Socio-economic and management risk evaluation criteria used in the design of construction facilities in the Arctic

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Abstract. The article addresses the evaluation of criteria and the choice of technologies, materials, structures, machinery, and products needed to arrange the construction of infrastructure facilities in the Arctic region. The main task, tackled by the researchers, is the study of a strategy for the minimization of investment risks, that may arise in the course of the implementation of projects in the harsh weather conditions of the Far North. The authors consider ten principles of the management system, including efficiency, environmental friendliness, energy efficiency, logistics and others. The authors focus on the need to minimize the risks, that may accompany the choice of technologies, materials, structures, machinery and products in the course of construction in the Arctic area. It is feasible if certain evaluation criteria are applied to ensure the long-term operation of facilities and infrastructure throughout their life cycle. Keywords: Project Management, Economic Efficiency, Construction and Infrastructure Facilities, Arctic Region, Investments, Technologies, Materials

1 Introduction

Throughout the centuries the Arctic region attracted various explorers. Since the 11th century, Russian sailors and travelers have crossed the seas of the Arctic Ocean. By the middle of the 18th century, numerous expeditions and pioneers had explored the Russian coast of the Arctic Ocean and plotted it on maps. V. Bering, S. Dezhnev, S. Chelyuskin, the Laptev brothers, S. Malygin and many other researchers of the Russian North paved the way for contemporary explorers. [1, 2, 3]

Currently, scientists and researchers, studying the socio-economic development of this area [4, 5, 6], focus on a number of factors affecting this process: 1) physical and geographical features of the region (extreme weather conditions); 2) the state of international relations; 3) the state of the global economy and the demand for resources (primarily hydrocarbons); 4) the evolution of technologies, backing the development of this area (since few countries have access to these technologies); 5) changes in the Russia's role in the world. [4]

International organizations are established to study, develop, and explore the Arctic region and ensure the continental cooperation. They are the Council of Barentsev-Euro-Arctic Region (CBER) and the Arctic Council, established in 1996. Presently, it has such

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member countries as the United States [7], Canada [8], Denmark [9], Iceland, the Kingdom of Norway, the Republic of Finland [10], the Kingdom of Sweden [11], and the Russian Federation. The Arctic Fund has been established as a platform for research and education via online interaction between the Arctic states. It hosts international science and practical conferences, fosters research projects [12], and devises programmes on the development of the Arctic region by promoting the Arctic solidarity. [13] The Arctic university was established in 2001 at the initiative of the Arctic Council. In 2022 it comprises 138 universities and research institutes. The Arctic strategy is implemented by one of the leading universities of Russia, the Northern (Arctic) Federal University, that trains specialists ready to work in the Northern territories and the Arctic region.

The Russian Arctic region is the territory stretching from the Murmansk region to Chukotka. The width of its continental part varies from several hundreds to 2,000 kilometers, including all islands, located in the Arctic Ocean. Hence, the Arctic region occupies 60.0% of the Russian territory. [14]

The Russian Arctic region boasts an enormous resource potential. Researchers believe that this area is reach for mineral and other natural resources. The discovery of hydrocarbons in the shelf areas of the Barents and Norwegian seas and off the north-eastern coast of Greenland and other northern areas justify the relevance of further studies and the development of the Arctic region. At present, large amounts of hydrocarbons are extracted in this area (natural gas – 90.0% and crude oil – 60.0% of the total amount extracted in Russia), which undoubtedly makes this region strategically important for this country.

The intensive development of the Arctic region draws increasing attention to its economic development and management. The exploration and development of the Arctic region as well as the implementation of construction projects there need a comprehensive development approach to its long-term undertakings in the coming decades. Any construction-focused effort, invested in the Arctic region, should take account of and evaluate: 1) any technologies used in the Arctic region, 2) any materials, structures, machines and other products used there, 3) the environmental component to reduce the uncontrollable economic and political consequences for Russia.

2 Materials and methods

The purpose of this research is to study the past experience in selecting and evaluating the criteria that allow for the application of technologies, materials, structures, and machinery in the Russian Federation with regard for the minimization of risks that may arise in the course of construction in the Arctic region. Given the relevance of the further development of this territory, the authors analyzed the applicability of new approaches to the design of construction facilities and infrastructure to ensure a comfortable environment for the local residents.

The following objectives were formulated to attain this goal:

- the study of publicly available works on the Russian experience in solving problems arising in the course of construction of buildings and structures in the Arctic zone;
- selection and evaluation of criteria applied to choose technologies, materials, constructions, machinery, and products needed for construction in the Arctic zone with regard for the assessment of socio-economic and management risks;
- the study of their applicability and adaptability to the present-day environment.

In the article, the authors rely on the analysis of the statistical materials collected by the statistics authorities of the Russian Federation, as well as the analytical materials, proceedings of science and practical conferences available in the public domain. Descriptive, comparative, economic, statistical and logical methods were used in the study. The authors also rely on the achievements in such areas of knowledge as economics, construction, sociology and management.

3 Results

Large deposits of mineral resources in the Arctic region have boosted the activities of potential investors and raised the issue of the integrated development of this region. [15] Researchers, who have been studying the potential of the Arctic zone [16], with a focus on its further development, propose to consider this territory as a "dynamic composite system". Its elements interact and exert certain mutual influence.

To ensure a synergetic effect, researchers suggest that construction organizations, participating in the development and reconstruction of this area, consolidate their efforts and integrate their goals into a general plan of regional development by public-private partnerships. [17]

The need for a comfortable environment and consolidation of all forces and resources for the benefit of human life and activities are undoubtful. When studying and analyzing the global experience in erecting buildings and structures in the Arctic zone, the authors realized that it was, to a great extent, consistent with the Soviet and Russian construction experience. [18, 19]

The Russian Federation has built several times more industrial and civil facilities, highways and railroads than all the Arctic countries taken together, and these facilities are still in operation. [20]

Therefore, the main challenges faced by the researchers, are formulated as follows: "What characteristics should buildings and structures, materials, constructions, machines and products have to ensure the lowest costs and the highest durability throughout the life cycle in the Arctic zone? What are the criteria for this choice?"

Let's consider several principal indicators.

3.1 Economic efficiency

This criterion is a most important one. The main challenge faced by the project developers is to understand whether and to what extent this project will be cost effective. If a project cannot pay its way and it's not durable enough, it cannot be implemented in the Arctic region.

Cost effectiveness is a complex property, defined as a set of properties, characterizing the cost of construction, possession (operation) of a facility within the estimated period of its service.

Lean design in construction is a project implemented using minimal elements or resources, mostly without the formation of any new elements.

The issue of construction technologies is raised at the stage of selecting an investment project, taking into account all factors and risks. The economic efficiency analysis, made within the framework of a BIM research project, can identify the best construction undertaking.

Table 1. Comparative indicators of the cost and dates of construction of housing, social and cultural facilities (net of networks).

Construction method	Price per 1 m^2	Construction term 100 m^2/days	Foundation costs
Brick	1.000-1.200	30-40	1
Concreting	700-900	25-35	1
Panel structure	600-800	15-25	1

SIP* panel	250-350	Up to 3 days	0.2-0.3

SIP*, a structural insulated panel (SIP) is an extremely strong three-layer monolithic structure, consisting of two oriented strand boards (OSB). More than 500 thousand square meters of these panels are produced a year (by three shifts working according to a staggered schedule). During an eight-hour shift, an automated factory can make up to five sets of 100 m² houses. One house a day can be erected; hence, the labour intensity goes up 6-8 times. The SIP seismic resistance is nearly 8 points. The service life is 100 years. The acceptable outdoor temperature ranges from minus 60 to plus 50 degrees Celsius. The startup cost will reach $ 12 - 14 million, of which the factory equipment is about $ 8 million. Cases: Novye Veshki village - 400 homes in the Moscow Region; a three-storey construction facility (about 4,000 m²) in the South Pole area.

3.2 Eco-friendliness

The weather conditions of the Arctic region require a special method of strengthening buildings. Builders, willing to ensure the stability of buildings, use pile foundations in permafrost areas.

Nowadays, researchers draw attention to soils (thawing) in the Far North whenever they address climate change [21, 22, 23, 24, 25] and rapid warming. [26] This situation cannot but affect pile foundations of buildings and structures; they will no longer have sufficient bearing capacity, and this state of affairs can have disastrous consequences.

Temperature changes in the Northern hemisphere, as well as rapid warming can cause a catastrophe: 1) gas and crude oil recovery can stop at Urengoyskoye, Zapolyarnoye, Yamburgskoye, Bovanenkovskoye, Vankorovskoye and other gas and oil fields; 2) railroad and motor road traffic will stop, since these structures are built with account taken of the principles of the permafrost conservation; 3) the safety of civil construction facilities (houses, schools, hospitals, kindergartens, etc.), as well as the safety of each individual cannot be ensured.

Therefore, Russia may incur losses worth tens of trillions of dollars. In our opinion, to minimize such global risks, a system of ongoing monitoring is necessary throughout the Arctic region. Its data must be consolidated with the annual analysis of soil thawing. Permafrost preservation actions must be taken everywhere. These issues have been studied by numerous researchers. [27] This problem needs the attention of the representative authorities. Any research on soil transformations requires certain resources, and special control over the situation should be exercised by the Government of the Russian Federation.

Besides the state standards applied to the assessment of the environmental efficiency, the following indicators must be taken into account in the course of the project implementation: 1) environmental performance; 2) measurable performance of an environment management system; 3) environmental performance indicators (EPI) at each stage of the project life cycle.

The compliance of a construction project with the environmental requirements should be continuous, starting from the production of its constituent parts and structures, materials and machines, to transportation, installation and operation, demolition and recycling. Quantitative indicators are determined by the project itself. In case of non-compliance with the requirements at any stage of the project life cycle, the construction project must be rejected.

3.3 A class of the energy efficiency

The difference between outdoor and indoor temperatures can reach 80-90 degrees Celsius in the Far North. That's why A class of the energy efficiency is most appropriate for the Arctic region. There are no alternatives.

Stable indoor temperatures, reduced energy consumption will ensure high-quality operation at low costs. The analysis of the energy efficiency class of a building is an energy efficiency characteristic, identified for each structure. Energy efficiency is a design value used at the design stage. This indicator applies equally to social and industrial facilities. It is very important to revise class A characteristics, at least, once a year.

3.4 Pace of construction work

The Arctic region is the area where the number of warm days is limited to 3 to 5 months. Against this background, the time factor is of ultimate importance, since some types of construction works cannot be performed at low temperatures. Therefore, the pace of construction is essential in these conditions.

Construction standards and rules set the requirements for the calculation of construction terms. In the Arctic region, compliance with construction regulations ensures pace of construction of buildings and structures. Whenever construction work is performed in the Arctic region, these requirements must be fully complied with, because in case of their violation, the construction term is extended, leading to a delay of construction and finishing works till the next warm season.

3.5 Logistics

It is a very important criterion for evaluating construction projects implemented in the Arctic region. It is necessary to analyze the manageability of material, financial and information flows reaching the ultimate consumer in a way that ensures optimal economic performance. Logistics enables the study of the processes of planning, control and management of transportation, warehousing, processing, and other operations in the course of delivering finished products to consumers.

The choice of logistic patterns of cargo delivery is a cost-intensive element of construction projects implemented in the Arctic region, and it can reach up to 60-70% of the total costs. It is noteworthy that there may be four or more cargo transshipments on the way from the producer to the construction site. For example, the construction of a boiler house in the Moscow region costs one unit, while a similar one, located at a distance of 450 km from the town of Pevek, can cost 10-12 times more. Hence, optimal delivery determines the project success, both in terms of timing and costs.

3.6 Low weight

Other things being equal, the low weight of structures and machinery can be of critical importance for construction on permafrost soils. In severe weather conditions, if the total weight is low, the design loading of pile foundations will ensure a longer stable operation period, even in case of thawing soils. The number of surface structures, made of heavy reinforced concrete and regular concrete, should be limited.

3.7 Innovative materials and constructions

In our opinion, the application of innovative materials and constructions in the Arctic area will help to solve some economic and technology problems of construction and operation of buildings and structures. In this case, only in-house equipment and standards will allow to successfully tackle the Arctic development problems and achieve the GDP growth rates of 75-90% within the framework of the import substitution strategy.

Moreover, there is an opportunity to boost the reduction of energy consumption in the course of the GDP production. The current energy consumption exceeds the values, reported by the mature economies, more than twice.

The following indicators of the labour productivity growth can be identified:

- improvement up to 10%;
- high novelty up to 50%;
- revolutionary novelty by a factor of 2 or more. [18]

The following criteria can be applied to evaluate the innovative nature of a product:

1. Safety assurance (environmental (green projects), fire safety, etc.);
2. A 20% increase in the economic efficiency;
3. A 15-20% increase in the labour productivity;
4. A 15-20% cost reduction;
5. A 20% energy efficiency increase.

Breakthrough technologies are to be applied as the most important step:

1. Pre-assembly ensures a 2 to 8-fold increase in labour productivity;
2. BIM, or digital technologies of design, manufacturing, testing and operation;
3. Additive and digital manufacturing. Additive manufacturing is the use of a digital 3D model to combine materials needed to manufacture structural elements. It saves up to 70% of the cost of a building frame as compared with traditional construction technologies. [18]
4. Composite materials.
5. Reduced energy consumption is one of innovative indicators of the Arctic region development.

3.8 Pre-assembly

The idea of using the pre-assembly technique was implemented in the course of development of Yamburg crude oil and gas condensate field in the eighties of the twentieth century. Pre-assembled factory workshops were dragged to the field along the frozen winter road. The workshops were large units, whose dimensions exceeded the maximal dimensions of cargoes, transportable by rail, and their weight ranged from 200 to 1,000 tons. [14] This method of construction of industrial facilities has numerous strengths in the Far North, that has no infrastructure:

1. The economic effect reached 40% of the standard financial budget;
2. The assembly of equipment in the factory environment means high-quality installation of all elements;
3. Ongoing system control was in place;
4. Fewer cases of colds and cold-related injuries were registered;
5. This technique extended the service life of structures.

Presently, the success of this method has been proven by the case of the Lomonosov floating nuclear power plant in Pevek. The pre-assembly method has a strong application potential.

3.9 Choice of technologies

An investor evaluates technologies applied in the course of the project implementation on the basis of the criteria and characteristics that were discussed earlier. The Far North is unforgiving of minor miscalculations, that, if made at the initial stage of construction, can grow into disproportionately large costs at the stage of operation.

For example, the technology proposed for the development of Sabetta gas condensate field was initially evaluated in the early 2000s. In 2015, LNG shipment was initiated. Innovative materials and designs can only be used, if the experience of China is applied, whereby new approved technologies, materials, products, and machines become mandatory for application in the design of new facilities six months after their approval.

3.10 Project Management

The project implementation phase encompasses all stages of its life cycle, such as the feasibility study, design, construction, operation, liquidation and recycling. The planning, organization and control of the workforce, financial, material and technological resources of the project are calculable values. The subject of management is the investment cycle, in the course of which investments are made, the project documentation is developed and implemented in the course of production. Resources are purchased, the quality of construction is controlled, etc. Project management is the core activity. The main purpose of management is to reduce deviations from the standards, set in the project development and implementation plan.

4 Discussion

Russia's development will be fostered by Siberia. According to the estimates, in the coming 10 - 15 years, 25 - 45 trillion rubles will be invested in the development of the Arctic region, 60 - 70% of this amount will be contributed by state-owned companies or the state budget, while the remaining amount will be provided by private investors, including foreign ones.

The main task facing the researchers is to minimize the investors' risks that may accompany the implementation of projects in the extreme climate of the Far North.

In our opinion, it is necessary to use an integrated approach to the management system in charge of investment and construction activities in the Arctic region. An integrated approach, that takes account of every economic and technological factor of the project development, can help to track all potential risks that the developer may experience. The authors have pioneered to standardize class A energy efficiency on a mandatory basis, since no strict norms or requirements have been applied to buildings in the Arctic zone. The establishment of the management system should also be comprehensive to encompass such requirements as the pre-assembly, the choice of technologies, materials, etc. The analysis of all potential construction-related risks, that may arise in the Arctic area, can generate effective results. Without taking these suggestions into account, failures and errors will boost costs at the stages of construction and operation.

The authors have analyzed and proposed the basic criteria and technologies. The risks, associated with the choice of technologies, materials, constructions, machines and products at the stage of construction in the Arctic zone can only be minimized by applying certain evaluation criteria. High-quality long-lasting operation is feasible, if project management supplements economic efficiency throughout the life cycle.

There is no doubt that this is not an exhaustive list of criteria and technologies. Substantial academic and analytical research will allow to expand and itemize it. The resulting work will be formulated as the "Methodology of the criteria assessment and the choice of technologies, materials, machines and products for the Arctic zone" to be approved by a decree of the Russian Government. The past practical experience needs supplementary research, that will serve as the basis for this methodology.

A successful project management case is the LPG production facility in Sabetta, South-Tambeisky license area. Russia's largest LNG plant is being built there. The preliminary stage of the feasibility study of a crude oil/gas condensate recovery project was implemented in the Yamal peninsula in 2002. At the second stage, the technology of gas production and conversion into LPG was pilot-tested in 2005-07. The project participants, including Russia, China, France, as well as the target markets and LPG transportation facilities, were identified. The third stage encompassed the design of the project facilities; it was scheduled for 2005-15. The fourth stage encompassed the construction work, it was scheduled for 2010-17. The facility was put into operation at the end of 2017.

5 Conclusion

Having studied the global experience in erecting buildings and structures in the Arctic region, we can highlight the following ideas: in general, foreign builders, performing construction and installation works in the Arctic region, apply and rely on the construction experience accumulated by the Soviet and Russian engineers.

The overwhelming part of the global expertise, applied in the course of construction of buildings and structures in the Arctic area, represents the Soviet and Russian experience.

If the Arctic zone is considered as an economically profitable area, one should bear in mind that the Arctic is a least modified region on Earth, although it is exposed to the negative impact of climate change. It is necessary to reduce uncontrolled state-induced actions in this territory, which may have a negative impact on its ecosystem, to eliminate any additional anthropogenic stresses, ensure the sustainable development of the area, preserve its climate and natural resources for the future generations.

In the state programme titled "The socio-economic development of the Arctic Zone of the Russian Federation (AZRF) through 2035", the key factors affecting the socio-economic development of the Arctic Zone of the Russian Federation include: 1) extreme weather conditions, including low air temperatures, strong winds and the ice covering arctic seas; 2) uneven industrial and economic development of the territory and low population density; 3) remoteness from major industrial centres, high resource intensity and reliance of its economic activity and life of the population on fuel, food and essential goods supplied by other Russian regions; 4) low sustainability of its ecological systems, which determine the biological balance and climate on Earth, as well as their dependence on minor man-induced impacts.

Towards this end, we suggest that the "Methodology of evaluating the criteria and the choice of technologies, materials, machines and products in the Arctic zone" is approved by a Decree to be issued by the Government of the Russian Federation to minimize socio-humanitarian, technical, economic, environmental risks, that may accompany the development of territories in the Arctic region, to intensify the construction of buildings and structures in the long term, to ensure the continuous development of the territory and a comfortable living environment for its population.

An integrated approach, proposed by the authors, takes account of economic and technology-focused factors. It will reduce the risks that may be experienced by developers in the course of setting the management framework for investment and construction activities in the Arctic region.

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