Principles of Formation of Sustainable Architectural Objects in Extreme Conditions of the Habitat Determined by Physical and Climatic Parameters

Kristina Andreevna Pshenichnikova[a]
Moscow Institute of Architecture (State Academy), Moscow, Russia

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Abstract: The article is devoted to the actual problem of the formation of sustainable architectural objects for extreme living conditions, caused by physical and climatic parameters. It has been established that globalization, the acceleration of the pace of scientific and technological progress, the growth of the global population and the increasing pressure on the environment caused by these factors lead architects, engineers and researchers to the need to quickly respond to changing conditions and form a favorable artificial environment in extreme environments, which are determined by physico-climatic, anthropogenic physical and socio-economic parameters. The purpose of the study is to identify the principles of the formation of architectural objects in extreme conditions in the context of international architectural and engineering trends. The methodological approach to the study of this issue is based on system analysis and is based on the materials of implemented and designed buildings and structures, as well as the study of open scientific research. The materials of the article can be used for the theory and practice of the formation of an artificial environment for extreme living conditions.

1 INTRODUCTION

An extreme environment is a part of the environment that, by its psychophysiological, climatic, natural, economic and geographical characteristics, is unfavorable for life.

With the passage of time and the development of technology, man has learned to create the necessary environment for artificial habitats, however, today, the anthropogenic and natural components are closely intertwined with each other, which leads to the need to search for structured principles of organizing a sustainable balance.

Extreme physical and climatic conditions create difficulties for architects and designers, so buildings should be designed that respond in response to environmental parameters, not only as a protective measure, but also for the well-being of future generations. In response to these requirements, architectural objects must be designed and built in accordance with the ideas of sustainability and energy efficiency. Housing construction, in particular, should provide autonomy to reduce dependence on external infrastructure networks.

Thus, the design of a habitable built environment must be based on an effective response to scarcity, inaccessibility and unpredictability - factors that are characteristic of extreme conditions.

An analysis of world practice in the field of architecture of extreme environments shows that the information on this issue is quite extensive. The following specialists and institutes have been engaged in theoretical research, design and experimental developments, including related works, at various times: Saprykina, N.A., Timantseva N.L., Kartashova K.K., Lezhava G.I., Rakov A.P., Kronenburg R., Horden R., as well as researchers from the Royal Danish Academy, Department of Building Construction and Design: Institute of Architecture and Design - Vienna University of Technology", "SHEE Consortium". At the Moscow Institute of Architecture (State Academy) on the basis of the department "Architecture of Industrial Structures", the department "Architecture of Extreme Environments" (AEE) was organized to perform

[a] https://orcid.org/0000-0003-2781-1973

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qualifying research and design work of masters, as well as to perform work within the framework of international and interuniversity cooperation.

2 MATERIALS AND METHODS

When studying this issue in order to identify the basic principles for the formation of architectural objects for extreme living conditions, due to physical and climatic parameters, it is necessary to determine the historical prerequisites for the development of the issue and the classification features of extreme environments. The study includes the study of bibliographic sources and Internet resources, conceptual and implemented design solutions, as well as the analysis and systematization of the experience of forming architectural objects in extreme habitat conditions.

2.1 Historical Preconditions

The historical prerequisites that cause the expansion of architectural typology into the area of extreme living conditions were global natural disasters, the problem of overpopulation and the likelihood of climate change.

Since the middle of the 20th century, the typology of architectural objects has been developing, which is closely related to the development of new living conditions by humans (Rakov, 2017). Today, there is an active development of the Arctic and Antarctic, space tourism projects are being created, as well as research programs aimed at colonizing the Moon and Mars. Since the 1960s, space organizations have been exploring planetary science to understand the nature of climate change.

A design methodology incorporating the basic principles of extreme environment architecture to provide habitable space is required for future developments that include sustainable adaptive design, an important factor in creating livable conditions in extreme environments.

2.2 Classification of Extreme Habitat Conditions

The NASA Astrobiology Institute (NAI) defines an extreme habitat as an environment that is characterized by extreme physical conditions that are outside the boundaries in which humans can comfortably live. These conditions include: pressure, air temperature, humidity, air quality, radiation, and alkalinity/acidity (Bannova, 2014).

Today, the extreme environment is determined by location, but due to the negative factors described earlier in the article, unfavorable environments can develop in different areas (Timantseva, 2010). Thus, the scope of architecture of extreme conditions has expanded and includes natural and anthropogenic layers.

2.2.1 Natural Layer

In the natural layer, negative factors are associated with *physical and climatic conditions* (Timantseva, 2010):

1. Extreme natural zones - South, North, high-altitude areas;
2. Extreme natural environments - earth, water, air, space;
3. Extreme natural elements - water, terrestrial, air.

2.2.2 Anthropogenic Layer

In the anthropogenic layer, in addition to physical parameters, such as restrictions on building development, protected natural and historical landscape, and inaccessibility, extreme social parameters can be distinguished (Saprykina, 2019):

1. Public - social conflicts, project constraints, extreme recreation;
2. Political - foreign policy (state of war, territories with consequences of military actions, other foreign policy conflicts);
3. Economic - lack of resources, social housing, resource conservation;
4. Environmental - over-compaction, deviations in the normative indicators of the environment - humidity, pollution, etc., the proximity of man-made sources of danger - highways, metro lines, railways, factories, urban landfills.

2.3 Types of Extreme Environments

In the course of the analysis to determine the classifications of extreme living conditions in order to identify the principles of the formation of architectural objects, the boundaries of the study were determined within the framework of *physical and climatic conditions* - an *extremely hot climate*; *extremely cold climate*; *water environment*; *air space*; *Space*.

2.3.1 Extremely Hot Climate

In an extremely hot and arid climate with high temperatures, humidity and dust flows, it is important to take into account climatological features. Sustainable or "bioclimatic" design in extremely hot and arid climates must take into account the following factors: microclimate, emissivity, glare and dust collection, solar radiation control, wind control, evaporation control (Shady and Ingrid, 2014).

To take into account these factors, the design should include light translucent structures (pneumatic shells), a high percentage of vegetation, water spaces, as well as alternative energy sources that increase the energy efficiency of architectural objects in extremely hot and arid climates.

An example of a «green» facility in a hot climate is the implemented project of the Zaha Hadid Center for Oil Exploration and Research, built in Riyadh (Figure 1). In the complex named after King Abdullah of Saudi Arabia, scientists from all over the world will be engaged in research in various scientific fields, united by a common theme of energy. Three main areas are identified: politics and economics, energy and environmental technologies, and energy information and modeling (Frolova, 2010). The main building takes into account the principle of *modularity* and consists of hexagonal cells with permeable overlaps and a free plan that stimulates dialogue between scientists of different specialties.

Figure 1: King Abdullah Oil Research Center.

2.3.2 Extremely Cold Climate

Harsh climatic conditions that challenge comfortable living conditions characterize the difficulties in designing architectural objects in the North, Arctic and Antarctica, taking into account the irregular load from strong wind, snowfall, avalanches and cold. When forming habitable architectural objects in the conditions of the North, it is necessary to respond to scarcity, inaccessibility and unpredictability with innovations characteristic of extreme climatic conditions (Rok, Spela, 2014).

Extreme factors of construction in a cold climate include: hydrometeorological phenomena (ice, severe frosts, icing, fog); hydrogeomorphological phenomena (avalanches); endogenous (earthquakes, tsunamis, volcanism).

Extreme climate conditions and related phenomena, of course, have a significant impact on both the operational characteristics of the structure of buildings and the psychological and emotional state of a person living in these areas. Thus, objects built in such conditions should be completely *autonomous* and *mobility*.

Autonomy implies its own heat supply, arranged taking into account the location, ventilation, its own source of electricity - batteries or alternative sources.

Mobility in relation to architectural objects is applied in two aspects. On the one hand, this means that the dwelling corresponds to the *changing needs* and lifestyle of people, on the other hand, it is understood as physical mobility, manifested in *transformation* and *movement* (Saprykina, 1986).

Examples of projects in extreme cold conditions that implement the principles of autonomy and mobility are the work of «Iceberg Living Station» by MAP Architects and «Halley VI Antarctic Research Station» by Hugh Broughton Architects.

The Iceberg Living Station architectural project by MAP Architects aims to design with minimal environmental impact (Figure 2). To achieve this, the architects sought to avoid traditional construction methods, which involve transporting materials that will never leave Antarctica (Iceberg Living Station, 2013). Instead, the residential station is dug into a large iceberg that covers an area of about 2.5 square kilometers and will eventually melt in 7-10 years. The architects took into account that icebergs are compacted snow, which turns into ice at a depth of 25 meters and serves as effective insulation, as the experience of building the Igloo shows.

Figure 2: Iceberg Living Station.

Located on the frozen floating Brunt Ice Shelf in Antarctica, Hugh Broughton Architects' Halley VI Antarctic Research Station is the world's first fully mobile and relocatable polar research station and was designed for scientists working in some of the most extreme environments on Earth. (Figure 3). In order

Figure 4: Drilling Water-Scraper.

to minimize the impact on the fragile environment during the entire life cycle from construction to decommissioning, the necessary energy efficiency of the plant was taken into account - reducing water consumption and improving the waste management strategy.

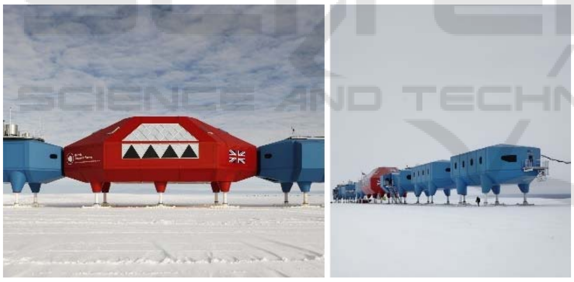

Figure 3: Halley VI Antarctic Research Station.

2.3.3 Water Environment

Modern scientists predict that the critical level of overpopulation of the Earth may occur in the middle of the 21st century. The solution to the problem can be «hydropolises», which are underwater skyscrapers (Vorobieva, 2019). Researchers hypothesize that living in them is more comfortable than on land, since there are no atmospheric phenomena, earthquakes, pressure and temperature drops under water. It is assumed that underwater cities will receive energy using tidal power plants and generators operating on temperature differences, which is consistent with the principles of energy *efficiency* and *sustainability*.

The relevance of the design of architectural objects on water and under water is determined by the need to expand comfortable and safe housing in large metropolitan areas that are overpopulated (Shumskaya, 2014), as well as taking into account global climate change, which necessitates the adaptation of residential spaces to floods and technologies for creating an environmentally friendly and operational construction in the aquatic environment.

As examples of architectural objects in the aquatic environment, it is advisable to cite the projects «Drilling Water-Scraper: Power Plant And Underwater Recycling Center" from architects Xuejun Bai, Chucheng Pang, Lei Zhai, Yuyang Sun, Dianao Liu, which was presented as part of the 2020 Skyscraper Competition, as well as the Ocean Gate Observatory by Antireality.

The architects of «Drilling Water-Scraper: Power Plant And Underwater Recycling Center» are addressing the recycling of marine waste as well as the discovery of pure combustible ice in the deep sea (Figure 4). The team suggests using plastic waste for 3D printing and creating new building materials (Barandy, 2020). There are two main paradigms in the project: downward materials and upward energy. The energy tower turns plastic waste into 3D printing materials and prints the building as well as the energy reservoir along the main cylinder, making the skyscraper self-evolving and «growing».

The architects from Antireality have developed the concept of an underwater observatory «Ocean Gate» for the Bahamas (Naser, 2021). The aim of the project is to try to create a marine observatory whose structure will be integrated with the beach area without overloading the seaside landscape (Figure 5).

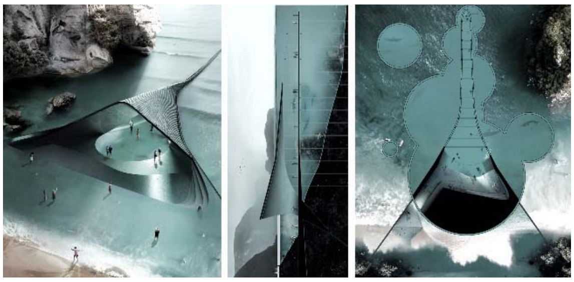

Figure 5: Ocean Gate Observatory.

2.3.4 Air Space

One of the first ideas of floating architecture was presented in the USSR in 1928 by Krutikov G. (the graduation project of flying communal houses) and Iozefovich I., who designed the flying House of Congresses of the USSR, since early Soviet architects strove for the ideal, futuristic and sublime (Krivitsky, 2018, Saprykina, 2016). Today, flying architecture is of interest to modern architects in connection with the ecological orientation of society to solve the problems of *sustainable development*.

An example of a floating building project is the Dandelion Vessel: Inflatable Skyscraper For Natural Disasters, designed by architects Wei Ke Li, Sheng Jiang, Xing Chun Zhi Zhang as part of the 2016 Skyscraper Competition (Figure 6).

The project was created for the hard-to-reach part of Northern Guangxi Rongshui County as a refuge from natural disasters and to provide residents of hard-to-reach areas with the necessary medical equipment. Air shelters are designed from pneumatic structures, and the surface of the master station is made of strings and connected to a balloon that can lift it to the desired position (Friis, 2016).

2.3.5 Space

New advanced space exploration programs around the world demonstrate the growing demand for human factors research, interactions between space station inhabitants and the environment, as well as problems associated with long distances from the Earth, mission time and architecture of space structures.

The methodology for designing habitable shells in outer space should include the ability to adapt to extreme environments such as the Moon, Mars, and current and future extreme locations on Earth (Dede, 2022).

The architectural approach to the design of space structures affects all elements of the constructed environment. When designing space systems, architects need to address the experience of living in similar conditions on Earth (submarines, bunkers, Antarctic bases) and take into account the provision of physical and psychological comfort while in space.

It should be noted that adaptive design strategies are valuable tools in creating livable conditions and should include the principles of *autonomy*,

Figure 6: Inflatable Skyscraper For Natural Disasters.

Figure 7: Punch O., University of Limerick.

modularity, *mobility*, *sustainability*, as well as the principle of *«self-deployment»* previously outlined in the study. In addition, it is advisable to use innovative digital modeling and 3D printing technologies.

Examples of projects that reflect the above principles of the formation of architectural objects in space are the work of Punch O. from School of Architecture, University of Limerick (SAUL), Ireland and «Self-deployable habitat» from SHEE Project. The architectural project Punch O. is dedicated to research in extreme conditions and aims to create a structure using the materials of the surrounding landscape using sustainable building methods (EAM Best Diploma Projects, 2015). Located on Mars, the complex explores the need for architectural responses to extreme environments that may also occur on Earth and considers the possibility of innovative design - adaptability of form, function, structure and resilience to new challenges (Figure 7).

SHEE Project's work uses an alternative approach to designing a habitat that can be deployed using rigid shells. SHEE is a self-deployable habitat that can save crews time when creating quarters in remote locations such as Mars (Osborne, 2016). Each module provides support for two crew members during a mission lasting at least two weeks. Several modules can be connected together to create a "SHEE settlement", which allows you to increase the number of crew, the duration of the mission or software capabilities (Figure 8).

Figure 8: Self-Deployable Habitat (SHEE)

3 RESULTS AND DISCUSSION

Thus, in the course of the study, the main principles of the formation of architectural objects in extreme conditions, determined by *physical and climatic parameters* and including extremely hot climate, extremely cold climate, water environment, air and outer space, were identified:

1. *The principle of modularity* is a constructive approach that subdivides the building system into smaller parts - modules that can be created and combined in various configurations independently of each other, and then used in different systems. The principle of modularity is also characterized by functional separation.
2. *The principle of autonomy* implies relative engineering (power generators, water supply, etc.), technological, planning and design independence of the structure and its elements from neighboring objects at various levels with

the possibility of regulating or changing the degree of autonomy.

3. *The principle of mobility* based on transformation and movement is to change the building by transforming the internal elements while maintaining its constant dimensions, which ensures the multifunctional use of the internal space; changing the size and configuration of the building (constructive transformation), as well as the possibility of moving the structure, which is carried out in an assembled form or already ready for operation (Saprykina, 1986).
4. *The principle of sustainability* lies in the combination of engineering and architectural solutions, with the help of which it becomes possible to balance the high quality of the natural environment of human life in order to maintain ecological balance. The principle includes *energy efficiency* - reducing the consumption of energy resources (renewable and non-renewable) and improving the construction and operation of buildings.
5. *The principle of «self-deployment»* consists in the possibility of creating self-deploying modules that can be assembled on site in extreme environments in a short time and without the involvement of builders and special equipment. The principle of self-deployment can be applied both in designing in space conditions and in extreme environments due to anthropogenic physical and social parameters.

The identified principles of the formation of sustainable architectural objects for extreme living conditions within the framework of physical and climatic conditions can be applied at all stages of design and operation in order to create dynamic, adaptive and energy-efficient buildings and structures.

4 CONCLUSIONS

Summing up the results of the study, the following main conclusions can be formulated. The development of the field of extreme environments in architecture is determined by the influence of various factors and prerequisites. It is advisable to consider the phenomenon of extreme architecture comprehensively, since its development is due to successes in various fields of science.

Only taking into account innovative achievements in the field of creating new materials, technological and digital tools, having studied the factors influencing the formation of architectural objects in various extreme conditions, as well as the principles of their creation, it is possible to make a forecast of the further development of this direction in architecture.

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