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DOI
10.1016/j.tust.2020.103726

Publication date
2021

Document Version
Final published version

Published in
Tunnelling and Underground Space Technology

Citation (APA)
Cui, J., Broere, W., & Lin, D. (2021). Underground space utilisation for urban renewal. *Tunnelling and Underground Space Technology*, *108*, 1-10. Article 103726. https://doi.org/10.1016/j.tust.2020.103726

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Tunnelling and Underground Space Technology 108 (2021) 103726

Contents lists available at ScienceDirect

Tunnelling and Underground Space Technology incorporating Trenchless Technology Research

journal homepage: www.elsevier.com/locate/tust

Underground space utilisation for urban renewal

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ARTICLE INFO

Keywords:
Urban underground space (UUS)
Underground space utilisation
Urban renewal
Cities

ABSTRACT

The rapid increase in world population in the 21st century, with associated transport and environmental problems, has encouraged the development of urban underground spaces as an optimal solution in many occasions, including urban renewal schemes. This paper reviews literature on the utilisation of urban underground space for urban renewal to provide a better understanding of how urban underground space can contribute to urban renewal, and of challenges and successes in achieving the goals. The paper concludes that urban underground space present new development opportunities (e.g. land/space supply, less traffic congestion, compact city development, and urban sustainable development) in regeneration of existing urban land. Urban underground spaces, as valuable resources and efficient and effective tools for urban renewal, should be considered by decision-makers for transforming existing urban areas, stimulating vibrant and denser development and mixed land use.

1. Introduction

Many cities in the world are confronted with rapid population growth, resulting in greater concentration of population in urban areas. This has allowed the development of urban underground space (UUS) as an appealing approach to solving transport, environmental and land use problems that occur during the urban development process. Urban underground space has been developed in various forms in many cities around the globe. Some well-known large-scale underground space utilisation examples include London's and Shanghai's subway systems, underground pedestrian systems in Montreal and Toronto, urban underground expressways in Paris and Madrid, and Tokyo's underground shopping complexes. Urban underground space utilisation has contributed to solving the problems of modern cities (Broere, 2016) and significantly impacted on urban development and planning (Cui et al., 2013, 2015). Urban underground space promotes a healthier urban system, by improving the resilience of cities (Sterling and Nelson, 2013), building liveable cities (Hunt et al., 2016), and promoting sustainable urban development (Bobylev, 2009; Sterling et al., 2012; Hunt et al., 2014; Cui and Lin, 2016).

Urban renewal is an important concept in urban development and planning. Urban renewal refers to "a set of plans and activities to upgrade neighbourhoods and suburbs that are in state of distress or decay. Urban renewal programs address the physical aspects of urban decay. Urban problems such as deteriorating housing, poor physical infrastructure (including water and sanitation services), and poor community services such as sports and recreational amenities are addressed through such programs" (Richards, 2014, p. 294). In some countries, terms that cover similar concepts to urban renewal include urban regeneration, urban revitalisation, urban redevelopment, and urban rehabilitation. For example, In the United Kingdom (UK), urban renewal is often called urban regeneration, and in the United States (US), the term often used is urban redevelopment. Urban renewal has been considered an effective tool for solving land shortages, optimising urban spatial layout and functional positioning (Liu et al., 2019), combating environmental degradation, increasing land values (Adams and Hastings, 2001), and promoting desirable physical and socio-economic transformation (Keddie and Tonkiss, 2010). Urban renewal has become an important urban development policy (e.g. for urban sustainable development) in many countries and regions (Zheng et al., 2014).

Urban renewal brings changes in the use of urban land and buildings, which lead to changes in where, how and under what conditions people live, work, and enjoy entertainment. This brings opportunities and challenges; for some people these changes result in improvements in living conditions, while for others the opposite occurs (Couch, 1990). Urban renewal was believed to be the restoration of the original

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https://doi.org/10.1016/j.tust.2020.103726
Received 6 June 2020; Received in revised form 12 November 2020; Accepted 12 November 2020
Available online 16 December 2020
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functions that had been damaged or lost. A US study based on urban planning reports and proposals found that urban renewal projects were expected to achieve new development while preserving old physical and historical values. Urban renewal had been characterised as strengthening the central city, enhancing human interaction, and valuing nature and neighbourhood (Jeong et al., 2010). The characteristics and dilemmas of urban renewal highlight the significance of UUS use. UUS provide an opportunity to restore the natural landscape and ecology. Therefore, UUS developments are sometimes called "green roofs". Developing below ground is also a significant approach in protecting cultural and historical values above ground (Carmody and Sterling, 1993; Cui et al., 2019; Goel et al., 2012; Kishii, 2016; Ronka et al., 1998; Sterling et al., 2012). New underground developments accommodate additional urban functions to reinforce the central city without the loss of the physical and historical values of existing land and buildings.

Urban renewal is not a new concept. Comparatively, the inherent merits of underground spaces for urban renewal have been more recently realised, and underground development has been used in many cities to achieve urban renewal goals. Given the rapid development of UUS for urban renewal in the world, and the escalation of research in this field, a review of existing research in the field is necessary. The purpose of this review is to map out and describe UUS utilisation for urban renewal, and to understand the nature and significance of utilising underground space in urban renewal. The review provides researchers and practitioners with up-to-date understanding of the rationale for and forms of UUS utilisation, and key messages for the challenges and success of its use for urban renewal throughout the world. The research aims to answer the following questions:

- How can UUS utilisation contribute to urban renewal?
- What forms of UUS utilisation have been documented as contributing to urban renewal?
- What are the challenges of UUS utilisation for urban renewal?
- What are the key messages for the successful utilisation of UUS for urban renewal?

The rest of the paper is structured as follows: first, we describe the research methodology and review methods in the Methodology section; then we discuss the research findings in the following sections; finally, we summarise key research findings and suggest future research directions in the Conclusion.

2. Methodology

This paper reviews articles derived from searches of major databases including Scopus, Web of Science Core Collection, and Google Scholar, ensuring high quality and inclusiveness of search results. These databases index literature, including journals, books and conference proceedings in multiple disciplines, e.g. engineering, science, social sciences, medicine, and arts and humanities. Search terms were identified from existing literature, and through the expertise of the research team. To ensure the inclusiveness of the search results, the search terms included "underground space" and terms that have similar concepts, including "sub-surface" and "subterranean space"; and "urban renewal" and terms that have similar concepts, including "urban regeneration", "urban revitalisation", "urban redevelopment", and "urban rehabilitation". We conducted a keyword search of titles and abstracts in the databases, with no limitation on publication year. Since the purpose of this review is to map out and describe UUS utilisation for urban renewal, the selection of the articles focuses on empirical studies that can provide original evidence about the research topic. Literature review papers that normally do not provide empirical evidence were excluded from this review. In the screening process of the search results, we conducted title/abstract screening, followed by full-text screening. Studies were excluded on the basis of the following criteria: they did not discuss one or more forms of underground space utilisation; they did not discuss underground space utilisation for urban renewal; or they did not provide empirical evidence about the research object. Only English articles were selected. We focused on the planning and design of UUS utilisation from the perspective of urban studies. Articles were cited according to the relevance and value of the articles to the research questions. A summary of the literature reviewed is shown in Table 1. Studies were conducted in both developed and developing countries. This review presents research findings for many countries, particularly Brazil, China, Canada, Greece, Italy, Japan, Korea, the Netherlands, Spain, US, and UK (see Table 1). The framework of the review is shown in Fig. 1. The following sections discuss findings from the review to answer the research questions of this paper.

3. How underground space utilisation can contribute to urban renewal

3.1. Coping with urban development and associated problems

Existing literature has highlighted the role of UUS utilisation in coping with urban development and associated problems. Nowadays, many cities have significantly expanded, with rapid growth of urban population, and both concentration and extension of urban functions. Excessive expansion of urban spaces has caused various problems with regard to transport, environment and culture, resulting in reduced quality of life (Han et al., 2012; Tajima, 2003; Tong, 2007; Zhao et al., 2016). In order to promote efficient use of urban functions and improve living environments, urban renewal and regeneration projects have been undertaken. In urban regeneration, horizontal expansion of urban spaces has limitations in accommodating the expansion of urban functions in a sustainable way. Therefore, it was suggested to integrate UUS, since UUS provide opportunities for environment-friendly urban regeneration (Han et al., 2012). In cities where widespread urban expansion has caused the destruction of much farmland, to control urban overspread and build more compact, liveable and prosperous cities, urban revitalisation and redevelopment have utilised UUS to accommodate urban functions (Li and Pei, 2009). In cities like Montreal, pedestrian-vehicle conflicts in the city centre, high population density and willingness to develop a compact city meant that underground development became a comprehensive solution to accommodate transportation, commerce, service and other functions in urban development, improving the quality of urban life without necessarily expanding the urban area beyond the city's borders (Durmisevic, 1999).

3.2. More efficient use of resources

UUS contributes to more efficient use of resources e.g. land, space and energy. High land prices have promoted increasing concentration of urban functions and intensive use of urban spaces (e.g. in the form of high-rise buildings). Unfortunately, this has not necessarily offered citizens pleasant urban environments. The use of UUS has the potential to improve urban functioning and urban environments by creating modern urban spaces with multiple levels. Creating living spaces on the surface that are full of bright light and green areas offers residents peaceful and comfortable experiences while taking advantage of basements in high-rise buildings to accommodate urban functions (Nishida and Uchiyama, 1993). For example, underground transport infrastructure (e.g. underground roads) can effectively reduce transport congestion in existing road networks above ground, providing opportunities to reclaim valuable surface space and resulting in urban revitalisation and regeneration (Benardos et al., 2013). In Boston's case, the Central Artery/Tunnel project (alternatively called the Big Dig) established transport infrastructure to support the expansion of the city centre into the semi-abandoned seaport district, while reducing vehicle traffic on the street for better pedestrian amenity and an improved environment (Salvucci, 2003). Although renovation and expansion of the urban road network was the primary aim of the Central Artery/Tunnel project, the

Table 1
Literature on underground space utilisation for urban renewal.

Reference	City, Country	Form of underground space utilisation	Area/project	Goals of using underground utilisation in urban renewal
Benardos et al., 2013	Athens, Greece	Underground Road	Heart of Athens	Reviving city life
Bi and Liu, 2013	Lanzhou, China	Underground Commercial Space	Commercial district of Xiguan Cross	Promoting urban vitality and sustainable urban development
Bushouse, 2002	Boston, US	Underground Expressway	Boston Central Artery/Tunnel project	Improve Boston traffic conditions
Church, 1990	London, UK	Metro	London Docklands	Improving local transport system and congested surrounding area in East London
Demers, 2016	Montreal, Canada	Underground Pedestrian Network	Downtown Montreal	Restoring the continuity of Montreal's central business district (CBD) via bridging the historic Old Montreal and the existing CBD
Durmisevic, 1999	Montreal, Canada; Randstad, the Netherlands	Underground Pedestrian Network; Underground Metro Station; Underground Shopping Centre	Place Ville-Marie and Eaton Centre in Montreal; Wilhelminaplein and Beursplein in Randstad	Preserving the city as a cultural, social and economic centre that requires more compact solutions
van den Ende and van Marrewijk, 2019	Amsterdam, the Netherlands	Metro	Amsterdam East-line Metro	Establishing opportunities in the city centre, and enhancing the transport connections between the city centre and surrounding suburban areas
Han et al., 2012	Seoul, Korea	Underground Expressway	Seoul	Enhancing efficient use of urban functions and improving living environments
He et al., 2016	Hong Kong, China	Underground Pedestrian Network	Tsim Sha Tsui	Promoting urban commercial development
Jia and Fang, 2016	Lanzhou, Ningbo and Chongqing, China	Underground Transport System	Lanzhou West rail station, Ningbo rail station, Chongqing West station, and Lanzhou Zhongchuan airport transport hubs	Maximising the social benefit
Lee et al., 2013	Seoul, Korea	Underground Shopping Centre	COEX Centre	Being part of mixed-use developments; improving built environments; revitalising social life and local culture
Li and Pei, 2009	Qingdao, China	Metro; Underground Road; Underground Parking Space; Underground Public Space; Underground Commercial Space; Underground Storage Space	Qingdao	Regenerating regional vitality
Little, 2018	New Haven, US	Underground Library	Yale University	Meeting demands on the spaces and collections of academic libraries
Ma and Peng, 2018	Qingdao, China	Underground Road	Shinan District	Upgrading road infrastructure to improve traffic condition
Masuda et al., 2004	Tokyo, Japan	Underground Infrastructure	Tokyo Bay	Promoting the establishment of efficient urban systems in normal days and capital functions in the emergency occasions
Nishida and Uchiyama, 1993	Tokyo, Japan	Underground Parking Space; Underground Mechanical Room; Underground Storage Room	Tokyo	Promoting efficient use of urban land; providing better living environments
Qiao and Peng, 2016	Luoyang, China	Underground Parking Space	Luoyang	Addressing historic resource conservation and urban redevelopment
Qiao et al., 2019	Shanghai, China	Underground Transport System	Hongqiao CBD	Constructing transport facilities that are complementary to the existing transport system
Russo et al., 2017	Naples, Italy	Metro	Toledo station	Regenerating spaces above underground stations
Salvucci, 2003	Boston, US	Underground Expressway	Boston Central Artery/Tunnel project	Improving Boston traffic conditions
Sassano et al., 2017	Basilicata, Italy	Underground Building; Underground Parking Space	Cocuzzo neighbourhood	Improving urban spaces
Shang, 2016	Beijing, China	Underground Residential Space; Underground Public Space; Metro leading to comprehensive development of underground space; Underground Parking Space; Underground space in open squares and old buildings	Beijing old city	Conserving old city; providing better living environment
Shi et al., 2017	Montreal, Canada	Underground Pedestrian Network; Underground Public Space	Place des Arts	Rehabilitating urban open space
Sung, 2014	Tokyo, Japan	Sunken and Underground Street	Station area of Tokyo	Revitalising decayed central area of city
Tajima, 2003	Boston, US	Underground Expressway	Boston Central Artery/Tunnel project	Improving Boston traffic conditions
Terranova, 2009	Dallas, US	Underground Pedestrian Network	Dallas	Motivating economic renewal
Tong, 2007	Beijing, China	Underground Parking Space; Underground Shopping Centre; Underground Infrastructure	Zhongguancun West Zone	Solving problems in urban development; developing a large-scale central high-tech business zone
Valdenebro and Gimena, 2018; Valdenebro et al., 2019	Pamplona, Spain	Urban Utility Tunnel	Historical city centre	Protecting the historical and cultural heritage in urban development that requires new social and functional needs to be addressed

(*continued on next page*)

Table 1 (*continued*)

Reference	City, Country	Form of underground space utilisation	Area/project	Goals of using underground utilisation in urban renewal
Waisman et al., 2014	São Paulo, Brazil	Underground Parking Space	Batata Square	Redeveloping a significantly deteriorated area via creating large open spaces and enhancing the activity centre through integrating intermodal transport
Yokotsuka et al., 2013	Tokyo, Japan	Underground Pedestrian Network	Central Tokyo area	Shaping Tokyo to be an international financial city
Yokotsuka et al., 2016	Tokyo, Japan	Underground Energy Network	Yaesu-Kyobashi-Nihonbashi District	Achieving a low-carbon society
Zacharias and He, 2018	Hong Kong, China	Underground Pedestrian Network	Tsim Sha Tsui area of Kowloon	Attracting people from the underground system to the surrounding area on the surface to revitalise local commerce
Zhao et al., 2016	Qingdao, China	Underground Transport System; Underground Commercial and Public Space	Qingdao	Solving urban problems and improving urban space functions to achieve sustainable development

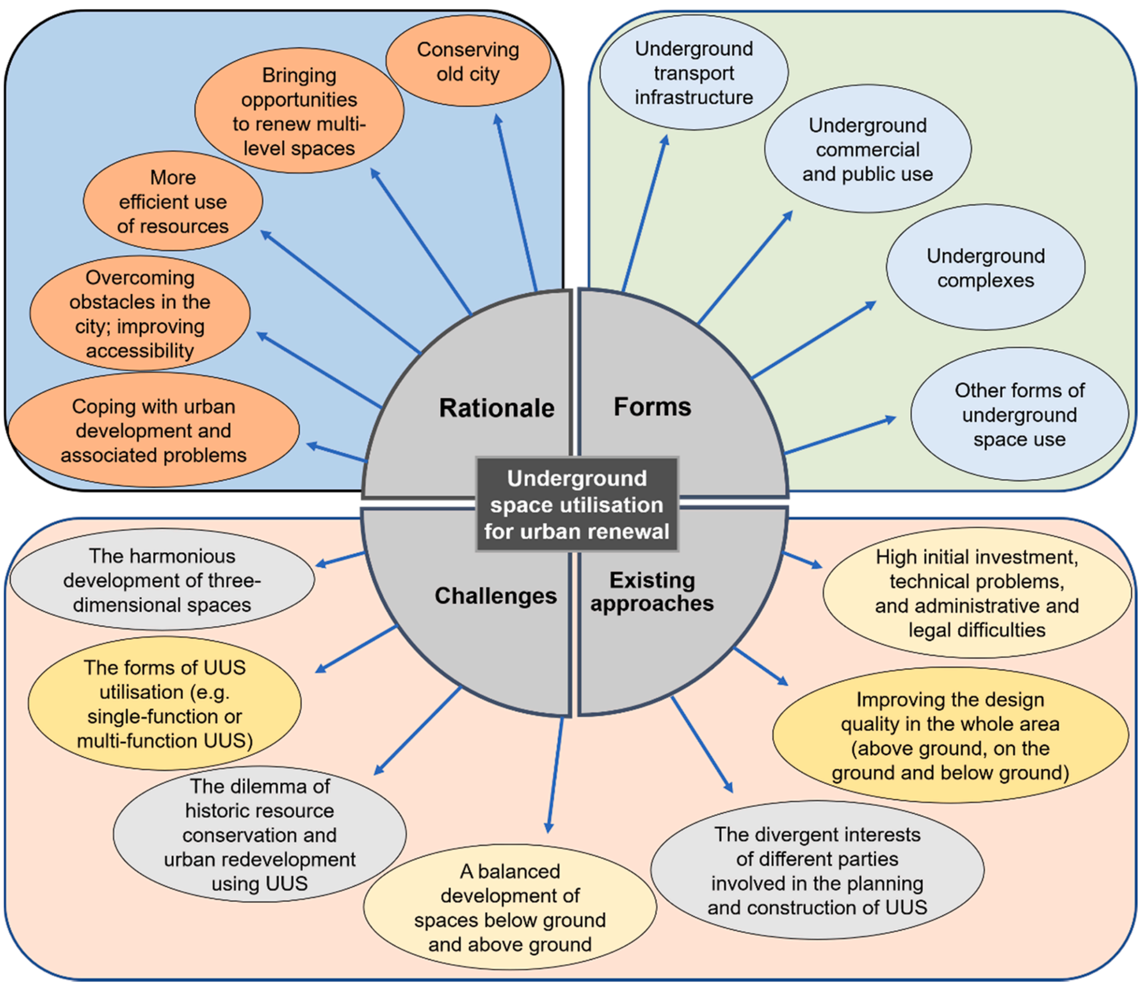

Fig. 1. A framework for the review of underground space utilisation for urban renewal.

relocation of an elevated highway to below ground led to a significant improvement in surface conditions and regeneration of the city beyond the strict project boundaries (ITA Working Group - Urban Problems Underground Solutions, 2012). UUS development also contributes to more efficient use of energy. In Tokyo, Japan, urban revitalisation projects in the Yaesu-Kyobashi-Nihonbashi area were estimated to result in doubling of the total building floor area and trebling of energy load and CO_2 emissions. An underground energy network could provide stable energy supply to the area, save unused energy, improve the cityscape by removing equipment from roofs, contribute to disaster prevention, and result in labour saving in facility management and space saving from machine room reduction (Yokotsuka et al., 2016).

3.3. Old city conservation

Underground space utilisation has contributed to old city conservation in urban renewal projects. In historical cities in the world (e.g. Beijing and Luoyang in China, Randstad in the Netherlands and Pamplona in Spain), the contradiction between development and conservation is always a challenge. In order to protect historical city centres while providing necessary facilities and infrastructure for modern city development, it is reasonable to develop UUS to relieve development pressure at the street level (Durmisevic, 1999).

In cities like Beijing, the old city form has created many problems (such as shortage of residential and public spaces, traffic jams and parking shortages due to narrow roads, less functional urban space, and presence of old buildings) that restricted the city's development. Despite various approaches to achieving urban renewal in Beijing's old city, utilisation of UUS has become a new direction in practice that is believed to be a unique and effective solution to the contradiction between development and conservation. More functions can be accommodated in underground spaces without greatly increasing space use above ground. The old city of Beijing can be preserved, while the problems mentioned above can be addressed with minimal impact and change on the ground spaces, thus meeting the requirements of preserving historical and cultural areas in Beijing's old city (Shang, 2016). Luoyang, China, has three UNESCO World Cultural Heritage Sites and 43 sites and monuments that have been officially protected at the national level in China. Expansion of the urban areas is restricted by surrounding historical sites. In addition, vertical development is constrained as urban redevelopment in the conservation area has to obey height limit requirements. As in many other historical cities, the traditional urban fabric, which featured narrow roads with commercial destinations in the conservation area, as well as booming tourism and lack of parking spaces, worsened traffic conditions, resulting in severe traffic congestion. Moreover, the city's master plan and conservation scheme indicate the need to reduce development pressure on the conservation area and to focus on developing new areas. As a result, the infrastructure and living environment in the old city (the conservation area) lags far behind those of new districts and areas. The utilisation of UUS in the old city has great potential to contribute to rehabilitation and conservation of historic districts by offering additional spaces to accommodate urban functions, e.g. transport, infrastructure, and parking (Qiao and Peng, 2016).

Like Beijing and Luoyang, the city of Pamplona, Spain, also was confronted with difficulties in protecting its historical heritage in urban development that requires new social and functional needs to be addressed. In Pamplona's case, underground space utilisation in the form of urban utility tunnel (UUT) systems emerged as an optimal solution for sustainable renewal of the old city centre (Valdenebro and Gimena, 2018; Valdenebro et al., 2019). Like other cities in the world, in the majority of cases, the urban basic service networks (such as water, electricity, gas, sewerage and telephone) in Pamplona at the end of the last century were either run through the subsoil or run in a disorderly manner on the facades of buildings. Problems were caused by this arrangement. For example, narrow streets prevented the application of safety regulations with regard to minimum distance between utilities. When repair or modification of streets is needed, access of vehicles and people is disrupted. Other problems include coordination impact (the existence of pipes, ducts and cables of different companies without any coordination, leading to difficulties in locating them); visual and functional impact (e.g. in the process of selective collection and recycling of waste); and archaeological impact (archaeological potential in the subsoil that is required to be protected and may challenge or prevent new trench development for utilities). Through the utilisation of UUT systems in the renewal of historical city centres, work with utility networks (e.g. maintenance, renewal and expansion) can be conducted conveniently with less disruption to people's access to streets and less visual pollution caused by facade wiring. In this way, people in the historical city centre can enjoy high-quality urban basic services and infrastructure (Valdenebro and Gimena, 2018).

3.4. Overcoming obstacles in the city and improving accessibility

Underground space utilisation has contributed to urban renewal because it overcame obstacles in the city and improved accessibility. Montreal's city centre was broken by an underground expressway constructed in the 1960s. To create a bridge to the old business district and restore the continuity of the city centre, new UUS development emerged as a viable strategy for major urban renewal of Montreal's city centre (Demers, 2016). In Tsim Sha Tsui, an important central business district (CBD) area in Hong Kong, an underground pedestrian connection was built, with the effect of enhancing access to commercial land. According to He et al. (2016), the underground pedestrian network served as an alternative to walkways at the street level, and impacted on the entire pedestrian environment. Therefore, through careful planning of subways and arrangement of exits, the underground pedestrian network that redistributed pedestrian flows was able to contribute to maximising commercial development.

3.5. Bringing opportunities to renew multi-level spaces

Large-scale underground space developments (e.g. the extensive underground pedestrian systems in Hong Kong and Montreal) that have heavy investment and significant impacts on urban economies provides opportunities to renew multi-level spaces. Hong Kong has developed a multifunctional underground pedestrian network to connect underground concourses and streets with the aim of attracting people from metro stations and underground commercial facilities to the surrounding areas on the surface (Zacharias and He, 2018). In Montreal, Canada, the multi-layer system of public open space in Place des Art created opportunities to connect the locations of regular festival events in three districts (eight neighbourhoods) via surface walkways, underground walkways and metro systems in the process of urban rehabilitation (Shi et al., 2017). The development of the Toledo underground railway station in Naples, Italy, provided the opportunity to regenerate spaces above ground (e.g. the public squares above the two station entrances), including space above the main entrance that was developed into a busy pedestrian area with street market stalls (Russo et al., 2017). The contribution of underground pedestrian networks to urban economic renewal of declining city centres (see Cui et al., 2013) has been seen in North American cities such as Charlotte, Cincinnati, Los Angeles, Portland and Dallas. In Dallas, development of an underground pedestrian network attracted people to the city centre to enjoy the comfortable and temperature-controlled environments for dining, shopping, relaxing and entertainment (Terranova, 2009), resulting in increased retail sales, increased property values and higher lease rates in the city centre.

4. What forms of underground space utilisation have been documented to contribute to urban renewal

4.1. Underground transport infrastructure

Underground transport infrastructure has often been used to regenerate urban land to improve mobility, accessibility and connectivity. Underground railways and stations, underground parking spaces and underground pedestrian networks are the main forms of this utilisation (Cui and Nelson, 2019). In many cities in the world, due to narrow roads and traffic congestion, using UUS has proven to be a wise choice for improving mobility and accessibility. Among the underground development strategies, underground railway and station development has the effects of significantly improving public transport patronage, improving traffic conditions and enhancing accessibility. Moreover, underground railway and station development drives comprehensive development of underground spaces in the area around the stations and along railway lines, stimulating urban renewal (Shang, 2016). In China, metro planning and development comprehensively guide urban renewal along metro lines and stations (Zhao et al., 2016). In cities like Qingdao, underground space utilisation has always been considered a tool for activating urban vitality in urban renewal and regeneration projects. As a vital part of underground development, underground railway lines and stations connect the city centre, commercial and shopping malls, and residential areas (Li and Pei, 2009). In London, UK, the Docklands had suffered from a declining economy in the docks and local manufacturing since the 1960s. The local transport system and the heavily congested surrounding area of East London called for an improved public transport system. New underground railway lines and the extension of existing underground railway lines were key components of urban regeneration in this area (Church, 1990).

Underground parking is an essential element in numerous urban renewal projects. In the Batata Square Urban Renewal Project in the City of São Paulo, Brazil, underground parking spaces were developed to meet the parking needs of hundreds of cars and motorcycles (Waisman et al., 2014). Unsurprisingly, taking advantage of the basements of high-rise residential and business buildings means that the most prevalent form of UUS utilisation in many cities is car parking (Qiao and Peng, 2016). By developing underground parking spaces to save space above ground for streets, squares and green belts, urban environments were beautified, and urban spaces were humanised (Shang, 2016). In fact, with driving becoming a key transport mode in modern cities, there is high demand for parking spaces in urban areas. The shortage of parking garages in the old city of Beijing resulted in great inconvenience in parking; increasing numbers of private cars worsened the parking situation. Streets were occupied by parked vehicles, and walking became difficult. This has become a phenomenon within Beijing's old city. As it becomes less likely that parking garages would be built above ground, developing underground parking garages was seen as an important solution to the increasingly severe parking problem. By developing underground parking garages after carefully considering the relationship between underground parking garages and conserved areas (e.g. historical and cultural heritage sites), the parking issue can be solved, spaces at the street level can be saved, and access to heritage sites can be improved. In China, underground car parks were connected to the main roads of the residential areas directly to allow green space on the ground (Li and Pei, 2009).

Underground roads were also considered an efficient solution in urban renewal projects. In the heart of Athens, Greece, that suffered from severe traffic congestion, underground roads enhanced mobility and reduced travel time. In addition, by developing underground roads, environmental impacts (e.g. noise and air pollution) can be decreased and valuable urban surface space can be reclaimed, offering an opportunity for green space and pedestrian walkway development to achieve urban regeneration (Benardos et al., 2013). The well-known Central Artery/Tunnel project moved an elevated six-lane highway at the centre of Boston to below ground to provide better traffic conditions with less environmental impact, a better city image, improved pedestrian access, green space and views, and more leisure opportunities (Tajima, 2003). In Qingdao's Shinan District in China, the planning of the underground road network aimed to upgrade road infrastructure to improve traffic conditions and address increasing road traffic demand and pedestrian-vehicle conflicts (Ma and Peng, 2018).

Underground pedestrian networks have played an important role in major urban renewal projects as well. Recently, nearly 1.3-kilometre-long underground corridors were created in Montreal's city centre to provide connections to two isolated parts of the underground pedestrian system in the area where three metro stations are located, and to provide enhanced accessibility to walk to the city centre of Montreal (Demers, 2016). In central Tokyo, with dramatic increases in traffic predicted, the development of safe and comfortable underground pedestrian systems, particularly around metro stations to channel commuters, was believed to be a component of urban renewal for making Tokyo an international financial city (Yokotsuka et al., 2013). The development of large-scale underground pedestrian networks in Dallas, US and Hong Kong, China was effective in stimulating economic revitalisation in the city centre by offering opportunities for various activities e.g. shopping, dining, transport and entertainment in weather-protected and temperature-controlled walking environments that are safe, comfortable and convenient (He et al., 2016; Terranova, 2009; Zacharias and He, 2018).

4.2. Underground commercial and public use

Underground spaces are commonly used for commercial and public purposes as well. An underground shopping centre that comprised restaurants, recreation facilities, car parks, stores and shops was developed along with the renewal of the Qingdao Railway Station in China (Li and Pei, 2009). The COEX Mall in Seoul, Korea, the largest underground shopping centre in Asia, connects various functions and spaces, including shopping, transport, offices, hotels, and cultural spaces (Lee et al., 2013). Beijing's old city has developed many recreational spaces below ground to take advantage of underground spaces, because leisure and entertainment spaces can be noisy, and they have low requirements for natural light. Similarly, fitness rooms were constructed below ground for efficient use of space. There is also a lack of outdoor squares for sports use in the old city of Beijing. Therefore, in urban commercial centres (e.g. Xidan and Dongdan), spacious underground passages are used by many citizens spontaneously as their sports and fitness spaces. Public cultural and educational purposes are also accommodated in underground spaces; Financial Street Community Cultural Centre and the National Theatre of Performing Art are good examples (Shang, 2016). In some cities, there are scattered underground commercial spaces that have not been efficiently used. Further development of existing underground commercial spaces to intensify the use of land, improve spatial quality, accommodate more urban functions, and release traffic pressure was also applied in practice as an important approach for the renewal of old cities (Bi and Liu, 2013).

4.3. Underground complexes

Comprehensive developments consisting of multiple forms of UUS in multiple stories may provide a comprehensive solution in urban renewal projects. In Montreal's city centre, from the early milestone project, Place Ville-Marie, dating from 1962 to the Eaton Centre built in the 1980s, the gradually formed underground pedestrian network linked metro stations, office spaces, underground shopping centres, underground parking facilities, restaurants, cinemas, and shops. The underground complex addressed increased demand due to population growth by offering additional functions and qualities and reduced extension of the urban fabric horizontally beyond the city's border. With the goal of retaining the city's vitality and identity, urban renewal via underground development extended the city centre's functional capacity. By increasing the possibilities of cultural, shopping and entertainment activities while improving accessibility and public transit, the city centre was regenerated (Durmisevic, 1999). Recent UUS utilisation in China's cities often features comprehensive, large-scale, multi-functional development. In China where high-speed rail networks have been formed, transport hubs around high-speed rail stations were developed in major cities like Beijing, Shanghai, Guangzhou, Shenzhen, Lanzhou, Ningbo and Chongqing. For example, in Lanzhou West rail station transport hub, the underground development consisted of two stories: commercial spaces and public parking spaces in the first underground floor; and public parking spaces, a taxicab depot, commercial areas, and a metro station in the second underground floor. Underground spaces, as a key element of transport hubs in urban renewal, played a significant role in promoting the regional economy (Jia and Fang, 2016). In Beijing's Zhongguancun West Zone, the 500,000 square metres (m^2) underground buildings and structures in three stories provide nearly 10,000 parking spaces, three large-scale shopping centres and a multi-purpose infrastructure tunnel that includes a transport corridor, water and gas pipes, and electricity and communication cables (Tong, 2007). The comprehensive development in Hongqiao CBD, Shanghai, consisted of three metro lines, numerous underground parking spaces and an underground pedestrian network that connects offices, shopping malls, and hotels to parking spaces and metro stations. The development meets transport and parking demands and also provides shopping, dining, and entertainment services (Qiao et al., 2019).

4.4. Other forms of underground space use

Other forms of UUS have been utilised in urban renewal projects, e.g. UUT, underground storage spaces, underground residential spaces, underground buildings and other underground spaces. Studies have been conducted on how UUTs contributed to urban renewal and regeneration of old and historic city centres. In the city of Pamplona, Spain, UUTs for sustainable renewal of the old city centre were regarded as an optimal solution to address the social and functional needs of a changing society, while at the same time protecting the old city's historical and cultural heritage (Valdenebro and Gimena, 2018; Valdenebro et al., 2019). Masuda et al. (2004) proposed the use of deep underground spaces in Tokyo for infrastructure for gas, water and electricity for urban renewal. Li and Pei (2009) surveyed over 50 newly built residential areas through urban regeneration in Qingdao, China and found a few projects that used the semi-underground space for storage purposes. Nishida and Uchiyama (1993) examined areas with completed urban renewal projects in Tokyo and found that in most cases, the basements of buildings were used as mechanical and storage rooms in addition to parking spaces.

Some uncommon forms of underground space use for urban renewal include underground residential space, underground buildings and underground spaces. In some large cities such as Beijing, a large number of migrant workers with comparatively low incomes working in retail, catering, and other traditional service-based industries choose to live close to their working places in urban commercial centres. Due to their heavy workloads, extensive working hours and comparatively low incomes, living in basements, a type of economical housing in residential areas near commercial centres, became a general choice. Despite some poor-quality underground residential spaces, such as dark rooms in the centre of basements with poor ventilation and natural lighting that hardly meet living environment requirements, excellent practice has been demonstrated in how to transform group rental basements into quality residential/office space. Since this type of economical rental housing is needed to meet the housing demands of a large number of migrant workers, the development/improvement of basement housing would contribute to better living environments for people, as well as enhancing urban renewal (Shang, 2016).

Underground spaces in open squares and old buildings can improve spatial quality. Through adding new or complementary functions and helping improve spatial quality, development of underground spaces has allowed urban space and old buildings that were useless to become suitable for new use, such as via increasing the floor area, changing the scale or form of a building, expanding the useable area of heritage buildings, and enhancing cultural surroundings (Shang, 2016). In the suburbs, underground space utilisation can also contribute to urban renewal, and this has been demonstrated by an underground building and parking development in Basilicata, Italy (Sassano et al., 2017).

5. Challenges and existing approaches of underground space utilisation for urban renewal

The existing literature provides important information with regard to challenges and approaches to utilising underground space for urban renewal. The harmonious development of three-dimensional spaces (including spaces above ground, on the ground and below ground) is the key to successful urban renewal. However, in practice, there have been many cases where planning for underground spaces has not been included in city plans, resulting in disorderly development of underground space. Messy distribution patterns prevent efficient use of spaces and impede further large-scale development in the future (Bi and Liu, 2013). The concept of integrating/coordinating development of spaces at different levels (above ground, in the ground and below ground) has been highlighted by many studies (e.g. Bi and Liu, 2013; Nishida and Uchiyama, 1993; Sung, 2014; Tong, 2007). Early studies (e.g. Nishida and Uchiyama, 1993) recognised the importance of the integration of the surface and subsurface to provide opportunities to create communities with great amenities and safe environment. Underground space development in urban renewal should not be viewed as individual project that is isolated from urban development on the surface. Instead, harmonious development of three-dimensional spaces is the key. Sung (2014) pointed out that urban regeneration, in many cases, was characterised by mixed-use development. In order to efficiently use land and urban space, mixed-use development in both horizontal and vertical directions, and at multiple levels, thus mixing and overlapping different uses, allows for successful urban regeneration. High-rise, large-scale complex development in urban regeneration has been seen in recent years, such as in mega-cities in Asia (e.g., Seoul, Tokyo, Shanghai, Hong Kong, and Singapore). In these cases, spaces above ground, in the ground and underground have formed three-dimensional spaces which connect the city to facilities.

Integrated planning of aboveground and underground developments is important. The well-known Underground City in Montreal were developed over decades. Although different complexes and metro stations have their own individual identities and atmospheres (resulting in strong senses of space and place), underground spaces were well planned and often designed simultaneously with the aboveground buildings (Durmisevic, 1999). The Zhongguancun West Zone project in Beijing shows the three-dimensional redevelopment approach, which starts from the planning stage and carries through the whole process of construction. Aboveground redevelopment and underground development were constructed simultaneously (Tong, 2007).

UUS should be developed as an integral part of the urban fabric to form an underground city with safe and pleasant environments in harmony with the development of the urban area on the ground. To achieve integrated development of spaces at different levels, cooperation among planners, potential users and administrators is important (Nishida and Uchiyama, 1993). The connection between different levels needs to be cleverly designed. Accessibility to an underground space via an aboveground building, and provision of natural light and a "viewable" outside world were part of the design success of Montreal's underground complex (Durmisevic, 1999). Spacious sunken plazas, streets and parks were effective in introducing people to underground naturally. Developing metro stations linking to underground commercial spaces has proven to be a high-quality practice (Bi and Liu, 2013).

In cities where underground spaces were developed over a long period of time, underground spaces were developed for different purposes at different stages. In Chinese cities for instance, underground space development over decades has been done in a disorderly manner, without detailed planning rules. The construction resulted in the fragmentation of underground commercial spaces. In addition, without connection to metro systems, underground commercial spaces relied on the transport systems above ground. Due to historical reasons for developing underground spaces, underground commercial spaces had poor lighting and ventilation conditions, and poor humanisation design (e.g. lack of resting spaces) and different depths of adjunct underground spaces, resulting in low-quality shopping environments. These presented major obstacles to efficient use of land in the city core and to future urban development (Bi and Liu, 2013). According to Shang (2016), more than 12,000 m^2 of underground spaces were developed first for Civil Air Defence purposes in the old Beijing city in the1960s and 1970s, and then reused for public functions in the 1980s and 1990s. In the 21st century, more large-scale underground space development in various forms has been seen in Beijing. This resulted in the quantity and quality of underground spaces being unevenly distributed geographically. Great effort needs to be made to integrate scattered underground spaces and improve poor underground spaces. In Qingdao, China, even for UUS in the same area, organic organisation and interconnection between adjacent underground areas have been rarely seen. For decades, UUS development was independent of residential and commercial real estate projects. More recently, after metro projects began, the benefits of joint development among adjacent UUS have been gradually recognised, and this type of development has been encouraged as a more advanced UUS development approach (Zhao et al., 2016).

The forms of UUS utilisation (e.g. single-function or multi-function UUS) present challenges. In Tokyo, an early study in the 1990s found that for completed urban renewal projects involving buildings and basements, most basements were used as parking spaces, mechanical rooms, or storage rooms. Almost no underground networks were formed as part of urban renewal projects. Encouraging the creation of underground networks (e.g. connections between buildings and subway stations) using multiple-level basements is a great challenge, and this is important for attracting potential users of the spaces and promoting future use of the spaces (Nishida and Uchiyama, 1993). Although this study conducted in Japan more than two decades ago, there may be cities in the early stage of UUS development that have such characteristics. In Luoyang, 52.67% of UUS use is for car parking, providing about 13,000 underground parking spaces (the single function of UUS in many other cities such as Qingdao, according to Zhao et al., (2016)). UUS was developed using the basements of residential and business buildings. During working hours, UUS (car parking spaces) underneath residential buildings has a high vacancy rate, while during non-working hours, UUS (car parking spaces) under business buildings has a high vacancy rate (Qiao and Peng, 2016). The solo form of UUS use, in this case, could challenge the efficiency of the use of precious underground space resources, and this is an important aspect for planners, practitioners and decision-makers to consider.

Complex underground development is likely to be more efficient in addressing complex problems (e.g. transport congestion, environment degradation and heritage protection) associated with urban development. Urban developments require a change in function of underground spaces in the CBD, from a single function to complex functions to support urban development better (Bi and Liu, 2013). Large underground systems allow underground spaces to be an essential component in urban renewal. An example is Montreal's Underground City, whose advantages include scale (with over 32 km in length and 12 square kilometres of tunnels), connectivity (connecting directly to 60 buildings), accessibility (24 hour access to public transport facilities including seven metro stations, two railway stations and one long-distance bus terminal), seamless integration between surface and subsurface (by more than 200 metro entrances), functionality (serving numerous shopping malls, hotels, offices and museums), pleasant walking environments (air-conditioned and weather-controlled), and quality public space (safety monitoring management and art design) (Shi et al., 2017). Montreal's case may not necessarily be the ideal model of UUS development for many other cities. However, comprehensive development of UUS has shown the advantages of this model, and it appears to be the trend in recent projects.

The dilemma of historic resource conservation and urban redevelopment using UUS is a primary concern for the planning and development of UUS particularly for historical cities. In Pamplona, Spain, UUT systems emerged as the optimal solution for addressing historic conservation and urban renewal. The utilisation of UUS in the form of UUT systems allowed high-quality urban basic services and infrastructure to be provided in the old city for the renewal of historical city centres. The maintenance, expansion and renewal of utility networks can be conducted conveniently with less disruption to people's access to streets and less visual pollution of the street's image (Valdenebro and Gimena, 2018; Valdenebro et al., 2019). Luoyang, China, a representative historical city and the capital city of 13 ancient dynasties in the history, is characterised by numerous historical and cultural resources. Luoyang's planning experience provides valuable information for addressing the difficulty of balancing conservation and development. A series of measures were taken, including quality evaluation of underground space resources, spatial control of underground space development, and regulatory measures that clarified prohibited areas for underground space use and areas for limited underground space use (e.g. shallow underground spaces within 10 m below the surface were not permitted in the development control areas; and shallow and middle underground spaces within 30 m below the surface were not permitted in areas with potential buried relics) (Qiao and Peng, 2016).

A balanced development of spaces below ground and above ground can be difficult to achieve. In some cases, the success of UUS for urban renewal can also present challenges. For example, Dallas's underground pedestrian network was successful in attracting people to conduct various activities, including shopping, dining and entertainment activities, thus helping to revitalise the urban economy. However, the underground pedestrian network functioned too well in that pedestrians and their activities were removed from streets that had already been challenged by a declining economy. In addition, it was discovered that activities and urban life occurred in the underground pedestrian network only during a limited time period (i.e. in the middle of the day) while the space was almost vacant after lunch time (Terranova, 2009). Whether or not the development of an underground pedestrian network achieves economic renewal and maintains the vitality of life on multiple levels of urban spaces (e.g. on the ground, below ground and above ground) may be related to the population density of city centres. Dallas' population density in the city centre is not high enough to support activity both on the ground and underground levels (Terranova, 2009). In contrast, in Hong Kong, China, limited developable land and extremely high pedestrian density resulted in that the development of a multiple-level pedestrian network (on the ground, below ground and above ground) strongly supported urban life and economy in the city centre (Wan, 2007). In some cases, through careful design, UUS may contribute to directing people from the underground system (metro systems) to the surrounding area on the surface to revitalise commerce on the surface. Hong Kong's experience indicates that for maintaining street vitality, the development of underground pedestrian networks to provide access to shopping malls associated with metro stations is more effective than direct connections to streets (Zacharias and He, 2018).

The divergent interests of different parties involved in the planning and construction of UUS present challenges. In the East-line Metro development in Amsterdam, where large-scale urban regeneration of the Nieuwmarkt neighbourhood was an initial aim of the city council in opting for an underground metro line, the subsequent social unrest initiated by this project has weakened the success the underground development achieved for urban regeneration (van den Ende and van Marrewijk, 2019). During the urban renewal of Montreal's downtown, one challenge was the divergent interests of public sectors involved in the project regarding the major urban planning intervention using underground spaces. The Ministere des Transports was not interested in creating the corridor to bridge Old Montreal to the existing CBD that was isolated by an underground expressway, and the Ministere du Revenu and the riverside community were interested in increased tax revenues (Demers, 2016). The case of the underground library at Yale University showed the importance of public participation in the success of underground space utilisation to decrease public anxiety generated by new development/urban renewal projects (Little, 2018). Continuing support from different parties is extremely important for large-scale, heavily-funded UUS projects that may present significant economic, environmental and social impacts during and after the construction. For example, for the enormous and costly Central Artery/Tunnel project, planners spent considerable effort and funds and worked with businesses, citizens, and interest groups to minimise disruption during construction and find workable mitigation solutions for the project (Bushouse, 2002).

The challenge of improving the design quality in the whole area (above ground, on the ground and below ground) confronted Montreal's urban renewal via developing underground spaces. The large-scale project consisted of restructuring the public domain of eight hectares to create a user-friendly environment, enhancing public transport and walking (e.g. connecting underground pedestrian networks and enhancing access to the metro) while reducing car traffic and car parking (Demers, 2016). In many cities, underground space development in old cities was confronted with similar design and management problems. Existing underground spaces, especially in underground public spaces associated with development at the ground level, appeared to be fragmented, and the overall design was not unified and humanised. Humanisation design to allow more enjoyable environments for people to use underground spaces is also a key for urban revitalisation, e.g. introducing natural light, and adding recreational and relaxing spaces (Bi and Liu, 2013).

High initial investment is the main common challenge for all forms of underground space utilisation. Only in exceptional cases have UUTs been adopted by municipal authorities for renewal and regeneration of historical centres of cities (Valdenebro et al., 2019). The actual cost of UUS utilisation is difficult to predict accurately, particularly for large projects, and the transition between planning and construction phases is difficult to manage. In the Central Artery/Tunnel project, the 6 billion USD estimate in 1990 was escalated to 15 billion USD in 2003, thus damaging the reputation of UUS development and creating national (and international) concern about large UUS projects (Salvucci, 2003). Despite high construction costs, studies have indicated the significance of partnerships between private developers and government in developing Montreal's underground complex (Durmisevic, 1999) and constructing underground railway lines in urban regeneration in London's Docklands (Church, 1990). The public–private partnerships can be an effective funding model for UUS development, particularly underground infrastructure development to renew urban areas. Furthermore, due to the difficulties and complexities in developing below ground, technical problems were highlighted in many studies (thus potentially increasing costs). These problems, such as developing an underground expressway in the city centre, requiring dealing with tunnel stability, air circulation, interaction between facilities below ground and above ground, and environmental problems, need to be considered and solved when constructing underground systems (Han et al., 2012). In addition to technical difficulties in the system design and construction stages, administrative and legal difficulties may be obstacles to utilising underground spaces. When utilising UUT systems for urban renewal (e.g. in the old towns of cities), the service providers may not be interested in investing in the systems because they are already serving their subscribers. Moreover, to what extent the companies that provide the services are aware of their legal rights could present legal difficulties (Valdenebro and Gimena, 2018).

6. Conclusion

In cities across the globe, there is often a piece of land (large or small) that is dense and requires underground space development. With population growth and urban development, for efficient use of land resources, utilisation of underground space is becoming an optimal approach for urban renewal.

Urban underground spaces have undergone rapid development in recent years and contributed to urban renewal. Underground space utilisation has played an effective role in urban renewal, such as coping with urban development and associated problems, achieving more efficient use of land, space, and energy resources, contributing to old city conservation, overcoming obstacles and improving accessibility in the city, and bringing opportunities to renew multi-level spaces. Various forms of underground space utilisation for renewing urban land were documented. Increased use of underground infrastructure helps to stimulate the regeneration of decayed central areas of cities (Roberts, 1996).

As a unique layer of additional spaces below ground that is underutilised but full of potential, empirical evidence has discussed challenges and suggested approaches to achieve successful utilisation of underground space in urban renewal. Harmonious development of three-dimensional spaces (including spaces above ground, on the ground and below ground) is the key to successful urban renewal. Integrated planning of aboveground and underground developments is important. Underground and surface spaces should not only co-exist in urban renewal; instead, they should be integrated and work together (Hooimeijer and Maring, 2018). UUS should be developed as an integral part of the urban fabric to form an underground city with safe and pleasant environments in harmony with the development of the urban areas on the ground. In addition, in cities where underground spaces have been developed over a long period of time, underground spaces were developed for different purposes at different stages. Greater effort needs to be made to integrate scattered underground spaces and improve poor underground spaces. Moreover, the form of UUS utilisation (e.g. single-function or multi-function UUS) may present some challenges, and this is an important aspect for planners, practitioners and decision-makers to consider. Complex underground development is likely to be more efficient in addressing complex problems (e.g. transport congestion, environment degradation and heritage protection) associated with urban development. Furthermore, the dilemma of historic resource conservation and urban redevelopment using UUS is a primary concern for the planning and development of UUS particularly for historical cities. Existing planning experience provides valuable information for addressing this difficulty. Further, balanced development of underground and aboveground spaces can be difficult to achieve. Multiple options (including underground options) need to be considered before choosing a preferred solution and making a detailed design based on very rough comparisons and the city's individual situation. In addition, the divergent interests of different parties involved in the planning and construction of UUS may present challenges. Encouraging public participation and working with businesses, citizens, and interest groups are important for successful utilisation of underground space for urban renewal. Again, the challenge of improving design quality in the whole area (above ground, on the ground and below ground) has confronted underground space utilisation in cities. Humanisation design to allow more enjoyable environments for people to use underground spaces is also a key to urban revitalisation. Last but not least, high initial investment, technical problems and administrative and legal difficulties may be obstacles to utilising underground spaces, further hampering the use of underground space, as it is perceived to be risky, costly and undesirable. The public–private partnership could be an effective funding model for UUS development, particularly underground infrastructure development to renew urban areas. The advancement of technology has been proven to be an efficient tool to help overcome the challenges of underground space. For example, in recent years, 3D modelling of geological and anthropogenic deposits was used to contribute to decision-making for sustainable urban regeneration in cities, and preservation of cultural heritage (de Beer et al., 2012).

This study focuses on exploring how underground space utilisation contributes to urban renewal. Other contributions of underground space development are not the focus of this study and have been little discussed in this study. Future research needs to investigate further with regard to the full contribution of UUS utilisation, to provide empirical evidence to develop a better understanding of UUS utilisation. The methods of this review paper fit the objectives of this study to understand the nature and significance of the topic. It is also important to examine various features of urban renewal in different periods of urban development and therefore different needs for UUS use. Moreover, this review summarised the challenges of UUS use in urban renewal and discussed existing solutions, e.g. decision-making, planning, architectural design, public–private partnerships, and conservation of historic resources based on empirical evidence. Future research is needed to further investigate the challenges of UUS development and propose innovative solutions to inform and guide planning practitioners and decision-makers on utilising UUS in urban renewal. In the context of urban development, UUS use for urban renewal should be part of the continuing research and policy agendas.

CRediT authorship contribution statement

Jianqiang Cui: Conceptualization, Methodology, Formal analysis, Writing - original draft, Writing - review & editing. **Wout Broere:**

Conceptualization, Methodology, Writing - original draft, Writing - review & editing. **Dong Lin:** Conceptualization, Methodology, Formal analysis, Writing - original draft, Writing - review & editing.

Declaration of Competing Interest

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

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