Salo, V. V. (2024). Principles of architectural and planning organization of underground research complexes. *Actual Issues of Modern Science. European Scientific e-Journal, 34*, __-__. Ostrava: Tuculart Edition, European Institute for Innovation Development.

DOI: 10.47451/cul2024-10-01

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Principles of architectural and planning organization of underground research complexes

Abstract: The issue of the architectural and planning organization of underground research complexes is a significant criterion of modern urban planning, considering the limited surface areas, the rapid development of scientific fields, and growing urbanization. Designing underground facilities requires a specific safety, functionality, and comfort approach. The article focuses on the principles of architectural and planning organization of underground research facilities. The author has analyzed works of foreign and Ukrainian scientists and considered world analogs of underground laboratory design in Europe and the United States. Based on the analysis, the basic principles of scientific relevance, autonomy, ergonomic compliance, and spatial development are identified. The author discusses the critical characteristics of each principle that affect the optimal conditions for conducting experimental research in physics, astrophysics, geology, biology, and chemistry. The author pays special attention to the issues of isolation from external influences, the organization of an ergonomic environment, and the possibility of adaptation to the complex. The importance of using alternative energy sources to ensure the autonomy of the complex and the use of modular solutions is substantiated. Recommendations for further research are proposed: improvement of automated life support control systems; introduction of innovative materials for insulation; study of ergonomics and psychological comfort of personnel; development of modular solutions for spatial development.

Keywords: underground research complexes, underground urbanism, principles of architectural organization.

Introduction

In recent decades, global megacities have been characterized by rapid urban infrastructure development. The advantages of developing underground space are the ability to solve several problems inherent in modern cities: territorial, transport, energy, demographic, and environmental. Underground space can provide citizens free movement, access to the city's remote or densely built-up areas, and access to water and energy resources. In modern realities, one of the key advantages of the integrated use of Ukraine's underground space is the ability to accommodate various facilities. They include research facilities and military and defense industry facilities, which contribute to public safety and the development of these industries (*Pankratova et al., 2020*).

The relevance of building underground research facilities lies in the need for their operation in physics, astrophysics, geology, geophysics, and biology. Underground research complexes can provide the necessary conditions for experimental research in physics and astrophysics, which require ultra-clean and ultra-quiet environments, and for research of geological processes in the deep layers of the Earth.

Research by foreign and Ukrainian scholars: E. Reynolds (*Reynolds & Reynolds, 2015*; *Reynolds, 2019*). H. Admiraal and A. Cornaro (*Admiraal, 2015*; *Admiraal & Cornaro, 2016*; *Admiraal & Cornaro, 2018*; *Admiraal & Cornaro, 2020*), R. Sterling (*Carmody & Sterling, 1987*; *Sterling & Nelson, 2013*), G. I. Gayko (*Gayko, 2014*; *Gayko, 2018*; *Gayko, 2019*), S. Ryndiuk (*Ryndiuk & Maksymenko, 2021*), focus on the theoretical basis of underground urbanism, the peculiarities of the volumetric-spatial organization of underground buildings and structures, the complexity of underground space in the context of sustainable development. In the works of foreign physicists: A. Bettini (*Bettini, 2003*; *Bettini, 2008*; *Bettini, 2012*; *Bettini, 2014*), E. Coccia (*Coccia, 2006*), L. Votano (*Votano, 2010*), Jose Manuel Carmona (*Carmona, 2021*), A. Ianni (*Ianni, 2020*) provide an overview of the technical characteristics and schematic view of the world's underground laboratories. The architectural and planning organization of underground research complexes is relevant and requires further and in-depth study.

The article aims to determine the basic principles of architectural and planning organization of underground research complexes that are important for design theory and practice. The object of research is underground research complexes. The subject of the study is the architectural and planning organization of underground complexes.

Materials and methods

The methods the author uses in the study are based on the systematization of the architectural and planning organization of the world's underground research complexes. The general methodology of the study includes comparative analysis, graphoanalytical method for determining the characteristic features of the functional, planning, and urban planning organization of existing underground research complexes; conceptual analysis, during which the features of the volumetric and spatial organization of underground complexes were investigated; typological method for determining the leading types of underground complexes and significant principles of architectural and planning organization of their environment.

The study considered the works "Underground Urbanism" (*Reynolds, 2019*), "Underground Spaces Unveiled" (*Admiraal & Cornaro, 2018*), "Think Deep: Planning, development and use of underground space in cities" (*Admiraal, 2015*). The articles "Underground space development key planning factors" (*Stones & Tan, 2016*), "Underground Laboratories" (*Votano, 2010*), "Considerations on Underground Laboratories" (*Ianni, 2020*), "New Underground Laboratories: Europe, Asia and the Americas" (*Bettini, 2014*). The study covered world analogs of designing underground research complexes, such as Gran Sasso in Italy (*Bettini, 2003*), SNOLab in Canada (*Smith, 2012*), Sandford Underground Center in the United States, and Canfranc Laboratory in Spain.

Studying the principles of architectural and planning organization of underground research complexes is uncommon among world scientists, so this topic requires further study.

Results

The study revealed the key principles of underground research complexes' architectural and planning organization.

The principle of scientific conformity. The peculiarities of the scientific field and the course of experimental research require certain conditions to be met at all stages of design: minimizing external noise and vibrations for the accuracy of experiments, ensuring stable temperature and chemical characteristics of the air, and optimizing the organization of above ground and underground space. The scientific specificity of the complex has an impact on:

- urban planning organization: selection of the design site, which should consider geological conditions, groundwater levels, and seismic risks; functional zoning of the ground territory, which is determined by the quantitative and qualitative composition of premises, buildings, and personnel; interaction with the surrounding infrastructure: population intensity, transport accessibility, availability of underground utilities, transport structures, industrial tunnels, and the possibility of expanding the ground part;
- volumetric and spatial structure: the arrangement of experimental halls, research laboratories, auxiliary and service premises, and functional connections between them is determined by the physical and technical characteristics of the experimental facilities. The different sizes and layouts of research, analytical, administrative, sanitary and hygienic, and technical premises;
- architectural and planning organization: a clear functional division of the underground and above-ground parts of the complex, logical functional connections between groups of premises;
- subject-spatial organization: the use of modern technologies and materials; safety in planning to minimize risks; compliance with ergonomic requirements; use of generally accepted means of visual communication to designate different functional areas.

The following principle identified by the author is *the principle of autonomy*. This principle implies the use of renewable energy sources: solar panels, wind turbines, and geothermal systems; availability of independent life support systems: water supply and sewage system, heating system, ventilation, air conditioning, and filtration of incoming air with the possibility of its purification; waste disposal system; ensuring information autonomy: availability of monitoring systems, control systems, and local servers and databases; use of alternative sources of electricity: equipment In this context, it is advisable to consider *the factor of environmental friendliness* in terms of sustainable development. Given their scientific specificity, speaking of these facilities' one hundred percent environmental friendliness is impossible. However, it is possible to apply specific environmental approaches to their design: the use of modern materials and energy-efficient technologies to minimize energy consumption, multipurpose functional purpose, reduction of energy and greenhouse gas emissions; organization of a sanitary zone on the territory of the complex; organization of measures to adapt to climate and natural changes.

Applying *the principle of ergonomic compliance* creates comfortable conditions for the work of scientific, technical, and service personnel. Among the critical aspects of this principle, the author identifies the following:

- creating an easy and understandable environment, providing quick and unhindered access to the functional areas of the complex;
- meeting ergonomic requirements: designing light as it is on the surface; giving preference to natural sunlight, which is possible only by placing the upper levels of the complex directly under the surface; and designing artificial white lighting to simulate the spectrum of sunlight; designing rooms with noise insulation and noise absorption requirements; ensuring disinfection of personnel and the object-spatial environment;
- satisfaction of psychological, physiological, and social needs: organization of communication zones, areas of privacy, relaxation, separation of work processes and flows; creation of an optimal color and texture solution; optimal distribution of functional zones, variety of individual spaces, optimal layout of work and individual spaces, use of optimal materials and textures;
- arrangement of shelters and emergency tunnels; consideration of evacuation routes with the possibility of evacuation outside the complex; location of firefighting equipment; arrangement of a medical and paramedic station with the possibility of providing first aid; prevention and minimization of occupational risks;
- organizing a system of perimeter paramilitary security with access to their permanent base on the complex's ground territory and to the weapons depot.

The spatial development principle is the possibility of transforming, adapting, and modernizing underground research facilities in a limited space. The key aspect of this principle is modularity: the use of standardized block modules of four types. These modules can be used to construct underground buildings and structures for various functional purposes. Experimental block modules can be used in the design of underground industrial facilities and oil and gas storage facilities. Research modules can be used for the construction of underground parts of hospitals, laboratory facilities of institutes, and computer laboratories. These modules can also construct administrative, educational, cultural, and entertainment facilities. Since the auxiliary modules are designed for personnel to stay in them, they should be used to construct shelters and underground premises that perform administrative, communication, and recreational functions. D-shaped transport modules of reinforced concrete tubes should be used to construct transport and pedestrian routes, roads, and railroad tunnels.

Thus, using this principle in the design of underground research complexes will allow the possibility of adapting the plan to new scientific tasks thanks to mobile partition structures. Using these structures will allow you to quickly change the configuration of certain rooms and provide flexibility in the planning structure. It is necessary to consider the possibility of expanding the complex horizontally by creating new horizontal tunnels and cells and vertically by creating new levels, provided that geological conditions are favorable. It is crucial to maintain the primary functional connections between different areas. During the design stage, it is necessary to provide reserve areas that can be used to expand the complex if necessary. Further research and study of the principles of architectural and planning organization of underground research complexes is an urgent issue and one of the critical stages in designing this type of complex.

Discussion

The author highlights the fundamental principles of architectural and planning organization of underground research complexes based on analyzing the complexes' scientific specifics, ergonomic requirements, autonomy, and spatial development. These principles are important to consider not only for research complexes but also for underground complexes in general. The author pays special attention to the practical aspects of the principles and prospects for future underground complex development.

1. The study results are consistent with the author's hypothesis that the scientific specificity of the complex impacts the architectural and planning solutions of the complex. The functional zoning of the space depends on the type of research: experimental halls, research and analytical laboratories, storage facilities, staff quarters, and auxiliary and service areas, which should be designed to meet the requirements for noise, vibration, and sterility. It is essential to create conditions to ensure uninterrupted experimental research and comfortable working conditions for staff. One of the most influential factors is the accessibility of the premises, ventilation, and filtration of the incoming air, like ergonomic requirements. One of the critical aspects of designing this type of complex is modularity, which allows you to adapt the space to experimental needs by expanding the functional and planning structure of the complex and modernizing individual elements. Ergonomic conditions also play a significant role. They are especially relevant for the design of underground spaces, as there are requirements for lighting design, noise insulation, and meeting the psychological and physiological needs of staff. The determining factor is also the autonomy of life support systems, which must ensure the smooth operation of the underground complex. In general, applying the principle of scientific conformity in the design of underground research facilities can increase their efficiency and functioning.

2. It is critical to compare the principles of architectural and planning organization of underground research facilities with underground complexes of transport and engineering infrastructures and shelters and to study their standard features. Safety, ventilation, and autonomy aspects can be adapted for underground research facilities, including maintaining optimal working conditions for personnel and experimental facilities. Much attention is paid to the optimal planning and use of spaces in parking garages and underground warehouses. However, some design techniques differ between underground research and development complexes and underground complexes of other functional areas. The design of underground complexes focuses on functional and logistical aspects. The specifics of underground R&D facilities require taking into account such factors as special requirements for sterility, noise insulation, environmental stability, and the volumetric and spatial characteristics of the premises. In addition, underground R&D facilities require the installation of more complex life support systems, such as ventilation, air conditioning, air filtration, heating, and electricity.

3. The principle of spatial development is crucial to underground research facilities' architectural and planning organization. It allows the designer to adapt architectural and planning solutions to new conditions. These conditions may be due to scientific specifics, such as using new experimental facilities, integrating modernized equipment, and expanding the complex territory. Modular planning systems involve standardized structural elements, which are especially important in limited underground space use conditions. The advantage of using different functional modules is to minimize the impact on the current structures in expanding the complex's territory. This ensures the continuity of research work even during changes. The

process of adaptation and transformation is accompanied by some challenges: ensuring optimal air chemistry, ergonomic requirements, access, and integration of the modules' life support systems into the existing general life support system.

Conclusion

The study's results show that the architectural and planning organization of underground research complexes is a complicated process considering several fundamental principles, including scientific relevance, ergonomic relevance, the principle of autonomy, and spatial development. These principles are based on ensuring functionality, safety, and sustainability. They are essential for creating an environment that will meet the requirements for experimental research in physics, astrophysics, biology, geology, and chemistry.

A significant factor influencing the urban planning, volumetric-spatial, architectural, and planning organization of underground research facilities is creating an environment isolated from negative external influences, such as noise, vibration, and temperature. Adherence to the principle of ergonomic compliance contributes to the development of comfortable working conditions in the underground space. This is achieved by minimizing transport routes, separating transport and passenger flows, efficiently using space, and providing evacuation routes and shelters from potentially dangerous areas. The author believes it is significant to use energy-efficient technologies, ensure uninterrupted power supply to the complex, and manage life support systems, which will contribute to the efficient operation of all structures and allow for compliance with the basic principles of sustainable development. The introduction of modern technologies, automation of life support systems, and the use of energy-efficient materials can improve the safety characteristics of the complex and provide the necessary degree of isolation of experimental and research facilities. The author's use of modular approaches to the design of underground research complexes, which is the basis of the principle of spatial development, can increase the adaptability of underground complexes to changes that may be caused by the use of new experimental facilities within the complex.

The process of architectural and planning organization of the underground environment is complex and time-consuming. It involves an integrated approach combining functionality, sustainability, innovative materials and methods, and aesthetic expression. The author argues that the key principles considered in the study aim to create an environment capable of meeting not only the scientific community's current requirements but also the potential for further development.

Conflict of interest

The author declares that there is no conflict of interest.

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