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MODERN TRENDS OF ORGANIZATION OF THE UNDERGROUND URBAN SPACE

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Abstract
The article is devoted to important issues of perspective modern organizational tendencies of underground urban space. Innovative world experience of organization of underground space and its use by creating underground buildings and structures for optimal working, living, recreation and movement of the urban population, increasing the area of open green spaces on the surface, creating a comfortable and aesthetically attractive urban environment are reviewed. The ecological, economic, political and cultural features that influence the formation and development of underground space in terms of sustainable development are analyzed. The architectural and spatial structure and functional features of underground permanent cities are considered. The basic modern tendencies of the organization of underground urban space are defined in the town-planning architectural-spatial, functional aspects and aspects of sustainable development.

Keywords: **Architecture; Earthscraper; Sustainable development; Underground buildings and structures; Urban space.**

1. INTRODUCTION

Exploration and development of underground urban space in the context of sustainable urban development is a global trend. It is facilitated by the process of urbanization, as cities are the main sources of pollution and energy consumers. This means a constant increase in urban population and an increase in the number of road transport, which provokes modern urban problems – territorial, transport, environmental and energetic. Uncontrolled development of urban areas leads to increased traffic jams and as a consequence of air pollution, to absence of green spaces and deterioration of water supply, which is incompatible with the concept of sustainable development.

The strategy of innovative development of underground urban space is the scientific discipline of underground urban planning. Underground urbanism is an area of architecture and urban planning, associated with the integrated use of underground space of cities and other settlements, which meets the requirements of urban aesthetics, social hygiene, as well as technical and economic feasibility [1].

The efficiency of urban development of underground space as an underground part of the territory in conditions of shortage of land suitable for development is maximum. Underground placement of architectural objects that can be operated under artificial lighting creates conditions for the preservation or rehabilitation of natural and historical landscapes, decreases the number of storeys and improves such architectural and urban environmental parameters as accessibility, security and energy. The advantages of developing the

underground space of cities to achieve sustainable development also include stability of the microclimate, isolation from noise, vibration, radioactivity, gassiness, seismic resistance and optimal use of groundwater, geomaterial and geothermal energy. Within the city, underground structures can be located almost anywhere, with minimal impact on the natural landscape and the environment. They are reliably protected from the direct influence of climatic factors. Underground structures are characterized by high vibration resistance and acoustic insulation. And protected from the effects of seismic waves and penetrating radiation, which ensures their invulnerability to mass destruction [1, 2].

The purpose of the article

The purpose of the article is to determine the current trends in the development of underground space as one of the possible ways of developing an urbanized environment in the conditions of an acute shortage of territories for the development of already existing cities, agglomerations and conurbations and the formation of new ones.

2. METHODOLOGY

The theoretical study is based on the works of scientists Kenneth B. Labs [3], H. Admiraal, A. Cornaro [4], who considered conceptual approaches to the formation of underground space. Rethinking the architectural and urban planning situation of cities taking into account the architectural and spatial organization of the underground environment was studied by E. Reynolds [5], Von der Tann Loretta [6], P. Stones, Tan Yoong Heng [7]. P. Gilbert [8], H. Admiraal, A. Cornaro [4] dealt with issues of sustainable underground development of cities. The issue of protection against the influence of underground radiation on people, in particular, recommendations to place residential blocks in a certain sequence and consider them as temporary housing, were considered by V. Praslova, Y. Riabets, V. Shchurova, O. Zinovieva, M. Harbar [9], some ecological aspects in the use of underground space were investigated by H. Brown [10]. It should be noted that the vast majority of works consider the development and organization of underground facilities and structures within superlarge cities and urban space. But depending on the functional direction, there are objects that are deliberately taken outside the city limits, turning over time into new places of attraction. Therefore, in the study, the authors consider the entire picture as a whole and classify underground complexes according to their location within the country. The study consists of a systematic and comparative analysis of the organization of underground space and underground sustainable cities and settlements that emerge in leading countries. The analysis of literature, normative, graphic, analytical documents, information sources and photofixation were used in the study. The following methods were used to study the processes of organization: architectural and urban planning, functional planning and conceptual-artistic. The architectural and urban planning method is used at the stage of forecasting the place of organization of underground space and involves taking into account the existing urban context in the formation of architectural features of the environment. The functional-planning method allows to determine the main structural functional blocks and zones that are part of the blocks, to identify appropriate connections between them and to develop an effective model of the planning structure of space on the basis of these parameters. The conceptual-artistic method is designed to create a concept of organization of underground space and to form a unique artistic image and atmosphere of the environment, which has integrated all the methodological components of the project [11].

3. EXAMPLES OF ORGANIZATION OF UNDERGROUND URBAN SPACE

3.1. Earthscraper in an industrial environment

A progressive global trend is the formation of a compact city model [2, 12]. These are theories of “new urbanism” and “smart development” with a focus on human interests, creating a high-quality green urban environment, giving priority to pedestrians and cyclists, accessible public spaces and services, a variety of multifunctional and coordinated natural scale buildings, approaching housing and work. This model corresponds to the urban development of underground space, which is widely developed in many cities around the world. This direction allows you to develop underground space within an artificial environment and is a good way to implement the principles of sustainable development [2, 12, 13]. An interesting example of the organization of underground space within industrial development is the project of Mirny city in Yakutia ECOCITY 2020, developed by the architectural bureau ELIS in 2009 [14]. **Urban aspect**: In the suburbs of Mirny in Yakutia, there is a huge quarry left after the industrial diamond mining. This quarry, with a diameter of more than 400 meters and a depth of about 520 meters, is the second largest

23 artificial hole on the planet's surface. These parameters determined the location of the design solution. **Architectural and spatial aspect** The ELIS Architectural Bureau has developed the ECOCITY 2020 project, proposing to cover this quarry with a translucent dome, turning it into a multi-level underground city or earthscraper. The term "earthscraper" is used by analogy with "skyscraper", meaning a multi-level underground structure. The area of the city will be 2 million square meters. About 100,000 people will be able to live in this area. The project provides the creation of stepped levels of the city, interconnected by elevators and other transport devices. In the central part of "Ecocity 2020" there is a vertical atrium, through which sunlight penetrates to all levels. The city's transparent dome will house solar panels, which will be the city's main source of energy. **Functional aspect**: autonomous with the following functional zones: developed housing, as well as industrial, social communication and recreation, sports, entertainment, consumer services, technical and transport. Some of these areas other than residential can develop outside the underground space, organically combining with it. **The aspect of sustainable development**: meeting energy needs, renewable energy sources, strong focus on innovation, automation, efficient transport systems and advances in elevator technology on electromagnetic propulsion provide optimal hyper-dense urban environment [15].

3.2. Earthscraper in a historical environment

The works [16, 17] consider the city as a single three-dimensional hierarchical multilevel system. According to this concept, people, buildings and structures are the structural elements of the system and form the structural layers of the city. The configuration and parameters of the layers depend on physiological, material and economic needs [2]. Each of them is responsible for addressing certain social needs. Groups of structural layers form the "backbone" of the city and the urban planning structure – the "body" of the city. According to the functional purpose, the social, production, auxiliary and managerial layers are distinguished [2]. The base layer is land and water area. Its other parts are the airfield and underground space. The underground space is considered as one of the levels of the single volumetric multilevel urban space. It is developing in the direction of creating underground buildings and structures for the people's full existence and stay underground. This trend, characteristic of the development of the historic centre, sets itself the task of sustainable development of the city without interfering with the historical environment [2, 16, 17]. An example of such an organization is the project The Earthscraper in Mexico City from BNKR Arquitectura, created in 2009 [15, 18, 19]. **Urban aspect**: under the historic Piazza Zocalo in central Mexico City. There are unique architectural monuments of Mexico City around this square: the cathedral, the National Palace and the city government building. Therefore, the underground structure of Earthscrapers is the result of increasing the existing space, which meets the criteria of construction and laws on the preservation of historical heritage. **Architectural-spatial aspect**: resembles an inverted pyramid 304 m below ground level, designed to be visited by 100 thousand people. The free central space is covered by inclined translucent enclosing structures, which narrow to the bottom according to the spatial shape. **Functional aspect**: autonomous with functional zones connected by vertical blocks, each of which has ten levels. Therefore, a developed cultural and museum block is located closer to the surface of the earth, a shopping block is below. Even lower there is a block of residential areas and a block of office space, stretching vertically to 35 levels. Between these blocks are green levels of social communication, entertainment and recreation. The Monitoring and Evaluation (M&E) technical area is located at the lowest level. **Aspect of sustainable development**: meeting energy needs, efficient use of existing resources, strong cultural orientation and economic interest [15].

3.3. Earthscraper in the transport network environment and interchanges

The transport network is the basis for the functioning of any city. Therefore, one of the important current trends in the organization and development of underground urban space is the use of existing transport tunnels and the active creation of new ones to preserve their main function and to introduce other functions needed by the city to harmonize the existing environment. Depending on the location in the structure of the city, the underground space is characterized by the possible location of all modes of transport: road, air, rail, urban public (mostly subway), as well as a river when placing the complex in the water area. These are transit underground and aboveground transport tunnels, overground and overground roads and car parks, which in one case are integrated into the structure of space and become the basis of its framework, and in the second case are

located on the perimeter of urban spaces and often divide spaces into isolated parts [2, 20]. The first case is typical for European countries, where the transport system with transport interchanges has been formed and is developing for a long time in the concept of general development of the city. The second case is typical for the development of underground space in our country. An interesting example of self-development based on this trend is the innovative underground network Hydro-Net, designed by Iwamoto Scott Architecture in 2018 to ensure the viability of San Francisco, USA in the XXII century in the City of the Future competition from History Channel [21]. **Urban aspect**: The Hydro-Net concept is like a huge symbiont or mycelium that penetrates the urban space of the aquaculture zone with reservoirs and consists of deep tunnels and nodes of underground space and land skyscrapers. This new infrastructure is designed to maximize and rationally allocate resources in a constantly growing urban population, which is projected to double in the near future. **Architectural-spatial aspect**: the network of underground tunnels and nodes of Earthscraper and terrestrial skyscrapers covers low-lying areas that have been affected by global warming and partially flooded. The underground urban space is organised at key hub junctions and HYDRO-NET tunnel intersections, which strengthens the links between aboveground and underground urban space. The artistic image of the new architecture is reminiscent of opportunistic "urban caves, reeds and outgrowths", creating new social spaces and urban forms that are fed by the resources and connections provided by HYDRO-NET. **Functional aspect**: underground-terrestrial infrastructure network can collect and distribute water, electricity, fuel and goods and provide transportation for both residents and tourists. The algae grown here are raw materials for the production of hydrogen fuel, which is stored and distributed in a network of tunnels. Lower levels are used as technical and service areas. There are tanks for water and hydrogen, they circulate automatic hovercraft controlled by computers. It is planned to expand the underground urban space for the organization of public functional processes. **Aspect of sustainable development**: this ecological city of the future is self-serving and self-sustaining. The HYDRO-NET symbiotic and multiscalar system is an urban infrastructure that organizes critical flows of the city. HYDRO-NET provides an underground arterial network for hydrogen-powered vehicles while collecting, distributing and storing water and electricity from aquifers, as well as geothermal energy located in the land near San Francisco. Tunnel constructions made of carbon nanotubes are built using automated drilling robots. Drinking water is extracted from underground aquifers and fog trappers, called Fog Flower. They are located in places where the concentration of fog, due to the terrain, is highest. The city accumulates energy from raw materials for the production of hydrogen fuel in the Algae Tower eco-towers filled with seaweed and sunlight, as well as in geothermal stations called Geothermal Mushroom. In this way, energy needs are met through renewable energy sources, composting of biomaterials and waste processing into energy [22].

3.4. Earthscraper in artificial relief

This direction corresponds to the trend of biosphere-compatible, human-developing cities [23], viable and self-developing populated cities [24]. At the same time, the city is considered as a complex natural and human-made system that harmoniously combines the sociosphere and ideosphere, and is designed for comfortable living, human reproduction and evolutionary development. In particular, in [16, 17] it is proposed to consider the city as a space that is divided into subspaces as part of one whole. The hierarchy of bases and layers is multilevel. The structural elements of the city are people (society as a basis for the stratification of the surrounding space), anthropogenic objects (buildings and structures) and the territory as a space within the jurisdiction of the city. The configuration and parameters of the layers depend on the set of social needs (physiological, material, economic) [2, 25]. Within the framework of this trend, the development of underground cities in artificial excavations, canals, dams, dumps and quarries, which remain after the industrial extraction of minerals on the planet's surface. The use of this approach can be illustrated by the example of the project Rhizome Tower: A Thousand Underground Plateaus, designed by architects Federico Tinti, David Mariani, Enrico Tognoni in 2011 [9, 26]. **Urban aspect**: the underground urban space is self-organizing in response to abrupt climate change and ecological catastrophe in the artificial relief of our planet without attraction to existing cities. The rhizome is not the only element, it is a network structure containing a large number of underground complexes that work together as an underground city [26]. **Architectural-spatial aspect**: The project really resembles a rhizome, the volume of which is divided into four different parts and grouped vertically around the open space of the central core. The cen-

tral core is open to natural light due to the street atrium. The part, which is located above the ground, has three levels and contains agricultural fields, farms and greenhouses. The translucent facade of this part forms an enclosed space and gradually flows into the sloping covering of the central atrium, which narrows to the bottom, repeating the architectural form. The second underground block consists of 60 levels. This unit is changing and adapting to emerging functional needs due to different variations in the use of modules rooms of several sizes. The third and fourth blocks are located in the deepest part of the ground. These units are dedicated to the study of geothermal energy and provide self-service. **Functional aspect**: autonomous isolated structure with functional zones connected by vertical blocks. The first part contains recreational, as well as food, production areas, agricultural fields, farms and greenhouses. The second block consists of 60 levels. This unit has a living area, with a wide range of housing modules according to family size. The third and fourth blocks are located in the deepest part of the ground. These units are dedicated to the study and collection of geothermal energy and are used as research laboratories, office, technical and service areas. Between the blocks at the top of the structure are the levels of social communication, recreation and landscaping, combined with horizontal pedestrian connections. **Aspect of sustainable development**: The main idea is to develop an underground city that collects natural resources above and below ground for self-service and full nutrition of residents at the expense of the surrounding areas. Satisfaction of energy needs is arranged at the expense of renewable energy sources, efficient use of resources and processing of waste for energy. In particular, photovoltaic elements for solar energy collection are located on the translucent facade, several places are equipped with wind turbines. The city's self-sufficiency in energy is also due to the collection of geothermal energy [26].

3.5. Earthscraper in natural relief

No less innovative trend of organization and self-development of the underground urban space is the unity of the city and nature by analogy with the biosociety (such as ants or bees) [2, 27]. Successful implementation of this trend is possible, with a balance achieved between the social, technical and biological spheres. Emphasis is placed on the functions of the city that meet the rational needs of residents: providing a comfortable life, culture and creativity, connection with nature, recreation and entertainment [23, 28]. The city becomes capable of organization and self-development with the predominance of order over chaos, which stabilizes the urban structure, functioning and development of its society [2, 29]. Analysis of the experience of the organization of underground cities has identified a number of possible places that allow you to arrange structures using concave natural relief. These are inactive volcano mouths, hollows, river valleys and underground aquifers. A good example of such an organization is the underground city of Sietch Nevada, designed in 2009 on the lakes near Silver Peak in Nevada, USA by Toronto University scientists: Andrew Kudless (Design), Nenad Katic (Visualization), Tan Nguyen, Pia-Jacqlyn Malinis, Jafe Meltesen-Lee, Benjamin Barragan (Model), based on innovative technologies for conserving drinking water reserves of urban infrastructure in southwestern America [30]. **Urban aspect**: it is a prototype of an underground city in the conditions of possible future disappearance of water sources. Sietch Nevada is a dense underground network that self-organizes in the natural terrain of our planet without attraction to existing cities and self-develops on the principle of building honey bees' hives. The honeycomb network based on catchment canals contains a large number of underground structural units that work together as an underground city. **Architectural and spatial aspect**: Each honeycomb structural unit has an open spatial central core, which is naturally illuminated and, if necessary, covered by a protective translucent dome. The centre of the nucleus is located above the natural underground lake, around the perimeter of which are grouped rooms. These structures have approximately the same parameters in width, length and height and have 10 underground levels on average. They constitute a new typology of neighbourhoods and act as an intermediary between the underground urban network and surface-level activities, as well as underground residential and commercial buildings. **Functional aspect**: Honeycomb structures provide autonomous urban life and function like underground Venice. At the surface level, there are economic, food, production and functional zones. Levels closer to the ground floor are diverted to housing. Canals connect the city with huge aquifers deep underground and provide transport links as well as agricultural irrigation. Lower levels are used as technical and service areas. **Aspect of sustainable development**: the idea is to develop an underground city that collects natural resources above and below ground and is fully self-sufficient. Satisfaction of

energy needs is possible due to the efficient use of resources. At the surface level, rainwater is collected, energy is produced, and urban agriculture and aquaculture activities take place.

4. CONCLUSION

The study of modern trends in the organization of underground cities relies on architectural and urban planning, functional-planning, conceptual and artistic methods and is based on a number of key aspects: urban planning, architectural and spatial, functional and sustainable development. Analysis of current trends in organization of underground urban space revealed the following groups of trends: urban planning (within ultra-large cities: in the historical environment of central and industrial parts, based on transport network and interchanges; outside cities in areas free from development in the natural or artificial relief of the planet with the possibility of using the ground level; compactness of building; network system of urban planning organization based on modular structural units), architectural-spatial (transition to vertical deep-spatial organization; open spatial central core; typological diversity of services), functional (development within ultra-large cities) cultural, public, commercial, entertainment functional areas, removal of industrial, residential, research functional areas outside of the cities, the development of protective function and autonomy), sustainable (self-service and nutrition of residents through the use of natural resources above and below ground; meeting energy needs through renewable energy sources, efficient use of resources, processing of waste for energy, composting of used biomaterials).

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