RISK-ORIENTED APPROACH TO THE RECONSTRUCTION OF RESIDENTIAL BUILDINGS AND STRUCTURES IN THE ARCTIC ZONE

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Abstract

The report is dedicated to the study of various approaches in regards to the reconstruction of residential buildings and structures in the Arctic zone using a risk-based approach. The aim of the research is to develop methods that take into account the specific climatic and geological conditions of the Arctic in view to minimising risks in the design and construction works. The objective of the study includes the following (i) analysis of existing methodologies, (ii) assessment of their applicability in Arctic conditions and (iii) development of new approaches that take into consideration the regional specificities. The relevance of the topic is due to the growing interest in the development of the Arctic and the need to ensure the safety and comfort of living in harsh climatic conditions.

The study uses data on climatic and geological peculiarities of the Arctic zone, as well as modern methods of risk analysis. Modelling and forecasting methods have been applied to assess the impact of various factors on the stability and durability of buildings. Expert judgements and empirical data from research and monitoring of existing construction projects in the Arctic have also been used.

The results of the study have shown that the application of a risk-based approach can significantly improve the reliability and safety of reconstructed buildings in the Arctic zone. Key risk factors were identified, such as interalia geotechnical risks, risks of heat losses and energy efficiency of buildings, specificity of building materials, risks in adapting to changing climate, transport and logistics. An algorithm for calculating the degree of risks in the reconstruction of buildings and structures in the Arctic zone was designed accordingly, which includes 4 actions. The formula for assessing the degree of risks in reconstruction in the Arctic zone is developed. Weight characteristics of each risk factor are determined by the method of expert evaluations. Variation of each risk factor at three levels: unsatisfactory, good, excellent is performed. An adapted scale for qualitative assessment of the degree of risk in reconstruction in the Arctic zone was also developed.

The details of the obtained results have an important practical significance for construction and reconstruction of facilities in the Arctic. This implies that the recommendations can be used in the design and planning of construction works, which will reduce the probability of accidents, risks and hazards, thus increase the durability and life span of buildings. The implementation of the proposed methods shall largely contribute to the sustainable development of infrastructure in the Arctic zone, hence ensuring the safety and comfort of living.

Keywords: Arctic, reconstruction, residential buildings, risk-based approach, climatic conditions, geological features, wind loads, construction technologies, efficiency improvement

I. Introduction

The Russian Federation has significant territories in the Arctic region, and therefore development and research in this area is challenging to the Russian Federation. The Arctic zone comprises of extensive natural resources, including oil, gas, mineral wealth and fish. Infrastructure development and residential renewal are becoming crucial for attracting investment and creating a favourable economic background. The Arctic has significant potential for development and research aimed at improving the comfort of human habitation in this climatic zone [1-3].

The Arctic region is currently undergoing a gradual transformation in the context of global climate change which will cause this location to become a centre of intense change. Given the fact that this unique region, known for its distinctive climate, is undergoing significant transformations, same will as a result affect all aspects of its existence. Against this background, special attention is being given to residential structures, which face the dual challenge of maintaining their functionality and efficiency in order to cope with the increasing warming of the Arctic region, as well as adapting to the potential threats posed by these changes [4-6].

The unique climatic conditions of the Arctic zone, such as fluctuating temperatures, regular snowfalls, high winds and changes in permafrost conditions, affect residential buildings, making them more vulnerable and requiring comprehensive solutions to maintain their functionality and safety. These atmospheric conditions can cause significant damage to wall cladding materials, roofing and windows, making it necessary not only to modernise but also to change building standards to meet the new Arctic conditions. In this regard, the issue of reconstruction of buildings and structures becomes even more urgent with the active development of Arctic territories and the increasing need for housing [7,8].

Reconstruction of buildings and structures in turn helps to solve the problem of providing people with comfortable and safe housing. Our participation in the research on reconstruction in the Arctic zone gives Russia an opportunity to become actively involved in the design of updated standards, norms, guidelines and regulations in the region. The development of innovative technologies and solutions will subsequently strengthen the country's position as a key participant in international cooperation and partnership in the Arctic area [9].

The purpose of this research is to study the peculiarities of reconstruction of residential buildings in the Arctic zone under the conditions of modern climatic changes, as well as to identify ways and means to reduce risks related to the organisation of reconstruction work on buildings and structures.

Taking into consideration the gradual warming of the Arctic region, and its impact on the overall building structure as well as the technical issues associated with permafrost thawing and extreme weather events, it will be our responsibillity to detect, diagnose and identify these specific problems. Consequently we will propose new approaches to organising reconstruction works aimed at improving the sustainability of residential buildings in this region.

The main direction of the scientific research is to develop a risk-oriented approach to the reconstruction of residential buildings and structures in the Arctic zone. It differs significantly from the current understanding of the problem [10-12]. This approach complements and deepens the already known methods, offering new solutions to improve the stability and durability of buildings in a changing climate [13-15].

In addition, the article introduces new facts, conclusions and recommendations based on the conducted research. The obtained results have an important practical significance and can be used in the design and planning of construction works, which will reduce the probability of accidents and increase the durability of buildings.

The purpose of this report proceeds from the scientific problem and consists in the study of the peculiarities of reconstruction of residential buildings in the Arctic zone using a risk-oriented approach [16]. Methods that allow taking into account specific climatic and geological conditions of the region are thoroughly discussed in this report, and innovative solutions are being proposed to mitigate risks in the design and construction works. This study will serve as a basis for the development of a comprehensive methodology to improve the efficiency of the organisation of reconstruction of buildings and structures in the conditions of the far north and the Arctic zone of the Russian Federation, based on neural modelling. The use of modern information technologies and artificial intelligence will significantly improve the quality of management and planning processes in the reconstruction of buildings and structures [17-19].

II. Methods

In the Arctic region, where climate and natural conditions pose specific risks for residential renovation, an in-depth study of the problems and the development of effective strategies and technical solutions are required. By analysing the main types of risks, such as geotechnical risks, heat losses, building material features, adaptation to changing climate and transport and logistics risks, ways to address them have been identified.

The table laid down below gives a comprehensive view of the risks and the corresponding solution strategies. Each category of risks is described in more details, thereafter the main areas of technical solutions are presented. This analytical approach outlines the main risks in reconstruction in the Arctic zone and identifies strategic methods to effectively address these technical risks.

Table 1: *Risks and solutions for reconstruction in the Arctic zone.*

№	Name of risk	Description	Solutions
1	Geotechnical risks	In Arctic permafrost conditions, ground thawing can lead to deformation of foundations and walls of buildings. This creates the need to develop special geotechnical solutions aimed at stability and prevention of deformations due to changes in frozen soils.	Permafrost thawing: Develop engineering methods to stabilise frozen ground, such as freezing technologies. Introduction of freezing systems that use refrigerants to keep the ground stable. Foundation deformations: Application of pile foundations to account for changes in frozen soils. Investigation of optimal pile depth and pile location parameters to minimise the impact of permafrost thawing.
2	Heat loss risks and energy efficiency of buildings	The Arctic zone is characterised by low temperatures, which causes the problem of heat loss in buildings. Efficient insulation and innovative heating technologies become important to maintain comfortable conditions inside the dwelling and reduce energy consumption.	Innovative insulation: Development and use of new thermal insulation materials such as vacuum panels and thermal insulation coatings. This will help to reduce heat loss and ensure efficient heat retention in buildings. Heating technologies: Introducing heat pumps and thermal storage technologies to provide an efficient heating system capable of maintaining comfortable conditions in cold climates.
3	Specificity of construction materials	Traditional building materials may not be able to cope sufficiently with the Arctic climate. For example, moisture freezing in the structure of walls can cause damage. The development and use of specialised	Heat resistant materials: Development of building materials capable of maintaining structural integrity at low temperatures and preventing moisture from freezing inside walls. Introduction of new formulations resistant to arctic conditions. Use of composites: The use of composite materials that combine strength with

		building materials that are resistant to low temperatures is becoming an important aspect of reconstruction.	thermal insulation properties to create more resilient structures in Arctic conditions.
4	Risks in adapting to a changing climate	Projected changes in the climate, such as increasing temperatures and the frequency of extreme weather events, require the development of buildings that can adapt to variable conditions. This includes strengthening structures, improving drainage systems and adapting to new building standards.	Reinforcement of structures: Developing structures that can withstand high winds, snowfall and other extreme weather conditions. Strengthening structural elements of buildings to increase their resilience to variable conditions. Drainage Improvements: Designing effective water collection and drainage systems to prevent the negative effects of snow and ice melt on roofs and around foundations.
5	Transport and logistics	The remoteness and inaccessibility of the Arctic territories create difficulties in the delivery of construction materials and equipment. Logistical problems can significantly increase costs and complicate the reconstruction process.	Local production bases: Establish local production bases for building materials, reducing dependence on long-distance supplies and simplifying logistics. Delivery technologies: Introduce delivery technologies such as drones or mobile warehouses to deliver materials and equipment to remote areas more efficiently and reliably.

In the context of residential building renovation in the Arctic zone, facing technical challenges requires not only engineering solutions, but also careful analysis, evaluation and process optimisation. Based on the results of the study, key challenges have been highlighted:

- Geotechnical risks
- Heat loss risks and energy efficiency of buildings
- Specificity of construction materials
- Risks in adapting to a changing climate
- Transport and logistics

In order to achieve our goal, it is necessary to solve the tasks, approaching it in a systematic way. This approach requires not only traditional engineering solutions, but also the introduction of modern technologies.

III. Results

One of the contemplated areas of state-of-art technology is the use of neural modelling for real-time prediction, optimisation and decision making. Neural networks have proven their effectiveness in a variety of areas including data analysis, process optimisation and forecasting. The application of neural modelling can play a key role in addressing the identified risks presented in our table, providing accurate and adaptive approaches to complex engineering problems.

Such an integrated approach, combining traditional engineering methods and neural modelling capabilities, can improve the efficiency, accuracy and sustainability of reconstruction processes in the Arctic zone. The following table systematises the problems and solutions and assesses the feasibility of applying neural modelling in each area.

Table 2: *Ways to predict and address risks using neural modelling.*

Risks and Aspects	Solutions	Neural modelling capabilities
Geotechnical risks	- Development of technical solutions for stabilisation of frozen soils. -Application of pile foundations taking into account changes in frozen soils.	Prediction of ground deformations and optimisation of foundation parameters based on data on local climatic conditions.
Heat loss risks and energy efficiency of buildings	-Development of new thermal insulation materials. - Introduction of heat pumps and heat storage technologies.	Optimisation of heating and ventilation systems using neural networks to adapt to changing temperatures.
Specificity of construction materials	- Development of building materials resistant to low temperatures. - Use of composite materials.	Analysis of material properties, prediction of their behaviour under Arctic climate conditions.
Risks in adapting to a changing climate	- Strengthening of structures. - Improvement of drainage systems.	Prediction of extreme weather conditions and optimisation of structural changes in buildings.
Transport and logistics	-Creating local production bases. -Use of delivery technologies.	Optimisation of logistics networks and prediction of optimal routes for material delivery

The result of the study is the formed algorithm for calculating the degree of risks in the reconstruction of buildings and structures in the Arctic zone, which includes 4 actions: analysing and assessing risks; correlating the risk factor with Table 4, determining the quantitative value of risk according to Formula 1, determining the qualitative value of the degree of risk according to Table 5. In order to assess the degree of risk, we can use a mathematical apparatus to quantify the degree of risk. The formula for assessing the degree of risk in reconstruction in the Arctic zone can be presented as follows:

$$R = (W1 \times F1 + W2 \times F2 + \cdots + Wn \times Fn) \tag{1}$$

Where:

R - risk level

Wi - weighting factor for each risk factor

Fi - value of each risk factor

Each risk factor will be assigned the following designations: F1-Geotechnical risks, F2-Risk of heat loss and energy efficiency of buildings, F3-Specificity of building materials, F4-Risk in adapting to a changing climate, F5-Transport and logistics.

The next stage of the study was to determine the weighting characteristics of each risk factor using the expert judgement method. The method of expert judgement allows to create a certain collective consciousness formed from the opinion of a group of experts. This approach is more effective than the opinion of a single person.

In our case, expert analysis can be used to determine the weighting of factors. The experts participating in the study were included in the national register of specialists. This fact allowed us to judge about the competence of experts and their extensive experience in the field. Upon completion of the experts' questionnaires, data processing was carried out. The results were plotted in a graphical form for better visualisation and understanding, a histogram of factors with the minimum limit of significance of factors was built.

Weighting factors: W1 = 0,3 (Geotechnical risks); W2 = 0,2 (Heat loss risks and energy efficiency of buildings); W3 = 0,2 (Specificity of construction materials); W4 = 0,15 (Risks in adapting to a changing climate); W5 = 0,15 (Transport and logistics)

In Table 3, each of the risk factors is represented as one of three alternatives: unsatisfactory, good, excellent. In order to further use these qualitative characteristics in the form of quantitative ones, the concept for unsatisfactory 0,3, for good 0,5, for excellent 0,8 was introduced.

Table 3: *Varying organisational and technical factors.*

Risk factor	unsatisfactory- 0,3	good-0,5	excellent – 0,8
Geotechnical risks	-Frost thaw does not exceed 10% of the total area of the construction site. -Foundation deformations do not exceed 5% of the total building height.	-Melting of permafrost does not exceed 5% of the total area of the construction site -Foundation deformations do not exceed 2% of the total building height.	-Frost thawing is absent or does not exceed 1% of the total area of the construction site. -Foundation deformations are absent or do not exceed 1% of the total building height.
Heat loss risks and energy efficiency of buildings	-Heat losses through walls and roofs do not exceed 20% of the total heat load of the building. -Energy efficiency of heating and air conditioning does not exceed 10% of the total energy consumption of the building.	-Heat losses through walls and roofs do not exceed 10% of the total heat load of the building. -Energy efficiency of heating and air conditioning does not exceed 5% of the total energy consumption of the building.	-Heat losses through walls and roofs are absent or do not exceed 5% of the total heat load of the building. -Energy efficiency of heating and air conditioning is absent or does not exceed 2% of the total energy demand of the building.
Specificity of construction materials	-Resistance to low temperatures does not exceed 50% of the total area of the building materials. -Resistance to wind loads does not exceed 30% of the total area of the building materials.	-Resistance to low temperatures does not exceed 70% of the total area of the building materials. -Resistance to wind loads does not exceed 50% of the total area of the building materials.	-Resistance to low temperatures is absent or does not exceed 90 per cent of the total area of the building materials. -Resistance to wind loads is absent or does not exceed 70 per cent of the total area of the building materials.
Risks in adapting to a changing climate	-The increase in temperatures does not exceed 2°C from the average temperature over the last 10 years. -An increase in the frequency of extreme weather events does not exceed 10 per cent of the average frequency over the last 10 years.	-The increase in temperatures does not exceed 1°C from the average temperature over the last 10 years. -An increase in the frequency of extreme weather events does not exceed 5% of the average frequency over the last 10 years.	-Temperature increase is absent or does not exceed 0.5°C from the average temperature over the last 10 years. -An increase in the frequency of extreme weather events is absent or does not exceed 2% of the average frequency over the last 10 years.
Transport and	-Accessibility to the construction site does	-Accessibility to the construction site does	-Accessibility to the construction site is absent

logistics	not exceed 50% of the total construction site area.	not exceed 70% of the total construction site area. -Transport problems do not exceed 10% of the total area of the construction site.	or does not exceed 90% of the total construction site area. -Transportation problems are absent or do not exceed 5% of the total construction site area.

One of the most convenient ways to construct an integral indicator is the generalised Harrington desirability function. This function is based on the transformation of natural values of private indicators of different physical nature and dimension into a single dimensionless scale of desirability (preference). We adapted this scale to our obtained data, and the adapted scale was summarised as detailed in the table below (Table 4).

Table 4: *Adapted scale of the degree of risk.*

Risk level R	Risk assessment
Low risk	R < 0,39
Medium risk	0,4 ≤ R ≤ 0,6
High risk	R > 0,61

This range allows us to assess the degree of risk qualitatively. Low risk: the degree of risk is below 0,39 which indicates that the risk is minimal and does not require special attention. Medium risk: the degree of risk is between 0,4 and 0,6 which means that the risk is moderate and requires some attention and appropriate measures to minimise it. High risk: the degree of risk is above 0,61 which shows that the risk is high and requires serious attention and urgent measures to minimise it.

IV. Conclusions

The research conducted on the topic of risk-based approach in the reconstruction of residential buildings and structures in the Arctic Zone has highlighted key aspects that influence the efficiency and success of the reconstruction process in an extreme climate. The main results of the research are presented below:

- The study confirmed the urgency of the problem of reconstruction of residential buildings in the Arctic zone, especially in the context of a changing climate and warming.
- The study highlighted the technical challenges faced by engineers in reconstruction in Arctic conditions, such as: geotechnical risks, heat loss risks and energy efficiency of buildings, specificity of construction materials, risks in adapting to the changing climate, transport and logistics.
- An algorithm for calculating the degree of risks in the reconstruction of buildings and structures in the Arctic zone was formed.
- An approach to the assessment of reconstruction efficiency is developed, including criteria of satisfactory, good and excellent performance for the main factor.

References

[1] Tsygankova A.A., Romanchenko O. V., Shemetkova O. L. Infrastructure of the Arctic zone of the Russian Federation: state, economic instruments of development and priority projects. Regional Economics and Management: electronic scientific journal. - 2016. - №. 4 (48). - p. 181-193.

[2] V. Savinova, M.M. Brodach, Features of design and construction in the Arctic region. High Technology Buildings. - 2018. - № 4.

[3] N.S. Kalinina, N.V. Morozov, Architectural, technical and design features of designing residential and public buildings in the Far North. System Technologies. - 2019. - № 3(32).

[4] Khubaev, A.O. Improvement of the production process of winter concreting on the basis of the potential of organizational and technical solutions: specialty 05.02.22 "Production organization (by branches) »: dissertation for the degree of Candidate of Technical Sciences /2022. - 178 p.

[5] Khubaev A.O., Determination of the efficiency of the production process of winter concreting based on field studies. E3S Web of Conferences: Ural Environmental Science Forum "Sustainable Development of Industrial Region" (UENF-2023), Chelyabinsk, April 25-28, 2023. Vol. 389. - Chelyabinsk: EDP-Nauka, 2023. - P. 06012. - DOI 10.1051/e3sconf/202338906012.

[6] A. Lapidus, A. Khubaev, T. Bidov, A. Regression analysis of the calculation of organizational and technological potential for the production of cold-weather concreting. IOP Conference Series: Materials Science and Engineering: 23, Construction - The Formation of Living Environment, 55 Giai Phong Road, Hanoi, September 23-26, 2020. - 55 Giai Phong Road, Hanoi, 2020. - P. 072033. - DOI 10.1088/1757-899X/869/7/072033.

[7] T.H. Bidov, A.O. Khubaev, A.A. Shabanova, Organizational and technical modeling of the complex system of concrete works production in winter period during the construction of residential buildings. Construction and Geotechnics. - 2021. - T. 12, № 2. - p. 15-25. - DOI 10.15593/2224-9826/2021.2.02.

[8] A.A. Lapidus, A.O. Khubaev, Increasing the efficiency of winter concreting production through the use of software "potencial-cwc". Izvestiya Tula State University. Technical Sciences. - 2020. - № 5. - p. 18-26.

[9] Akshov E.A. Use of computational design and artificial intelligence in modeling architectural objects. Architecture and Modern Information Technologies.-2023.-№. 2(63).-p.298-315.

[10] S. O. Abioye, L. O. Oyedele, L. Akanbi, Artificial intelligence in the construction industry: A review of present status, opportunities and future challenges. Journal of Building Engineering. – 2021. – Vol. 44. – P. 103299. – DOI 10.1016/j.jobe.2021.103299.

[11] Koshelev V. A. Risk management mechanism in construction. Voprosy ekonomiki i prava. - 2014. - №. 74. - p. 122-127.

[12] S.S. Korabelnikova, S.K. Korabelnikova, Digital technologies as an element of risk reduction in construction. Discussion. - 2019. - № 2(93). - p. 18-27. - DOI 10.24411/2077-7639-2018-10002.

[13] A.A. Lapidus, I.L. Abramov, T.K. Kuzmina, A.I. Abramova, Sustainability of the activity of construction organizations under the conditions of risk factors. Industrial and Civil Engineering. - 2023. - № 11. - p. 97-104. - DOI 10.33622/0869-7019.2023.11.97-104.

[14] Abramov I., AlZaidi Z. A. K., Evaluation of the Effective Functioning of Construction Enterprises in the Conditions of Occurrence of Diverse Risk Factors. Buildings. – 2023. – T. 13. – №. 4. – p. 995. – DOI 10.3390/buildings13040995.

[15] A. Lapidus, I. Abramov, T. Kuzmina, Abramova A., Alzaidi Z.A.K. Study of the Sustainable Functioning of Construction Companies in the Conditions of Risk Factors. Buildings. – 2023. – Vol. 13, No. 9. – P. 2282. – DOI 10.3390/buildings13092282

[16] Schreiber, I. Abramov, Z. Al-Zaidi, Assessment of risk-forming factors of construction production in conditions of uncertainty. E3S Web of Conferences. – EDP Sciences, 2021. – T. 258. – p. 09052. – DOI 10.1051/e3sconf/202125809052

[17] Aleksandr Makarov, "Organization of Construction Quality Control based on a Priori Risks of Works," International Journal of Engineering Trends and Technology, vol. 71, no. 1, pp. 134-140, 2023. Crossref, https://doi.org/10.14445/22315381/IJETT-V71I1P212

[18] P. Szymanski, “Risk management in construction projects”, Procedia Engineering 208, 174–182 (2017). https://doi.org/10.1016/j.proeng.2017.11.036

[19] T. Wang, et al, “A meta-network-based risk evaluation and control method for industrialized building construction projects”, Journal of Cleaner Production 205, 552–564 (2018). https://doi.org/10.1016/j.jclepro.2018.09.127

[20] B. G. Hwang, X. Zhao and L. P. Toh, “Risk management in small construction projects in Singapore: Status, barriers and impact”, International Journal of Project Management 32(1), 116–124 (2014). https://doi.org/10.1016/j.ijproman.2013.01.007