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The role of underground Architecture in solving contemporary urban problems

By

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Abstract

Today, urban centers are facing increased challenges and contemporary urban problems, the most important of which is the rapid urban growth imposed by the huge rise in the population. Therefore, today there is a scarcity of surface areas along with the high demands for facilities and general services by residents. Therefore, the use of underground spaces in city centers is one of the best alternative solutions to meet these increasing demands while preserving the overall structure of cities and avoiding damage to the natural and environmental resources, with emphasizing that underground solutions for city centers should be taken into account in the early stages of planning and developing cities in order to make them more successful and effective. Hence, this paper will highlight the most prominent problems experienced by highly populated urban cities and how to find solutions to these problems through the optimal use of underground spaces.

Keywords: urban problems; investigations; underground Architecture

Introduction

The world is an increasingly growing urban environment. Since 2008, more than half of the world's population has lived in cities. This number is expected to increase to 70% by 2050 according to statistics by United Nations. The world's urban population will be more than double compared to the beginning of the century (Broere, 2018, p. 1528). The world population is expected to rise to nearly 10 billion people in the next four decades (UN & DESA, 2013) . Along with the increase in population density, the number of cars on the streets will increase as well, which in turn will raise the level of mechanization for city residents. Thus, creating a comfortable environment for residents will become a problem that is difficult to be dealt with (Simankina, Braila, & Kanyukova, 2016, p. 1758). Since most of this population growth will occur in developing countries, they will be subjected to rapid expansion to meet increasing demands on urban infrastructure systems. Without an effective transport infrastructure, cities will expand away from their urban core, which in turn leads to stress on the natural environment by creating more traffic congestion, increased travel time, loss of agricultural land and unfair allocation of natural resources (Chen & Donald, 2002). In developed countries, urbanization is less rapid than in the developing countries, but the population structure will change. These changes will lead to new requirements on jobs that the city must provide through continuous improvement of city planning in accordance with the standards of sustainable urban development in order to ensure efficiency of resources usage (Broere, 2015, p. 245). The pursuit of developing large urban areas is also a global phenomenon that needs additional space due to the restriction of urban sprawl, which has contributed to increasing the heights of

buildings and thus increasing the cost in addition to a number of challenges associated with providing infrastructure that grows in proportion to the size of the city (Hunt, Makana, Jefferson, & Rogers, 2015, p. 1)

The increased level of awareness among urban residents also contributes to enhancsing the quality of life in urban areas by imposing increasing demands on the environment in relation to several factors including; safe transport lines for goods and people, water distribution stations and sewage systems, environmental sustainability and limited urban sprawl, green spaces and recreational areas, reducing energy use, reducing emissions and noise levels, heritage preservation and effective use of public places and real estate (Broere, 2015, pp. 245 -246). It is worth noting that in urban city centers at present, these demands pose significant challenges and obstacles because the spaces needed to improve existing jobs or develop new jobs are often not easily available. Therefore, placing infrastructure and other underground facilities is the best solution to obtain the required spaces as most of the areas above the ground have been exhausted with a lack of other solutions that may address complex urban problems. In addition, the high demand for land and natural resources, and air and water pollution due to unsustainable urban development are common challenges, especially in major cities, whether in the developed or developing world (ITA G. W., 2012, p. 7).

Urban underground spaces

For centuries, humanity has used underground space to serve it. Over time, the uses of underground structures have evolved from shelter primarily to infrastructure spaces in addition to a wide range of functional facilities (Broere, 2018, p. 1528). Hence, underground urban spaces are defined as spaces under urban areas that are characterized by their ability to provide the city with several services such as geothermal energy, groundwater supplies and others (Hunt, Makana, Jefferson, & Rogers, 2015, p. 1), meaning that they have the four basic resources for living, namely space, materials, water, and energy (Parriaux, Blunier, Maire, & Tacher, 2007). Each of these resources also has different degrees of regeneration depending on the method and rate of exploitation (Sterling, et al., 2012, p. 241). Today, these spaces serve as a dynamic medium through which anthropological systems and ecosystem services interact and affect each other through vital interdependence, which ultimately affects the functions of urban systems (Rogers, Lombardi, Leach, & Cooper, 2012, p. 5). Therefore, underground spaces are a particularly important area in city centers, whether in the developed or developing world, as these cities have no choice to develop, expand or become sustainable cities except to go higher or dig deeper (ITA G. W., 2012). The increasing uses of these spaces make them of great importance in meeting basic human needs in major cities not only in order to make them habitable but also livable and prosperous. Underground structures can be considered as one of the best solutions to urban problems since they are used widely to improve living conditions within cities for several functions, including transport tunnels (highways and metro), public service facilities (water supply and sanitation), green spaces and recreational areas, in addition to some industrial, Storage and other facilities (Hanamura, T., 1998).

Urban problems and solutions of Underground

The use of underground urban space has increased significantly in most of the world's major cities. The reason for this increased growth is mainly the high population density with the lack of surface areas and the need for a better environment (Bobylev, 2015, p. 40).Therefore, urban environments are facing many problems due to lack of basic infrastructure such as transportation, distribution of resources and services, in addition to

traffic congestion, poor environmental conditions due to air pollution and noise, lack of security, public safety and protection from natural disasters such as earthquakes and floods, lack of sufficient spaces for work and entertainment, aging infrastructure placed for distributing resources, transporting and treating waste water, in addition to restrictions on preserving the urban environment in areas of historical and cultural value (Broere, 2015, pp. 245 -246). Consequently, the requirements of residents in urban centers have increased. They want to obtain a higher quality environment by providing several requirements such as establishing safe and reliable transport lines for people and goods, providing advanced systems for distributing water and sanitation, paying attention to environmental sustainability and absorbing the expansion that has taken place, providing green spaces that match population growth, efficiency in energy consumption, reducing emissions, noise control, effective use of land and others (ITA G. W., 2012). All this requires constant improvement of planning, sustainable urban development, and efficiency in the use of resources. This can be achieved through the use of underground structures.

Despite the possibility of advanced construction techniques today to provide effective solutions to reduce the problem of traffic congestion or improve the standard of living environment in addition to energy efficiency, however, the main goal of using underground spaces in urban environments of city centers is to provide surface areas to meet the needs of other residents and improve the living and environmental conditions of these cities (Beigli & Lenci, 2016, pp. 1-2).

This research was divided into three sections to present the most prominent uses of underground urban spaces. The first section will address the most important problems and challenges mainly driver to the use and development of underground spaces in order to provide the best alternatives and solutions in accordance with the technical progress made. The objective fields to be discussed are building quality, security and public safety, traffic congestion, air quality, noise, water distribution systems and flood control.

In the second section of the research, the most leading model solutions that can be provided by underground spaces through metro systems, underground factories, water transport systems, sewage and rainwater treatment will be presented.

The third section will present the major global experiences of using underground urban space as an ideal solution for developing and expanding city centers.

The Most important urban problems

City centers are the most concentrated areas of human activities, characterized by urban growth that is unprecedented in terms of size and speed, especially in emerging global countries, where the economies of these cities are increasing significantly, which in turn is considered a threat to urban living environments in terms of urban land scarcity and rapid population growth (Yua, Kang, & Zhai, 2020, p. 1). Therefore, most of the rapidly urbanized city centers, in addition to being densely populated, face many problems and challenges. The reason is mostly due to the lack of transport infrastructure and the distribution of resources, goods, and services. (Broere, 2015, pp. 245 -246). Therefore, the urban environment cannot absorb the continuous increase in population numbers without making fundamental improvements to their infrastructure systems. The most distinguishable challenges faced by these cities are the need for more housing units, roads, water distribution systems, power, and sanitation, in addition to the importance of addressing the problem of air and noise pollution, problems of protection from natural disasters, severe shortage of work and entertainment spaces, as well as the restrictions on heritage preservation and old infrastructure (Burghignoli,

Callisto, Rampello, Soccodato, & Viggia, 2013). Urban sprawl outside city centers also leads to more traffic congestion with increased travel times, loss of arable lands and unfair allocation of resources (Chen D. , 2000).

Thus, the most common urban problems in the current era can find alternative solutions through the trend towards exploiting underground spaces, especially for rapidly growing urban centers. The most important of these problems are high population density with lack of work and entertainment space, traffic congestion, old infrastructure that does not meet the new requirements, air pollution and noise, city view and quality of the urban environment, safety, security and protection from natural disasters such as earthquakes and floods, transport and treatment of wastewater.

High population density and lack of lands

Urban centers suffer from high rates of continuous population growth. According to Khan Admiral[1], by 2050, more than 70% of the world's population will live in city centers (Mezhdunarodnogo, 2012), meaning that urban living environments are threatened by several problems (for example, scarcity of urban lands, population growth, etc.). Thus, the limited resources for the urban lands will face significant challenges due to rapid urbanization (Yua, Kang, & Zhai, 2020, p. 1). This in turn forms major challenges and obstacles to the infrastructure systems of these cities due to their inability to meet the needs of the population (Simankina, Braila, & Kanyukova, 2016, p. 1759). Along with the lack of infrastructure systems, an analysis of global development trends indicates that major cities have reached a critical limit in the possibility of horizontal expansion and that the possibilities available to add new construction to them are in the vertical direction only (Mulder, Baardman, Bernice, & Kate Arthur, 1997).

Traffic congestion and travel time

The need to reduce traffic congestion in the streets of the city, especially at peak times, is one of the most noticed problems experienced by urban centers today. Where along with the increase in population growth, the number of cars on the streets will increase as well, and the level of mechanization will be highly increased as a result. This in turn leads to the creation of large and continuous traffic congestion in these cities (Simankina, Braila, & Kanyukova, 2016, pp. 1759-1760). Accordingly, the use of separate railway systems can reduce traffic pressure during peak hours in addition to its role in saving hundreds of hours for each user annually (J.Godard, 2008). In addition to what has been mentioned, these mass transport systems have other advantages in terms of exploitation of surface area. Studies show that car traffic occupies 30 to 90 times more space than metro systems, depending on the type of use, whether for work, entertainment, or shopping. Similarly, public road transport systems above ground occupy 3 to 12 times more space than underground mass transport systems (M.Thewes, et al., 2012). Therefore, transforming the flow of underground transport systems improves access, traffic flow, reduces travel times and reduces the risk of collisions and road accidents (J.Cui & Lin, 2016), additionally providing serious public spaces, parks and squares and creating functional contacts and cultural and historical relations between parts of the city (Simankina & Popova, 2013, pp. 71-78).

Noise and air pollution

One of the most critical problems in urban areas is the noise and emissions caused by vehicles on highways. Therefore, sound barriers are often created to reduce the impact of noise, but in return these barriers have a significant negative visual impact on the urban landscape of

[1] Chairman of the International Expenditure Consortium's Underground Space Committee

the city. The value of lands near highways is usually lower, especially if it is residential properties. This is due to vehicle waste from noise and exhaust emissions (ITA G. W., 2012). Therefore, switching from using cars to travel to mass transport systems reduces the noise levels and local pollution rates in cities. Also, mass transport systems tend to be more energy efficient by going to metro systems (ITA w. g., 2003).

Protection from natural disasters

Due to the high population density in the city centers, their infrastructure systems are more subjectable to failures and damages. The reason is either because they are old and cannot meet the requirements of the population growth or because they are affected by natural factors over time (Broere, 2018, p. 1534). This population rise does not only mean that more consumers rely on the same existing infrastructure systems, but the facilities that residents may need to add later may increase the problem level highly. The high population rates also mean more built-up areas that may worsen the problem of floods in the rainy season as well as the loss of water resources that recharge groundwater stocks (ITA G. W., 2012). In this regard, underground construction can contribute to solving the problem through the possibility of establishing underground rivers to increase surface water flow or divert floodwater to them. Underground structures are often less vulnerable to natural disasters, primarily earthquakes and seism. Throughout history, it is noticed that underground metro systems have suffered little or no damage in times of major earthquake (Wallis, 2010).

Underground urban solutions:

Urban underground space is defined as a geographical area below urban lands that provides a range of services to the city such as groundwater supplies or geothermal energy. This area includes rocks geologically formed soil over time, artificial areas, and caves of various origins (Bobylev, 2015, p. 40). As for the man-made underground urban spaces, they consist of underground urban infrastructure systems, which are defined as a group of artificial structures that are located entirely or partially below natural ground level and are functionally and structurally interconnected (N.Bobylev, 2007). For centuries, these structures have provided shelter and storage for residents, they also helped to exploit valuable and limited spaces in urban city centers by placing service facilities underground and liberating the surface from them (H.Admiraal, 2012). These structures include a variety of service facilities, transportation lines that include railway tunnels and cars, basements within buildings that are used as warehouses or parking lots, in addition to shopping stores, public areas for pedestrians, and others. Therefore, the services provided by the underground urban space to the city can be summarized as follows:

Storage (such as food, water, petroleum products, industrial goods and waste), manufacturing, energy production facilities (thermal and ground energy resources), transmission lines including (railways, pedestrian tunnels, car roads), service facilities (including stations of water, gas, electricity and communications), waste disposal units (sewage complexes), providing public and recreational places (shopping malls, hospitals, parking lots, civil defense facilities) in addition to private spaces created by residents, including cellars under houses, home garages and underground dwellings (Bobylev, 2009) (Sterling, et al., 2012, pp. 241-254).

Transportation lines (tunnels)

Tunnels have been an important part of the urban fabric of cities for a long time, dating back to the late eighteenth and early nineteenth centuries (Sneh, Weinberger, & Shalev, 2010). In modern times, tunnels have played an important role in cities, where they

were initially railway tunnels and later developed into tunnels for the metro system within cities. It is worth noting that some major cities today, New York, for example, cannot operate as a city without its own subway system (Berry, 2009).The use of transport tunnels provides clean urban surface areas that serve as green spaces or recreational places for the city and reduces the impact of vehicles and mechanical means of transport on the environment. Effective and sustainable infrastructure systems have become vital to the economic development of cities. That is why major urban cities have established and expanded underground rapid transport systems in addition to service spending to be able to deal with the high demand for infrastructure systems caused by urbanization and high population growth rates (Admiraal & Cornaro, 2015, p. 1).

Infrastructure systems

Effective and sustainable infrastructure systems have become vital to the economic development of cities. That is why major urban cities have built and expanded underground rapid transport systems in addition to service tunnels to be able to deal with the high demand for infrastructure systems caused by urbanization and high population growth rates (Admiraal & Cornaro, 2015). The urban underground space can contain a large number of basic infrastructure systems for a city and its residents, including:

Drinking water storage and distribution systems

Access to clean drinking water is essential for human life. Today, there are a number of techniques and methods for delivering and treating drinking water (Tender, Couto, & Bragança, 2017, p. 266). This water is stored in dams and then distributed through either open channels or pressure pipes. Lake water, archways or water from deep aquifers may also be used to produce fresh drinking water.These systems share the fact that water needs to be stored, treated, and then distributed. This process requires large and integrated systems that include networks of basins for storage, pipelines for transporting and distributing water and pumping stations (Broere, 2018, p. 1534). It is worth mentioning that groundwater storage systems have been used in the past for more than 2000 years. These systems have evolved with the development of technology. They are equipped with filters and different methods to purify water intended for consumption by humans by providing additional protection to water against air pollution, making water supplies safer (ITA G. W., 2012).

Sewerage and rainwater drainage systems

The problem of dealing with the effects of rain and floods has become worse in overcrowded urban cities. Due to the large number of buildings, there is little possibility of rainwater infiltrating the ground (ITA G. W., 2012). The problem has been exacerbated by the conversion of areas near toilets and sewage stations to areas that are inhabited or used for economic purposes, in addition to the high intensity of floods and hurricanes due to climate change factors. Therefore, to deal with the effects associated with floods, there are several solutions and applications that may contribute to solving this problem: (Broere, 2018, p. 1534)

- Re-establishment of natural storage areas.
- Using drainage pipelines and tunnels to improve water drainage capacity.
- The possibility of establishing temporary tanks above ground to treat rainwater and sewage before discharging it into the natural water streams.

In addition to the above, the use of multi-purpose underground space systems is one of the most intelligent and interesting solutions that can address the problem without harming the environment and the population.

Underground energy storage and distribution networks:

The distribution of fuel and electric power requires an advanced system of infrastructure networks. It is necessary to ensure the continuous provision of these resources to urban areas. The subsoil plays a major role in providing and distributing energy to buildings. It has several options that contribute to providing several types of energy, including: (ITA G. W., 2012)

The urban heating systems for densely populated locations that use steam to generate and distribute heat through a network of thermally insulated pipes. Heat is generated in a central location either by burning fossil fuels in a co-generation plant, through biomass, or using geothermal heating and central solar heating.

Geothermal energy that is produced from the ground is an important source of heat and cold. It acts as a thermal reservoir suitable for many uses and applications due to the large volume available and the stability of ground temperatures. Thermal energy is obtained from the ground through geothermal heat exchangers or by pumping groundwater. Also, it should be noted that this method is used for both heating and cooling purposes.

Underground tanks are an important method to store gas and fossil fuels. Tanks are placed in underground cavities and then discharged through the pipeline networks. This leads to the release of large areas of the Earth surface used for other uses. In addition, it has provided a great potential for the development of residential areas. Also, this method improves the reliability of the system, allowing easy inspection and maintenance.

The development of the transfer of fossil fuels, fresh water, sewage, and electric power through an underground pipeline network emerged strongly during the nineteenth century. This transport process is a cost-effective method to transport liquids and compressed gases across long distances. It also guarantees easy and smooth distribution of energy and fresh water to urban residents.

Waste storage systems

The establishment of waste storage and transportation systems under the ground plays a role in reducing air pollution rates in the city, in addition to the lack of need for containers, the movement of garbage trucks above the ground and the accompanying damages, whether on health or environmental, or their impact on the urban landscape of the area (C.Delmastro, Lavagno, & Schranz, 2016).

In addition to waste facilities, and with the increased use of natural resources such as oil and gas, there is a constant need for mining at greater depth, which urges establishing carbon storage and transport systems, where placing carbon tanks underground is an effective alternative to avoid the impact of deposits that may be left on the ground. Also, these systems include storing nuclear waste. The increase in the production of electrical power in nuclear plants leads to a continuous increase in this waste (L.Sousa, 2000).

Underground shopping malls, Cultural and recreational facilities:

Shopping malls and recreational facilities such as libraries, museums, sports facilities, public places for gatherings and events, as well as green spaces in urban areas, are essential to what is known as the “quality of life” of these areas. Life in cities is closely linked to these facilities as they represent one of the important factors to attract people and contribute to staying and living in the city center. (C.Delmastro, Lavagno, & Schranz, 2016)

Due to the limited spaces in city centers, some of these cities have moved to establish their entertainment centers underground, which is the most successful alternative solution in accommodating the communities witnessed by these facilities while not affecting open areas and green spaces in addition to the urban landscape of the city (Broere, 2018, p. 1534).

Underground parking

It is a building or part of a building designed specifically for parking the cars and it is located underground. It is mostly reached by a slope starting from the level of the natural ground. It may also consist of one or several floors. Underground parking is becoming most common and used in cities around the world rather than multi-story above-ground parking lots (ITA G. W., 2012).

Underground offices and residential units

Due to the harsh climatic conditions, lack of heating and cooling resources, in addition to the lack of space above ground and the increasing need to provide additional space, especially when the building or area is of historical importance and is intended to be preserved, underground housing solutions have been used. In addition, the placement of some underground facilities such as laboratories or factories is more suitable for reasons related to safety standards, fire protection, protection from weather fluctuations, noise reduction, vibration and others.

Global experiments with urban underground space

Sustainable and effective infrastructure is essential for economic development. Therefore, most major urban cities have built and expanded rapid transport systems and underground service facilities to meet the demand for these facilities due to their increasing population growth. (Brown, 2011). Through an analysis of global trends in the development of major cities, it has been concluded that these cities have already reached a critical point in terms of the possibility of horizontal expansion. The possibility of building in them is in the vertical direction only. Therefore, the development of major city centers in the coming decades will be linked to the intensive and expanded use of underground spaces. This use is not considered one of the possible solutions to meet the contemporary challenges of these cities, but rather the only solution for the optimal development of major cities. (Belyaev, 2012, p. 254). As well, in countries such as Japan, China, Norway, Netherlands, Finland, Sweden and others, underground space is an essential component of city planning considerations due to the continuous increase in the population numbers and, as a result, increased pressure on the use of lands and resources (T.Hanamura, 2002).

China is one of the leading countries in the use and development of underground spaces in urban areas in particular because of its great role in improving the social reality of the city. In 2007 in Beijing, nearly 30 kilometers of these areas were reclaimed and the number increases annually by 10%. Today, about 200 cities in China have their entire shopping centers located underground.

Shanghai is one of the successful examples of the rapid development of underground spaces. It is the largest city in the world with a population of more than 25 million people. In 1995, it had one subway line, then in 2010 it owned 11 underground rapid transport lines with a total length of about 410 kilometers and 267 metro stations. According to the city development plan, seven more subway lines are scheduled to be built there by 2025 (Simankina, Braila, & Kanyukova, 2016).

In United States of America, the Boston Tunnel construction project is one of the most successful experiments in the exploitation and development of underground spaces. It is the most expensive in the United States at an approximate cost of 15 million dollars. It has contributed to significantly improve the traffic flow. Also, it is of a significant role in enhancing the environment of the city, reducing carbon monoxide, providing green spaces and public assembly areas.

Some major cities in the world are now entirely built underground. The development of underground cities began in the sixties of the last century in Montreal, Canada. Today, it is the largest underground city in the world with an area of 12 km2, with a total tunnel length of 32 km.

The development of the underground city has greatly facilitated mobility and movement as it has become possible to reach any area in the city by car without traffic congestion. The underground city also contains a wide range of services and recreational facilities that serve the city residents, such as shopping malls, hotels, offices, banks, museums, in addition to residential units, all of which are connected underground through the tunnel network (Simankina, Braila, & Kanyukova, 2016).

The city of Helsinki has succeeded in using and developing underground spaces since the sixties of the last century. The city has a plan project according to a long-term strategy to organize and develop the construction and exploitation of underground spaces. This development plan includes expanding pedestrian areas above ground and providing green spaces and public gathering areas for the city by building 400 underground facilities and developing more than 200 kilometers of transport tunnels

Results and discussion

All over the world, there is a necessary need to establish new infrastructure. Therefore, most urban centers are today rehabilitating, expanding and developing their existing infrastructure in order to be able to meet the demand for these facilities due to the huge increase in population in these cities. Therefore, the development of underground spaces has become an important tool in developing, expanding and reforming urban centers as the best solution to meet contemporary and future challenges, most of which the severe shortage of land and natural resources, the corresponding increase of population growth, in addition to energy efficiency.

Therefore, the exploitation of the subsoil through the establishment of infrastructure facilities and main transport lines in addition to many service facilities in the city offers an opportunity to achieve new jobs in the centers of these cities without compromising the basic structure of them, destroying its cultural and cultural history (especially in cities of historical value) or negatively affecting its surface environment. In addition, moving towards the subsoil in urban areas gives high potential in terms of improving the environmental level of the city and the efficient use of natural spaces and resources.

Through addressing a small number of global experiences about using the subsoil to meet the most prominent contemporary urban challenges, it can be seen that most underground construction and planning solutions play a prominent role in solving and improving the problems faced by city centers, such as rapid urban development, environmental challenges and pollution, traffic congestion, and the huge increase in the population.

In addition to the severe shortage of green spaces, the need to protect against natural disasters such as earthquakes and floods, which are increasing today as a result of global climate change, the scarcity of food infrastructure resources and the increasing consumption of non-renewable energy resources, as well as facing the problems of providing safe drinking water and wastewater treatment.

Therefore, it has become necessary for engineers, planners, and decision makers to include underground spaces in the plans of expanding and developing urban cities. The most important thing to plan is the subway and underground infrastructure systems as they can be considered the main step towards the organized use of urban underground spaces.

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