Principles for the Design of Architectural Objects based on Air-Supported Structures in Extreme Conditions: the Example of the Covid-19 Epidemic

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Abstract. The article is devoted to identifying the current principles of designing architectural objects based on pneumatic air-supported structures in extreme conditions using the example of the Covid-19 pandemic. The object of the research is project proposals and realized pneumatic buildings and structures of the XXI century, created during the period of the Covid-19 epidemic. The objective of the study is to identify the basic principles for improving the design concepts of pneumatic air-supported objects in a pandemic and post-pandemic period in the context of international architectural and engineering trends to predict the vector of their further development. The methodological approach to the study of these problems is based on a systematic analysis of the features of the formation of pneumatic structures and is based on the materials of the implemented and designed buildings and structures of pneumatic architecture, as well as the study of open domestic and foreign scientific publications in this area. The findings of the study demonstrate the key advantages of using pneumatic air-supported structures in the creation of architectural buildings and structures based on the identified design principles, considering modern measures of epidemiological safety. The results obtained can be useful for architects, designers and engineers.

1. Introduction

1.1. Problem

With the rapid spread of the acute respiratory virus (SARS-CoV-2) that led to the 2019 coronavirus disease (Covid-19), architects, engineers and designers were tasked with identifying methods to contain the pandemic and minimize environmentally mediated transmission. ways through constructive and architectural solutions [6].

This is due to the fact that the factors of the natural and socio-cultural environment that change over time affect the architecture, which must react and adapt in response to the changes taking place. It is necessary to look for new spatial and constructive solutions, forms and materials in the context of current environmental conditions. Natural and artificial crises have always had an impact on architecture, which is also reflected in the relationship between the built environment and sanitary and epidemiological requirements.

The current requirements for isolation and social distancing to prevent the spread of viruses as an architecture response to epidemics have already been applied, however, environmental aspects are also
important, including an assessment of the imperatives of the environment and health, as well as the principles of forming adaptive architectural objects that have the necessary characteristics to function in extreme conditions [1].

1.2. Solution concept
In the course of the study, it was found that the use of pneumatic air-supported structures will allow the development of rational design solutions for the creation of architectural objects in the extreme conditions of the COVID-19 epidemic and the subsequent post-pandemic period. The concept is driven by an increasing trend towards the use of up-to-date structures and materials, contributing to the creation of environmentally friendly, energy-efficient and pre-fabricated buildings and structures. During the study, it was determined that architectural objects based on pneumatic air-supported structures that meet the specified requirements and are adapted to the type of disaster (earthquakes, epidemics, refugee migration), which can help victims in extreme conditions, have been used since the middle of the XX century [20].

1.3. Background and history of research
First of all, it should be noted that pneumatic building structures represent a class of soft shells, which are made of synthetic film materials, stressed by excess or negative air pressure to ensure the bearing capacity and shape the architectural object. Pneumatic structures are usually divided into two main groups: air-supported and air-borne. An air-supporting structure is a supporting structure of an object, which is supported by air, which is under its envelope under a pressure that does not significantly exceed atmospheric pressure. Air lenses and air bags work on the same principle as air bags. Air-borne structures are separate elements: prestressed pneumatic panels and pneumatic rods, which are not independent structures [8, 18, 20].

A number of domestic and foreign researchers studied pneumatic structures at different times: Bird W., who conducted research on materials and technologies and designed the first air dome, Lundy V.A, who collaborated with Bird W. and his firm Birdair; Frederick W. Lanche ster, who patented the idea of the first pneumatic air support structure; Bini D., who researched the technology of thin-walled concrete domes with pneumatic formwork; Otto F., who studied the structural search for forms of pneumatic architecture [2, 3, 15, 19]. Developments in the XX century were also carried out by domestic scientists, architects and engineers: Pokrovskij G.I., made a great contribution to the development of aerostatic architecture, Ermolov V.V. co-authored with Bird W., Bubner E. and other researchers published the book "Pneumatic Building Structures" in 1983. Orsa Y.N. in the dissertation "Features of the architectural composition of pneumatic structures" revealed the specifics of pneumatic structures, features of their shape formation and types of volumetric-spacial composition [8, 18].

Foreign research of the XXI century belongs to McLean W. and Silver P., who investigated modern developments in the field of materials and technologies in architectural objects based on pneumatic structures. It should be noted LeCuyer A., who described the main stages of development of the ETFE material. Research on materials and technologies of pneumatic structures is also reflected in the works of Knippers J., Cremers J., Gabler M., Lienhard J., Jeska S. and other researchers [12, 13, 14, 17].

In the course of the study, it was determined that pneumatic structures began to be used in extreme conditions from the middle of the XX century, for example, for integration with deep space and ground platforms. The architectural objects based on pneumatic structures of the XXI century, used in this area, include extreme environments, including orbital and lunar planetary structures, shelters after military, epidemiological and climatic disasters, polar stations, sea surface and underwater habitats, as well as complexes in natural environments with extremely hot climates [20].

An example of the use of pneumatic structures in extreme conditions is the 2004 adaptive pneumatic shelter project after military and climatic disasters by architects Hensel M., Menges A. of the Architectural Association School of Architecture (AA) [11]. In addition, worth noting is the work of the 2015 NASA-backed competition for construction in extreme conditions and extraterrestrial habitats within the framework of the Lunar Habitat project. The Foster + Partners Architectural Bureau and the
Foster N. architect proposed the Mars Habitat project, which provides a reliable 3d-printed modular habitat on Mars using pneumatic structures [9]. An example of the application of pneumatic structures in environments with low temperature conditions is the implemented project of the station of the ski resort "Grasjoch Bahn", Austria by the architects "Obermoser", 2013 [10].

2. Hypothesis and research methods
In the course of the research, a hypothesis was formulated: designing architectural objects based on pneumatic air-supported structures in the XXI century in the context of the Covid-19 epidemic is possible with the help of scientifically based principles of their formation in order to create eco-sustainable adaptive buildings and structures that meet modern epidemiological safety requirements. This approach will allow the architecture to respond in real time to emerging crises: refugee migration, natural disasters, political conflicts and epidemics. The analysis made it possible to develop a number of principles for the formation of architectural objects based on pneumatic air support structures in the context of the Covid-19 pandemic and the post-pandemic period.

The study included a study of bibliographic sources and Internet resources, conceptual and implemented design solutions, as well as an analysis and systematization of experience in the design and construction of architectural objects based on pneumatic structures of the XX-XXI centuries, including the period of the Covid-19 epidemic.

3. Results
Based on the prerequisites and trends in the creation of architectural objects based on air-supported structures in extreme environmental conditions, the following principles of their formation in the architecture of the XXI century in the context of the Covid-19 epidemic were developed.

3.1. Spatial adaptability principle
In the formation of architectural objects based on pneumatic structures in the context of the Covid-19 pandemic and other emergencies, the principle of spatial adaptability is to create structures that respond to changes in operational parameters using functional and technological metamorphoses. This principle can be applied to the creation of adaptive buildings of various typologies - public facilities, which consider epidemiological safety measures and medical institutions for the simultaneous reception of both infected patients and for the care of non-infectious patients who go to a hospital to receive medical care of a different spectrum.

To implement the principle of spatial adaptability in the design of hospitals, it is necessary to provide for the possibility of functional modification of standard wards in intensive care units, as well as planning adaptive configurations with zones of infected patients and patients located in a "clean zone" in a hospital environment [7].

An example of the application of the principle of spatial adaptability is the 2020 project of the architectural bureau "MMW Architects". The authors developed a modular hospital in response to the ongoing Covid-19 pandemic. The design of the adaptive hospital is based on the use of recycled shipping containers and pneumatic air-supported structures. The hospital includes wards for uninfected patients and isolation wards, and the horseshoe-shaped plan will allow ambulances to drive directly to the wards of patients with the Covid-19 virus to avoid moving patients through the corridors of the hospital (figure 1). The construction of containers and a pneumatic air-supported shell complies with environmental requirements and includes the use of solar energy for the operation of the necessary technical installations, and the materials used are subject to secondary use [7].
The actual scenario of spatial solutions in a public building, reflecting the principle of adaptability, was proposed in the project Institute for Advanced Architecture of Catalonia, Faculty of "Master in City & Technology" Quinto A. and Saraiya K. architects have developed adaptive structures based on pneumatic air-supported structures with the possibility of autonomous control that respond to the needs of visitors. Several scenarios for the use of structures are considered, allowing the implementation of public and semi-public spaces, as well as separate pneumatic shells for private events (figure 2). This approach will allow generating the shape of the membrane, in accordance with the specified parameters, which are activated remotely over the local network. The parameters of the control system are configured considering the need for social distancing [21].

3.2. The principle of rapid construction
The principle is the ability to respond quickly to emergencies, including epidemics that lead to a rapid increase in infected patients and a shortage of hospital beds. Prefabricated pneumatic air support structures are in such cases temporary objects that, if necessary, can be installed anywhere without additional costs and loss of time. The design of prefabricated medical institutions based on pneumatic structures in an epidemic is the transportation of buildings and structures for their rapid construction after arrival at the site. This principle includes methods for assembling objects on a hull or chassis with the integration of robotic installations. The idea of using these methods is to transform the method of pre-assembly of a pneumatic object outside the construction site.

An example of the introduction of the principle of rapid construction when creating a structure based on pneumatic air-supporting structures is the project of a portable structure for isolating infected patients in the Covid-19 pandemic from the Colombian architects Manrique, C. A. N., Pérez, A. L. P., Calonge, H. G. R. and Quin, C. A. C. The authors proposed the idea of rapid construction of a pneumatic hospital structure made of PVC fabrics, consisting of a complex of geodesic domes that are interconnected by cylindrical spaces (figure 3). The structure can be used to treat infected patients in aseptic ventilated areas and to isolate medical personnel and equipment that have been exposed to the virus [16].
3.3. The principle of mobility

This principle is interrelated with the principle of rapid construction and is also characterized by the ability to respond quickly in emergency situations. Mobile pneumatic structures serve as temporary objects, which, if necessary, can be transported from one point to another, due to the low weight of the structures. The principle of mobility is relevant for the construction of aid points, pavilions for medical tests and hospitals based on air-supported structures in the context of the Covid-19 epidemic. Structures designed with mobility in mind can function as an ancillary unit of an inpatient hospital or be transported as field health care facilities to remote communities.

The idea of creating architectural objects based on the principle of mobility was presented by students of the University of Toronto, John H. Daniels Faculty of Architecture, Landscape, and Design, with financial support from the U of T Covid-19 Student Engagement Award. Masters of Architecture have developed the concept of pneumatic mobile structures for use in a pandemic and other emergency situation (figure 4). The design without metal components made it possible to create a compact and lightweight structure that can be transported in a backpack with the necessary air pump. The students also presented a project of pre-fabricated dome-shaped capsules that consider social distancing measures, which are folded into a portable package [5].

Figure 4. Daniels students tackle pandemic-related projects with funding from the U of T COVID-19 Student Engagement Award, 2020.
3.4. The principle of transformability

The principle of transformatility of architectural objects based on pneumatic structures in the conditions of the Covid-19 pandemic is the transformation of the external or internal volumes of the building, depending on the environmental conditions and the specified parameters. This principle is applied when creating permanent and temporary structures, in order to combine and change the configurations of individual elements of the building. In large-span air-supported objects, it is possible to transform the coating depending on the purpose and weather conditions.

An example that meets the principle of transformability is the project of the Italian architects Ratti C. and Rota I., who designed and implemented modular intensive care wards based on transport containers and pneumatic structures for the expansion of inpatient hospitals (figure 5). Mobile wards, designed for two patients, are equipped with the necessary medical equipment, including an installed ventilation system that creates negative pressure inside. Modules can function separately or be combined with pneumatic air-supported structures in convertible configurations to create large-scale complexes near existing hospitals (for example, in car parks) to increase the number of intensive care units or deployed in areas remote from hospitals [4].

![Figure 5. Shipping-container intensive care units for coronavirus treatment, Ratti C. and Rota I., 2020.](image)

4. Discussion of research results

Summarizing the study, the following important points can be identified:

1. Changing factors of the social, cultural and natural environment influence the architecture, which needs to respond in response to the challenges of the time. The Covid-19 pandemic has affected all spheres of human activity, which leads architects to search for ways to contain the transmission of the virus by artificial means and the need to create relevant spatial and constructive solutions that meet the necessary epidemiological and social conditions.

2. Identifying the necessary principles and methods for designing architectural objects in extreme conditions of an epidemic and other emergency situations will allow creating adaptive buildings and structures.

3. The use of modern materials and technologies will provide architects with the opportunity to design adaptive and aesthetically diverse projects that meet the necessary environmental, economic and epidemiological requirements.

5. Conclusion

As a result, the principles of designing architectural objects based on pneumatic air-supported structures in extreme conditions, identified during the study, in the context of considering epidemiological safety measures in the context of the Covid-19 pandemic, allow us to conclude that it is possible to create mobile buildings and structures for organizing a comfortable spatial environment in a changing reality. It is determined that the advantage of using pneumatic air-supporting structures is their spatial and functional adaptability, rapid construction, mobility and transformativity.
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