a diagram (as shown in Fig. 1) to facilitate the discussion in the paper. First, a historical perspective was applied to illustrate the relationship between transport priorities and urban planning, showing how three-dimensional (street-level, elevated and underground) pedestrian systems were developed based on historical precedents. Subsequently, the discussion on how to build underground pedestrian networks in cities is conducted, combining examples from Asian and North American cities where a large number of underground pedestrian networks exist and the development, planning, and design of such networks have been well documented. The discussion highlights important considerations (such as dense cities, sustainability, and resiliency) in developing underground pedestrian networks. Furthermore, it discusses significant aspects in planning and designing such networks, including ease of orientation, convenience, and transport integration. The paper also discussed policy implications in developing underground pedestrian systems and the building of three-dimensional pedestrian networks in cities.

2 Transport priorities and urban planning

An urban environment is a complex system that includes many elements, such as infrastructure for various transport modes, streets, buildings, and people. Newman and Kenworthy (1999) nominated transport priority as one of three factors (the other two factors being economic priorities and cultural priorities) that determine urban form. Prior to the invention of the modern automobile (an open-air tricycle with a small one-cylinder petrol engine) in Germany by Karl Benz in 1885, urban transport systems at the street level had been dominated by pedestrian traffic for thousands of years. However, in the 19th century, particularly in cities of the industrialised world, this changed to some extent as horse-drawn carriages became more commonplace. The emergence and increase in automobile transport replaced this traditional transport priority, changing the city's form to a considerable extent.

The discussion of the relationship between transport priorities and urban planning begins with a review of pedestrian dominance in ancient times, followed by an examination of the impact of automobile development on pedestrians and cities, particularly pedestrian–vehicle conflicts. The discussion revealed that early attempts to separate vehicular and pedestrian traffic were implemented in numerous United States (US) and European cities. Investigation of more recent urban redevelopments and a global 'walking' renaissance in city centres that resulted in the initiation and evolvement of elevated and underground pedestrian networks helps to provide theoretical explanations for the development of three-dimensional pedestrian network strategies.

2.1 Pedestrian dominance

For a long time, pedestrian systems have been fundamental in urban life and transport. Traditional

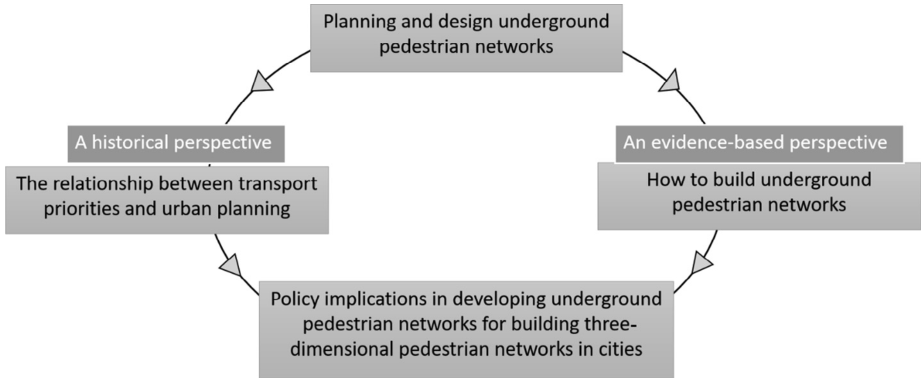

Fig. 1. Research process flow diagram.

pedestrian-oriented streets and squares of human-scale had been dominant in ancient times, and city size was determined by walking distance (Wang, 2004). Walkability was the most vital component considered in the planning and design of ancient cities. Mumford (1961) assumed that the scale of ancient cities was restricted by the manner of communication, which was typically determined by walking. Hence, the scale of ancient cities was limited to the distance of people's walking capability (typically 30 minutes, which is equivalent to a distance of approximately 2.5 kilometres). Newman (2003) shared a similar viewpoint with Mumford – he named ancient cities 'walking cities' because walking from one side of the city to another would only require half an hour.

Miletus, in ancient Greece, which was planned by Hippodamus in the 15th century BC, is representative of cities that were predominantly designed for pedestrians. It adopted a grid plan for its road network, an important feature that maximised walkability by allowing travel paths to be as direct as possible. The city's blocks measured 30 m × 52 m. It was defined by its human scale and moderate pedestrian distances (Benevolo, 1980).

In the later Middle Ages, the development of industry and commerce advanced rapidly as people began to rely on horse-drawn vehicles for transport. Linear road systems were subsequently developed to facilitate horse-drawn vehicular transport. The City of Aigues-Mortes at the mouth of the Rhone, France, founded in 1246 by the French King St. Louis IX, is representative of this type of city (Benevolo, 1980). Although horse and wagon transport increased significantly during the second half of the 1800s, they mainly served the peerage or people making long-distance trips. Walking was still the most common mode used for travelling, working, and social life. Conflicts between vehicles and pedestrians were not severe, although city planners began to use sidewalks, kerbing, and covered sidewalks to achieve formal separation between vehicles and pedestrians (Grava, 2002). The invention of the modern car in 1885 and its subsequent mass production in the early 20th century, as typified by Henry Ford's Model T car, significantly increased the popularity of cars and were set to intensify conflicts between vehicles and pedestrians in cities.

2.2 Automobile-oriented city

Newman and Kenworthy (1999) stated that automobile-oriented transport began to shape cities around the Second World War, offering convenience to low-density housing and increasing trip distances, which helped to decentralise and disperse cities. These changes, in turn, reinforced automobile dependence as a dominating characteristic of urban life in cities of the developed world. Accordingly, during the 1950s and 60s, the volume of pedestrians has steadily declined on the streets of city centres. Robertson (1993, p. 361) explained that:

> To accommodate motor vehicles, cities have narrowed their sidewalks to permit additional lanes of traffic. Insensitive building design, manifested in blank walls and parking ramps and a decrease in street-level shops and activities have undermined the attractiveness of downtown streets for pedestrians. Greater distances between buildings and activity centres have made downtowns less walkable. Finally, concerned with their personal safety and put off by the sense of isolation, people hesitate to venture on downtown streets.

The increase in number of private cars is antithetical to the needs of pedestrians and the planning and design of pedestrian networks in cities. The more car prioritised cities became, the more the needs of pedestrians were neglected with walkways disappearing completely in some places, poor integration of pedestrian networks into transport systems, and cities lacking pedestrian amenities (Grava, 2002; Southworth, 2005). Pedestrians had to endure danger, pollution, and vapidity; thus, walking became a dangerous and unhealthy activity (Robertson, 1991). Pedestrian volume decreased to the extent where Americans on foot constituted an endangered species (Robertson, 1993). Pedestrian spaces involving high-quality interpersonal interactions were sacrificed as city developers and planners reoriented cities toward cars. As a result, interesting pedestrian activities decreased in cities. Figure 2 shows that the percentage of commuters who walked to work in the US steadily declined, dropping by an astonishing three-quarter from 10.4% to 2.9% from 1960 to 2000.

2.3 Exploration of pedestrian–car separation

To cope with the situation caused by the increasing popularity of cars and the need to protect pedestrians in cities, planners in European countries and the US investigated techniques to rediscover the pleasure gained from walking and reinstate its role as a critical mode of urban accessibility at the local level. This included theories that demonstrated the concept of effective pedestrian–car separation whilst maintaining local accessibility and overall road network functionality, such as the Neighbourhood Unit by Clarence Perry, the Radburn Principle by Stein and Wright, and the Radiant City concept by Le Corbusier.

The theory of Neighbourhood Unit was initially proposed by Clarence Perry in the 1929. The principle of the theory was to create a scheme for the arrangement of family life in a comfortable and safe community with local amenities, protected from a burgeoning sea of vehicular traffic. Hence, the road system should be arranged to minimise conflicts between pedestrians and vehicular traffic, and non-local traffic should be excluded from residential areas. Clarence S. Stein and Henry. Wright created the new community of Radburn in Fair Lawn, New Jersey (US), which they founded in 1929. The aim of Radburn was to build an integrated self-sustaining community with specialised car access routes that linked roads, buildings, and expressways, and a total separation between pedestrian and car traffic (Patricios, 2002; Sun, 2007). Solutions to the conflict between cars and pedestrians were not only considered in two dimensions, but also explored in three dimensions. The 'Radiant City' by Le Corbusier is an example. In the 1920s and 1930s, one of the pioneers of modern architecture, Le Corbusier, attempted to solve urban problems through rebuilding cities themselves. He proposed a highly efficient urban transport system composed of subways and elevated highways that completely separated pedestrians and cars, deeming that the urban road system should not affect the convenience of pedestrians. The floor directly above a pilotis was allocated for communal services. Under the pilotis, pedestrians could walk unobstructed in all directions (Gold, 1998; Sun, 2007).

In the second half of the 1940s, as a result of reconstruction efforts after the Second World War (1939–1945), many large European cities were rebuilt. As a complement and extension to traditional walking spaces at the street level, indoor and underground shopping streets were developed. The development of pedestrian streets and malls revitalised pedestrian system development, ultimately extending city centres and subsequently becoming one of the most vital components of a large number of cities (Rubenstein, 1992).

From the 1960s, road construction on a large scale and the unrestricted growth in the ownership of cars resulted in a number of interrelated urban problems: (1) severe conflicts between cars and pedestrians; (2) development of car-oriented suburban shopping malls attracting customers and competing with city centres for commercial status, resulting in the decline of commercial functions of city centres; and (3) traffic congestions related to urban sprawl and land shortages. To recapture their vitality, urban renewal schemes were implemented in city centers, in which the improvement of a city's living environment was a prime objective. To achieve this objective, pedestrianisation was applied on a large scale (Grava, 2002).

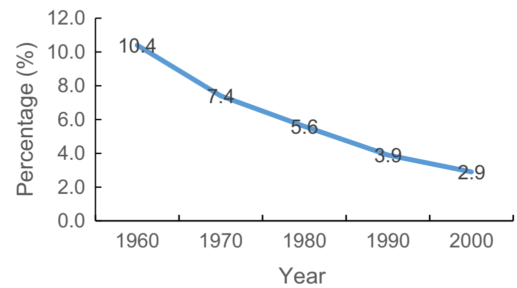

Fig. 2. Percentage of commuters who walk to work in the US between 1960 and 2000. (Source: the author, edited from Federal Highway Administration of US Department of Transportation, 2011).

The construction of pedestrian streets burgeoned during this period. Pedestrian streets expanded into pedestrian precincts and three-dimensional pedestrian systems. Classic examples of pedestrian precinct developments include those in Munich, Germany and Copenhagen, Denmark. Meanwhile, large-scale skywalk systems (elevated pedestrian networks) can be found in Minneapolis-Saint Paul, Rochester, and Cincinnati in the US and the Hong Kong Special Administrative Region (SAR) of China, while successful underground pedestrian networks were developed in Tokyo (Japan), Seoul (Korea), Toronto (Canada), and New York (US).

It can be argued that three-dimensional pedestrian networks have been developed based on historical precedents – from the early concepts of car–pedestrian separation characterised by the Neighbourhood Unit and Radburn Principle, to the Radiant City by Le Corbusier and the more recent practice of planning and developing three-dimensional pedestrian networks in cities (i.e., over multiple levels) – and that contemporary three-dimensional pedestrian networks were the outcome of often contradictory and conflicting planning objectives aimed at reducing traffic conflicts and achieving an improved integration of vehicular traffic and pedestrians.

Reducing traffic conflicts and achieving an improved integration of vehicular traffic and pedestrians may be important for the development of underground pedestrian networks. However, as mentioned previously, the rationale driving the development of underground pedestrian networks is more complex (see Cui et al., 2013b). In the context of building three-dimensional pedestrian networks in cities, several considerations are important in developing underground pedestrian networks. The following section discusses important considerations in planning and designing underground pedestrian networks.

3 Planning and designing underground pedestrian networks

Combining examples from Asian and North American cities presented by a textual analysis of documents associated with planning and designing underground pedestrian networks, this section discusses important considerations in building such networks. These considerations include dense city development, disaster mitigation and protection, and urban functions. Further discussion focuses on key aspects in planning and designing underground pedestrian networks, such as safety, comfort, convenience, accessibility, ease of orientation, signage systems, and transport integration.

3.1 Dense cities

Underground pedestrian networks were typically developed in dense cities – such as in the major cities of China and Japan – to achieve a compact city. Shanghai's underground pedestrian network is an example of utilising underground pedestrian networks to achieve a compact city in a unique Chinese context to accommodate urban growth and improve the urban environment for an optimal quality of life.

According to the Shanghai 6th population census in 2010, Shanghai, with a population of 23 million, an average population growth rate of 3.5%, and a city with the highest population density in China (Shanghai Municipal Statistics Bureau, 2011), implemented urban underground space development as an important strategy for managing its future urban development. Underground pedestrian networks comprise layered urban functions in multiple levels, thereby increasing the efficiency of land use and improving the urban environment compared with when the concentration of urban functions is located at or within a few levels above the ground level in a conventional 'street-oriented city'. Underground pedestrian network projects in Shanghai – such as those in People's Square, Jing'an Temple, and Xujiahui – are examples where urban environments were improved by implementing better 'layering' and concentrating functions. In the three cases, their surrounding environments were improved by relieving surface pressure, developing better public transport systems, reducing noise pollution, maintaining green spaces in city centres, and reducing travel distances through concentration of urban functions. Underground pedestrian networks have improved citizens' daily lives by providing convenient, comfortable, and safe transport, shopping, and entertainment alternatives. Through specific designs, underground pedestrian networks have also improved the quality of underground environments.

3.2 Disaster mitigation and protection

In some countries, such as China and Japan, underground infrastructure schemes have been designed to provide urban safety through disaster mitigation and protection. The underground pedestrian network in People's Square in Shanghai, when completed in the 1990s, was the largest underground project for disaster mitigation and protection (Shanghai City Local History Office, 2007). The project represented the harmonisation of disaster mitigation and protection strategies with urban development strategies through the development of underground pedestrian networks, which is currently the dominant ideology of underground pedestrian network development in Chinese cities. An independent spatial layer of communication and services can be created by extensive development of underground infrastructure including critical facilities that enhance a city's coherence regarding networked systems of infrastructure and its resilience to the onslaught of catastrophic events.

3.3 Urban functions

Underground pedestrian networks comprise three key urban functions – commercial, transport, and social (Basner, 2017). Commercial activities in underground pedestrian networks may account for a small portion of commerce in a city. However, commerce functions accommodated by underground pedestrian networks satisfy a portion of shopping demand (e.g., from commuters) in a city. Shopping activities that are associated with commutes in an underground pedestrian network (which decrease specific trips for shopping) result in considerably less emissions and energy consumption than those in travel activities associated with shopping at the street level owing to reduced motor vehicle traffic and congestion. Underground pedestrian networks in Shanghai and Shenzhen in China demonstrate this type of development (Lan, 2016). In the Hong Kong SAR, underground pedestrian networks benefited surface commercial facilities through optimal designs of exit locations, with exits directing numerous pedestrians generated by underground networks to the surface commercial facilities (He et al., 2016).

Integration with various transport modes, especially with the subway system, has significantly improved the mobility of pedestrians accessing and leaving underground pedestrian networks. Moreover, pedestrian travel in city centres has improved considerably in terms of convenience, efficiency, and affordability. The interaction between underground pedestrian networks and the subway system not only plays a significant role in creating and expanding underground pedestrian networks, such as the underground pedestrian networks in Montreal and Toronto (Barker, 1986; Boisvert, 2009), but also contributes substantially to sustainable transport (see Cui & Lin, 2016).

It has been indicated in previous research that underground pedestrian systems can function as a place for people to meet, conduct business, shop, study, entertain, or relax, which has contributed significantly to the social life of people (Besner, 2017; Cui et al., 2013b). In Tokyo, Japan, linking underground pedestrian networks with surrounding areas by providing a sunken garden or other spaces where people can interact with each other, is necessary for fulfilling the social functions of underground pedestrian networks (Shirane, Nakamura, Masuda, & Kasuya, 2016). Arts and cultural activities in underground pedestrian networks add value to the social functions of the networks. For example, Coco Park's sunken plaza in Shenzhen, China, regularly hosts community performances and exhibitions (Lan, 2016). In Montreal, cultural events and services are accommodated in its underground pedestrian network, such as a public library located in the mezzanine of the McGill Station as well as various free cultural events and exhibitions held in the Grande Place of the Complex Desjardins (Besner, 2012).

3.4 Safety, comfort, convenience, accessibility, and ease of orientation

Safety, comfort, convenience, accessibility and ease of orientation are important qualities of underground pedestrian networks for optimising pedestrian networks and promoting walking. Underground pedestrian networks were perceived as a safe walking environment in both day and night. For example, in Cincinnati and Minneapolis, crimes in the city centre that occurred in the networks were few (Daniels, 2005; Forusz, 1980). In fact, various safety measures were implemented in underground and elevated pedestrian networks, such as security patrols, television surveillance cameras, and voice-activated alarms in Montreal and Minneapolis' underground and elevated pedestrian networks (Boivin, 1991; Daniels, 2005). In Shanghai, safety is enhanced by the large number of people using underground pedestrian networks – there is safety in numbers. This may explain why the integration of commercial facilities, especially underground commercial spaces, into underground pedestrian networks has been encouraged in Shanghai. This integration has also benefited retailers owing to the vast amount of commuter traffic moving to and from subway stations past retailing establishments for many hours of the day, which has subsequently helped to maintain safety and vitality during all retail operation hours, even outside peak commuting travel times.

With regard to comfort and convenience, the design and landscape of the underground pedestrian networks, merchandise categories of commercial facilities in underground pedestrian networks, services and functions, and the scale of corridors are important. Coco Park's sunken plaza in Shenzhen, China, features retail and food establishments that are outward facing, allowing easy connections between the underground pedestrian network and the sidewalk above. With wide corridors and high ceilings filled with natural lighting, and public seating at key nodes, as well as shops, cafes and restaurants, Shenzhen's Link City is an example of how underground pedestrian networks can replicate the sidewalk experience (Lan, 2016).

However, underground pedestrian networks with underdeveloped facilities for elderly and disabled people (such as lifts, escalators, benches, and blind tracks) would discourage the use of the networks by the abovementioned group. Moreover, signage system requires additional attention in design. The issue of being underground without buildings at the street level for orientation would be further exacerbated in the case of a large number of first-time users. New users of underground pedestrian networks primarily rely on signage systems for orientation instead of their familiarity with the underground environment (Mi, Xu, & Tang, 2007); this situation may contribute to high expectations of the function of signage systems. Experiences can be learned from large-scale underground pedestrian networks, such as those in Toronto and Montreal, which have demonstrated significant investments in their maps, logos, and landmarks to assist with user orientation, including a comprehensive signage package known as 'PATH' in Toronto and a strategically arranged 'Underground City Logo' in Montreal (Barker, 1986; Sijpkes & Brown, 1997). In addition, innovative architectural designs together with strong integrations with street-level and above-street-level uses may offer solutions; however, more research is required to determine the best solutions for particular local circumstances.

4 Policy implications in building three-dimensional pedestrian networks in cities

Based on this study, it is discovered that a few significant factors are worth considering for developing underground pedestrian networks. Cities worldwide need to supplement policies related to the development and management of underground pedestrian networks.

4.1 Consider walking in city centres

Pedestrianisation in city centres needs to be considered to address conflicts between different transport modes and the efficiency of each transport mode. Addressing the needs of walking as a transport mode can provide benefits and vitality into a city centre at multiple levels. Underground pedestrian networks are not an optimum choice for all cities. It is worth noting that the purpose of study is not to argue which pedestrian system (underground pedestrian systems, elevated pedestrian systems and sidewalks) is superior to another. To combat complicated urban problems (arising from factors such as weather, transport, economic, social, and environmental concerns), no single solution exists that suits every city. The appropriateness of pedestrian system alternatives depends primarily on the urban environment of an individual city. A comprehensive evaluation of natural and built environments of a city should be performed for the application of pedestrian networks to a particular city.

4.2 Optimise functionality of underground pedestrian networks

The integration of underground pedestrian networks with other transport modes can improve the experience of network users with opportunities for virtually seamless travel. Access for people with disabilities needs to be considered in the design of underground pedestrian networks. For example, escalators in the close proximity of entrances/exits would ease the access of networks for the general public, especially disabled persons, pregnant women, children, and elderly persons. The locations of stairs, escalators, and particularly lifts connected to underground pedestrian networks should be marked appropriately on maps and on signs distributed internally throughout and outside the networks. The installation of seats and benches as well as the provision of seating areas associated with dining, cultural, and entertaining activities can improve pedestrian comfort and convenience in the networks. Comfortable seating, restaurants, fast food booths, and tea rooms provide varied options for rest and relaxation. Ideally, these activities should be accompanied by other activities, such as cultural and entertainment activities including exhibitions, fashion shows, and concert performances, which can help enrich the use of the space in underground pedestrian networks, thereby yielding economic benefits to the networks and achieving broad social benefits. In addition, privacy in public resting areas within the vicinity of sculptures and art walls should be provided.

4.3 Strengthen the contribution of underground pedestrian networks to urban development

It is essential to integrate an underground pedestrian network within the overall urban pedestrian network. An underground pedestrian network needs to connect seamlessly with other pedestrian networks (whether at or above the street level) to provide a continuous and smooth walking experience in a pleasant and interesting walking environment. An underground pedestrian network needs to be designed and developed to complement the movement needs of pedestrians and improve the overall urban pedestrian system. In addition, integration with other transport options to provide convenient transfers is equally important for the function of an underground pedestrian network as an organic component of urban transport systems.

The integration of an underground pedestrian network into an urban public space network and within the urban fabric can be achieved through ensuring smooth connections with public spaces at the ground level, allowing an extension of urban functions from the street level into underground pedestrian networks. Moreover, the creation of a high-quality underground pedestrian network environment is essential for facilitating public activities within the underground pedestrian networks. For example, inclusion of artworks and the accommodation of cultural activities would enrich the significance of underground pedestrian networks as a provider of important public spaces, which would maximise social interactions in the underground pedestrian networks and assist in the provision of urban public spaces that are otherwise lacking at the street level.

4.4 Integrate underground pedestrian networks into an urban economy

This requires the implementation of a strategy to achieve multiple wins in commerce, transport, environment, and society. An underground pedestrian network offers an intensive and efficient way to utilise urban spaces, with the effect of improving the commercial environment, increasing pedestrianisation and improving public transport, beautifying the urban environment at the street level and preserving the streetscape/historical sites, all of which ultimately lead to a revitalisation of the local urban economy. An underground pedestrian network requires appropriate commercial components to achieve a favourable commercial environment, and once the commercial environment is established, it can generate substantial economic and social benefits. The high profit yields of commerce in an underground pedestrian network from the rental of retail space and car parking fees can help offset the maintenance costs of public walkways and provide a return on the development costs of an underground pedestrian network. Accommodating commercial functions in an underground pedestrian network can ensure a return on investment of the development costs, provide convenient and efficient pedestrian flows, and promote local economic prosperity. In developing an underground pedestrian network, the economic development of an area is assured through balancing and reinforcing the transport functionality of a centre (for pedestrians and with public transit systems) and its commercial functionality.

5 Conclusion

This study revealed that three-dimensional pedestrian systems were developed based on historical precedents. It highlighted important considerations (such as dense cities, disaster mitigation and protection, and urban functions) in developing underground pedestrian networks in cities. Furthermore, it discussed significant aspects in planning and designing these networks, such as safety, ease of orientation, and convenience. The paper contributes to a better understanding of the development of underground pedestrian networks. Moreover, it also enriches dense city development and urban sustainable development theories and practices by considering the third dimension of urban spaces for pedestrians. However, this study only focused on underground pedestrian networks. Future research should focus more on elevated pedestrian networks and sidewalks at the street level and examine how to build three-dimensional pedestrian networks as part of an integrated transport system, as well as how to build pedestrian networks in three-dimensional transport networks in cities. In addition, future research on pedestrian traffic simulation systems would benefit the optimisation of the development of three-dimensional pedestrian networks significantly. Developing and applying pedestrian simulation models to

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test alternative designs may improve the safety, comfort, and accessibility of pedestrian networks.

Declaration of Competing Interest

The author declare that she has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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