Ecological Construction and Reconstruction of Underground Space of Cities

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Abstract. This article focuses on the effective ecological technologies for the development of the underground space of cities (the use of the alternative energy sources: sun, geothermal heat, wind, etc.). The article summarizes and analyses the foreign and domestic experience in the sphere of ecological construction and reconstruction of the "underground cities" and spaces. Three directions in the field of the ecological underground construction are considered here: the construction of the autonomous underground ecocities; the ecological underground construction in the conditions of the current real estate development of the city; the ecological use and reconstruction of the already existing underground constructions. The study of foreign and domestic experience shows that the optimum conditions for ensuring the sustainable development and comfortable living conditions in the cities and urban agglomerations which are, for example, similar to Moscow, according to such indicators as total area, population, the ratio of historical and modern buildings, are reached at a share of 20-25% of the underground constructions in relation to the total area. It is possible to conclude that the ecological underground construction is justified, and, as any other type of the ecological construction, is going to become one of the priority directions of the development of cities in the near future.

1. Introduction

The population growth in big cities of the world results in the fact that about 80% of the total population is concentrated in them. In these conditions the problems of the development of megalopolises have become aggravated: the expansion of cities and the increase in the number of storeys of buildings and constructions; the aggravation of the transport problem; the reduction of the green areas; the appearance of a lack of institutions necessary for the population (schools, preschool institutions, hospitals, policlincs, shops, etc.); the increased expenditures on water supply, heating, waste disposal, etc.; the environmental degradation in the big cities.

Let us consider the last direction – the environmental degradation in the city –and the ways which may help to correct or adjust it. One of the most effective solutions of this problem is the development of the underground space. Our purpose is the development of the new concepts of creation and preservation of the native habitat, the achievement of the priorities of the ecological wellbeing and sustainable development and the creation of comfortable living conditions for people by the use of the underground space of the big cities.

The underground construction should be eco-friendly and should be characterized by: the use of ecologically effective technologies for the development of the underground space; the development of
actions for the prevention of possible negative consequences of construction of the underground constructions (building subsidence, violation of the hydrogeological mode of the underground waters, penetration of water from the pressure tunnels, etc.); the identification of the decompression zones dangerous for the construction of the underground constructions in the rock massif; the construction of the underground, comfortable and safe constructions of a new generation.

2. Literature review

The history of use of the underground spaces goes to the paleolithic era: the construction of the underground grave mounds in the ancient Egypt (the 2nd millennium BC); the construction of the underground cities of 18 floors in Anatoly (1-2 centuries AD); the construction of the underground monasteries in Georgia (6-13 centuries AD); the construction of the underground dwellings in the territory of China, Bulgaria and in other countries [1,2].

The transport tunneling has been developing since the 17th century (France, England, Germany, the USA and other countries). In the second half of the 19th century in Russia the underground reservoirs have been built, and at the beginning of the 20th century the first underground hydroelectric power stations (Germany, Sweden), industrial facilities (France, the USA, Japan and other countries) have been constructed [2,3].

The main objective of the scientifically based approach to the development of the underground space taking into account the ecological requirements is the use of the new technologies in the underground construction. New technologies assume the elimination of the ecological crisis in the difficult system "rock – technology – underground construction – environment".

At the present time in the field of the ecological underground construction the following three directions are considered: 1. the construction of the autonomous underground ecocities; 2. the ecological underground construction in the conditions of the current real estate development of the city; 3. the ecological use of the already existing underground constructions.

3. Materials and methods

In the first direction Japan has succeeded [5,6]. It is connected with small limited territories and the large numbers of the population. For this reason the concept "Geotropolis" providing the development of the underground urban environment is put forward. If the concept of "Geotropolis" leads to the creation of the comfortable inhabited environment underground, the Japanese will be able to take such advantages as the excellent thermal insulation and the reliable protection against earthquakes (Fig. 1).

At a depth of 50 meters the underground city with its own shopping streets and stations of high-speed underground trains is created.

One more of the proposed Japanese projects of the underground construction "Alice" is named after the heroine of the fairy tale of L. Carroll (Fig. 2).

The project provides for the creation of two cylinders with a height of 65 meters, embedded for 165 meters in the earth and with a diameter of 260 meters each, in the space of which it is possible to place the power generation equipment, the equipment for air conditioning and for the utilization of household waste. Each of the cylinders is connected by the underground corridors to the artificial spheres where shops, theatre and concert halls, sports facilities, hotels and offices are placed.

Figure 1. “Geotropolis” project, Tokyo, Japan

Figure 2. “Alice” project, Tokyo, Japan
At the lower level the objects of transport infrastructure and the metro stations are settled down. Sunny atriums, holographic images of the surface and plenty of open space at the higher levels have to protect people from the possible occurrence of the feeling of claustrophobia. The heating costs are minimized due to the use of the geothermal energy of heat generated by the city residents.

The strictest requirements within the framework of the project relate to the problems of heat, sound insulation and seismic stability. Such complex could support the existence of 100 thousand people.

Within the framework of the project "The city geogrid" of the "Shimizu Corporation", the construction of the underground cities includes the creation of the impressive network of the underground atriums connected together by tunnels where the offices, banks, sports facilities, libraries, and showrooms will be placed. This complex is planned to be embedded in the earth for 55 meters (Fig. 3).

![Figure 3. "The city geogrid" project, Japan](image)

The project envisages not only the maintenance of comfortable microclimatic conditions, but also the natural sunlight transferred to the underground rooms by means of the mirrors. The underground city of about 1250 km² could accept half a million residents.

The second direction is presented by the new ecological underground construction in the conditions of the current real estate development and is connected with certain aspects.

The problem of such underground construction is connected with the repurposing of the already constructed underground facilities and the construction of new ones in much more constrained conditions. A good example of this is the underground shopping spaces built in the nineties of the last century in Osaka (Japan). In terms of the underground areas filled with restaurants and shopping spaces Osaka ranks among the highest in East Asia (Fig. 4) [8].

The underground crosswalks, the shops in the basement floors of the department stores and office buildings, the new underground shopping centers form the complex network of the underground streets. It took Japanese 60 years and large financial investments to turn the underground complex into the comfortable environment for people.

Despite this illustrative example, the underground construction is often unsystematic and separate. In this case it is necessary to apply not only the horizontal, but also the vertical one (Fig. 5).

The ground surface (the 1st level) has to be adapted for the placement of the residential buildings, the constructions intended for the long-term residence of people, the green areas. On the 2nd level it is desirable to place the objects of the commercial character (cinema halls, shopping centers), garages, stations, transport hubs.

Such positioning gives the possibility to provide objects with the optimum natural sunlight. Infrastructure and communications in the 3rd level do not provide the best communication between the objects of the 2nd level and the constructions placed below. At the same time the noise level, influencing the surface can be much lower. At the 4th level it is better to place the objects which presuppose the minimal presence of people: warehouses, refrigerators, industrial facilities with the automated processes. The levels should be connected by transitional zones for ensuring the most optimum interrelations. Let the h depth be 400 meters. It is enough for the use of the low-potential geothermal energy of the earth.
One more example of the competent realization of the multilevel underground complex is the "Path" complex in Toronto, Canada [8,9]. The well-planned underground way that is 28 kilometers long allows to move around the city without rising to the surface; it provides the connection of all large buildings, skyscrapers in Toronto the quantity of which is more than 50. In the territory of the underground city the shopping spaces (more than 1500 points of sales), the personal service facilities, the commercial structures, the hotels, and the railway terminal are located.

Figure 4. The underground center “Umeda”, Osaka, Japan
The buildings connected by the underground crosswalks
The shopping spaces, etc.
(1) Whity Umeda; (2) Diamor Osaka; (3) Hankyu Sanbangai; (4) The underground shopping center “Dojima”; (5) The shopping space with fountains; (6) Kitashinchi station, JR Tozai line; (7) Umeda Station, Midosuji subway line; (8) Higashi-Umeda station, Tanimachi subway line; (9) Nishi-Umeda Station, Yotsubashi subway line; (10) Hanshin Umeda Station

There are some interesting ideas on the design of the railway stations. Architects Galmidi Vittsgar and Valkzayn Eliran have offered the project of the underground railway station in Tel Aviv, Israel (Fig. 6) [10]

Figure 6. The underground railway station in Tel Aviv, Israel
Figure 7. The underground railway station in Malmö, Sweden
At the station the solar illumination is provided. White walls also ensure the light reflection that increases the intensity of illumination of the station in general and ensure more space. One of the examples of reconstruction of the underground construction is the railway station in the city of Malmö, Sweden (Fig. 7) [10].

The building has a round roof with a diameter of 45 meters and with 52 openings for providing the access to sunshine. According to the initial conceptualization of designers, the illumination should ensure the safe and comfortable environment for passengers.

Among the examples of experience of the use of the underground space for the placement of sports facilities we can mention the sports center "Bilbao Arena" in the city of Bilbao, Spain (Fig. 8) [10].

The "Bilbao Arena" Center has a capacity of 10 thousand seats and is intended for holding the basketball games, concerts and other public events. The sports center is located on the hill and is visible from all directions. The design of the center fits the landscape – the upper part is associated with the tree crowns. The image of the lower part is associated with the rock. The dominating color in the design of the building is green and is associated with the color of foliage or grass; it is used not only in the external finishing of the frontage, but also in the interior design. Within the building there is the natural ventilation and the system of the longest possible use of natural lighting by changing the position of mobile green steel plates from which the upper part of the stadium is made. The rooms with various functions are divided by glass partitions to ensure the dispersion of light through the entire space of the center. One of the important principles of the project is the full compliance with the current trends of eco-architecture.

The next example of the use of the underground space is the underground stadium "Al Ain Stadium" in the UAE (Fig. 9) [10].

The use of the underground space allows to place a huge construction in harmony with the surrounding landscape. The second purpose of such decision is the use of technologies of passive cooling of the object which reduces the energy costs for its maintenance.

The project of the residential complex “Above Below”, Bisbee, Arizona, USA
The third direction is the ecological use of the underground objects of the anthropological character presupposes the use of the abandoned quarries in the first turn. So in the State of Arizona, in the city of Bisbee, USA, it is planned to build the underground residential complex named "Above Below"; this construction is considered to be a tower of 270 meters in depth (Fig. 10) [10].

The project of the residential complex designed by the architect Matthew Fromboluti has been created for the annual competition of projects of skyscrapers. The depth of a pit is 275 m, and the width is 90 m. The construction will represent a self-sustaining system with the recycling water supply and climate control, it will be capable to generate not only energy, but also the transparent cupola and numerous light windows located on the ground surface. In the city itself, on terraces, it is planned to make gardens, parks and recreation areas.

The underground complex will receive the electric power from the solar batteries and wind turbines installed above the ground surface.

Similar projects on the use of the abandoned quarries are not a rarity. The Moscow architects from "AB Alice" bureau intend to cover with a glass cupola the second-large quarry in the world where the production of diamonds near the polar city Mirny is carried out (Fig. 11) [10].

This project called "Ecocity 2020" provides the construction in the pit with a diameter of more than 400 m and with the depth of 520 m the city with step levels – the terraces connected by elevators and other vehicles.

In the middle of the city there will be the big open-type mine with the help of which the sunlight will get to the deepest levels. On the transparent cupola of the city the solar batteries will be located, which will be the main sources of energy for the city. As a source of heat it is offered to use the heat of the earth and the energy emitted by the city and its residents.

The ecological use of other underground objects is also possible – for example the air-raid shelters, the abandoned enterprises and other engineering constructions. There are a lot of such objects, including both under the territories of the cities and out of the settlements. The use of the similar constructions can be one of the priorities for the development of the underground space.

As an example it is possible to use the idea of the American architect James Ramsey who has invented the technology allowing to collect the sunlight and to send it under the earth where it can be stored in special panels. He is planning to turn the unused old tram depot into the underground park - the city garden "The Lowline" in New York (Fig. 12) [12].

In Moscow there is the "Bunker 24" created in 2006 in the former secret military facility of the USSR, the spare command post "Tagansky" of 7000 m² and with the footing depth of 60 m. It is used now as the Military and historical museum and as the museum-entertainment complex for conducting the excursions, buffet receptions, team paintball games, etc., fig. 13[10].

The mechanism of the development of underground space is confirmed now by the continuous increase of volumes of the underground construction around the world. Nowadays it is difficult to imagine many cities without the underground shopping centers and parkings. In Russia the underground objects of the commercial real estate started to be constructed relatively recently. The study of foreign experience shows that the optimum conditions for ensuring the sustainable development and comfortable living conditions in the urban agglomerations which are, for example,
similar to Moscow, according to such indicators as total area, population, the ratio of historical and modern buildings, are reached at a share of 20-25% of the underground constructions in relation to the total area of the commissioned facilities. In Moscow the share of the underground constructions put into operation from 2005 to 2015 does not exceed 10%. According to the volumes of the underground construction in Russia Moscow is the undisputed leader.

As for the ecological underground construction in Russia, at the present moment it is limited to the construction of private underground objects. The use of ecological technologies in the construction on land is much more widely-spread, but this tendency is characteristic not only of Russia, but also of all countries of the world. Nevertheless, the tendency of the ecological use of the underground space could be extended also to Russia. Most likely, the first decisions will be connected with the realization of the potential of geothermal energy.

4. Results
When using the thermal energy of the earth it is possible to allocate two types of thermal energy – high-potential and low-potential. The sources of high-potential thermal energy are the hydrothermal resources – the thermal waters heated as a result of the geological processes to a high temperature that allows to use them for heat supply of buildings. However the use of the high-potential heat is limited to the areas with certain geological parameters, for example, Kamchatka, the Caucasus, the regions of Hungary, Iceland, France, etc.

The use of the low-potential heat of the earth by means of the heat pumps, however, is possible almost everywhere. Now it is one of the dynamically developing directions of the use of the nonconventional renewable energy resources. As the examples given in article show, all above mentioned aspects are successfully realized within various objects and fully justify their use.

The urban planning efficiency of the integrated ecological use of the underground space includes:
- the use of the spatial formation of the real estate development includes the following aspects: architectural and planning, three-dimensional, social and economic, ecological, engineering and technical, esthetic;
- the achievement of the increased comfort of living conditions and public service in residential areas is caused by the expanded nomenclature of the subsidiary premises and facilities placed in the underground space: shopping centers, cinemas, hotels, sports facilities, warehouses, garages, stations and other transport and infrastructure facilities;
- reduction of the energy consumption for heating and ventilation by 50-80% in comparison with similar ground facilities due to the use of high- and low-potential thermal energy of the earth;
-savings on the given costs: for land use engineering through reducing the volumes of earthwork operations and combination of engineering networks, the use of sound-proofing and vibration-isolating properties of the earth.

5. Discussion and conclusions

The widespread development of the underground space, i.e. the construction of the second "underground" city is one of the principles of the ecological reconstruction of the cities. The Russian construction complex has the real possibility of transition to the ecological development of the underground space based on the available foreign experience, bypassing the stage of the unstructured use of the underground environment which is taking place at the moment. It is possible to conclude that the ecological underground construction is justified, and, as any other type of the ecological construction, is going to become one of the priority directions of the development of cities in the near future.

References

[1] Avdotyino L. N., Lezhava I. G., Smolyar I. M. 1989 Urban design. M.: Stroiizdat.
[2] Borodin V. I. 1995 Industrialization of underground space-a global perspective of the XXI century. Almanac of scientific and technical information. Pril. to the journal. Underground space of the world vol. 5-6.
[3] 1996 Digest of foreign information: ADJ. to the journal. Underground space of the world vol. 1-2.
[4] Degtyarev B. M. 1998 State, prospects and problems of underground space use in Moscow Proceedings of the international conference "Underground city: Geotechnology and architecture". - SPb.
[5] Ivakhnyuk V. A. 1999 Construction and design of underground and buried structures. M.:ASV.
[6] Konyukhov D. S. 1999 Use of underground space. M. Architecture-C, p. 204.
[7] Kulinova E. Yu. 1998 Ecological safe technologies of underground construction. Gorny Vestnik vol. 1.
[8] Petrenko E. V., Petrenko I. E. 2001 Problems of underground space development with the account of economy globalization. Underground space of the world. Vol.1-2.
[9] Petrenko E. V., Petrenko I. E. 2001 Problems of underground space development in the twentieth century. Problems of transport and engineering communications. Pril. to the journal. Underground space of the world. Vol. 3-4.
[10] Materials of the Internet resource http://www.worldarchitecturenews.com/
[11] Koretsky, V. E., Peace, A. N. 2011 Economic and environmental concerns of alternative energy. Clean city vol. 2 (54) pp. 3-13.
[12] Yazhlev I. K. 2012 Ecological improvement of polluted industrial and urban areas: Monograph.: ASV.
[13] Wolfson V. L., 2004 Reconstruction and overhaul of residential and public buildings. M.: Stroiizdat.
[14] Kasianov V. F., Gutseriev V. S. 1997 Special issues of renovation of buildings. Textbook.-Moscow: MGSU.
[15] R. I. Fokov 2012 Ecological reconstruction and improvement of urban environment. monograph Moscow : ASV.
[16] Mavlyutov R. R. 2015 Spatial development of large cities of Russia in the period of post – industrial transition [Electronic resource. Volgograd: Volgograd state University of architecture and civil engineering.