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Underground space utilisation and new town development: Experiences, lessons and implications

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ABSTRACT

In the urbanisation process of the past few decades, the use of urban underground space (UUS) has contributed to new town developments in many cities in the world. This offers an opportunity to map out and systematically describe the potential contributions of UUS for transport, land use, economic, environmental and social development in new towns for planners, designers and policy-makers to consider. This review synthesises key papers on UUS utilisation and new town development. It indicates that the requirements of intensive use of land resources, accessibility reasons, avoidance of urban problems experienced in old cities, cultural and modernity considerations, and the goal of building smart, low-carbon and sustainable cities drive UUS utilisation in new developments. Underground spaces have been developed in new towns in various forms, with subway, underground parking facilities and underground utility infrastructure being the more prevalent forms of UUS utilisation, and UUS utilisation in new towns varying in scale. UUS utilisation for new developments may confront many challenges related to various issues: relationships between new towns and old city centres; compact and high-density urban forms; transit accessibility; awareness of the significance of UUS; balance between market forces and government intervention; coordination of development; full utilisation of UUS resources; and decision-making support. Existing practices used in UUS development provide lessons from which to learn.

1. Introduction

Rapid urbanisation is resulting in increased numbers of people living in slums, insufficient and overburdened infrastructure and services, increasing air pollution and urban sprawl (United Nations, 2019). Well-managed urbanisation can allow the benefits of agglomeration to be maximised, and environmental degradation and other potentially adverse outcomes of increased numbers of people living in urban areas to be minimised (United Nations, Department of Economic and Social Affairs, Population Division, 2019). It is impossible for cities to meet the fast-growing demand for urban space without managing densification. Sustainable densities that ensure vertical urban growth rather than horizontal urban expansion can be achieved through densification of dwellings and other buildings (UN-Habitat, 2020).

Underground space has been widely recognised as a valuable resource and is a new dimension of cities. The use of underground space can help cities meet increased demand for space while at the same time remaining compact. In many cases, underground solutions to urban problems are the last to be considered, after above-ground options. Considering and evaluating underground solutions from the planning and initial project stages would allow optimal solutions to be found (Broere, 2016). Many studies have focused on underground space utilisation for addressing urban problems in old cities (Bushouse, 2002; Church, 1990; Demers, 2016; Han et al., 2012; Shang, 2016; Terranova, 2009; Valdenebro and Gimena, 2018; Yokotsuka et al., 2013). The significance of urban issues related to underground space justified the inclusion of UUS in urban indicator systems (Bobylev, 2016a). In central areas, old road systems, poor traffic conditions, environmental deterioration, facility degradation and poor quality of life require comprehensive solutions. UUS utilisation is the optimal option for achieving urban renewal (Cui et al., 2021) and sustainable development (Jefferson et al., 2006) in many old cities. Comparatively, UUS utilisation for new town development has received less attention. In the last decades, particularly in recent years in cities with high population density and rapid urbanisation, UUS utilisation has been seen as an essential component in the development of new areas. An increasing number of

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studies of new town development and underground space use provide an opportunity to consolidate the existing knowledge on this topic and enhance understanding of the relationship between UUS utilisation and new town development.

With rapid urbanisation in cities around the world, new town developments that are close to existing urban fringes have been developed to accommodate increasing populations (Wu et al., 2019). New town development is not a new concept. The concept began in the late 1800s in the United Kingdom (UK) when cities became more populated, congested and unsanitised, and quality of life in cities had declined. The development of public transport networks paved the way for an explosion of towns and cities. In 1898, Ebenezer Howard in his book, *Tomorrow: A Peaceful Path to Real Reform*, published his ideas for reforms to produce better urban quality of life. Howard's "garden cities" that were surrounded by "country belts" soon brought the new towns movement to the world (Aldridge, 1979; Seik, 2001). The British practices were intended to develop self-contained and socially balanced new towns (Hills and Yeh, 1983). In the practices of Howard's followers, the notion of garden cities was extended to building safe and peaceful satellite cities surrounded by greenbelts, as demonstrated by plans for Radburn in New Jersey, United States (US), and suburbs in Letchworth and Welwyn in the UK in the early 20th century (Cervero, 1995). In many urban areas (e.g. Amsterdam, Paris and London), new town development aimed to achieve jobs-housing balance, allowing new towns to be highly self-contained. However, since these new towns had close connections to the old cities, they have never been highly self-contained (Jun and Hur, 2001; van Rooijen, 1990). In addition, in such early European and US new towns, transit was not a prominent feature (Cervero, 1995). In some other countries, new town developments were varied. For example, in Stockholm, Sweden, after World War II, new towns could be viewed as self-contained satellite communities served by subway systems (Cervero, 1995). The limited attention to transit integration, the focus on car mobility, and the perceived ample availability of space that allows low density developments also mean that integration of UUS is hardly considered in the planning of new towns during this period (de Roo and Miller, 2000).

In Asia, many recent new towns in Korea (e.g. Bundang, Ilsan, Pyeongchon, Sanbon and Jungdong in Seoul) (Jun, 2012; Lee et al., 2005), Japan (Tama New Town and Chiba New Town in Tokyo) (Miyoshi et al., 1979) and China were connected to old towns through subway systems. In Hong Kong, large populations live in nine new towns in the New Territories, which were developed in the 1980s and 1990s. These new towns were likely to have close proximity to subway stations (Forrest et al., 2002). In the New Town of Tsuen Kwan O in Hong Kong, Tseung Kwan O Station in the subway, located in the town centre and integrated with property development, formed the heart of the Town Centre functions (Hill and Lam, 2002). Since the early 21st century, with the new town movement in China, many new towns and new areas with significant underground space development have appeared (Yuan et al., 2019). In many newly urbanising districts in China's cities, UUS is viewed as a symbol of modernity. As a result, UUS utilisation was rooted in the planning of the new towns, and UUS planning was conducted and implemented simultaneously with traditional urban planning in new towns such as Beijing's Central Business District (CBD) and Yizhuang New Town and Tongzhou New Town in Beijing; Guangzhou's Zhujiang New Town; Shanghai's Jiading and Baoshan New Towns; Hangzhou's Qianjiang New Town; Zhengzhou's Zhengdong New Area; Wuhan's Wangjiadun CBD; and Tianjin's Binhai New Area (He et al., 2012). In particular, in the last decade, UUS in new towns that takes advantage of subway development tends to be developed into a systematic network with large-scale and rapid development (Yuan et al., 2019). For example, in Yujiapu district in Binhai New Area in Tianjin, about 4 million m^2 of connected underground commercial space were built, linking 30 buildings in the new Financial District (Lan, 2016). In recent construction planning for UUS in Hangzhou (2016–2020) by the city government, UUS in new urban areas was described as "wholly (UUS) zoning development", and 25 million m^2 of additional UUS were planned for development by 2020 (Chen et al., 2018).

Underground spaces are utilised for various considerations, such as urban renewal (Cui et al., 2021) and building liveable cities (Hunt et al., 2016), resilient cities (Admiraal and Cornaro, 2020) and sustainable cities (Bobylev, 2009). UUS contributes to building sustainable cities, since underground space meets four types of needs: extra space and denser cities; hiding what may be offensive to human senses, such as by being ugly or noisy, or by having bad smells; protection from view, intrusion and explosion; and containment (Duffaut, 2006). A number of questions arise with regard to UUS utilisation for new town development. Due to the unique built environment (e.g. transport, land use and density) in new towns, the reasons for UUS utilisation in new towns may differ from those in existing urban areas. What is the rationale behind underground space utilisation in new town development? Moreover, there are various forms of underground development that contribute to urban development, such as underground transport infrastructure and facilities (Cui and Nelson, 2019), underground utility infrastructure and facilities (Luo et al., 2020), and underground commercial use (Kishii, 2016). Another question arises with regard to the form of UUS utilisation for new town development. Are there varied forms or a dominant form of UUS utilisation? Using subway construction as an example, it has been indicated that, compared with existing urban areas, in new towns, fewer buildings are usually required to be demolished for subway development; it is a less complicated engineering situation; and it is less costly when UUS utilisation is combined with subway development (Chen and Shi, 2007). High demand and few constraints, which are the characteristics of space in core areas of new urban districts, can support UUS utilisation on a large scale (Chen et al., 2018). One more question arises with regard to the scale of UUS utilisation for new town development. Is UUS utilisation in new towns characterised as small-scale or large-scale? Last but not least, the challenges and experiences of UUS utilisation have been a focus of UUS research. In renewing existing urban areas, issues such as harmonious development of three-dimensional spaces, historical resource conservation and urban redevelopment using UUS, the divergent interests of different parties involved in the planning and construction of UUS, in addition to high cost, technical problems, and administrative and legal difficulties, challenge UUS utilisation (Cui et al., 2021). The last question arises in the context of UUS utilisation for new town development. What are the challenges, experiences and lessons of UUS utilisation for new town development?

Considering different urban contexts for UUS utilisation associated with new town development, emerging new towns in the recent wave of urbanisation, and introduction of the concept of sustainable development, a review of studies on underground space utilisation and new town development would make a timely and valuable contribution to advance understanding of this topic. The purpose of this review is to explore the relationship between UUS utilisation and new town development; in particular, how UUS utilisation contributes to transport, land use, economic, environmental and social development in new towns. The review provides researchers and practitioners with up-to-date understanding of the rationale, forms and scale of UUS utilisation, and the key messages for the challenges and success of its contribution to new town development throughout the world. The research aims to answer the following questions: (1) What is the rationale behind underground space utilisation for new town development? (2) What are the forms of underground space utilisation for new town development? Does underground space utilisation for new town development tend to be large-scale or small-scale? (3) What are the challenges, experiences and lessons regarding underground space utilisation for new town development?

2. Methodology

This paper reviews articles derived from searches of major databases, including Scopus, Web of Science Core Collection, and Google Scholar. Search terms were identified from existing literature, as well as through the expertise of the research team. The topic is underground space utilisation and new town development. "New town" in this paper is a broad term that can refer to a new city area, suburb or district, a new town, or a satellite city. The focus of this paper is to explore UUS utilisation and contribution in newly developed areas, and it explores the relationship between UUS and new town development at a macro-scale level. Search terms included two groups of key words: "underground space" and terms that have similar concepts (including "UUS", "sub-surface" and "subterranean space"); and "new town" and terms that have similar concepts (including "new business district", "new CBD", "new city", "new urban centre", "new urban area", "newly developed area", "satellite city", "new suburb" and "new district"). Only English articles were selected. Studies were considered if they provide evidence about the research topic. Studies were excluded if they do not discuss one or more forms of UUS or do not discuss UUS for new town development.

A summary of the reviewed literature on UUS utilisation for new town development is shown in Table 1. A framework for the review of UUS for new town development is shown in Fig. 1. The literature can be divided into three categories: (1) discussing UUS utilisation in both new towns and other urban areas (Duffaut, 2006; Jung et al., 2015; Kim and Byun, 2021; Li et al., 2013; Li et al., 2016; Ling, 2012; Luo et al., 2020; Miyoshi et al., 1979; Qian, 2016; Qiao and Peng, 2016; Wallace and Ng, 2016; Xu et al., 2015; Yang and Peng, 2016; Zhang, 2018; Zhang et al., 2019b; Zhao et al., 2014); (2) discussing both ground and underground spaces in new towns (Anderson, 2015; Antonson et al., 2017; Cervero, 1995; Cho and Kim, 2017; Clout, 1988; Firman, 2004; Gohaud and Baek, 2017; Hao et al., 2019; Jun, 2012; Jun et al., 2013; Kim and Song, 2015; Lee and Yoon, 2019; Lee et al., 2005; Marti and Masnou, 2014; Merlin, 1980; Ong, 2014; Park, 2011; Qian, 2011; Rumbach, 2014; Seelig, 2011; Seik, 2001; Sun and Hu, 2011; Wang and Heath, 2010; Wu et al., 2019; Xue and Zhou, 2007; Yang et al., 2017; Yu et al., 2014; Yuan et al., 2020); and (3) discussing UUS utilisation specifically for new town developments (Chen and Shi, 2007; Gao et al., 2019; Guo et al., 2013; Hua et al., 2011; Li et al., 2017; Peng et al., 2020; Qiao et al., 2019; Xing, 2020; Yang et al., 2019; Zacharias, 2014; Zhang et al., 2019a).

3. The rationale behind underground space utilisation for new town development

Many new towns feature high population densities, limited availability of land, high land prices, and compact development, which requires intensive use of land resources. As it is a small-sized country, Singapore's new towns are characterised by high-rise, high-density public housing developments. In Tampines New Town, underground infrastructure, including underground electricity and water supply, and sewerage and telecommunication networks, support a compact and interrelated urban system (Seik, 2001). In Hong Kong, a city with extremely high population density, many high-rise buildings for living spaces, and high land and residential and commercial property prices, exploring underground space utilisation (e.g. the subway system and water supply tunnels) to support new towns and other development areas has been a viable option for enhancing utilisation of land resources in recent decades (Wallace and Ng, 2016). In Iran's Hashtgerd New Town, a new town with compact urban form, low-rise and high-density design, and car-free neighbourhoods, underground parking spaces were developed in the basements of the neighbourhood units, creating direct accessibility to the neighbourhoods (Seelig, 2011). To accommodate heavy real estate pressure (e.g. high land prices), officetels with mixed office and residential use, and underground parking were developed in Bundang New Town in Seoul, Korea (Gohaud and Baek, 2017). In Hengqin Island in Zhuhai, China, a large and comprehensive system of underground utility tunnels saved 400,000 m^2 of new land compared with the traditional method of utility placement (Yang and Peng, 2016). Also, underground development (e.g. subway stations and underground parking spaces) in Seoul's new Songdo (Korea) and Shenzhen's Futian CBD (China), resulted in the release of space on the ground for urban green and open spaces for recreation (Anderson, 2015; Yuan et al., 2020). In China, CBDs that possess the most valuable land with the highest land prices in a city are mainly occupied by business offices. Underground commercial spaces with relatively lower land and leasing prices provide an opportunity to accommodate the fast food and supermarket stores that meet the eating and shopping needs of CBD workers. In addition, in CBDs with dense urban form and high land prices, the underground transport and municipal infrastructures (including underground pedestrian walkways, underground parking spaces and common utility tunnels) facilitate efficient movement and service provision (Peng et al., 2020).

Accessibility plays an important role in new towns' UUS development, although transit accessibility was not a key characteristic of early new towns in the UK and US, where workplaces for residents were usually located in nearby cities, and residents commuted by cars (Cervero, 1995). After World War II, Sweden's Stockholm began building satellite communities served by subway, according to the 1952 plan for Greater Stockholm and the new subway-Tunnelban-plan (1954). In the second half of the 20th century, Stockholm transformed from a monocentric city to a polycentric city. To maintain central Stockholm's vitality, an extensive subway network that links satellite new towns with central Stockholm was developed. With a large proportion of external commuting trips and high concentrations of housing and jobs around subway stations, new towns in Stockholm were developed in a way that is perfect for subway commuting. The new town planning facilitated efficient movement of all residents living in these towns, with less than 30 min of door-to-door travel to access jobs in central Stockholm by subway (Cervero, 1995; Merlin, 1980).

Transit accessibility was not a prominent feature of the early generation of new towns but of the later generation of new towns in cities like Seoul. For example, the first generation of new towns in Seoul was planned based on car-oriented development, and new towns were linked with Seoul through road networks rather than public transit. The second generation of new towns was planned with connection to Seoul and nearby areas through integrated wide transport networks, including subway and cycling- and walking-centred street network systems connected to public transit, a convenient transfer system and a traffic calming scheme (Park, 2011). The planning of subway systems has enhanced public transit accessibility of new towns significantly. In Yeongdeungpo-Gu's and Gangnam-Gu's CBDs in the southern parts of Seoul, the first circular line, Line 2, established in the late 1970s, resulted in considerable accessibility enhancement in the southern parts of Seoul (Kim and Song, 2015). In Seoul's Eunpyeong New Town, multiple subway lines (e.g. lines 1, 3, and 4) enhanced transport accessibility (Jung et al., 2015).

In more recent new towns with high population density, long distances to the old cities, and high jobs-housing mismatch, it is common for commuting to rely on public transit (e.g. subway). In China's cities, a job decentralisation policy was implemented in line with China's urban development. Chenggong New Town in Kunming, China, is about 30 km away from the central city, linked by a subway line. Commuters who relocate jobs in new towns and live in the central city still rely on the subway to commute, to a large extent (Yang et al., 2017). In Beijing, China, subway transit operates across the new towns of Tongzhou, Shunyi, Daxing, Changping and Fangshan, and has become the most important commuting mode in these new towns. Despite extensive residential and industrial developments in the new towns, city centres have remained a considerable employment source during the past 10 years. Jobs-housing mismatch is still significant in new towns. The underdeveloped industry and public service functions in new towns were believed to limit their further development to become sizeable new towns (Yu et al., 2014). In Seoul in the late 1980s, new town developments started when major large-scale suburban developments were implemented. Five new towns (Jungdong, IIsan, Sanbon,

Table 1
Summary of the literature on underground space utilisation for new town development.

Reference	City, Country/ Region	Form of underground space utilisation	New town	Goals of underground space utilisation for new town development	Main uses of underground space for new town development
Anderson, 2015	Seoul, Korea	Subway and underground parking spaces	New Songdo	To release ground space for urban green spaces and open spaces for recreation	2 3
Antonson et al., 2017	Gothenburg, Sweden	Underground parking garages	Porslinsfabriken	To meet parking requirements of residents in Porslinsfabriken	3 5
Cervero, 1995	Stockholm, Sweden	Subway	Vallingby, Farsta, Skarholmen, Spanga, Kista and Skarpnack	To link satellite new towns with downtown Stockholm	1
Chen and Shi, 2007	Beijing, China	Proposed multi-function underground space utilisation (comprehensive underground pipe corridor, underground parking lots, large underground municipal engineering facilities such as water plants and rubbish treatment facilities, large underground municipal engineering infrastructure facilities)	Eleven new towns	To develop new towns through transit-oriented development, to create good urban environment, and to maintain the intensive development of core areas of the new towns	1 2 3 4 5
Cho and Kim, 2017	Shanghai, China	Subway	Songjiang New Town	To provide public transport to serve the area	1
Clout, 1988	Paris, France	Road tunnels	La Défense	To separate pedestrians from vehicle traffic	3 4
Duffaut, 2006	Paris, France	Road tunnels, underground car parks, underground commercial centre, subway	La Défense CBD	To build a sustainable city	3 5
Firman, 2004	Tangerang, Indonesia	Underground central sewerage system	Lippo Karawaci New Town	To develop excellent infrastructure and facilities	3
Gao et al., 2019	Shanghai, China	Underground container logistics system and underground parking spaces	Jiading	To relieve ground traffic pressure caused by container trucks in a port	3
Gohaud and Baek, 2017	Seoul, Korea	Underground parking spaces	Bundang New Town	To accommodate heavy real estate pressure	2 3
Guo et al., 2013	Wuhan, China	Urban traffic link tunnel	Wuhan CBD	To effectively reduce ground traffic, to improve travel efficiency, to ease human-vehicle conflict, to enhance environmental quality, and to achieve low-carbon transport	3 4 5
Hao et al., 2019	Chengdu, China	Proposed multi-function underground space utilisation (including underground road traffic, underground pipe gallery facilities, underground parking lots, subways, and underground laboratories)	Tianfu New Area	To build an international modern new district	3 4
Hua et al., 2011	Beijing, China	Urban traffic link tunnel	Beijing CBD	To alleviate traffic jams	3
Jun, 2012	Seoul, Korea	Subway	Bundang, Ilsan, Jungdong, Pyeongchon, and Sanbon	To enhance transport accessibility	1
Jun et al., 2013	Seoul, Korea	Subway	Jungdong, IIsan, Sanbon, Pyungchon, and Bundang	To connect newly developed suburban areas and downtown Seoul	1
Jung et al., 2015	Seoul, Korea	Subway and underground parking spaces	Eunpyeong New Town	To enhance transport accessibility	1 3
Kim and Byun, 2021	Daejeon, Korea	Subway	A new residential town in the Northwest area	To connect the new residential town in the Northwest area with the old downtown in the Southeast	1
Kim and Song, 2015	Seoul, Korea	Subway	Yeongdeungpo-Gu CBD and Gangnam-Gu CBD	To enhance transport accessibility	1
Lee and Yong, 2019	Seoul, Korea	Subway	Wirye New Town	To serve the transport needs of the self-sustainable urban sub-centre	1
Lee et al., 2005	Seoul, Korea	Subway	Gwacheon, Bundang, Ilsan, Pyeongchon, Sanbon and Jungdong	To enhance transport accessibility	1
Li et al., 2013	Suzhou, China	Planned subways and three subway stations, underground pedestrian walkways, underground parking, and underground shopping centres	New CBD	To increase density and to save land	2 3

(*continued on next page*)

Table 1 (*continued*)

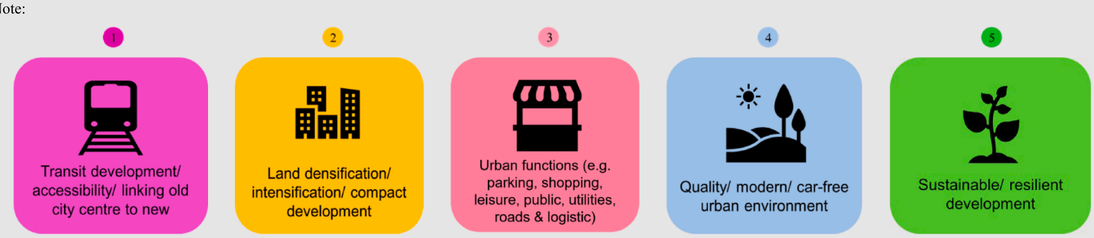
Reference	City, Country/ Region	Form of underground space utilisation	New town	Goals of underground space utilisation for new town development	Main uses of underground space for new town development
Li et al., 2016	Guangzhou, China	Underground commercial spaces	Zhujiang New Town	To accommodate important urban functions	3
Li et al., 2017	Chengdu, China	Underground parking garage	Tianfu New Area	To solve the problem of parking shortages to cope with increasing number of vehicles	3
Ling, 2012	Guangzhou, China	Subway, underground public spaces, underground shopping malls, underground bus terminus, underground car parks, road tunnels, and underground automated people mover system	Zhujiang New Town	To save surface land for urban greenery, and to create high-quality car-free open space for the public	3 4
Luo et al., 2020	Multiple countries	Multipurpose utility tunnels	Multiple places	To promote sustainable and resilient infrastructure development, to decrease the need for repeated excavations for intervention activities, and to reduce traffic congestion	3 5
Marti and Masnou, 2014	Hangzhou, China	Underground shopping mall and subway	Qianjiang Central Business District	To integrate UUS for creating urban space related to the cultural uses of the main buildings	3
Merlin, 1980	Stockholm, Sweden	Subway	New suburban areas	To develop new suburban areas in coordination with development of the new subway	1
Miyoshi et al., 1979	Tokyo, Japan	Subway	Tama New Town and Chiba New Town	To link new towns with the central part of Tokyo	1
Ong, 2014	Tianjin, China	Subway and underground parking garages	Sino-Singapore Tianjin Eco-City	To link the eco-city to Tianjin city centre and the rest of the Tianjin Binhai New Area, and to improve the residential living environment	1 3 5
Park, 2011	Seoul, Korea	Subway	Multiple new towns	To promote public transport	1
Peng et al., 2020	Shanghai, China	Subway, road tunnel, underground parking spaces, underground pedestrian walkways, underground commerce and recreation spaces, underground energy centre and transmission tunnels	Hongqiao CBD	To build a compact city, to complement urban functions, and to develop an environmentally preferable and low-carbon city	2 3 4 5
Qian, 2011	Hangzhou, China	Underground public facilities, and underground recreation and shopping facilities	Qianjiang New City	To improve the environment, to integrate urban functions, and to promote urban sustainability	3 4 5
Qian, 2016	Beijing and Ningbo, China	Underground roads, underground pedestrian walkways, underground commercial streets, underground public buildings, underground infrastructure, underground storage space and underground civil defence space	Beijing CBD, and business district in south Ningbo	To build a resource-saving and environment-friendly society	3 5
Qiao and Peng, 2016	Shanghai, China	Underground transport (e.g. underground pedestrian facilities, parking facilities, and roads and logistics facilities,); underground public infrastructure (e.g. underground plazas, commercial facilities, and recreational facilities); and underground municipal infrastructure (e.g. underground transformer stations and underground utility tunnels)	Lujiazui Business District, and Hongqiao CBD	To provide comprehensive function of transport, economy and public services for urban development	2 3 4 5
Qiao et al., 2019	Shanghai, China	Subway, underground pedestrian system, and underground parking spaces	Hongqiao CBD	To promote a low-carbon city	2 3 5
Rumbach, 2014	Kolkata, India	Underground sewer lines and underground drainage canals	Salt Lake New Town	To mitigate flood hazards	3 5
Seelig, 2011	Tehran, Iran	Underground parking	Hashtgerd New Town	To create direct accessibility in car-free neighbourhoods	2 3 4
Seik, 2001	Singapore	Underground infrastructure (underground electricity and water supply, and sewerage and telecommunication networks)	Tampines new town	To use underground infrastructure as a strategy for efficient and comprehensive planning of the new town	2 3
Sun and Hu, 2011	Zhengzhou, China	Subway	Zhengdong CBD	To transport mass populations and solve urban traffic problems	1
Wallace and Ng, 2016	Hong Kong SAR, China	Water supply tunnels and subway	New towns and other development areas	To intensify land use for building a dense city	1 2 3
Wang and Heath, 2010	Nantou, Taiwan	Underground drainage system and underground electric and telephone cables	Jhong-Sing New Village	To adopt Western inventions to develop an advanced society	3 4

(*continued on next page*)

Table 1 (*continued*)

Reference	City, Country/ Region	Form of underground space utilisation	New town	Goals of underground space utilisation for new town development	Main uses of underground space for new town development
Wu et al., 2019	Shanghai, China	Subway	Qingpu, Songjiang and Jiading	To meet most travel demand in the new town areas	1
Xing, 2020	Xi'an, China	Subway, underground commerce space, and underground pedestrian system	Fengdong New Town	To create an urban underground environment, and to promote the regional economy	3
Xu et al., 2015	Beijing, China	Subway	Tongzhou New City and other new cities	To link new towns and central areas	1
Xue and Zhou, 2007	Shanghai, China	Underground parking	Pujiang Town	To form a systematic and varied urban texture	3
Yang and Peng, 2016	Zhuhai, China	Underground utility tunnel	Hengqin Island	To save land and to intensify land use on the island	2 3
Yang et al., 2017	Kunming, China	Subway	Chenggong New Town	To connect the new town and the central city of Kunming	1
Yang et al., 2019	Nanjing, China	Underground parking	Nanjing South New City	To address land scarcity, traffic congestion, imbalance of public service facilities, and conflicts between urban construction and the ecological environment	2 3 4
Yuan et al., 2020	Shenzhen, China	Subway and underground pedestrian system	Futian CBD	To optimise urban function, to upgrade transport systems, and to promote compact city development and urban spatial integration	2 3
Yu et al., 2014	Beijing, China	Subway	Tongzhou, Shunyi, Daxing, Changping, and Fangshan	To develop a comprehensive passenger transport system with rail transit as the backbone	1
Zacharias, 2014	Beijing, Guangzhou and Shenzhen, China	Subway, underground pedestrian systems, underground public spaces, underground shopping facilities and underground public utilities	Beijing CBD, Guangzhou Zhujiang New Town and Shenzhen Futian CBD	To support CBD as the flagship project exemplifying China's impressive transition to a modern and information economy	3 4
Zhang, 2018	Tokyo, Japan	Underground public and recreational spaces	Newtown of Roppongi Hills	To integrate with ground space and above-ground space to create multi-level public space and to promote cultural aspects of the environment	3 4
Zhang et al., 2019a	Hangzhou, China	Underground parking system	Linping New City	To solve parking problems, alleviate ground traffic pressure and reduce traffic congestion	3
Zhang et al., 2019b	Hangzhou, China	Subway	Xiasha, Linping, and Xiaoshan	To provide rapid public transit for local residents	1
Zhao et al., 2014	Guangzhou, China	Subway and underground mall	Tianhe CBD	To form connectivity among transport, shopping and entertainment functions	3

Note:



Pyungchon and Bundang), with distances of 20–28 km from the old city and average population density higher than 17,000 persons per km^2, were developed. Subway accessibility has been a focus in new towns, and massive investment in subway systems has been made (Jun et al., 2013). In Korea, as a type of large-scale comprehensive development, new town developments aim to create self-contained urban sub-centres. For example, the Wirye New Town not only includes large-scale residential developments (nearly 43,000 housing units) but also comprises commercial and industrial land use, transport infrastructure and facilities (subway lines and transit malls), and utility facilities (Lee and Yoon, 2019). Many new town developments demonstrate the importance of subway in new towns' transit accessibility to external areas. Accessibility within the new town area is also an important consideration for UUS utilisation. In Shanghai Lujiazui CBD, which benefited from subway development, an underground pedestrian system was developed to enhance the internal connections of the new area. With high population density, high traffic volume and wide road networks that resulted in unpleasant and unsafe walking environments in the CBD, the underground pedestrian system has facilitated efficient movement and communication between buildings in the new area (Peng et al., 2020).

In addition to intensive land use and accessibility considerations for new towns, UUS utilisation in new towns also aims to avoid urban problems that have occurred in the old cities. To avoid urban problems such as traffic congestion, land shortage, unbalanced distribution of public facilities and services, and conflicts between urban development and ecological environment protection, an underground space developmental strategy and integrative development plan was enacted by the Nanjing government at the initial stage of the South New City development project. According to the plan, the ground and underground levels create a multi-level urban structure (Yang et al., 2019). To avoid land shortages, high land prices and traffic congestion due to increasing container throughput, an underground container logistics system between Shanghai Waigaoqiao Terminal and Jiading Northwest Logistics Park and an underground parking facility were proposed (Gao et al., 2019).

In some situations, UUS utilisation for new town development also relates to cultural and modernity considerations. In Qianjiang CBD in Hangzhou, China, Culture Wave is a complex of public cultural facilities

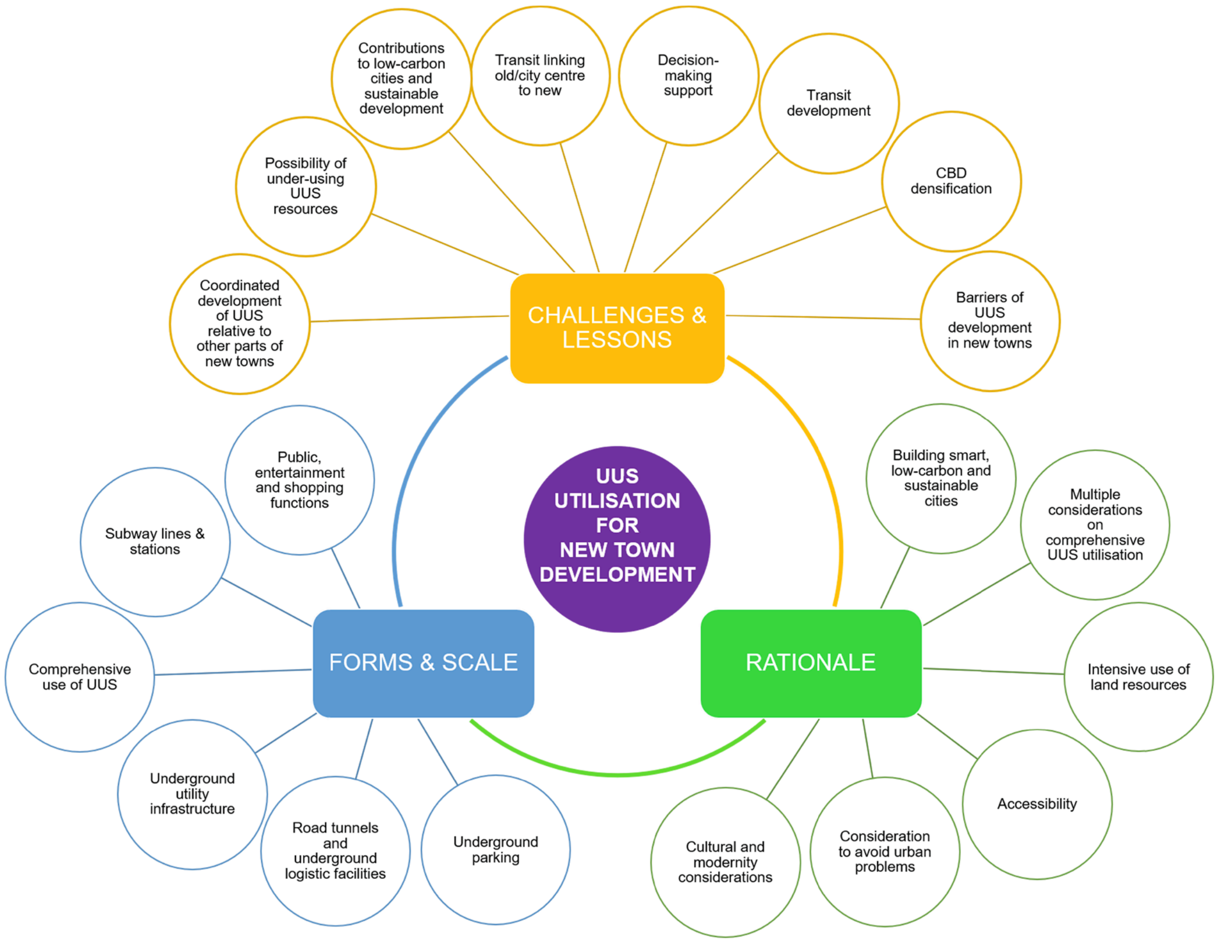


Fig. 1. A framework for the review of UUS utilisation for new town development.

linking multiple levels, with underground space playing a main role. The idea of Culture Wave refers to the tidal wave of the Qiantang River, the best-known tidal wave in China due to its size. The underground shopping mall inputs the main pedestrian flow that climbs to the balcony over the river, which creates an "urban wave" that reflects the cultural uses of the complex (Marti and Masnou, 2014). UUS utilisation is an important component in CBD development and regarded as a flagship project indicating China's great transition to a modern and information economy (Zacharias, 2014). In Nantou, Taiwan, Jhong-Sing New Village in the 1950s developed an underground drainage system and underground electric and telephone cables. It was a time when the adoption of Western inventions was viewed as a symbol of an advanced society (Wang and Heath, 2010).

UUS utilisation in new towns contributes to building smart, low-carbon and sustainable cities. UUS contributes to building low-carbon cities because it facilitates transport optimisation, compact form, mixed land use, green buildings and infrastructure, and renewable geothermal energy (Qiao et al., 2019). Policy-makers of China's CBDs gradually focused on environmental considerations in addition to economic considerations, with a special emphasis on improving quality of life in cities. The land saved due to UUS use (for traffic, parking, and utilities) can be developed for green spaces and public spaces, and the cityscape can be preserved. UUS can also contribute to low-carbon CBDs through subway and underground pedestrian networks that reduce motor vehicle traffic demand and facilitate efficient movement in the CBD (Peng et al., 2020). With the emergence of various forms of new towns in the Global South (e.g. smart city, eco-city and low-carbon city) in this latest wave of urbanisation, underground space also plays a role in achieving these new city concepts. In Sino-Singapore Tianjin Eco-City in Tianjin Binhai New Area, China, each residential apartment has an underground parking garage, with charging stations for electric cars. Street-level parking spaces are not available, and all parking spaces are underground in basements with direct connection to apartment buildings. A planned subway line connects the eco-city directly to Tianjin city centre and the rest of the Tianjin Binhai New Area (Ong, 2014).

There are many aspects that need to be considered with regard to comprehensive UUS utilisation. For example, in Hongqiao CBD in Shanghai, underground commercial and recreational facilities were included in the regulatory detailed plan of the CBD for intensive use of space resources to address height limits. In addition, underground pedestrian systems, underground parking facilities, road tunnels and underground logistics facilities were planned to enhance regional environment quality and promote low-carbon and sustainable development. Furthermore, underground municipal pipelines, common utility tunnels, underground energy centres and power transformer stations were planned, to improve environmental quality and achieve sustainable use of resources. Moreover, underground emergency protection facilities were planned to enhance urban integrated prevention capability (Qiao and Peng, 2016).

4. The forms and scale of underground space utilisation for new town development

Subway lines connecting new towns and city centres offer convenient and rapid public transport services in Japan, Korea, Sweden and China. In Tokyo, a subway line originates at Tama New Town, runs through central Tokyo, and terminates at Chiba New Town (Miyoshi et al., 1979). In Daejeon, Korea, a subway line connects a new residential town in the northwest area with the old downtown in the southeast (Kim and Byun, 2021). In Seoul's new towns (e.g. Bundang, Ilsan, Pyeongchon, Sanbon and Jungdong), subway provides good connection to Seoul, enhances public transport accessibility and relieves traffic congestion in the central city of Seoul (Jun, 2012; Lee et al., 2005). In Stockholm, Sweden, subway lines link satellite new towns (e.g. Vallingby, Farsta, Skarholmen, Spanga, Kista and Skarpnack) with downtown Stockholm (Cervero, 1995). Similar connections can also be found in Songjiang New Town, Shanghai (Cho and Kim, 2017), and Beijing (Xu et al., 2015). In Hong Kong, the subway network significantly expanded in the 1980s and 1990s, resulting in many subway lines serving new towns and linking them to other urban centres (Wallace and Ng, 2016). The extension of the Madrid Metro network southwards (Metrosur) served to socially and economically integrate existing towns south of Madrid and to allow for extensive new developments to occur in this area (Phelps et al., 2006).

It is not rare to see UUS used for public, entertainment and shopping functions in new towns. Japanese cities have early examples of underground public and recreation spaces, dating back to the 1930s. However, a gas explosion that occurred in the golden underground street in Shizuoka in 1980 resulted in restrictions on the number of underground streets in newly developed cities. Since the beginning of the 21st century, the advancement of construction technology and management methods has facilitated a more systematic and orderly way of developing underground public and recreation space. Underground space and surface space have formed interdependent and harmonious symbiosis relationships rather than subsidiary and complementary relationships, with Tokyo's Newtown of Roppongi Hills providing an excellent example. In Roppongi Hills, multi-layer public space was integrated with underground space, ground space and above-ground space, accommodating work, residential, transport, cultural, leisure and entertainment functions (Zhang, 2018). In Tianhe CBD, Guangzhou, the subway station connected underground shopping malls, forming a transport, shopping and entertainment complex (Zhao et al., 2014). In Hangzhou's Qianjiang New City, China, a magnificent cultural plaza connected three major signature buildings in the core area of the New City. The underground part of the cultural plaza was used for public facilities, recreation and shopping (Qian, 2011).

Underground parking is a common form of UUS utilisation in new towns, although the scale of parking facilities varies in different new towns due to variations in population and land-use intensity and scale. In Tianfu New Area in Chengdu, China, Chengdu New Century Global Centre, a multi-functional complex consisting of entertainment facilities, hotels, commercial areas and office spaces, provides over 5000 underground parking spaces (Li et al., 2017). In Porslinsfabriken, a new residential area in Gothenburg, Sweden, more than 200 parking spaces located in two underground garages are available for all residents to hire (Antonson et al., 2017). In Shanghai's Pujiang Town, underground parking areas integrating with street-level road systems and a river network, together with pedestrian walkways, pocket parks and open spaces, form a systematic and varied urban texture in the masterplan of the new town (Xue and Zhou, 2007).

To address traffic congestion, road tunnels and underground logistic facilities also attract attention in new town developments. In the business district in south Ningbo, in addition to the surface ring road network, road tunnels form another ring network at the underground level that is connected to adjacent basements of buildings by underground pedestrian walkways (Qian, 2016). La Défense in Paris, when planned six decades ago, was not to be simply a new business district but a mixed-use development comprising residential, commercial, educational, recreational and administrative facilities. The initial master plan considered the complete separation of pedestrians from vehicle traffic, with local road traffic to be directed to a circular boulevard and through traffic to pass in road tunnels under the business district (Clout, 1988). Such a complete separation between pedestrians, logistics and car traffic was realised for instance in the 1972 Munich Olympic Village, which is seen as an attempt to build high-density, high-quality neighbourhoods, but where its long-term success to deliver on its promises is contested (Viehoff and Poynter, 2015). In Wuhan's Wangjiadun CBD, an Urban Traffic Link Tunnel that comprises a main loop-shaped tunnel linked with other tunnels, was built for cars to travel to and from the underground parking facilities to significantly relieve traffic pressure at street level (Guo et al., 2013). A similar road tunnel system was developed in Beijing CBD (Hua et al., 2011). An underground container logistics system between Shanghai Waigaoqiao Terminal and Jiading Northwest Logistics Park and an underground parking facility are proposed to reduce ground traffic pressure (Gao et al., 2019).

Underground utility infrastructure in the forms of underground drainage infrastructure, underground central sewerage systems and multipurpose utility tunnels (MUTs) have been developed in new towns throughout the world. In Tangerang, Indonesia, Lippo Karawaci New Town is the only new town in the nation to have a municipal underground central sewerage system, considered to be an example of excellent infrastructure and facilities (Firman, 2004). In Hong Kong, since the 1970s, water supply tunnels have been gradually expanded to improve water supply to new towns and other development areas, and more than 200 km of water supply tunnels had been developed by 2012 (Wallace and Ng, 2016). In Kolkata, India, Salt Lake is a new town known for its resilience to environmental hazards (e.g. floods and high winds brought by tropical storms). Prior to the development of Salt Lake, the underground drainage infrastructure was installed for mitigating flood hazards. The underground sewerage system in Salt Lake new town is essential for reducing risk in flood-prone areas (Rumbach, 2014). Tampines new town in Singapore has developed underground electricity and water supply systems, and sewerage and telecommunication networks (Seik, 2001). MUTs that integrate all utilities (e.g. water and sewage pipes, and electrical and telecommunication cables) in one tunnel, tend to be an increasingly popular form of UUS utilisation in new town developments. China is a country that views MUTs as important infrastructure for urban resilience in new areas. Nanjing Jiangbei New Area has the longest MUT in China, at 53.41 km. For future MUT development by the Ministry of Housing and Urban-Rural Development of the People's Republic of China, the construction rate of MUT under new roads in urban new areas should reach 30% by 2020. Japan is also an exemplar country for MUT development in new areas. For example, a new subcentral area near the Tokyo Waterfront City has moved nine main pipes and cables (e.g. water, sewage, telecommunication, gas, cooling, heating, and garbage system, but not rainwater) to the 16 km MUT (Luo et al., 2020).

There are also many excellent examples of comprehensive use of UUS, including multiple forms to support new town developments. For example, driven by constructing subway stations, the comprehensive development of underground space in Fengdong New Town (new CBD) in Xi'an, China, includes subway, underground commercial facilities, and an underground pedestrian system, creating a three-dimensional city in Xixian New Area (Xing, 2020). Underground space utilisation for new town development tends to be large-scale in Chinese CBDs. The planned area of underground spaces in some CBDs (Qianjiang New City in Hangzhou, Beijing CBD and Hongqiao CBD in Shanghai) comprises about half of the above-ground floor areas. For example, in Qianjiang New City, the above-ground floor areas are about 4.6 km^2, while the planned areas of underground spaces are 2.0–2.3 km^2 (Peng et al., 2020). In Beijing CBD, five-storey underground spaces are used for transport, commerce, public, infrastructure, storage and civil defence purposes, and pedestrians and vehicles are efficiently separated (Qian, 2016). In Shanghai Hongqiao CBD, UUS below the CBD is used in a comprehensive and intensive manner. Three subway lines along with the planned airport express tunnel transport the majority of passengers to the CBD and Hongqiao Transportation Hub. An underground pedestrian network connects office buildings, hotels, shopping malls and parking garages. Underground parking facilities and municipal infrastructure have also been developed (Qiao et al., 2019). Comprehensive use of UUS not only offers an opportunity for large-scale UUS utilisation but also allows denser development of UUS. For instance, Bobylev (2016b) provides further insight with regard to transition to high-density UUS concepts.

5. Challenges and lessons of underground space utilisation for new town development

The relationships formed between new towns and old city centres is an important consideration. In the last several decades, experiences in Sweden, Spain, Japan, Korea, and China have indicated the role of subway in connecting new towns and old city centres efficiently (Cervero, 1995; Cho and Kim, 2017; Jun, 2012; Kim and Byun, 2021; Lee et al., 2005; Miyoshi et al., 1979; Wallace and Ng, 2016; Xu et al., 2015). In Stockholm, there were close social and economic connections between new towns and the old city centre and surrounds, and large numbers of new town residents commuted by subway to the old city centre; more than 50% of all new town workers and over a third of new town residents commute via public transit every day (Cervero, 1995). Whether subway is an optimal choice for public transit and how significant a role it can play in meeting the travel demands of new town residents, not only relies on the closeness of the relationship between the new town and the old city (e.g. social and economic linkages), but also on the distance between the new town and the old city, the quality of the subway service (e.g. accessibility and affordability), and the relative cost of alternative private transport. Many new towns are distant from the old cities, resulting in separation between homes and workplaces. This is the case in Hangzhou's satellite cities (Xiasha, Linping and Xiaoshan) and the old city centre, resulting in high transport demand between the satellite cities and the old city centre. Subway tends to be the fastest option for residents of satellite cities (Zhang et al., 2019b). Connecting new towns and old city centres and sub-centres and developing transit-oriented development (TOD) around the subway stations not only solved the transport demand of the large population, but also created a sound urban environment and facilitated intensive and compact development of new towns. Close relationships between old city centres and new towns and satellite towns have resulted in large population flows. The development of large-capacity rapid rail transit (e.g. subway lines) that can meet most travel needs should be prioritised (Chen and Shi, 2007). The early planning development of large capacity transit when developing new towns proves to be more cost effective than attempts to integrate these systems after the initial town development has taken place.

New town developments may be challenged with regard to compact and high-density development, partially due to the larger amount of land available, compared with infill development in existing urban areas. Land use in the new towns of Beijing was characterised by low density and lack of intensity. The scope of TOD allows UUS utilisation, together with the simultaneous construction of subway lines and stations, to be a likely approach (Chen and Shi, 2007). Subway contributes to the continuous population expansion of new towns that may promote compact development. In Hong Kong, Junk Bay was linked to Kowloon and Hong Kong Island by subway. It was estimated that with such a link, Junk Bay could reach a population of 300,000, while without such a link, Junk Bay could not grow its population over 150,000. The ultimate size of the new town would be determined primarily by the availability of the subway to connect the new town to other areas of Hong Kong (Hills and Yeh, 1983).

Transit accessibility plays an important role in promoting sustainable transport development. TOD in new town developments may need to consider the location and the density of subway stations that may impact on transport accessibility and subway use rates. Residential TOD developments around new towns' subway stations are common in Hong Kong's and Seoul's new towns. However, different locations of the subway stations have resulted in different levels of significance of subway in residents' travel mode share. In Seoul's new towns (Gwacheon, Bundang, Ilsan, Pyeongchon, Sanbon and Jungdong), with subway located in the external axis in Bundang and Jungdong, the two new towns had a low subway use rate of around 22%; with subway located in the central part of Ilsan, the new town had a comparatively high use rate of around 40%; and with a subway system penetrating the central location of Gwacheon, a small-sized new town, with all residents living close to subway stations (within 1.2 km radius), a high use rate of around 41% was seen (Lee et al., 2005). The impact of the locations of subway stations on subway use rate is significant. Therefore, careful planning and design of subway locations are vital to promote public transit for more sustainable transport development. In addition to the location of subway stations, the density of subway stations in new towns, relative to transit accessibility, also matters. In China's cities, rural areas in the urban fringe were transformed into new towns following the TOD concept. Due to long distances between new towns and the old city centres and jobs-housing mismatch, accessibility as a significant issue in new town development needs to be considered. Public transit, including subway, is expected to meet most of the travel needs in the new towns. Low-density subway stations, together with a dispersed population in new towns, has resulted in low accessibility (Wu et al., 2019). In the case of new town developments in Seoul in the 15 years from 1998 to 2013, a significant mode shift from transit to car commuting was seen. Those who lived further away from subway stations had a higher possibility of driving private cars for commuting (Jun et al., 2013). Although densification of the subway system could improve accessibility, the approach requires long-term implementation. Integrating other transport modes, e.g. buses, walking and cycling to subway to provide easy access to subway stations, could be a realistic short-term strategy to improve accessibility of non-subway areas (Wu et al., 2019).

UUS development in new towns may confront many barriers. Lack of awareness of the significance of UUS in new town development and economic considerations may lag behind UUS development, causing problems. In the case of Lujiazui CBD in Shanghai, UUS was not integrated within the plans made in 1990, and in the 1993 plan, UUS was added. However, at that time, it was the leadership's willingness rather than the market that dominated city planning, and as a result, underground planning in 1993 was not put into practice. In addition, the high cost of underground developments (normally 3–4 times that of similar development at ground) in a large-scale and systematic manner was a financial challenge for Lujiazui CBD. Consequently, underground facilities were developed in an unsystematic manner to supplement ground or above-ground functions, mainly using basements of buildings in 60 locations without interconnections, over two decades of development (Qiao and Peng, 2016). UUS utilisation in new towns requires a balance between market forces and government intervention. In new towns in Beijing, UUS in central areas was developed within the scope of TOD functions. A reliance on TOD, uncertainty of TOD implementation, adequate land supply in the short term, and absence of guidance, regulations and policies led to insufficient motivation for UUS development. Complete reliance on spontaneous market activities to develop UUS in new towns would delay UUS's potential contributions to compact and sustainable development of new towns. However, excessive government intervention resulting in excessive UUS being developed could cause a waste of spaces and a heavy burden for management. Therefore, it is important to have reasonable governance of the timing and order of UUS development in new towns (Chen and Shi, 2007). Careful planning and design pave the way for successful UUS development in new towns. In Shanghai's Hongqiao CBD, a regulatory detailed plan for UUS was compiled to achieve the strategic objectives of the CBD. Planning provided clear instructions or regulations (e.g. on development capacity, function allocation, transport organisation, and building dimensions and their connections) to ensure development of UUS in a scientific and systematic manner. Regulatory requirements for UUS were demonstrated by drawings and corresponding or explanatory text, and integrated into urban design. These efforts allowed Hongqiao CBD to become a successful example of UUS utilisation (Qiao and Peng, 2016).

New town development provides a significant opportunity for UUS utilisation in a systematic manner. Rather than developing individual underground buildings or a small area, new town development involves large areas of available land and may comprise large-scale multi-functional UUS utilisation. However, there are challenges regarding coordinated development of UUS relative to other parts of new towns. In China, subway-led UUS development was common in urban renewal and new town development. Impressive subway development occurred, with heavy investment in the last decade, and by the end of 2019, 37 cities in China had developed subway systems (Lin et al., 2021a, 2021b). However, there were coordination problems between planning and development of subways, buildings, streets and UUS, because they were conceived and controlled separately. In Beijing CBD, when the plan for a comprehensive system of UUS was released in 2005, the underground space of many buildings was already built on. The connections between planned adjacent underground space developments require a coordination group; however, such as group did not exist. In Shenzhen's Futian CBD, the TOD plan largely devoted underground space to pedestrian spaces and ground space to open space and traffic. In the Grand Theatre project, UUS integrated with subway stations featured generously dimensioned underground walkways, but they did not integrate with any public activity, commercial or service functions. As they were built within the scope of subway corporation, a connection with adjacent commercial spaces did not occur (Zacharias, 2014).

Large-scale UUS development in new towns has the possibility of under-using UUS resources. In Guangzhou's Zhujiang New Town, Flower City Square developed 500000 m^2 UUS, and 150000 m^2 UUS of this, Mall of the World, was used for commerce. Since its opening, due to much lower customer flow than expected, around two-thirds of its shops have closed. The unused or abandoned UUS caused a significant waste of space resources (Li et al., 2016). Underground parking remains an important function for UUS utilisation in new towns to meet most parking demand. Therefore, it is common to see numerous underground parking spaces built in new towns. However, how to improve the use rate of underground parking spaces and avoid significant waste of spaces caused by underuse is problematic. In Linping New City of Hangzhou, the strategy was to develop shared parking (8 interconnected underground parking lots offering more than 4800 parking spaces) in the CBD area, which increased the use rate and turnover rate of underground parking spaces (Zhang et al., 2019a). Large-scale underground facilities may be a challenge for their users as well. In Chengdu New Century Global Centre underground parking facilities in Tianfu New Area, more than 5400 underground parking spaces were provided. The problematic signage system (e.g. inconsistent guidance symbols, incomplete signage system, colour use and collocation causing confusion and negative psychological feelings, and unreasonable size and location of guide signs) may send confusing information to drivers and hinder them from making correct judgements (Li et al., 2017).

UUS in new towns could contribute to low-carbon cities and sustainable development, and this is an important consideration. The development of low-carbon cities and new towns, under the following considerations, could prioritise UUS use: first, subway playing a significant role in promoting sustainable transport, which could be developed with underground pedestrian systems and underground parking systems; second, shallow underground spaces could accommodate urban functions, increasing density and developing compact cities; last but not least, geothermal energy could provide a green energy alternative to traditional energy sources (Qiao et al., 2019). In practice, the strategy for sustainable development using underground space in new towns may confront unexpected challenges. For example, in Porslinsfabriken, a new residential area in Gothenburg, Sweden, to reduce car use and achieve sustainable urban development, a relatively restrictive parking requirement was applied. Five private housing cooperatives in Porslinsfabriken offered 298 parking spaces (either underground or on the street) for hire by all residents. However, the restrictive parking requirements applied did not result in a decrease in the possibility of parking spaces available, as residents had access to parking in neighbouring residential areas. This indicates the importance of implementing other measures, e.g. increasing parking charges and limiting the number of public parking spaces while introducing more restrictive parking requirements in new towns (Antonson et al., 2017).

UUS utilisation provides important development opportunities for new towns and requires strong decision-making support. Underground infrastructure and development (e.g. subway) in new towns can significantly affect urban land use, accessibility, real estate, transport and economy. For example, research indicated that the opening of subway to allow better accessibility in a new residential area in Daejeon, Korea, impacted significantly on land prices (Kim and Byun, 2021). In Zhengzhou's Zhengdong CBD, the subway stations were estimated to significantly affect the housing prices of real estate development within a distance of 1500 m from the stations (Sun and Hu, 2011). An evaluation of the potential impacts of UUS utilisation on new town environment would support decision-making regarding UUS development. Information on the underground resource (i.e. space) supply of new towns is also very important for decision-making. Li et al. (2013) assessed UUS's contribution to building density and saving of land for a new financial centre in Suzhou, China. This type of assessments can help decision-makers to avoid project risks, including over budget and unforeseen damages, and support economic development and urbanisation in new towns. Technology is playing an increasingly important role in supporting UUS decision-making. Three-dimensional geographic information system technology can overcome the disadvantage of traditional two-dimensional planning technology that cannot describe three-dimensional spatial and geological information adequately, thus assisting decision-making in the planning, construction, and management of UUS utilisation in new towns (Hao et al., 2019).

6. Conclusion

Although UUS has contributed to new town development for decades, the relationship between UUS utilisation and new towns – particularly how UUS utilisation can contribute to new towns' transport, land use, economic, environmental, and social development is a topic requiring exploration. This paper reports on the findings of a comprehensive review of existing literature on this topic and reveals the significant implications for UUS planning, design and development in new towns. The key findings of this review are summarised and discussed below.

First, UUS development for new towns is driven by a number of considerations. High population density, limited land availability, high land prices and compact development in many new towns require intensive use of land resources. Moreover, accessibility plays an important role in promoting new towns' UUS development. Transit accessibility has been a prominent feature of the later generation of new towns, with high population density, long distances to the old cities, and high jobs-housing mismatch resulting in reliance on public transit (e.g. subway) for commuting. In addition to transit accessibility to external areas, accessibility within the new town area is also an important consideration behind UUS utilisation (e.g. underground pedestrian systems). Furthermore, the need to avoid urban problems that have occurred in the old cities drives UUS utilisation for new town development. Further, UUS utilisation for new town development relates to cultural and modernity considerations. Also, UUS utilisation contributes to building smart, low-carbon and sustainable new towns. Last, there is a need to consider many factors that may impact on the development of comprehensive UUS utilisation projects.

Second, underground space utilisation contributes to new towns in various forms, including subway systems and stations, underground public, entertainment and shopping facilities, underground parking garages, road tunnels, underground logistic facilities, underground utility infrastructure, and comprehensive use of UUS. Subway lines connect new towns and city centres, offering convenient and rapid public transport services in cities in Asia and Europe. UUS has been used for public, entertainment and shopping purposes in new towns in countries like Japan and China. Underground parking is a common form of UUS utilisation in new towns, although the scale of parking facilities can be varied in different new towns due to variations in population and land use intensity and scale. Furthermore, road tunnels and underground logistic facilities have been developed to address traffic congestion in new towns. Also, underground utility infrastructure, e.g. underground drainage infrastructure, underground central sewerage systems and MUTs are increasingly popular forms of UUS developed in new towns throughout the world. Many excellent examples of comprehensive use of UUS, including multiple forms of UUS use to support new towns, can be found in more recent developments. Generally, subways, underground parking facilities and underground utility infrastructure are more prevalent forms of UUS utilisation in new towns, and the scale of UUS utilisation in new towns can be varied.

Third, UUS' contribution to new town development may confront many challenges. The relationships formed between new towns and old city centres is an important consideration. Many new towns are distant from the old cities, resulting in separation between homes and workplaces, and high transport demand between the new towns and old city centres. It may be a challenge for subways to well-serve the new towns (e.g. in capacity and quality). In addition, new town developments may be challenged with regard to compact and high-density development, partially due to larger amounts of land available, compared with infill development in existing urban areas. Moreover, transit accessibility plays an important role in promoting sustainable transport development. TOD in new town developments may need to consider the density of subway stations and their locations that could impact on transport accessibility and subway use rates. Furthermore, lack of awareness of the significance of UUS in new town development and economic considerations could lag behind UUS development and cause problems. UUS utilisation in new towns also requires a balance between market forces and government intervention. Careful planning and design pave the way to successful UUS development in new towns. Although new town development provides a significant opportunity for large-scale multi-functional UUS utilisation in a systematic manner, challenges exist with regard to coordinated development of UUS relative to other parts of new towns. It is also worth noting that large-scale UUS development in new towns may under-use some UUS resources. UUS's contribution to low-carbon cities and sustainable development of new towns, an important consideration, may confront unexpected challenges. Also, UUS utilisation provides important development opportunities for new towns and requires strong decision-making support. Existing practices of UUS for new town development provide experiences and lessons from which to learn.

This paper, through reviewing the literature on underground space utilisation and new town development, in the context of emerging new towns in the recent wave of urbanisation, and the introduction of the concept of sustainable development, makes a timely and valuable contribution to the understanding of this topic. Through summarising experiences of existing UUS utilisation in new areas, this paper delineates important implications with regard to development strategies to achieve better economic, environmental and societal outcomes:

- The significance of UUS in new town development must be recognised by planners, designers, and decision-makers. Attention needs to be paid to phasing and designing underground space use so that it can grow at an appropriate rate along with the overall development of new areas and overcome the shortcomings of the traditional piecemeal development approach. A balance between market forces and government intervention is needed in developing UUS in new areas, e.g. having reasonable governance regarding the timing and order of UUS development in new towns.
- Underground infrastructure and development (e.g. subway) in new towns can significantly affect urban land use, accessibility, real estate, transport and economy. The potential impacts of UUS development (e.g. contribution to building density and saving of land), and the demands of UUS for accommodating urban functions (e.g. for parking or commence) need to be assessed to support decision-making on UUS development. Wherever possible, technology, e.g. three-dimensional geographic information system technology needs to be applied to assist decision-making in the planning, construction, and management of UUS utilisation in new towns.
- Transit accessibility significantly impacts on sustainable transport development, population scale and density, land use, and compact development of new towns. The locations and density of subway stations need to be carefully planned and designed. To enhance transit accessibility, integrating other transport modes, e.g. buses, walking and cycling to subway to provide easy access to subway stations, could be a short-term strategy. In the long term, densification of the subway system could improve accessibility significantly. In addition, developing TOD around the subway stations, together with the simultaneous construction of subway lines and stations, could facilitate intensive and compact development of new towns.

Utilising UUS to contribute to new town development has been undertaken over several decades. In the future, with further urbanisation, to increase density and to solve transport, environmental and land use problems in urban areas and to effectively accommodate populations in new towns, UUS is a strategy that should not be ignored by urban planners and policy-makers. Some previous experiences of UUS development characterised by the inefficiencies and constraints of traditional piecemeal underground space development have limited its contribution to new area development. Therefore, an important area of research for new area development is how to phase and design underground space use so that it can grow at an appropriate rate along with overall development and overcome the shortcomings of the traditional piecemeal development approach. Future research on concepts for phased developments under different scenarios could prove helpful in shaping the planning for new town underground developments. Current research on UUS utilisation and new town development mainly focuses on individual new towns, or new towns in the same country or region. Future research can contribute to a better understanding of how UUS has been utilised for new town development in different urban contexts, through comparative studies of new towns in different countries and regions. In the development of new forms of new towns (e.g. smart city, eco-city and low-carbon city), underground space has great potential to play an important role in achieving these new city concepts. The contribution of UUS to developing new forms of new towns requires more empirical studies in the future. UUS could greatly impact economic, environmental and social development, require cost-benefit analysis in new town environments, and provide solid support for decision-marking regarding UUS strategies for new town development. Many new towns have utilised UUS for their development, while many other new towns did not have such a strategy. Comparative studies of different developments in new towns with similar urban contexts in the future would contribute significantly to understanding the relationship between UUS utilisation and new town development.

CRediT authorship contribution statement

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