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Development of a Unified Methodology for Assessing the Choice of Construction Type in the Arctic Based on the Aggregate Economic Effect of Key Regional Construction Parameters

Relevance of research. The growing importance of the Arctic Zone of the Russian Federation (hereinafter referred to as the AZRF) and the Northern Sea Route (hereinafter referred to as the NSR), particularly in enhancing various aspects of the national construction industry and achieving the objectives of national and economic security, motivates the scientific community to study the specific characteristics of the region more thoroughly. The extensive system of benefits and incentives offered for conducting financial and economic activities in the Arctic opens up significant prospects for optimizing costs and investment expenditures incurred by key economic actors in the region. However, the harsh climatic conditions, the generally low level of infrastructural development, and the vast total area of the AZRF represent substantial barriers to achieving the goals of sustainable economic development in Russia's Arctic. The application of advanced technologies and modern principles of economic management can significantly improve the region's economic performance.

Purpose of the study. To describe the methodological foundations and propose an algorithm for developing a methodology to assess the economic feasibility of applying a specific construction approach in the Arctic.

Methods. The unified methodology for evaluating the effectiveness of applying modular elements of maximum readiness (MEMR) represents a sequence of interrelated blocks (stages), with the overall result expressed in the form of a consolidated financial model of the project.

Results and novelty. A unified methodology for assessing the choice of construction type in the Arctic is proposed. Based on this methodology, it is possible to develop a consolidated financial model of a construction project in the region, which effectively becomes the first comprehensive tool for justifying modular construction in the Arctic — integrating regulatory requirements, economic feasibility, and managerial aspects into a single framework.

Keywords: *Economy, Arctic, project financial model, Arctic Zone of the Russian Federation, modular construction, economic effect, MEMR (Modular Elements of Maximum Readiness)*

When studying and conducting research in such a strategically important and complex region as the Arctic, special attention must be given to the economic sciences, as they are critically important both in the context of the Arctic Zone itself and in terms of economic activity within it. Several key factors affect the macroeconomic interests of the Arctic states, as well as other actors engaged in economic activity in the region.

The Arctic possesses an enormous mineral and resource potential, which makes it strategically significant for both the global and national economies. The region contains vast reserves of hydrocarbon resources located on the continental shelf and in coastal areas, and it is also rich in metals, minerals, and other valuable resources, including biological ones such as fish and seafood. Economic science plays a crucial role in assessing their profitability, forecasting demand and impact on global markets, also determining optimal models for extraction and transportation. The development of these resources requires large-scale construction of infrastructure, industrial, and extraction facilities.

Global warming and the melting of Arctic ice are creating the potential to transform the Northern Sea Route (NSR) into a year-round transport corridor, which also requires substantial investment. Economists analyze the NSR's potential as an international transit corridor¹, estimate the necessary

investments in icebreakers, ports, and navigation systems, and assess the route's competitiveness compared to traditional logistics pathways to Asia via the Cape of Good Hope and the Suez Canal.

The specific characteristics of the Arctic entail significant economic costs for any type of construction due to the harsh climatic conditions, limited logistics [1], infrastructural deficit, and short construction season, all of which increase both project costs and implementation timeframes. Economic analysis plays a key role in identifying the most efficient technologies and projects in terms of cost and benefit, taking into account the high expenses of construction, logistics [1], and operation under conditions of permafrost and low temperatures [2]. Moreover, economic science examines how financial, political, environmental, and technological risks affect the profitability of Arctic projects, contributing to the development of mechanisms for their mitigation — for example, through public-private partnerships or special tax regimes.

Thus, the economy serves as both a key driver and a limiting factor for the Arctic. It determines the feasibility, scale, and pace of regional development, while simultaneously underscoring the need to overcome significant financial and technological challenges [3, 4] associated with the unique conditions of Arctic construction. In this sense, the economy functions as a bridge between scientific discoveries and their practical, sustainable application in the interests of states and local communities within the region.

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¹ Urgent information for mariners, Glavsevmorput. Rosatom. 2005. URL: https://nsr.rosatom.ru/srochnaya-informatsiya/?ELEMENT_ID=208232 (rus.).

As mentioned above, construction in the Arctic Zone of the Russian Federation (AZRF) is characterized by specific conditions. According to regulatory documents, including CP 131.13330.2020², the effective construction season in the Arctic and adjacent regions lasts only 2–4 months per year. In practice, productive work is carried out for no more than 100–130 days annually, while the remaining time is marked by forced downtime. These factors result in the high cost and elevated risks associated with capital construction in the AZRF².

According to estimates, up to 70 % of the construction budget in the Arctic is spent on personnel logistics, accommodation, security, and rotation³. In addition, there is a high likelihood of project delays and the need to “conserve” construction sites until the following season, which leads to frozen investments and additional costs. Thus, there is an objective need for a methodology that enables the optimization of construction timelines and costs under conditions of a short building season and limited accessibility.

One of the promising solutions addressing the challenges outlined above is the use of Modular Elements of Maximum Readiness (MEMR) — pre-fabricated block modules manufactured at industrial facilities and assembled on-site within the shortest possible timeframe [5]. Modular construction is currently considered one of the most economically efficient technologies in the industry. The use of MEMR reduces construction time by 60–80 %, which not only shortens the overall duration of work but also mitigates the risks of project freezing and unforeseen budget overruns by ensuring a more predictable schedule of construction and installation activities [5].

However, the transition to modular construction in the Arctic Zone of the Russian Federation (AZRF) is constrained by the absence of a unified methodology for efficiency assessment and planning. Existing regulatory documents also fail to reflect the current level of development of modular technologies in construction across the Far North⁴ [4]. For instance, the state Strategy for the Development of the Arctic Zone of the Russian Federation until 2035⁵ and the sectoral Strategy for the Development of the Construction Industry until 2030⁶ both envisage an increase in construction volumes within the AZRF while simultaneously reducing costs and enhancing the environmental sustainability of projects. These objectives highlight the need for innovative methods of organizing construction processes. In the context of climate change [6] and growing institutional pressure toward decarbonization, the shift to modular construction is viewed by scholars as a strategically sound approach to the development of the North in the 21st century. Consequently, the development of a unified methodology for assessing

the effectiveness of MEMR implementation in the AZRF has become an urgent and essential task.

The Guidelines to SNiP 3.01.01–85⁷ specify that the comparison of organizational and technological solutions should be based on the minimum value of the reduced (brought) costs [7], which include current expenses (construction and installation costs) and standard deductions from capital investments, while also necessarily accounting for the economic effect resulting from the reduction of the project's construction duration. Formally, this is expressed through the indicator of reduced costs for each alternative:

$$Z_i = C_i + E_s K_i, \quad (1)$$

where C_i — the total cost of construction and installation works for the i -th alternative;

E_s — the standard coefficient of investment efficiency in construction;

K_i — additional capital investments (fixed assets, machinery, and equipment) required to implement the given alternative.

At present, the coefficient E_s is regulated at the level of 0.15 (15 %) for calculations in the construction industry⁷. The preferred option is the one with the minimum value of Z_i , which accounts for the effect of shortened construction duration; in cases where the results are equal, the alternative providing greater social benefit is considered more advantageous. This regulatory principle establishes the theoretical foundation for the proposed methodology — to reduce the total brought costs compared to the traditional approach by decreasing construction time and related temporal expenditures.

According to data from Rostekhnadzor⁸, the injury rate at northern construction sites operating under the shift method is nearly twice as high as the national average across the Russian Federation, whereas the transition to factory readiness significantly improves safety levels. All these factors were taken into account in the development of the proposed methodology in the form of corresponding coefficients, adjustment factors, and constraints.

Based on empirical data, the methodology also incorporates the regulatory and technical conditions of construction in the Arctic. It integrates the requirements of current codes and standards, including CP 131.13330.2020² (which regulates the specifics of foundations on permafrost soils, temperature regimes for construction works, etc.), GOST R 71617–2024⁹ (which defines the requirements for modular buildings and structures), among others.

Thus, the methodology synthesizes scientific knowledge and practical experience. It is important to note that the foundation of the methodology is complemented by modern digital planning tools. The use of Building Information Modeling (BIM) technologies and data analytics opens up new opportunities for implementing the unified methodology. Information models of modular elements (IMMEMR) enable the accumulation of all properties and characteristics of the modules in digital form [8]. So, the theoretical foundations of the methodology lie at the intersection of construction

² On approval of SPP 131.13330.2020 “SNiP 23-01–99” Construction Climatology”: Order No. 895/PR of December 24, 2020. Ministry of Construction of the Russian Federation. URL: <https://www.minstroyrf.gov.ru/docs/118243/> (rus.).

³ Features of Housing Construction in the Arctic Zone of the Russian Federation: Federation Council Committee on Federal Structure, Regional Policy, Local Self-Government, and Northern Affairs (Minutes No. 249 of April 12, 2021). URL: http://region.council.gov.ru/activity/activities/round_tables/126006 (rus.).

⁴ SNiP 1.04.03–85*. Standards for Construction Duration and Resources in the Construction of Enterprises, Buildings, and Structures. Part I (General Provisions. Section A). Electronic Collection of Legal and Regulatory Documents. URL: <https://docs.cntd.ru/document/1200000622> (rus.).

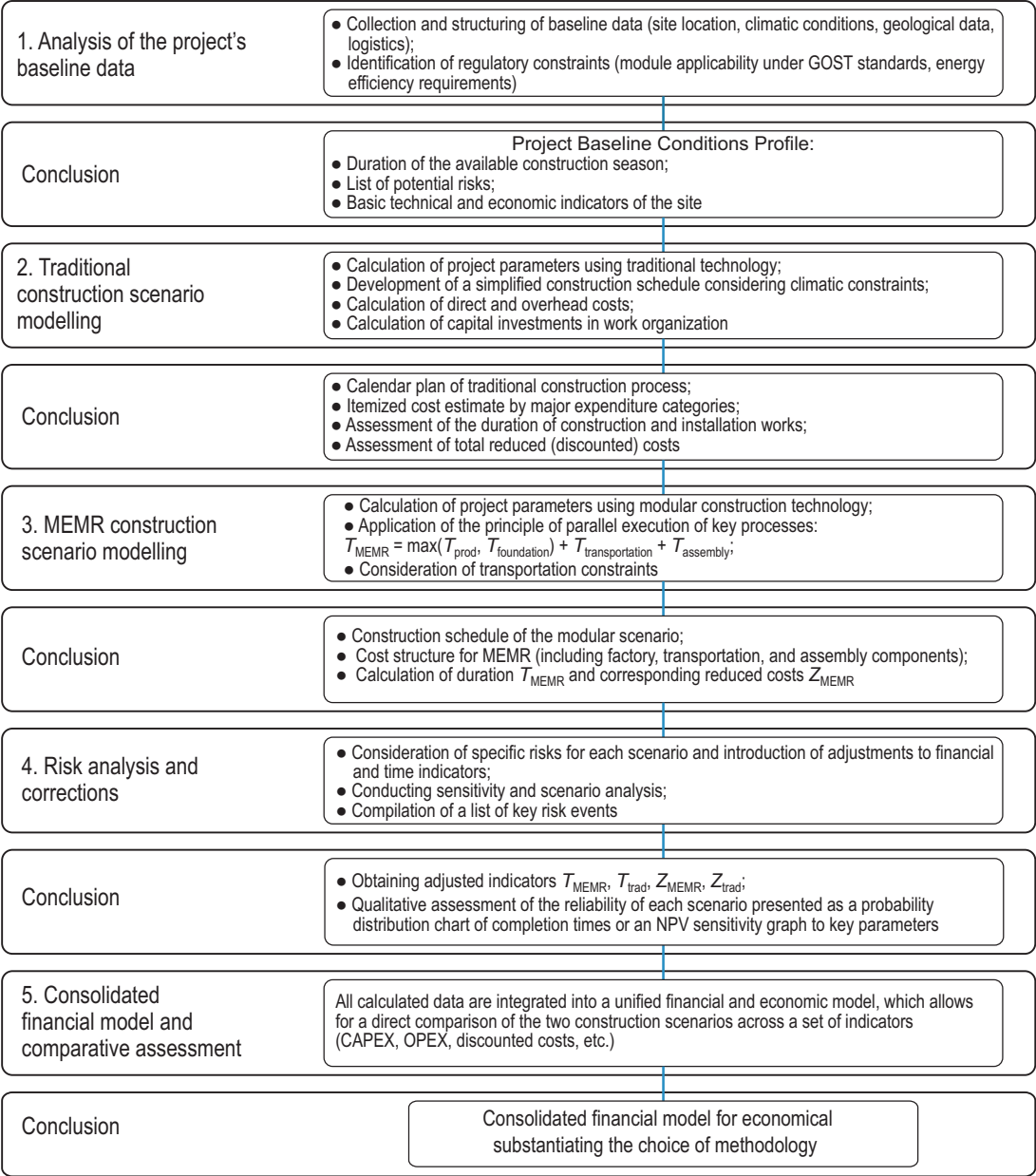
⁵ Strategy for the Development of the Arctic Zone of the Russian Federation and Ensuring National Security for the Period up to 2035. Ministry of the Russian Federation for the Development of the Far East and the Arctic. URL: https://strategy.arctic2035.ru/c/documents/strategiya-razvitiya-arkticheskoy-zony-rossiyskoy-federatsii-i-obespecheniya-natsionalnoy-bezopasnos/?sphrase_id=6355 (rus.).

⁶ Draft strategy for the development of the construction industry and housing and public utilities of the Russian Federation until 2030 with a forecast for the period until 2035. Ministry of Construction of the Russian Federation. September 30, 2021. URL: <https://www.minstroyrf.gov.ru/docs/18723/> (rus.).

⁷ Guide to Developing Construction Organization Projects and Work Production Projects for Housing and Civil Construction (to SNiP 3.01.01–85). Approved by Order No. 211 of the Central Research Institute of Industrial Construction of the USSR Gosstroy dated October 8, 1986. URL: <https://focdoc.ru/fd/pdf/pue/snipu/p3.01.01.pdf> (rus.).

⁸ Analysis of accidents at power plants supervised by Rostekhnadzor. Federal Service for Environmental, Technological, and Nuclear Supervision (Rostekhnadzor). URL: http://szap.gosnadzor.ru/activity/energonadzor/nesc_sluch/ (rus.).

⁹ GOST R 71617–2024. Modular Buildings and Structures. Terms and Definitions. Classification. Federal Agency for Technical Regulation and Metrology. Moscow, Russian Institute of Standardization, 2024. URL: https://gpao.ru/lib/u/file/Law_docs/gost_r_71617-2024.pdf (rus.).



Algorithm for selecting the optimal organizational and technical construction solution in the Arctic

economics, project management, and construction climatology, while its empirical foundations are based on real project performance indicators^{7, 10, 11} and current regulatory standards that confirm the effectiveness of modular technologies in the Arctic.

The unified methodology for evaluating the effectiveness of applying Modular Elements of Maximum Readiness (MEMR) represents a sequence of interrelated blocks (stages), with the overall outcome expressed as a consolidated financial model of the project. The architecture of the methodology can be presented as an algorithm for selecting the optimal organizational and technical construction solution in the Arctic Zone of the Russian Federation (AZRF), which includes the following key steps (Fig.).

¹⁰ Yamal LNG megaproject, Central Dispatch Office of the Fuel and Energy Complex website. 2023. URL: https://www.cdu.ru/tek_russia/articles/3/1107/ (rus.).

¹¹ Modernization of primary healthcare. Ministry of Health of the Republic of Sakha (Yakutia). URL: <https://minzdrav.old.sakha.gov.ru/modpervzvena> (rus.).

All the listed indicators are compiled into a summary table comparing the two scenarios. The table may include rows such as Construction Duration (months), Total Budget (million RUB), Reduced Costs (million RUB), NPV (million RUB), IRR (%), CO₂ Emissions (tons), etc., with two columns — Traditional vs. Modular. Based on the results of this comparative assessment, the economic and managerial effects of implementing MEMR are identified. As a rule of thumb, the modular option demonstrates a shorter construction duration and lower reduced costs, which indicates its overall efficiency.

The consolidated financial model represents these results in a form convenient for decision-making and also serves as an optimization tool. The application of the unified methodology for assessing MEMR provides a number of positive effects by reducing construction costs and increasing the predictability of both budgets and schedules. The modular approach makes it possible to lock in

▶ a significant portion of project costs already at the stage of the factory contract, which greatly facilitates project management.

The third significant effect is the improvement of quality and occupational safety. Modules are manufactured under controlled factory conditions, which enhances the structural quality characteristics. For investors, this translates into reduced costs for defect correction, increased building reliability, and an extended service life. Workplace safety is also improved, as hazardous operations are performed either partially in factory environments or to a much lesser extent on-site.

The fourth effect is rooted in environmental and social performance, which under current conditions translates into reputational and regulatory advantages. Within the framework of the methodology, these environmental effects can be accounted for in the form of reduced additional costs for environmental protection measures¹². Moreover, projects demonstrating improved environmental performance may qualify for sustainable construction certifications. The presence of such certifications and environmental benefits enhances the overall investment attractiveness of the projects.

Social effects are also significant. Within the methodology, the social effect can be considered indirectly. From a managerial perspective, the unified methodology contributes to the standardization and replication of successful solutions. Furthermore, it facilitates communication with the authorities and expert review bodies: the presence of a scientifically grounded efficiency assessment [9, 10] makes it possible to substantiate and convincingly demonstrate the advantages of the project.

For the sake of completeness, it is necessary to conduct a comparative analysis [7]. Traditionally, in Russian practice, the assessment of the economic efficiency of capital investments in construction has been based on the Guidelines for Determining the Economic Efficiency of Capital Investments (Gosstroy of the USSR, 1980s¹³) and subsequent methodological recommendations of the Ministry of Economic Development of the Russian Federation. However, these documents do not directly account for the specific Arctic factors. In contrast, our unified methodology directly integrates climatic and logistical constraints at the stages of data collection and calculation. The methodology anticipates these cost increases in advance, based on CP 131.13330² (seasonal limitations) and MDS 12-81.2007 [11] (work organization regime), while simultaneously offering an alternative solution in the form of a parallel workflow approach.

There are also specialized methodologies for comparing technical solutions in construction, for instance, the Guidelines for Evaluating the Efficiency of New Technologies and Inventions in Construction. Our methodology essentially extends this approach by applying it to the comprehensive technology of modular construction. The classical formula for calculating the annual economic effect (2) is as follows:

$$E_{year} = (C_{base} - C_{new}) + \Delta_{exp}, \tag{2}$$

where C_{base} and C_{new} — the cost under the baseline and the new technology;

Δ_{exp} — the change in operating costs under AZRF conditions is complemented by a time factor.

¹² Russia has approved the GOST R "green" standard for multi-apartment housing. Ministry of Construction of Russia website. 2022. URL: <https://minstroyrf.gov.ru/press/v-rossii-utverzhdyen-zelenyy-standart-gost-r-dlya-mnogokvartirnogo-zhilya/> (rus.).

¹³ State Planning Committee of the Council of Ministers of the USSR No. 40, State Committee of the Council of Ministers of the USSR for Construction No. 100, Presidium of the USSR Academy of Sciences No. 33. On Approval of the Standard Methodology for Determining the Economic Efficiency of Capital Investments : Resolution of September 8, 1969. URL: <https://normativ.kontur.ru/document?moduleId=1&documentId=145572&ysclid=mgwdicjbl629672276> (rus.).

The proposed methodology demonstrates that the advantages of modular technology are manifested through the reduction of total discounted costs due to shortened timelines and mitigated risks. Traditional methodologies typically do not emphasize the economic value of time reduction, whereas in Arctic conditions, time becomes one of the key economic categories. Our approach enables the quantitative assessment of the cost of construction time (through indicators such as reduced costs, NPV, and opportunity costs), thereby filling an existing gap in conventional evaluation methods.

When compared to international practices, it should be noted that methodologies for assessing modular construction at the global level are still in the process of formation. The proposed unified methodology effectively becomes the first comprehensive tool for substantiating modular construction in the Arctic, integrating regulatory requirements, economic feasibility, and managerial aspects into a single framework. The advantages of this methodology in Arctic conditions can be summarized as follows: it ensures an interdisciplinary approach, linking technical solutions with financial indicators and management risks — an aspect of particular importance in the Arctic context. The methodology has been specifically developed for the conditions of the Far North. Our tool accounts for extreme temperatures, permafrost, and the polar night, all of which are reflected in the calculations of time and cost.

Moreover, in the Arctic Zone of the Russian Federation (AZRF), logistics is often the determining factor for project success. In this context, logistics is treated as an integrated component: the methodology enables the planning of module deliveries within specific navigation windows, the assessment of freight costs, and the optimization of transportation routes. Our methodology provides a transparent and well-substantiated financial outcome, supported by references to regulatory standards and empirical research data. This greatly facilitates project review and approval processes. By incorporating environmental and social criteria, the proposed methodology ensures that projects align with the principles of sustainable development. In the AZRF, this is of critical importance, as the fragile ecosystem and the presence of indigenous communities require a careful and responsible approach.

Consequently, a project evaluated under our methodology is more likely to receive support within the framework of AZRF development programs and special investment regimes, and to avoid public opposition related to environmental concerns.

In conclusion, it should be emphasized that the unified methodology for assessing efficiency and the consolidated financial model for the application of MEMR in the AZRF do not contradict but rather develop and refine existing approaches. They provide a scientifically grounded decision-making toolkit that contributes to reducing construction costs and improving overall efficiency.

The primary advantage of this methodology in Arctic conditions lies in its ability to translate the region's unique challenges into quantifiable indicators that can be systematically analyzed and optimized. The initial study of the techniques and methods applied in this article highlights its economic significance in the context of Arctic research and economic activity in the region. By adhering to the algorithm described herein, economic actors operating within the AZRF can intensify their economic activity in the region and improve their overall financial performance.

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Создание унифицированной методики оценки выбора типа строительства в Арктике на основании совокупного экономического эффекта ключевых параметров строительства в регионе

Актуальность исследования. Повышение значимости роли Арктической зоны Российской Федерации (АЗРФ) и Северного морского пути (СМП), в частности, в совершенствовании различных аспектов строительной отрасли страны, достижение цели национальной и экономической безопасности государства мотивируют научное сообщество тщательнее изучать специфику региона. Широкая система льгот и преференций, предлагаемая в рамках ведения финансово-хозяйственной деятельности в Арктике, открывает широкие перспективы по оптимизации затрат и инвестиционных вложений, осуществляемых основными акторами хозяйственной деятельности в данном регионе, однако, суровые климатические условия, низкий уровень инфраструктурного развития региона в целом, а также большая совокупная площадь АЗРФ являются существенными барьерами в достижении целей устойчивого экономического развития отечественной Арктики. Применение передовых технологий и принципов ведения хозяйственной деятельности может существенно улучшить экономические показатели в регионе.

Цель исследования. Описать методологические основания и предложить алгоритм создания методики для оценки экономической целесообразности применения определенного подхода строительстве в Арктике.

Методы. Унифицированная методика оценки эффективности применения модульных элементов максимальной готовности (МЭМГ) представляет собой последовательность взаимосвязанных блоков (этапов), а совокупный результат выражается в виде консолидированной финансовой модели проекта.

Результаты и новизна. Предложена унифицированная методика оценки выбора типа строительства в Арктике, на основании которой можно строить консолидированную финансовую модель строительного проекта в регионе, которая фактически становится первым комплексным инструментом для обоснования модульного строительства в Арктике, собирающим воедино нормативные требования, экономическую целесообразность и управленческие аспекты.

Ключевые слова: экономика, Арктика, финансовая модель проекта, Арктическая зона Российской Федерации, модульное строительство, экономический эффект, МЭМГ

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