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Международный научно-технический журнал включен в Перечень рецензируемых научных изданий, в которых должны быть опубликованы основные научные результаты диссертаций на соискание ученой степени кандидата наук, на соискание ученой степени доктора наук.
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На обложке печатаются работы Хромовой Марины

Уважаемые читатели!

Тема нашего номера — крупные объекты, отличающиеся своей сложностью, стоимостью и сроками строительства.

К ним относятся АЭС–1200 ввиду наличия специального регулирующего законодательства и требований безопасности производственного и экспериментального процесса.

Недавно в г. Ханое (Вьетнам) состоялся 15-й Международный научно-практический форум, посвященный строительству и эксплуатации уникальных и сложных объектов, в том числе АЭС.

В современной практике рыночной экономики для организации строительства АЭС применяют контрактные формы взаимодействия лиц, участвующих в реализации инвестиционного проекта. Выделяют 2 основные формы контракта в сфере атомной энергетики — EPC и EPCM.

Контракт EPCM (инжиниринг, строительство, поставки и менеджмент) применяется при строительстве двух блоков АЭС–1200 во Вьетнаме (весь жизненный цикл фиксируется в «одних руках», в данном случае группе компаний ГК «Росатом»).

Научно-техническое сопровождение выполняют специализированные научные организации.

Надеюсь, в дальнейших номерах мы будем освещать строительство этой станции, а также строительство метро и технологически сложных объектов России.

С наилучшими пожеланиями,
главный редактор, **Пётр Грабовый**

Dear Readers!

The focus of this issue is placed on large-scale projects distinguished by the complexity, cost, and construction timelines.

These include nuclear power plants based on VVER-1200 reactor units, owing to the specific regulatory framework and safety requirements governing construction, operation, and experimental procedures.

Recently, the 15th International Scientific and Practical Forum on the construction and operation of unique and complex facilities, including nuclear power plants, was held in Hanoi, Vietnam.

In todays' practical market economy, contractual forms of cooperation among parties involved in the implementation of an investment project are used to organize the construction of nuclear power plants. There are two main contract forms in the nuclear energy sector: EPC and EPCM.

The EPCM contract (engineering, procurement, construction, and management) is used in the construction of two 1,200 MW NPP units in Vietnam (the entire life cycle is managed by a single entity, in this case the Rosatom State Corporation group of companies).

Scientific and technical support is provided by specialized research organizations.

It is hoped that in future issues we will cover the construction of this plant, as well as the construction of the metro and technologically complex facilities in Russia.

Sincerely, **Peter Grabovyy** Editor-in-Chief

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The Dawn of the Peaceful Atom: Prerequisites for the Intergovernmental Agreement and Prospects for Cooperation between the Russian Federation and Vietnam in the Field of Nuclear Energy Use

This article examines the current state and future trajectories of the Russian-Vietnamese partnership in nuclear power engineering, with a particular focus on the construction of nuclear power plants (NPPs). The current stage of cooperation between the two countries is reflected in plans to construct Vietnam's first nuclear power plant, the Ninh Thuan-1 NPP. The impact of the Ninh Thuan-1 NPP on the Vietnamese economy is anticipated to be multifaceted. The article considers the historical roots of bilateral interaction and analyses in detail the key provisions of the Intergovernmental Agreement governing the full scope of activities, from design to spent fuel management and personnel training. Particular attention is driven to the engineering parameters of the Generation III+ VVER-1200 reactor unit, its environmental performance and economic viability. The main feature of the VVER-1200 project is the unique combination of active and passive safety systems that make the plant as resistant as possible to external and internal impacts. A forecast assessment is provided of the plant's impact on Vietnam's fuel and energy balance, greenhouse gas emission reduction, the development of related industries, and regional infrastructure. The strategic importance of nuclear generation in the context of ESG principles and the green square concept is substantiated. It is concluded that implementation of the project will strengthen Vietnam's energy security, while enabling the Russian Federation to consolidate its presence in the high-tech Asian market.

Keywords: *nuclear power plant (NPP), Socialist Republic of Vietnam, Russian Federation, VVER-1200, Ninh Thuan-1, intergovernmental agreement, nuclear safety, economic multiplier, ESG, green energy, technology transfer*

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INTRODUCTION

Historical ties between Russia and Vietnam span decades of productive cooperation across various sectors, including oil and gas, automotive manufacturing, and military collaboration. The oil and gas industry, one element of the strategic partnership, is based on long-standing experience since 1975 and joint activities on the shelf of the South China Sea. On the Russian side, the main market player is Zarubezhneft. In addition, cultural and educational ties remain strong. Thousands of students have been educated at universities of the USSR, including MISI (now NRU MGSU). Tourism, as a rapidly developing area of business activity, should also be mentioned. In 2025, 690 thousand Russian tourists visited Vietnamese resorts. Over the first four months of 2026, Vietnam received 504,389 Russian travelers, indicating a four-fold increase compared with the same period in 2025.

The current stage of bilateral interaction is reflected in plans to build Vietnam's first nuclear power plant, the Ninh Thuan-1 NPP (Fig. 1, 2) which represents the second attempt by both countries to implement such an ambitious project [1, 2]. This step has specific features that make it strategically important both for Vietnam's energy future and for strengthening Russia's position in the international nuclear energy arena [3]. Importantly, Vietnam's nuclear power industry develops against the backdrop of the increasing importance of the global ESG agenda [4, 5].

The purpose of this paper is to analyse the provisions of the Intergovernmental Agreement and the engineering characteristics of the plant under construction, to assess the economic, environmental, and social effects of Russian – Vietnamese cooperation in the peaceful use of nuclear energy, and to substantiate the role of the NPP as a driver of integrated development not only in adjacent territories but also in nearby provinces.

CHARACTERISTICS OF THE NINH THUAN-1 NPP AND VVER-1200 REACTOR EQUIPMENT

The formula used to calculate the capacity factor (*CF*) is as follows:

$$CF = E_{act}/E_{nom} \cdot 100\ \%,$$

where *CF* is usually calculated for one calendar year;

E_{act} is actual electricity generated over the period (kWh);

E_{nom} is nominal reactor power (kW) multiplied by the number of hours over a period.

This factor is important for evaluating the efficiency of power plants (NPPs, TPPs, HPPs, and SPPs), as it determines the extent to which actual electricity generated over a period corresponds to the maximum possible output. Knowledge of this factor makes it possible to assess the profitability of a generating station, the actual load of equipment, and the efficiency of fuel use in the case of NPPs and TPPs.

Table 1. Main technical characteristics of the VVER-1200 reactor

Parameter	Value
Reactor type	Pressurised water — water power reactor
Thermal power	3,220 MW
Electrical power	1,200 MW
Fuel	Uranium dioxide (U-235) with a maximum enrichment of 4.95 %
Number of primary coolant circulation loops	4
Number of steam generators	4
Coolant temperature at reactor inlet	298.2 °C
Coolant temperature at reactor outlet	328.9 °C
Primary circuit pressure	16.2 MPa
Secondary circuit pressure	7 MPa
Primary circuit coolant consumption rate	86,000 m^3/h
Steam output of steam generators	6,400 t/hour
Design service life	At least 60 years (extendable by 20 years)
Capacity factor	> 90 %
Power plant efficiency	37 %

Fig. 1. Sketch of the future Ninh Thuan-1 NPP

For example, the *CF* is 90 % for Russian nuclear generation, approximately 40 % for hydroelectric power plants, and 29–35 % for gas- and coal-fired generation.

TECHNICAL DESCRIPTION OF THE NPP

According to Article 2 of the Agreement between the Government of the Russian Federation and the Government of the Socialist Republic of Vietnam on Cooperation in the Construction of a Nuclear Power Plant on the Territory of the Socialist Republic of Vietnam [1], the Russian Federation assumes the following obligations:

1. The Parties shall cooperate in the construction, on the territory of the Socialist Republic of Vietnam, of the Ninh Thuan-1 nuclear power plant (hereinafter referred to as the NPP) on a turnkey basis, consisting of two Generation III+ power units based on a water-water power reactor according to the Russian design, with an installed capacity of each power unit of up to 1.3 GW, based on the reference design of the Leningrad NPP-2 and the improved technology of water-water power reactors [2] (Table 1).

2. The cooperation provided for in this Agreement includes:

• updating the feasibility study and the site approval dossier;

Fig. 2. Construction site of the Ninh Thuan-1 NPP

- conducting engineering surveys at the NPP site for the development of NPP design documentation;
- conducting an environmental impact assessment;
- design, construction, and installation of NPP equipment;
- supply of the necessary equipment and materials;
- use of digital tools, including software and infrastructure, throughout the entire period of design, construction, and operation of the NPP;
- supply of nuclear fuel;
- commissioning of the NPP, including start-up and adjustment works;
- warranty operation of the NPP;
- management of spent nuclear fuel and radioactive waste throughout the entire period of NPP operation;
- decommissioning and dismantling of the NPP;
- training of personnel for the construction, operation, and maintenance of the NPP;
- operation, maintenance, repair, modernisation, and reconstruction of the NPP;
- safety regulation and related support measures for radiation and nuclear safety throughout the entire NPP operation period;
- improvement of the NPP infrastructure necessary for the construction and operation of NPP power units;
- development of the state safety regulation system for the use of atomic energy for peaceful purposes, necessary for the implementation of the national nuclear energy programme of the Socialist Republic of Vietnam;
- establishment of a physical protection system for the main and auxiliary NPP facilities;
- cooperation in the field of localisation and transfer of knowledge concerning the construction, operation, and maintenance of the NPP and the development of nuclear infrastructure, in accordance with agreements (contracts) to be concluded under this Agreement;
- response to radiation and nuclear incidents and emergencies;
- other areas of cooperation as may be agreed by the Parties in writing.

The above provisions are necessary for understanding the scale of cooperation between the two countries.

The planned NPP will have Generation III+ VVER-1200 reactors, which are known for their high environmental safety and efficiency.

Compared with traditional power units of the same type, the VVER-1200 design has a number of strengths that greatly improve its economic performance and safety (Fig. 3). For example, the reactor unit capacity has increased by 20 % compared with the previous generation (VVER-1000), staffing requirements have been reduced by 30 %, and the design service life of the main equipment has doubled to 60 years, with the possibility of extension by another 20 years.

The main feature of the VVER-1200 design is its unique combination of active and passive safety systems, which makes the plant extremely resistant to external and internal impacts. In particular, the VVER-1200 unit uses a “core catcher”, a device for localising the molten core of a nuclear reactor; a system of heat dissipation through steam generators, designed to ensure long-term heat removal from the reactor core to the atmosphere in the event of a complete loss of all power supplies; inner and outer containment shells

Fig. 3. Diagram of the reactor unit with a VVER-1200 reactor

constituting the hermetic zone; a passive heat removal system on the dome with hydrogen recombiners; and electromagnets that hold the absorber rods, which fall into the core under gravity when the NPP is de-energised. Thus, a number of safety systems do not require human intervention and operate under gravity. According to the project description, no operating plant in the world is equipped with such a configuration of safety systems [2].

ECONOMIC COMPONENT: CONTRIBUTION OF THE NPP TO VIETNAM'S NATIONAL ECONOMY

The impact of the Ninh Thuan-1 NPP on Vietnam's economy is expected to be multifaceted. First, it is expected to create new jobs both during the construction period, with peak employment of up to 15–18 thousand employees, and after commissioning, with approximately 2–2.5 thousand highly qualified specialists. Second, project implementation will stimulate investment in infrastructure and related industries, including road networks, port facilities, power transmission lines, building materials production, and logistics. Third, lower electricity tariffs resulting from the introduction of nuclear generation, with costs of approximately 4–5 cents per kWh compared with 6–7 cents at coal-fired TPPs, will increase the competitiveness of the national economy, particularly for energy-intensive industries.

One of the key values used to support decisions regarding the construction and operation of an NPP is the Levelized Cost of Energy (LCOE), which takes into account all types of NPP life-cycle costs, including design, construction, operation, and decommissioning. In practice, this value is used to calculate the cost of electricity, and this calculation is relevant not only for NPPs but also for any type of electricity generation.

LCOE is calculated as the ratio of the present value of total costs over the entire service life of the facility to the present value of all electricity produced over that period. It takes into account:

- capital expenditures (CAPEX), or capital costs for construction and purchase of equipment;
- operating and maintenance expenditures (OPEX), or costs of operation, repair, nuclear fuel, insurance, and taxes;
- financial costs, or interest on loans and project financing;
- decommissioning and dismantling costs at the end of service life;
- electricity generation, or the output over the life cycle, taking into account maintenance periods for nuclear fuel replacement;
- discount rate that accounts for the time-dependent value of money and inflation;
- planning period which is the service life of the capital asset; in the case of a VVER-1200 NPP, this is 60–80 years.

Formula:

$$LCOE = [\sum ((I\_t + M\_t + F\_t))/((1 + r)^t))]/(\sum E\_t/((1 + r)^t)),$$

where I_t denotes investment costs in year t;
M_t denotes operating and maintenance costs in year t;
F_t denotes fuel costs in year t;
E_t denotes electricity generation in year t;
r denotes the discount rate;
t — the life cycle of the system.

For a quantitative assessment of the economic effect, a multiplier is calculated using the methodology tested in the Akkuyu and El-Dabaa projects. The cost of constructing two VVER-1200 units is estimated at USD 10 billion (USD 5 billion per unit). The multiplier coefficient for the customer country, Vietnam, is taken as 1.4–1.5. In this case, the total contribution to Vietnam's GDP from direct, indirect, and induced effects is expected to reach approximately USD 14–15 billion during the construction period and the first years of operation (Table 2).

Table 2. Projected economic effects of the construction of the Ninh Thuan-1 NPP (two units)

Indicator	Value	Note
Total capital investment, billion USD	10–11	Including auxiliary infrastructure
Direct employment during peak construction, thousand persons	15–18	Including rotational staff and local residents
Permanent NPP staff, thousand people	2.0–2.5	Operators, engineers, and security personnel
Employment in related sectors, thousand people	8–10	Logistics, construction industry, and catering
Cumulative increase in Vietnam's GDP (over 10 years), %	+1.8–2.2	By analogy with projects in Turkey and Egypt
Reduction in the average-weighted wholesale electricity price by 2035, %	10–15	After design capacity is reached
Savings on coal and gas imports over 60 years, billion USD	45–55	Assuming constant fuel prices

Thus, the Ninh Thuan-1 NPP serves not merely as an electricity generator but also as a powerful driver of economic growth, job creation, and technological development for Vietnam.

ENVIRONMENTAL ASPECTS AND ROLE IN SUSTAINABLE DEVELOPMENT

In the context of global climate change, nuclear energy is considered one of the least polluting sources of electricity. According to international rankings, Vietnam is among the countries with a rapidly increasing carbon footprint, with CO_2 emissions growing by more than 5 % per year [6]. Coal-fired thermal power plants account for more than 50 % of generation, which creates serious environmental problems [7, 8].

An analysis of current greenhouse gas emissions and their possible reduction after the NPP is commissioned shows that replacing coal generation with nuclear power would prevent the emission of about 7 million tons of CO_2 per year per unit, assuming a capacity factor of 90 %. The two units of the Ninh Thuan-1 NPP would prevent the emission of approximately 14 million tons of CO_2 annually, which corresponds to about 5 % of the current emissions of Vietnam's entire energy sector [9, 10] (Table 3).

It is important to note the inclusion of nuclear energy in the so-called Green Square, a classification of sustainable sources recognised by the European Commission in the Taxonomy (2022) and supported by the IAEA. This opens access to "green" financing and increases the investment attractiveness of the project. The environmental advantages of nuclear energy should serve as an additional argument in favour of increasing its share in Vietnam's energy balance [11, 12].

Consequently, nuclear generation is comparable to renewable sources in terms of life-cycle emissions and is practically zero-emission during operation, while providing baseload power 24/7 without the need for storage systems [12].

CAPACITY DEVELOPMENT AND EDUCATIONAL INITIATIVES

To ensure reliable and safe operation of the NPP, a system for training specialised personnel must be established. The Intergovernmental Agreement provides for largescale educational initiatives. The Russian side undertakes to:

- allocate annual quotas for Vietnamese citizens at leading Russian industry-specific higher education institutions, including NRU MGSU, NRU MEPhI, Bauman Moscow State Technical University, and Peter the Great St. Petersburg Polytechnic University;
- organise internships for operating personnel at operating Russian nuclear power plants, including Novovoronezh and Leningrad NPPs, for at least 500–700 specialists in the five years before the plant starts operation;
- create a fullscale simulator (FSS) of the VVER-1200 at the Ninh Thuan-1 NPP site for operator training;
- develop training courses in nuclear physics, radiation protection, and automated control systems in the Vietnamese language.

By the time the first unit is commissioned, Vietnam is expected to have at least 600–800 qualified specialists capable of independently operating and maintaining the plant. This will lay the foundation for

Table 3. Specific CO_2-eq emissions for different types of power plants over the full life cycle

Source type	Emissions, g CO_2-eq/kWh
Coal (subcritical)	820–1,000
Gas (steam and gas unit)	380–490
Photovoltaic panels	30–60
Wind power generation	7–20
Nuclear energy (VVER-1200)	8–20
Hydraulic power plant	10–50

Source: IPCC (2022), NEA (2023), calculations for VVER-1200 [9–11].

further development of the national nuclear energy industry and possibly for the export of expertise to other ASEAN countries.

PROSPECTS FOR HEAVY INDUSTRY

The construction of an NPP has a positive effect on the development of related industries, including the production of specialised equipment and the provision of services. The transfer of technologies and know-hows, specified in Article 2 of the Agreement, will allow Vietnam to increase its own capacities for subsequent projects and to enter international markets.

Within the framework of the localisation policy, it is planned to:

- involve Vietnamese contractors in the performance of "non-nuclear" activities, including concreting, rebar installation, cable laying, and earthworks, as well as in the supply of materials and equipment not assigned to nuclear safety classes, accounting for up to 30–40 % of the total construction cost;
- establish joint ventures for the production of special construction materials, including high-density concrete and seismic-resistant structures;
- organise logistics hubs and port infrastructure for receiving largesized equipment;
- in the future, organise licensed production of individual components for small modular reactors.

For Vietnam, this means a transition from being an importer of technologies to becoming an adaptor and, potentially, an exporter of engineering services to the markets of Laos, Cambodia, and Indonesia.

ENSURING REGIONAL ENERGY SECURITY AND EXPORT POTENTIAL

Given the growth in energy consumption, with Vietnam showing an annual increase in electricity consumption of 8–10 %, the country requires stable sources of electricity. In addition to meeting domestic demand, the use of nuclear energy creates the potential for electricity exports to neighbouring countries, including Laos, Cambodia, Thailand, and the southern provinces of China. This direction could become a strategic instrument for strengthening energy security across the entire region.

Against this backdrop of increasing investment in the nuclear sector, the Russian side also gains a strategic advantage by strengthening its position in the Asian market. The Ninh Thuan-1 project serves as a showcase for Russian Generation III+ technologies for other ASEAN countries, demonstrating the reliability, safety, and economic efficiency of the VVER-1200 in tropical operating conditions, alongside the Akkuyu NPP currently under construction in the Republic of Turkey.

CONCLUSION

Cooperation between the Russian Federation and Vietnam in the field of nuclear energy, embodied in the Ninh Thuan-1 NPP project, opens up new opportunities for both parties. It will contribute to Vietnam's sustainable development by ensuring energy independence, reducing greenhouse gas emissions, creating highly skilled jobs, and developing related industries, while also providing impetus for deeper cooperation in education, science, and industry. The Russian Federation, in turn, will consolidate its position in the rapidly growing Asian market, replicate the successful turnkey export model of nuclear technologies with a full life cycle, and establish the foundation for a long-term strategic partnership with the Socialist Republic of Vietnam.

The implementation of the Ninh Thuan-1 project will become a tangible embodiment of the "dawn of the peaceful atom" in Southeast Asia and will confirm Russia's leadership in the global nuclear energy industry.

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Рассвет мирного атома. Предпосылки заключения Межправительственного соглашения и перспективы развития сотрудничества Российской Федерации и Вьетнама в области использования атомной энергии

В публикации анализируется текущее состояние и будущие траектории российско-вьетнамского партнерства в области ядерной энергетики с фокусом на возведение атомной электростанции. Современный этап взаимодействия двух стран находит отражение в планах строительства первой АЭС (Ниньтхуан-1) во Вьетнаме. Воздействие АЭС «Ниньтхуан-1» на экономику Вьетнама будет носить многосторонний характер. В статье рассмотрены исторические корни взаимодействия сторон, детально разобраны ключевые статьи Межправительственного договора, регламентирующего полный спектр работ — от проектирования до утилизации отработавшего топлива и повышения квалификации персонала. Углубленное внимание уделено инженерным параметрам реакторной установки ВВЭР-1200 (III+ поколение), ее экологической составляющей и экономической рентабельности. Главной особенностью проекта ВВЭР-1200 является уникальное сочетание активных и пассивных систем безопасности, делающих станцию максимально устойчивой к внешним и внутренним воздействиям. Представлена прогнозная оценка воздействия станции на топливно-энергетический баланс Вьетнама, сокращение эмиссии парниковых газов, эволюцию вспомогательных производств и региональной инфраструктуры. Обоснована стратегическая значимость атомной генерации в контексте ESG-принципов и концепции «зеленого квадрата». Сделан вывод, что реализация данного проекта укрепит энергобезопасность Вьетнама, а Российская Федерация упрочит свое присутствие на высокотехнологичном азиатском рынке.

Ключевые слова: *атомная энергостанция (АЭС), Социалистическая Республика Вьетнам, РФ, ВВЭР-1200, «Ниньтхуан-1», межправительственный договор, ядерная защищенность, хозяйственный мультипликатор, ESG, зеленая энергетика, трансфер технологий*

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Improving the Safety of Capital Construction Facilities During Mineral Deposit Development: Contested Mining Facilities, State Regulation, and Supervision

The article examines the legal qualification of facilities as items of capital construction. This work has a practical value because the status assigned to quarries, opening and preparatory work, dumps, tailings ponds, sludge ponds, underground chambers, ventilation systems and drainage facilities determines whether design documentation, engineering surveys, state expertise, construction permits, construction supervision, industrial safety control and environmental assessment procedures are required. The study aims to develop criteria for distinguishing mining operations as technological results from engineering structures that have a stable connection with land and subsoil, a long service life and an independent function in the safety system or production cycle. The sources include the Urban Planning Code of the Russian Federation, legislation on subsoil use, industrial and environmental safety, by-laws for the state expertise and approval of technical projects, official materials of Federal Environmental, Industrial and Nuclear Supervision Service (Rostechnadzor), the Federal Supervisory Natural Resources Management Service, and Glavgosexpertiza of Russia to ensure the safety of capital construction facilities during mineral deposit development, and academic publications on underground construction, cadastral accounting of dumps, risk-based control and mining safety. The results show that current regulation does not have comprehensive criteria to qualify disputed mining and technical facilities, while an exemption from a construction permit under Government Decree No. 1816 does not in itself prove that a facility is non-capital. The article proposes a functional legal test, a three-group classification of facilities, and a cross-departmental decision making algorithm. The proposed approach can reduce abuse by subsoil users, prevent the withdrawal of hazardous engineering facilities from state control and improve accident prevention at mining facilities.
Keywords: *capital construction facility, subsoil use, industrial safety, state expertise, state construction supervision, mining facility, quarry, dump, tailings pond, temporary structure*

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INTRODUCTION

The qualification of mining and technical facilities as capital construction facilities is not only a basic issue but also a matter of public safety and administrative control. The legal status of a facility determines the regime for engineering surveys, design documentation, state expertise, construction permits, construction supervision, industrial safety control, property accounting and environmental procedures [1–8].

The issue is especially sensitive for subsoil operations. Mining combines extraction, creation of mines and construction of surface and underground engineering structures as one production cycle. Many of these structures are used for long periods and directly affect industrial, environmental and geomechanical safety. In practice, some stable and technologically significant facilities may be described as temporary, auxiliary or inseparable from the mining process in order to limit the application of urban planning procedures [9–14, 15].

Official data confirm the practical relevance of this problem. According to Federal Environmental, Industrial and Nuclear Supervision Service (Rostechnadzor), in 2024 federal industrial safety supervision covered 2,731 mining, non-metallic-industry and underground construction facilities, including 62 facilities of hazard class I and 526 facilities belonging to hazard class II. The number of mining operations amounted to 1,632 million cubic meters and the number of employees reached 192,000. In the same period, 4 accidents were recorded, and fatalities increased from 28 in 2023 to 51 in 2024 [16].

The preventive role of design review is also confirmed by state expertise. Glavgosexpertiza of Russia reported that, based on 2020 results, the declared estimated cost of construction facilities was reduced by RUB 329 billion after verification, while 707 projects, or 27 % of the most complex and unique facilities, contained technical solutions that could create emergency risks [17]. Therefore, the unjustified exclusion of disputed mining facilities from the control regime means the loss of an important preventive barrier.

Amendments to Government Decree No. 1816 expanded the list of cases in which a construction permit is not required for works connected with mining operations [4]. However, a procedural exemption does not determine the legal nature of a facility. The broader the list of procedural exceptions, the greater the need for transparent criteria for the qualification of disputed mining and technical objects.

The purpose of this article is to propose a functional legal test for identifying mining facilities that should be treated as capital construction facilities or should at least be subject to the similar expert and supervisory control. The study also develops a classification of such facilities and an interdepartmental algorithm for reducing safety risks.

MATERIALS AND METHODS

The research is based on doctrinal and comparative analyses of the Russian legislation and law-enforcement materials. The regulatory base includes the Urban Planning Code of the Russian Federation, the Law of the Russian Federation On Subsoil, the Federal Law On Industrial Safety of Hazardous Production Facilities, the Federal Law On Environmental Expertise, Government Decree No. 145 on state expertise of design documentation and engineering survey results, Government Decree No. 1816 on cases in which construction permits are not required, Government Decree No. 2127 on projects involving mineral deposits and underground structures, and Government Decree No. 694 on state environmental expertise [1–8, 18, 19].

Official materials of Federal Environmental, Industrial and Nuclear Supervision Service (Rostechnadzor), the Federal Subsoil Resources Management Agency, the Federal Supervisory Natural Resources Management Service, and Glavgosexpertiza of Russia were used to assess the institutional logic of the regulatory system and the practical consequences of an erroneous qualification of a facility [16–22]. The study also relies on academic literature on underground construction, administrative regulation of subsoil use, the relationship between the rights of a subsoil user and a land owner, cadastral accounting of rock dumps, risk-based industrial safety, environmental limitations in subsoil use and the stability monitoring of quarry sides [23–35].

The initial legal rule is clause 10 of Article 1 of the Urban Planning Code, which defines a capital construction facility as a building, structure, construction or construction in progress, excluding non-capital buildings, structures and inseparable land improvements [1]. Clause 10.2 of the same article defines non-capital buildings and structures through the absence of strong connection with the ground, the possibility of relocation without disproportionate damage to their purpose and, as a rule, the temporary nature of use [1].

These legal definitions do not provide a ready-made answer for mining facilities. A quarry, a mine shaft, a dump, a tailings pond, an underground chamber, a drainage complex and a ventilation facility differ significantly in design, function, service life and risk profile. For this reason, the verbal description chosen by a subsoil user cannot replace a substantive legal assessment.

The legislation on subsoil use has its own set of design documents and approval procedures. Government Decree No. 2127 is about technical projects for deposit development, construction and operation of underground structures, and liquidation or conservation of mines, wells and other structures connected with subsoil use [6]. This confirms that subsoil use modes apply to a broad range of structures but do not automatically answer whether each structure is a capital construction facility under the urban planning law.

The methodological premise of this research is the distinction between four interacting regulatory tracks: licensing and subsoil use, urban planning and state expertise, industrial safety, and environmental assessment. A mistake at the qualification stage can remove a facility from one or more of these tracks and thereby reduce the level of preventive control.

RESULTS

The analysis shows that disputed mining and technical facilities can be divided into three groups:

- facilities presumed to be capital construction facilities;
- facilities presumed to be non-capital structures or equipment;
- facilities requiring individual assessment.

The proposed groups are presented in Table 1.

The least problematic cases are mobile facilities and equipment. The main conflict zone concerns quarries, dumps, storage facilities and other items that combine technological and engineering features. For such facilities, qualification should be based on a functional and legal test rather than the name assigned by the subsoil user.

The proposed test includes six positive criteria: stable spatial connection with land or subsoil, independent design solutions and engineering calculations, independent function in the safety system or production cycle, long service life, serious consequences of failure for employees, third parties or the environment, and integration into a hazardous production facility, especially the one classified as particularly dangerous or technically complex [1, 3, 6, 8, 16].

A facility should not be treated as capital merely because it is located within the area occupied by a mine. At the same time, the mere fact that a structure is functionally connected with the mining process should not, in itself, justify its withdrawal from the scope of capital construction legislation. Structural permanence, independent engineering function, high risk, and the nature of the facility must prevail over its formal designation.

As Table 2 shows, no critical risk arises at the licensing stage. It arises when the technical project of subsoil use is transferred to the urban-planning, industrial-safety and environmental authorities responsible for the qualification of the structures.

Current practice often replaces the qualification stage with a reference to the approval of the technical project for subsoil use.

Table 1. Functional and legal qualification of disputed mining facilities

Group of items	Standard examples	Key features	Preliminary conclusion	Main risk of qualification mistakes
Presumed capital construction facilities	Mine shafts; slopes; above-ground buildings; underground chambers; ventilation and drainage complexes	Long-term operation; stable connection with land or subsoil; independent engineering function	As a rule, capital construction facilities	Loss of design and construction control over facilities whose failure affects life and health
Presumed capital construction facilities	Tailings ponds; sludge storage facilities; dams; drainage and fencing structures	Permanent nature; environmental consequences of failure; post-operational impact	As a rule, capital construction facilities	Pulp breakthrough, pollution and long-term damage after mining is completed
Individual assessment	Quarries; opening and preparatory workings; dumps; side-protection systems; quarry-transport elements	Mixed technological and engineering nature; different degrees of connection with land; variable service life	Functional and legal test is required	Withdrawal from the capital-construction mode by formal name despite actual engineering capital
Non-capital facilities or equipment	Mobile installations; replaceable pumps; container modules; canopies; short-term installation sites	Mobility; collapsible nature; relocation without disproportionate damage	As a rule, non-capital facilities or equipment	Substitution of capital facilities with temporary labels, or unnecessary procedures for genuinely mobile equipment

Table 2. Stages of document management, competent authorities and legal result

Stage	Main document	Competent authority	Legal result	Key risk point
1. Licensing of subsoil use	License and terms of subsoil use	Authorized authority/ Rosnedra	Right to use the subsoil area arises	Project begins without verifying the composition of facilities
2. Technical project	Technical project for field development or underground structures	Rosnedra	Design solutions in subsoil use are approved	Approval of technical project is substituted for construction qualification
3. Qualification of disputed facilities	Qualification matrix or reasoned conclusion	Developer, designer, expert and competent authority where necessary	Capital or non-capital regime is determined	Formal naming replaces functional and risk analysis
4. Design documentation and surveys	Engineering survey results and design documentation	State expertise/ Glavgosexpertiza	Expert opinion where required	Actual capital facility is excluded from expertise
5. Construction permit	Application, title documents and design documents, or reasoned reference to exemption	Authorized authority	Permit or lawful application of an exception under Decree No. 1816	Procedural exemption is confused with non-capital status
6. Construction and industrial supervision	Work program, hazardous production facility information and production control documents	Rostekhnadzor/State construction supervision authority	Supervision during construction and operation	Gap appears between construction and industrial control
7. Environmental contour	Environmental impact and state environmental expertise materials	Rosprirodnadzor	Environmental conclusion and other results	Independent environmental regime is ignored

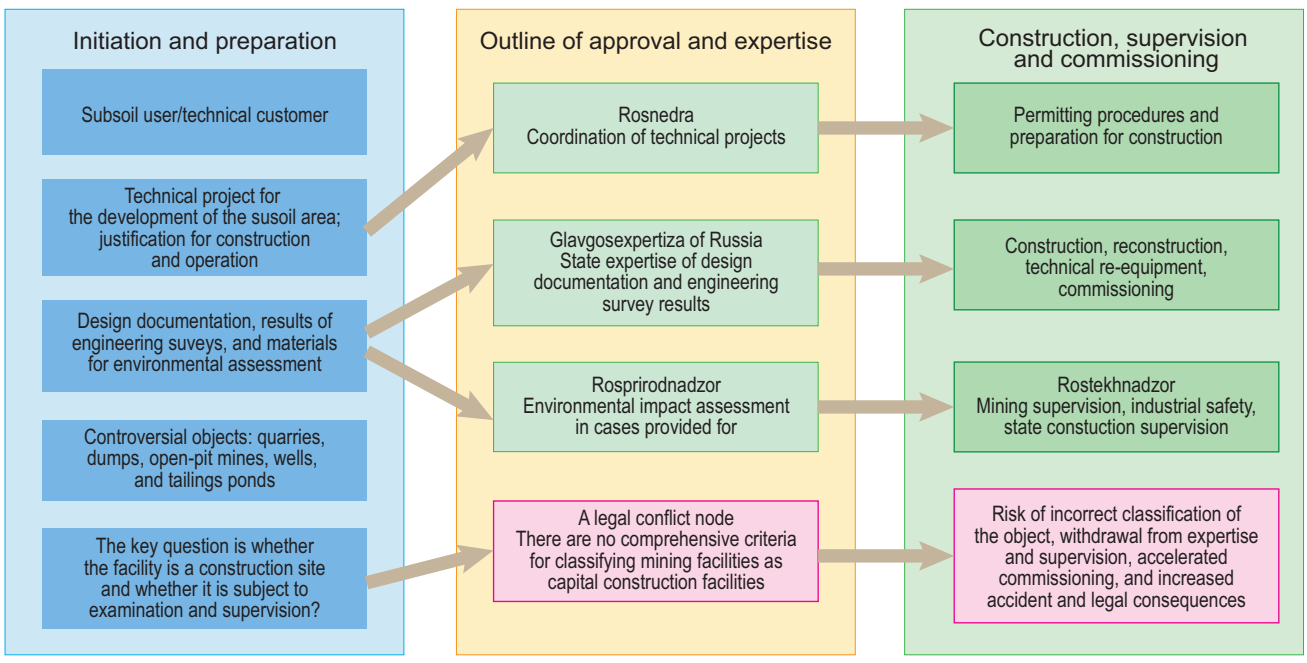

Fig. 1. Flow chart of documentation and qualification of facilities

This substitution is methodologically incorrect. The same facility may be considered by the Federal Subsoil Resources Management Agency as a subsoil item that is beyond the urban-planning and environmental control. The greatest uncertainty arises at the decision point shown in Fig. 1, whether subsoil use, urban planning, environmental control and industrial safety regulations should apply to a disputed facility at the same time.

The territorial structure of supervised hazardous mining facilities by hazard class in 2024 (Fig. 2) demonstrates the scale of the problem. Even where class III facilities predominate, the supervision system includes a significant number of class I and II facilities. For these facilities, any erroneous qualification involve particularly negative consequences.

The proposed system of criteria for practical qualification is summarized in Table 3. The criteria should be applied cumulatively. A single feature may be insufficient, but a combination of permanence, independent engineering function, long service life and high-consequence failure normally justifies a presumption in favor of the capital-construction regime or an equivalent expert-supervision regime.

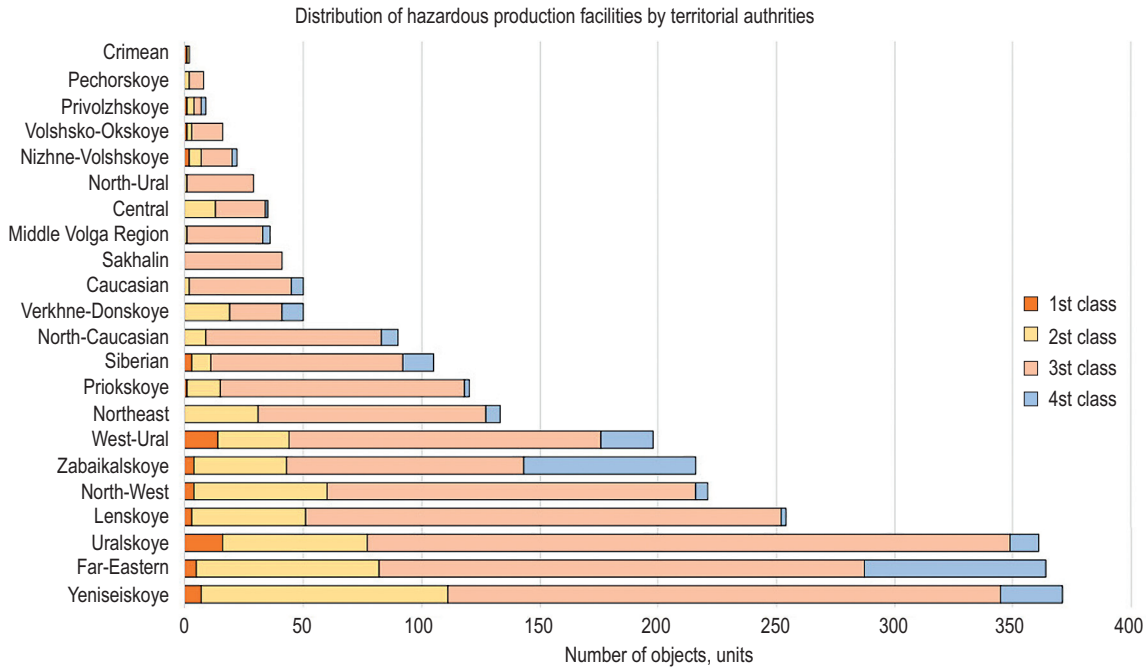

Fig. 2. Structure of supervised mining facilities by hazard class in 2024

Table 3. Proposed criteria for qualification of disputed mining facilities

Criterion	Signs in favor of capital construction	Signs against capital construction	Recommended result
Stable connection with land and subsoil	Facility is embedded in the mass or cannot be moved without destruction	Relocation is possible without disproportionate damage	Presumption in favor of capital construction
Independent design solution	Separate calculations of stability, drainage, ventilation, support or hydraulic protection exist	Object is described as a temporary technological position without independent calculations	Presumption in favor of capital construction
Independent function	Facility provides transportation, protection, drainage, ventilation, storage or treatment	Facility performs a short-term auxiliary function	Capital presumption during long-term operation
Service life	Operation continues for a significant part of deposit development or after closure	Use is limited to one short-term operation	Assessment based on the totality of features
Consequences of failure	Failure can cause injury, flooding, collapse, environmental pollution or shutdown of production	Damage is local and has no systemic impact	Enhanced expert-supervision regime
Integration into hazardous production facility	Facility supports operation of a particularly dangerous and technically complex complex	No connection with such a facility or only episodic connection exists	Presumption in favor of capital construction
Mobility and dismantlability	Absent or not confirmed	Expressed and constructively confirmed	Presumption against capital construction
Temporary nature	Not confirmed; actual operation is permanent	Confirmed by design and real dismantling possibility	Presumption against capital construction

DISCUSSION

The principal risk is that the formal withdrawal of a facility from the capital-construction category allows a subsoil user to minimize or avoid engineering surveys, preparation of design documentation, state expertise, construction permits and construction supervision [1, 4, 8]. For facilities with high technogenic hazards, this approach reduces the preventive capacity of the state.

Artificially classifying stable engineering facilities as temporary has several negative effects. First, the design quality may decrease because the developer has less incentive to conduct comprehensive engineering surveys and to design the facility as a durable item of infrastructure. Second, external expert control is weakened; the materials of Glavgosexpertiza of Russia show that expertise detects both inefficient and dangerous design solutions [17]. Third, interdepartmental diffusion of responsibility increases: Federal Environmental, Industrial and Nuclear Supervision Service (Rostechnadzor), the Federal Subsoil Resources Management Agency, the Federal Supervisory Natural Resources Management Service, expert organizations focus on different legal issues, and a facility may be found between them [18–22]. Fourth, misqualification can affect property, cadastral and tax accounting because the issue of capital construction also has civil law and cadastral consequences [12, 14, 15].

Federal Environmental, Industrial and Nuclear Supervision Service (Rostechnadzor) has a special role here. It acts simultaneously as an industrial safety supervisor, a mining supervision authority and, where the law provides, a state construction supervision

authority [16, 22]. If a disputed mining facility is both capital and part of a particularly dangerous or technically complex facility, the absence of construction supervision would create an artificial rupture in a consolidated safety system.

The analysis supports four regulatory proposals. First, it is necessary to clarify that being on the list of cases which require no construction permit does not determine non-capital status. This clarification can be incorporated into Government Decree No. 1816 or issued as an explanation [4].

Second, the Ministry of Construction, the Ministry of Natural Resources, Federal Environmental, Industrial and Nuclear Supervision Service (Rostechnadzor), the Federal Subsoil Resources Management Agency should adopt functional and legal criteria for classifying mining facilities as capital construction facilities. Such an act should include an indicative list of facilities presumed capital, facilities presumed non-capital and facilities subject to individual assessment.

Third, facilities whose failure may cause fatalities, flooding, destruction of quarry sides, breakthrough of pulp, environmental pollution or loss of stability of the rock mass should be subject to tighter design and expert control. This control should apply, among other things, to tailings ponds, sludge storage facilities, permanent drainage and ventilation complexes, side-reinforcement systems, protective barriers and major underground structures [23–30, 34].

Fourth, law-enforcement practice should apply the principle of substance over form. Where a facility exhibits the structural, functional, and risk-related characteristics of a capital construction facility, its classification should not be altered solely on the basis of the name assigned to it by the subsoil user.

CONCLUSIONS

The failure to qualify disputed mining and technical facilities as capital construction facilities is a systemic problem. It arises from the mismatch between the logic of urban-planning regulation, subsoil-use regulation, industrial-safety control and environmental assessment. Quarries, dumps, mines in operation, side-protection systems, tailings ponds, sludge storage facilities, and other integrated items give way for inconsistent and sometimes biased qualification.

Government Decree No. 1816 does not provide an exhaustive answer to the question of whether a disputed facility is capital or non-capital. Approval of a technical project for subsoil use by the Federal Subsoil Resources Management Agency also does not replace state expertise of design documentation, state environmental expertise or construction supervision. These regimes have different legal purposes and should not be substituted for one another.

For safety purposes, the decisive elements are not the formal name of a facility but its function, service life, connection with land and subsoil, consequences of failure and integration into the system of a hazardous production facility. Therefore, a special functional and legal test is necessary for disputed facilities. Its introduction can reduce abuse, improve design quality, limit conflicts and improve accident prevention at mining facilities.

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Повышение безопасности объектов капитального строительства при освоении месторождений полезных ископаемых: спорные горнотехнические объекты, государственное регулирование и надзор

В статье исследуется проблема правовой квалификации объектов, создаваемых при освоении месторождений полезных ископаемых, в качестве объектов капитального строительства. Актуальность темы обусловлена тем, что спор о статусе карьеров, вскрывающих и подготовительных выработок, отвалов, хвостохранилищ, шламохранилищ, подземных камер, вентиляционных и водоотливных сооружений нередко используется для вывода технологически значимых и потенциально опасных объектов из режимов государственной экспертизы, разрешительной деятельности и строительного надзора. Целью работы является выработка критериев, позволяющих разграничивать горную выработку как результат технологического процесса и объект капитального строительства, как инженерное сооружение, обладающее устойчивой связью с землей и недрами, длительным сроком службы и самостоятельной функцией обеспечения безопасности либо производственного цикла. В ходе выполнения работы были проанализированы положения Градостроительного кодекса Российской Федерации, законодательства о недрах, промышленной и экологической безопасности, подзаконные акты о государственной экспертизе и согласовании технических проектов недропользования, официальные материалы Ростехнадзора, Роснедр, Росприроднадзора и Главгосэкспертизы России. Установлено, что действующее регулирование не содержит исчерпывающих критериев квалификации спорных горнотехнических объектов, при этом освобождение от получения разрешения на строительство по постановлению Правительства РФ от 12.11.2020 г. № 1816 не тождественно признанию объекта некапитальным. Обоснован вывод о необходимости введения специального функционально-правового теста отнесения горнотехнических объектов к объектам капитального строительства, а также о необходимости нормативного разграничения объектов, презюмируемо относимых к объектам капитального строительства, объектов, презюмируемо относимых к некапитальным сооружениям, и объектов, требующих индивидуальной оценки. В данной статье будут предложены система критериев отнесения объектов к различным категориям и механизм межведомственного алгоритма, ориентированные на снижение рисков нарушения безопасности, а также на устранение злоупотреблений недропользователей.

Ключевые слова: *объект капитального строительства, недропользование, промышленная безопасность, государственная экспертиза, государственный строительный надзор, горные выработки, карьер, отвал, хвостохранилище, шламохранилище, временное сооружение*

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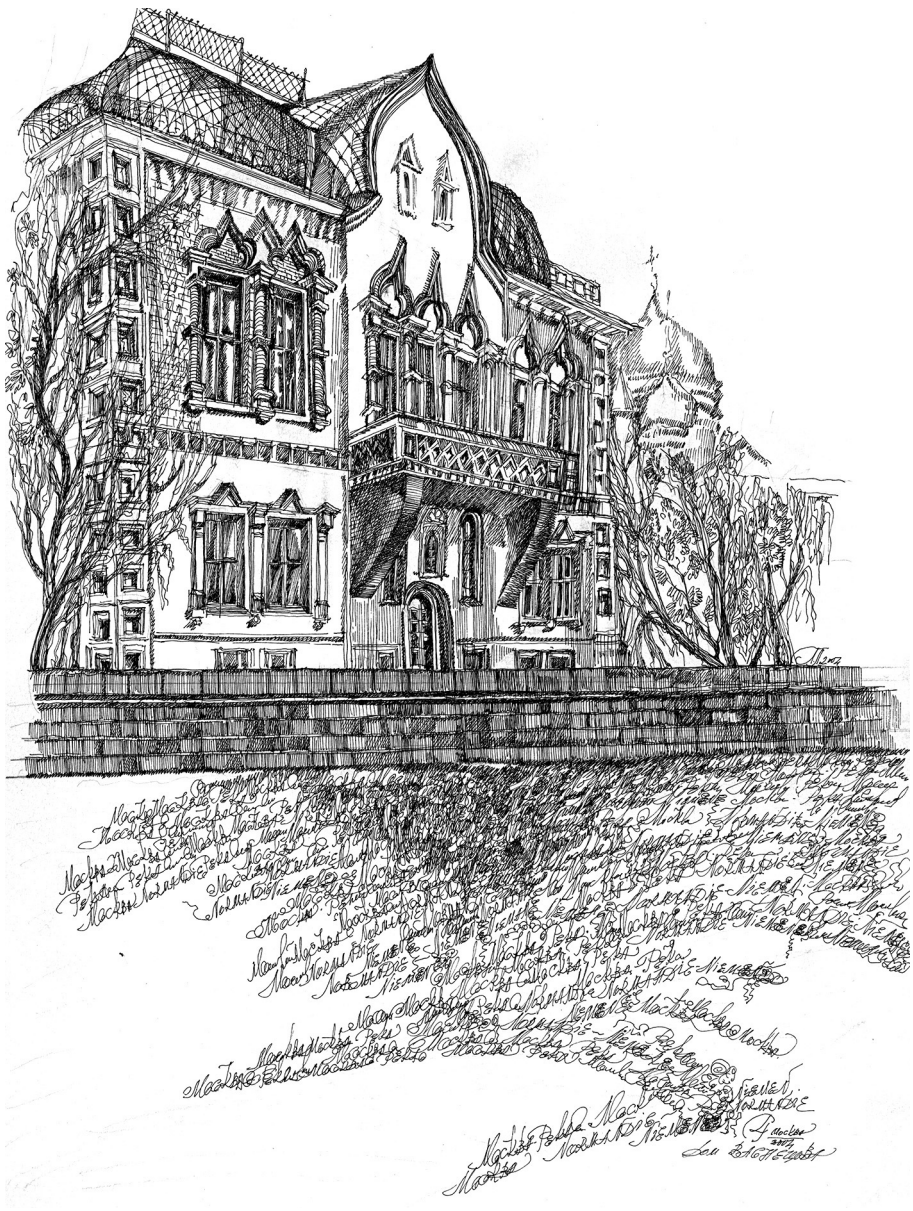

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The Scale, Determinants, and Trends of the Informal Housing Rental Market

The rental housing market in Russia is becoming an increasingly important component of the national housing system and can no longer be viewed as a secondary or marginal segment of the real estate sector. It fulfills a number of important socioeconomic functions, including promoting labor mobility, providing flexibility in housing choices, and offsetting the decline in the affordability of home ownership. In recent years, the role of rental housing has grown as a result of a combination of factors, including rising real estate prices, tighter mortgage lending conditions, and growing household demand for more flexible housing solutions. As homeownership becomes less accessible to a significant portion of the population, renting is increasingly viewed not as a temporary alternative but as a necessary and long-term housing strategy. At the same time, a significant portion of rental transactions in Russia takes place informally, outside the legal and tax framework. The shadow rental market refers to the conclusion of residential lease agreements without written physical documents, tax returns, or official registration. All of this significantly reduces the transparency of the housing market, prevents the collection of accurate statistics, narrows the tax base, and weakens the legal protection of all parties to the lease. This is particularly acute in the economy-class rental segment, where gray-market transactions predominate due to lower average rent payments, a desire to avoid associated costs, and limited incentives to follow official procedures. Drawing on official housing market statistics and academic research, the study identifies the main challenges and drivers of the shadow rental housing market. These include the perceived tax burden on landlords, the administrative complexity of drafting lease agreements, insufficient legal safeguards, limited enforcement of contracts, and low levels of trust in government institutions. Particular attention is paid to the dynamics of the housing market: changes in rental rates, an increase in the number of apartment rental listings, and a decline in mortgage lending volumes. Nevertheless, there is very little official data on the rental market, as a significant share of lease agreements remains in the shadow economy. All of this creates significant risks for both parties: landlords face major difficulties in recovering their losses from damage to the rented property and in collecting regular rent payments, while tenants remain vulnerable to early eviction, unagreed rent increases, and the lack of guarantees regarding continued occupancy of the rented property. The paper also examines international practices aimed at combating the informal rental market. The examples cited from Ireland, England and Wales, as well as a number of OECD countries, show that the most successful method for bringing rental transactions out of the shadow market is when governments combine simplified compliance procedures with tangible legal and financial benefits. The most effective tools of such a policy include: mandatory but user-friendly digital registration of lease agreements, an accessible and understandable system for planning and accounting for rent, the development of schemes to protect security deposits, and simplified tax regimes. Based on this analysis, the paper proposes a set of policy measures for Russia. These include the introduction of a simplified electronic system for registering lease agreements, the creation of a state-supported digital platform for housing rentals, legal advantages for registered agreements, strengthened protection of tenants' and landlords' rights, as well as tax incentives encouraging formal participation in the rental market. The findings indicate that the legalization of the rental sector should be approached as a comprehensive institutional reform, rather than merely as a measure to ensure compliance with tax legislation. To reduce the scale of informal activity in the rental sector, increase market transparency, strengthen legal certainty, and support the sustainable development of the residential rental sector in Russia, a balanced combination of regulatory, fiscal, and digital tools is necessary.

Keywords: *the rental housing market, the informal economy, shadow economy, real estate market, housing affordability, mortgage lending, rental payments, legal regulation, digitalization of the rental market, tax policy*

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The rental housing market in Russia is no longer a "secondary" issue in the housing sector: it serves as a macroeconomic stabilizer, a channel for labor mobility, and an increasingly significant factor putting pressure on the social security system. When market-rate mortgages become expensive or inaccessible, households quickly adjust — postponing home purchases and switching to renting, which, in turn, directly affects monthly housing costs as a result of changes in monetary and housing policy. This is not just a consumer story; it is a budget story, as the same shift expands (or narrows) the tax base depending on whether rental income is reported.

The sharp rise in the price per square meter of residential real estate is driven by record-low mortgage rates, supported by government subsidy programs. According to data from the Unified Interdepartmental Information and Statistical System, the average price of residential real estate in Moscow in the first quarter of 2025 exceeded 390,000 rubles per square meter, which is 57 % higher than in 2021 (Fig. 1) [1].

Thus, for those segments of the population who are unable to take advantage of government subsidies when obtaining a mortgage to purchase a home, high mortgage interest rates lead them to abandon home purchases and shift toward renting instead. According to Dom.RF, in 2024 the average interest rate offered by the top 20 mortgage banks was 29 %, which is an all-time record in the history of modern Russia (Fig. 2) [2].

Over the past five years, the rental housing market has grown significantly, both in terms of the quality and availability of properties and in terms of cost. From 2020 to 2025, rent for apartments up to 100 m^2

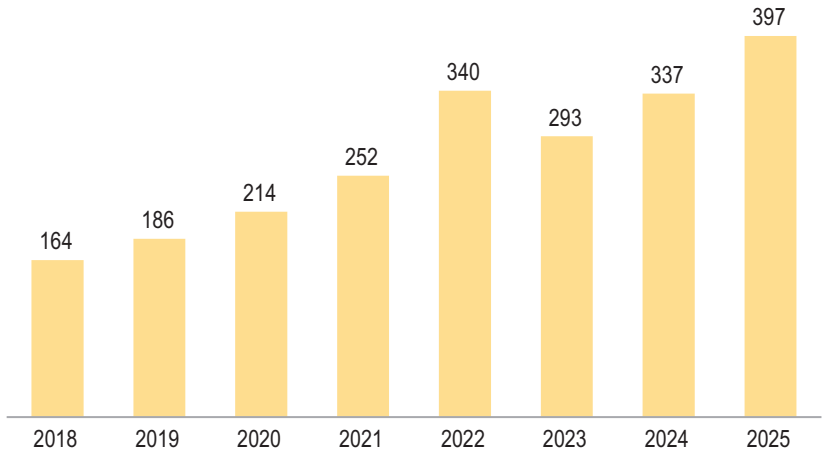

Fig. 1. Median price per square meter of living space in the Russian Federation, in thousands of rubles

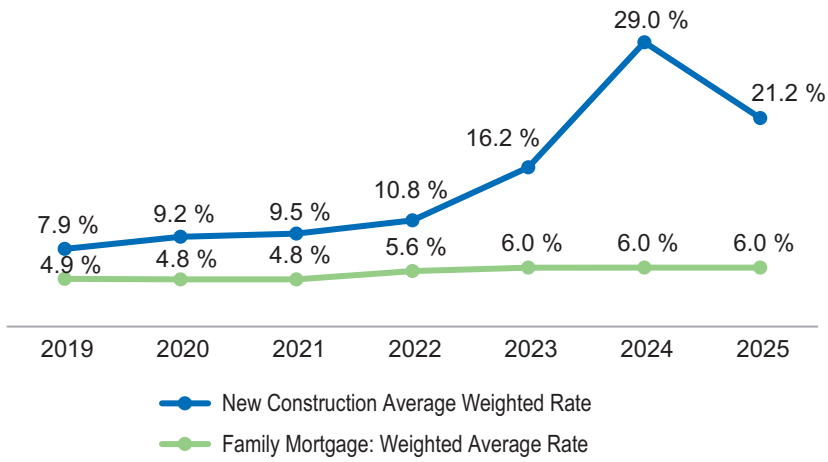

Fig. 2. Changes in mortgage interest rates, %

in Moscow rose by 44 %, reaching a peak in 2024 with an average cost of 101,000 rubles per month (Fig. 3) [3].

By the end of 2025, analysts at Dom.RF note a stabilization phase. This is attributed to persistently high market mortgage rates, combined with a 17 % year-over-year increase in active apartment rental listings (to 95,000 listings) (Fig. 4). The high level of supply is also putting pressure on rental prices, which in Moscow fell by 3 % in 2025 compared to 2024 and now stand at 97,800 rubles per apartment under 100 m^2 (Fig. 3) [3].

Data from Dom.RF on the number of active apartment rental listings confirms that supply and demand have stabilized. Following a decline in supply levels in 2022–2023, the number of listings reached an average of 80,000–100,000 per quarter in 2025 (Fig. 4) [3].

However, any analysis of rental offers in Russia must treat the "market" and the "observable market" as two overlapping but not identical realities. A significant portion of rentals takes place informally — often with cash payments, without a registered lease agreement, and without a tax declaration — which makes it difficult to monitor actual price levels, vacancy rates, and households' exposure to risk. Rent arranged without a formal contract is referred to as "shadow" rent. It falls under the "shadow" economy segment, and its share is an approximate expert estimate. According to an RBC report citing Dom.RF and interviews with experts, the "shadow" rental market may account for up to 95 % of the total real estate rental market and represents up to 6.4 % of the total housing stock (Fig. 5) [4].

The actions of a residential property owner become illegal when rental income is received but not reported, and when taxes required by law are not paid to the state budget. In 2018, the Federal State Statistics Service (Rosstat) conducted an analysis of the rental housing market and presented the government with an alarming conclusion: nearly half of all rental transactions in Russia take place in the shadow economy, which means that taxes on the income received are not paid [5].

Under current conditions, another notable trend is emerging: owners of high-end premium residential properties typically register their rental activities as a business, paying all applicable taxes and mandatory fees. In contrast, owners of economy-class apartments more often attempt to conceal their income and reduce related expenses. According to statistics, more than 80 % of transactions involving the rental of economy-class housing in the Russian Federation are conducted informally [6].

This situation can largely be explained by the characteristics of tenants in this segment. Those renting economy-class housing are typically low-income families for whom signing leases through real estate agencies is often financially burdensome. In addition, this category includes migrants from CIS countries and residents of other regions of Russia who move to large cities in search of work,

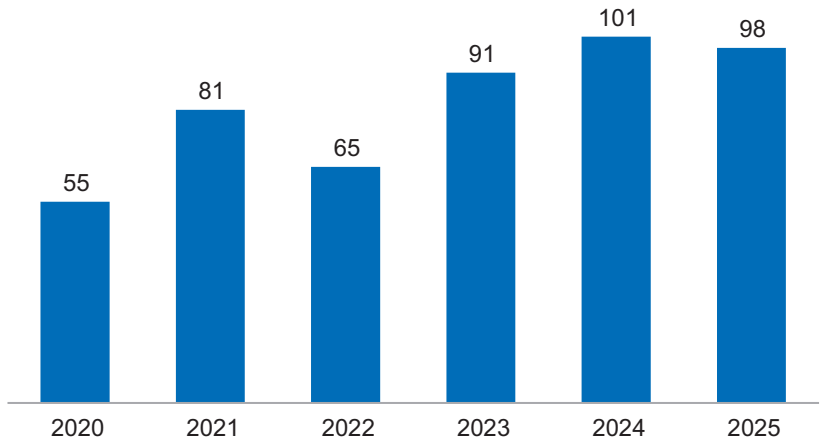

Fig. 3. Average monthly rent for apartments up to 100 m² in Moscow, in thousands of rubles

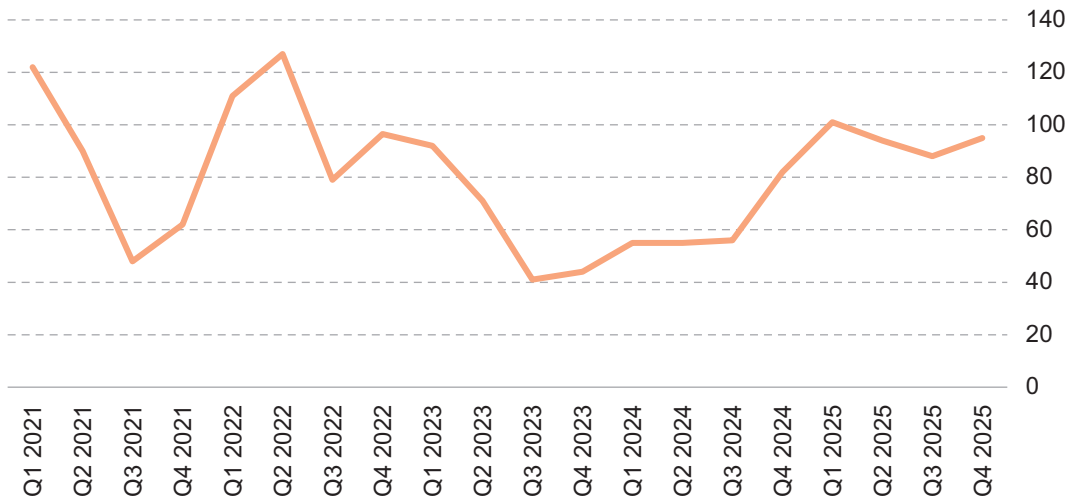

Fig. 4. Average number of active rental listings, in thousands

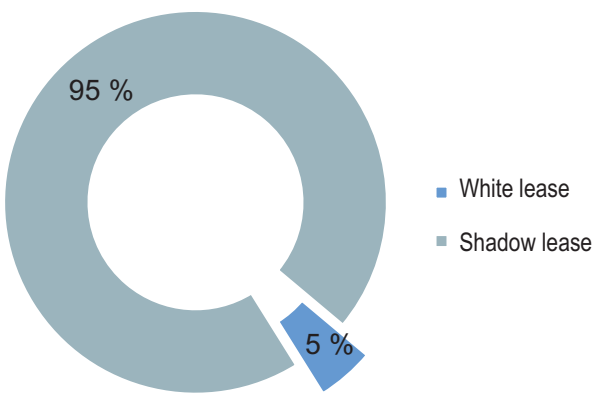

Fig. 5. Share of the "shadow" rental market in the Russian Federation, %

as well as local residents forced to move due to various life circumstances [7].

There are several legal ways to let out a flat, each with different tax implications [4]:

- individual — from 13 to 22 %;
- sole proprietor — from 6 to 15 %;
- self-employed — from 4 to 6 %.

Dom.RF also highlights the demand for self-employment among individuals who earn income from renting out real estate. As of August 2025, there were approximately 14.3 million officially registered self-employed individuals. Among them, about 286,400 people (approximately 2 %) listed renting out real estate as one of their sources of income (Fig. 6) [4].

Despite the growing proportion of people earning income from renting out property as self-employed individuals, this has little

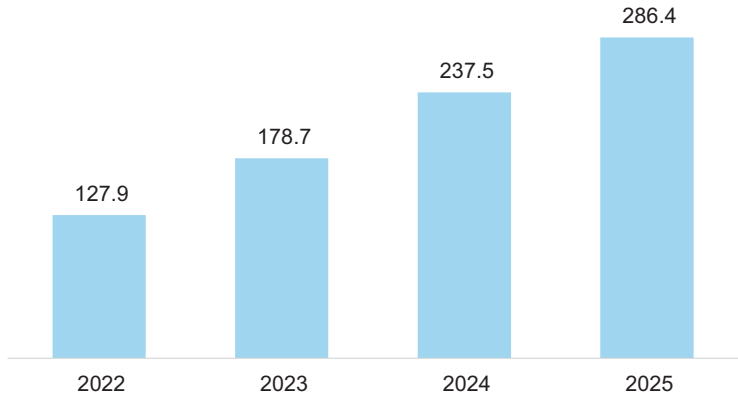

Fig. 6. Trends in the number of self-employed individuals whose income comes from renting out real estate, in thousands

impact on bringing the "shadow" rental market into the open. This problem is significant because it turns rent growth into lost revenue, weakens tenant protections (regarding eviction and dispute resolution), hinders compliance with immigration and registration laws, and creates a gap in law enforcement where the state's reach is structurally limited (Table) [8].

The legalization of the rental housing market should not be approached solely as a matter of ensuring compliance with tax laws. International experience shows that the "shadow" rental market shrinks when the government simultaneously reduces compliance costs, increases legal certainty for both parties, and creates digital tools that make formalizing contracts easier than leaving them unregistered. In other words, the most effective policy involves not only punitive measures but also institutional ones: landlords must have clear incentives to register rental agreements, tenants must receive significant protection from formal contracts, and the government must be able to collect reliable market data [9, 10]. A study by the OECD (Organization for Economic Co-operation and Development) examining the Baltic countries — Lithuania, Latvia, and Slovakia — confirms the hypothesis put forward: official registration of lease agreements, higher-quality data on rentals, tax incentives, and balanced regulation of tenant-landlord relations are among the most promising tools for reducing the "shadow" segment of the market [11].

One of the most effective international practices is the mandatory registration of lease agreements through a simple online system. Ireland serves as an excellent example. All residential lease agreements must be registered with the RTB (Register of Tenancies Board) upon signing the lease. The RTB maintains a public registry of all lease agreements, and successful registration in the system also provides simplified access to legal services for dispute resolution. Ireland has also established the RTB Rent Register, which is used to verify that rent setting or adjustments align with market rates. This combination of mandatory registration, digital administration, dispute resolution, and price transparency is crucial because it transforms a real estate lease transaction from a private agreement into a legally visible economic relationship [12].

Another example of best practice is the protection of rental deposits and the provision of affordable dispute resolution mechanisms. In England and Wales, landlords are required to deposit security deposits within 30 days into the government-approved Tenancy Deposit Protection (TDP) scheme, which ensures their safety until any dispute is resolved. A state-accredited digital deposit escrow system linked to registered lease agreements could serve as a Russian counterpart. Such a system would strengthen confidence in the official market and make it easier for both parties to verify compliance with requirements [13].

Based on these international examples, a number of legislative and institutional changes can be proposed to address the issue of "under-the-table" rentals in Russia:

1. *Introduction of mandatory but simplified electronic registration of residential lease agreements.* Registration should be

Advantages and disadvantages for landlords and tenants in "off-the-books" leases for both parties

Contracting Parties	Benefits	Disadvantages
Landlord	• no tax liability; • a simplified process for renting out a property without an official lease agreement or paperwork; • the ability to evict a tenant at any time at the owner's discretion	• risk of damage to or loss of property; • risk of facing administrative or criminal liability; • potential unforeseen expenses related to utility bills and telephone bills; • risk of late or non-payment of rent, while it is practically impossible to collect the debt and penalties through legal channels; • in the event of conflicts, it is difficult to contact law enforcement agencies (for example, in cases of theft or damage to property)
Tenant	• the possibility of using residential premises for purposes other than their intended use; • the possibility of unregistered individuals, including migrants, residing there, or of accommodating a large number of tenants; • the ease of entering into a rental agreement without formal documentation	• the risk of eviction at any time without warning; • unstable rent, which can be changed at the landlord's discretion; • if an illegal lease is discovered, a fine may be imposed: from 2,000 to 3,000 rubles, and if you are not registered in Moscow or St. Petersburg — from 3,000 to 5,000 rubles; • in the absence of a contract, the landlord may allow third parties to move into the apartment; • verbal agreements may be changed by the landlord; • in certain cases, the landlord may hold the tenant liable under Article 139 of the Criminal Code of the Russian Federation by reporting the matter to the police

possible online in just a few steps and without excessive bureaucratic requirements.

2. *Legal advantage.* The law could stipulate that only registered lease agreements entitle tenants to expedited legal protection, recognized security deposit escrow, access to government rental guarantees, and a simplified tax regime.
3. *Creation of a digital rental platform.* Using state infrastructure, users could enter into a standard contract, register it, pay rent through traceable channels, generate digital receipts, and automatically calculate tax liabilities.
4. *Tax relief.*

In conclusion, it should be noted that the legalization of the rental housing market should be approached as a comprehensive institutional reform rather than as a purely fiscal measure. International experience shows that reducing the informal rental sector is achieved through a combination of simplified compliance procedures, legal incentives, and digital infrastructure [14, 15]. Effective policies bring clear benefits to both landlords and tenants, making formalization more attractive than informality. For Russia, the introduction of mandatory yet user-friendly digital registration, legal advantages for registered contracts, reliable collateral mechanisms, and preferential tax regimes could significantly increase market transparency and reduce the scale of informal rental practices.

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Теневой рынок аренды жилья: масштабы, факторы формирования и направления трансформации

Рынок аренды жилья в России становится все более важной составляющей национальной системы жилищного обеспечения и уже не может рассматриваться как второстепенный или маргинальный сегмент сектора недвижимости. Он выполняет ряд важных социально-экономических функций, в том числе способствует мобильности рабочей силы, обеспечивает гибкость в выборе жилья и компенсирует снижение доступности жилья для покупки. В последние годы роль арендного жилья возросла в результате сочетания таких факторов, как рост цен на недвижимость, ужесточение условий ипотечного кредитования и растущий спрос домохозяйств на более гибкие жилищные решения. Поскольку приобретение жилья становится менее доступным для значительной части населения, аренда все чаще воспринимается не как временная альтернатива, а как необходимая и долгосрочная жилищная стратегия. В то же время значительная часть сделок по аренде жилья в России осуществляется неформально, вне правового и налогового поля. Теневой рынок аренды подразумевает заключение договоров аренды жилья без письменных физических документов, налоговых деклараций или официальной регистрации. Все это значительно снижает прозрачность рынка жилья, не позволяет собирать точную статистику, сужает налоговую базу и ослабляет правовую защиту всех сторон аренды. Особенно остро это ощущается в сегменте аренды жилья эконом-класса, где преобладают серые сделки из-за более низких средних чеков за аренду, стремления избежать сопутствующие расходы и ограниченных стимулов для соблюдения официальной процедуры. Опираясь на официальную статистику рынка жилья и научные исследования, в статье выявлены основные проблемы и стимулы развития теневой аренды жилья. К ним относятся воспринимаемое налоговое бремя для арендодателей, административная сложность оформления договоров аренды, недостаточные правовые гарантии, ограниченная возможность принудительного исполнения договоров и низкий уровень доверия к государственным институтам. Особое внимание уделяется динамике развития рынка жилья: изменение цены арендных площадей, рост числа объявлений о сдаче квартир и снижения объемов ипотечного кредитования. Тем не менее официальных данных о рынке аренды очень немного, поскольку значительная доля договоров аренды остается в тени. Все это создает значительные риски для обеих сторон: арендодатели сталкиваются с большими трудностями при возмещении собственных убытков от

ущерба сдаваемой недвижимости и при взыскании регулярных арендных платежей, в то время как арендаторы остаются уязвимыми перед досрочным выселением, несогласованным повышением арендной платы и отсутствием гарантий продолжения проживания в снимаемом жилье. В статье также рассматриваются международные практики, направленные на борьбу с теневым рынком аренды. Приведенные примеры Ирландии, Англии и Уэльса, а также ряда стран ОЭСР показывают, что наиболее успешный метод вывода сделок аренды из тени, когда правительства сочетают упрощенные процедуры соблюдения требований с заметными правовыми и финансовыми преимуществами. К наиболее эффективным инструментам такой политики относится: обязательная, но удобная для пользователей цифровая регистрация договоров аренды, доступная и понятная система планирования и учета арендной платы, разработка схем защиты арендных залогов и упрощенные режимы налогообложения. На основе этого анализа в статье предлагается комплекс мер политики для России. К ним относятся внедрение упрощенной электронной системы регистрации договоров аренды, создание поддерживаемой государством цифровой платформы по аренде жилья, правовые преимущества для зарегистрированных договоров, усиление защиты прав арендаторов и арендодателей, а также налоговые стимулы, поощряющие официальное участие в рынке аренды. Полученные результаты свидетельствуют о том, что к легализации сектора аренды следует подходить как к комплексной институциональной реформе, а не просто как к мере по обеспечению соблюдения налогового законодательства. Для сокращения масштабов теневой деятельности в сфере аренды, повышения прозрачности рынка, укрепления правовой определенности и поддержки устойчивого развития сектора аренды жилья в России необходимо сбалансированное сочетание регуляторных, фискальных и цифровых инструментов.

Ключевые слова: *рынок арендного жилья, теневая экономика, доступность жилья, ипотечное кредитование, арендные платежи, правовое регулирование, цифровизация рынка аренды, налоговая политика*

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The Real Estate Services Market as an Institutional System: Digital Transformation and Cyclical Dynamics

This article examines the real estate services market not as a secondary infrastructure element but as an independent institutional and economic system that plays a key role in coordinating real estate market players. The purpose of the study is to identify the mechanisms through which this market is transformed under the concurrent influence of digitalization and macroeconomic cyclicality. The methodological framework of the study comprises institutional economics, transaction cost theory, and the concept of information asymmetry, which together make it possible to reconsider the functional role of real estate services under conditions of incomplete information. The authors demonstrate that digitalization is a key factor in market restructuring by reducing search costs, accelerating transactions, and facilitating the formation of integrated digital ecosystems, whereas economic cyclicality does not so much determine the total market volume as shape its dynamic configuration by redistributing demand across segments. Given the limited availability of direct statistical data, the study applies an original proxy approach to assessing digitalization based on macroeconomic and infrastructure indicators. The scientific novelty of the study lies in the integration of digital and cyclical factors into a single extended econometric model that also accounts for the prevailing type of strategic behavior among participants. The proposed three-level model (operational, institutional, and digital levels) demonstrates that sustainable market development is possible only when long-term strategies dominate, ensuring institutionalization and technological transformation, while short-term strategies increase volatility and reduce the effectiveness of market mechanisms. The findings are relevant for improving the management and regulation of the real estate services market in the digital economy.
Keywords: *transaction costs, real estate management, institutional economics, digitalization, cyclicality*

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In modern economic literature, the real estate market is mainly analysed through the prism of the circulation of tangible assets. At the same time, the services that ensure the operation of this market are often regarded as secondary elements without independent economic value.

However, it is the services market that shapes the institutional environment in which economic agents interact, reducing uncertainty and coordination costs. In the context of digitalization and increasing macroeconomic volatility, the role of this segment as a key element of market infrastructure needs to be reconsidered [1].

From the perspective of institutional economics, the real estate services market can be interpreted as a mechanism that structures interactions between market players under conditions of incomplete information. In contrast to the classical approach, the focus shifts from describing types of services to analyzing their functional role in reducing transaction costs [2, 3].

Conceptually, the real estate services market performs three interrelated functions [4, 5]:

- informational: reducing information asymmetry;
- coordination: aligning the interests of market players;
- guarantee-related: reducing risks and uncertainty.

Thus, real estate services are not merely an auxiliary element but an institutional mechanism that ensures market stability.

The scientific novelty of the study consists in:

- interpreting the real estate services market as an institutional coordination mechanism;
- integrating digital and cyclical factors into a single development model;
- applying a proxy approach to assess market digitalization under conditions of limited statistical data.

Systems analysis makes it possible to identify three levels of market functioning:

1. Operational level — services directly related to the conclusion of transactions.

2. Support level — legal and valuation support.

3. Strategic level — asset management and investment consulting.

This structure reflects not so much a classification of services as the distribution of functions in the process of economic value creation [6].

The functioning of the real estate services market is associated with a number of systemic limitations arising from its institutional specificity.

A key feature is the heterogeneity of service quality associated with the absence of uniform standards and insufficient professionalization in individual segments. This leads to higher transaction costs and lower trust among market players [7, 8].

Another factor is limited information transparency, which amplifies information asymmetry and reduces the effectiveness of price signals [9].

The digitalization of the real estate services market is not a mere introduction of technology but a transformation in the logic of market functioning [10, 11].

The use of digital platforms, data-processing algorithms, and online interaction tools leads to:

- lower information search costs;
- faster conclusion of transactions;
- generation of new business models.

As a result, the market transitions from a fragmented structure to integrated digital ecosystems [12, 13].

In the absence of direct statistical indicators of the digitalization of the real estate services market, this study uses a proxy approach based on an analysis of the World Bank's infrastructure and macroeconomic indicators (Table).

Indicators of the digital and economic environment in selected major economies

Country	GDP, USD trillion	Internet users, %	Broadband access	Net foreign direct investment (% of GDP)
Russia	2.17	94	25.8	–0.4
USA	28.75	93	38.1	1.0
China	18.74	92	44.7	0.1

A comparative analysis showed that[1]:

- the United States has the most developed digital environment;
- China demonstrates the rapid scaling of digital solutions;
- Russia is characterized by a high level of basic digital accessibility but lags behind in terms of investment activity and infrastructure saturation.

Therefore, markets differ in their potential for digital transformation.

The real estate services market exhibits pronounced sensitivity to the phases of the economic cycle; however, this dependence is not linear but structural.

During phases of economic growth, the intermediary services segment expands, whereas during periods of recession, demand shifts towards asset management and crisis management consulting [14].

Thus, cyclicality affects not so much the overall volume of the market as the redistribution of functions among its segments.

Taking the identified factors into account, market development can be formalized as follows (1):

$$Y_{it} = \beta_0 + \beta_1 \cdot Dig_{it} + \beta_2 \cdot Mac_{it} + \beta_3 \cdot Invest_{it} + \beta_4 \cdot Cycle_{it} + \varepsilon_{it}, \quad (1)$$

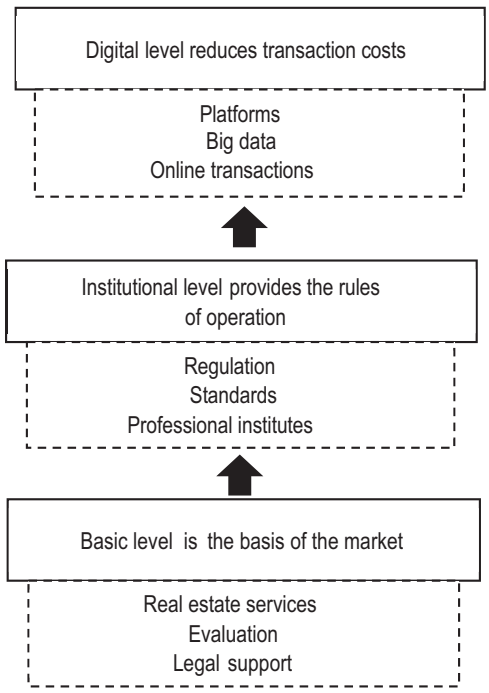
where Y_{it} denotes the share of digital services;
β_0 denotes the constant value;
β_1–β_4 denote weighting factors for variables;
Dig_{it} denotes a digitalization index;
Mac_{it} denotes macroeconomic dynamics;
$Invest_{it}$ denotes investments in the sector;
$Cycle_{it}$ denotes a phase in the economic cycle (growth/decline);
ε_{it} denotes the stochastic error term capturing the effects not explained by the included factors;
i denotes a country;
t denotes a year.

This model reflects the multicomponent nature of market transformation, in which digitalization is the main driver and macroeconomic dynamics determines the trajectory of change.

The proposed model has three levels (Fig.):

1. Operational level (provision of services).
2. Institutional level (rules and regulations).
3. Digital level (technological infrastructure).

[1] Property Technology (Proptech) Market Report 2026. Web-site "Research and Markets". URL: https://www.researchandmarkets.com/reports/5953272/property-technology-proptech-market-report#product--toc



A three-level model of real estate services market transformation

Economic cyclicality acts as an external parameter that modifies the interaction between levels and affects the speed of market transformation.

The development of the real estate services market is largely determined by the strategic orientations of its players, which can be broadly divided into short-term and long-term orientations.

A short-term strategy, focused on rapid profit generation, is characterized by a concentration on intermediary services, high transaction intensity, and minimized infrastructure development costs. Under this model, market players focus on current market conditions, which increases market sensitivity to price fluctuations and contributes to the growth of speculative activity.

By contrast, a long-term strategy involves the formation of sustainable business models based on real estate management, the development of service infrastructure, and the introduction of digital technologies. Long-term-oriented players invest in improving service quality, standardizing processes, and developing customer relationships.

Comparative analysis shows that the predominance of short-term strategies leads to market fragmentation and reduced institutional stability, while the dominance of long-term strategies contributes to the formation of integrated ecosystems and a reduction in transaction costs [15, 16].

The strategic orientation chosen by market players is closely related to phases of the economic cycle. During periods of economic growth, the share of short-term strategies increases, driven by higher market liquidity and opportunities for rapid profit. In the context of an economic downturn, by contrast, the importance of long-term strategies focused on asset management and risk reduction increases.

Thus, economic cyclicality affects not only the volume of the real estate services market but also the strategic structure of the play-

ers' behavior patterns. The cyclical model can be expressed as follows:

$$Y_{it} = \beta_0 + \beta_1 \cdot Dig_{it} + \beta_2 \cdot Mac_{it} + \beta_3 \cdot Invest_{it} + \beta_4 \cdot Cycle_{it} + \beta_5 \cdot Strat_{it} + \varepsilon_{it}, \quad (2)$$

where β_1–β_5 denote weighting factors for variables;

$Strat_{it}$ denotes the prevailing type of strategic behavior of market players.

To describe market dynamics more accurately, a variable reflecting the prevailing type of strategic behavior among participants (short-term or long-term orientation) is introduced into the model to account for the impact of the investment horizon on the structure and stability of the real estate services market.

The results indicate that sustainable development of the real estate services market is possible only when long-term strategies dominate, ensuring the institutionalization and digital transformation of the market. The predominance of short-term strategies, by contrast, increases volatility and reduces the effectiveness of market mechanisms.

The study makes it possible to consider the real estate services market as a complex dynamic system whose development is determined by the interaction of technological, institutional, and macroeconomic factors.

The study establishes that digitalization is a key driver of market transformation, while economic cyclicality shapes the structural dynamics of the market. Taking these factors into account can increase the efficiency of management and regulation in the real estate services market.

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Рынок услуг в сфере недвижимости как институциональная система: цифровая трансформация и циклическая динамика

В статье рассматривается рынок услуг в сфере недвижимости как самостоятельная институционально-экономическая система, обеспечивающая координацию участников рынка объектов недвижимости. Цель исследования заключается в выявлении механизмов трансформации рынка услуг недвижимости под влиянием цифровизации и макроэкономической цикличности. Методологической основой выступают положения институциональной экономики, теории транзакционных издержек и концепции информационной асимметрии. В работе применяется прокси-подход к оценке цифровизации рынка на основе совокупности макроэкономических и инфраструктурных индикаторов. В результате установлено, что цифровизация выступает ключевым фактором структурной перестройки рынка услуг недвижимости, тогда как экономическая цикличность определяет его динамическую конфигурацию. Предложена расширенная модель, учитывающая взаимодействие технологических, институциональных и макроэкономических факторов.

Ключевые слова: *транзакционные издержки, управление недвижимостью, институциональная экономика, цифровизация, цикличность*

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Organizational and Economic Mechanisms for Synchronizing the Construction of Educational Infrastructure within Comprehensive Territorial Development Projects

This article examines the imbalance between the pace of housing construction and the development of educational infrastructure within comprehensive territorial development (CTD) projects. The study aims to systematize and further develop organizational and economic mechanisms that ensure the synchronization of housing commissioning with the delivery of educational facilities. Based on an analysis of data from Rosstat and the Ministry of Education of the Russian Federation, the study shows that, despite the achievement of the targets set by the national project "Education", a substantial proportion of newly built educational institutions operate beyond their design capacity because educational infrastructure is delivered later than residential occupancy. The article identifies three basic financing models, including a budget-funded model, a developer-led model, and public-private partnership (PPP), and compares them in terms of implementation time, budgetary burden, and facility quality. International experience from the Gulf states and the European Union is also reviewed, demonstrating the effectiveness of statutory developer obligations and employing the issuance of infrastructure bonds. The article proposes a conceptual three-pillar model of the organizational and economic synchronization mechanism, comprising regulatory, financial-economic, and organizational-managerial components. Key risks for project participants are identified, together with mitigation measures, including the wider use of standard design documentation (SDD) and urban digital twins. The practical significance of the study lies in the applicability of the proposed measures for shifting from "catch-up" to anticipatory planning of social infrastructure in CTD projects.
Keywords: *integrated territorial development, educational infrastructure, synchronization of construction, public-private partnership, organizational and economic mechanism, infrastructure bonds*

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The national development goals of the Russian Federation for the period up to 2030 envisage not only an increase in housing construction volumes but also the formation of a higher-quality urban environment [1]. Comprehensive territorial development (CTD) projects are a tool for achieving these goals, as they are intended to ensure the balanced development of residential, engineering, and social infrastructure. However, recent statistics consistently indicate a systemic imbalance: housing is commissioned significantly faster than schools and kindergartens. Despite the achievements of the national project "Education", the problems of second-shift schooling and overcrowded schools persist in many dynamically developing regions [2]. The causes of this gap are related not only to demographic fluctuations but also to shortcomings in the organizational and economic mechanisms regulating interaction among public authorities, developers, and investors.

The scale of these disproportions can be assessed using the following data. In 2025, Russia commissioned 108.1 million sq. m of housing, which was 0.4 % higher than in 2024 [1]. However, comparable dynamics in the commissioning of educational institutions were not observed. During the same period, no new kindergarten places were created in 51 regions of the country, and no new school places were created in 37 regions [3]. According to estimates by the Accounts Chamber of the Russian Federation, 53.6 % of schools built in 2019–2024 are already operating beyond their design capacity [4]. One of the main reasons for this situation is the mismatch between planning horizons. As shown in Fig. 1, the investment and construction cycle for housing development typically lasts 3–5 years, whereas the full cycle for developing budget-financed educational infrastructure takes 5–7 years, largely due to lengthy procedures for inclusion in targeted investment programs. The resulting time lag of 2–4 years is a key source of the "infrastructure gap".

The uneven provision of social infrastructure is especially evident in comparisons across regions. Data on the availability of nearby schools and kindergartens in new residential developments (Table 1) show that, even in the leading constituent entities of the Russian Federation, only about half of new buildings are provided with educational infrastructure within walking distance, whereas in lagging regions this value remains below 20 %. This situation reduces quality of life, contributes to commuter flows, and has an adverse effect on housing prices.

It is noteworthy that the Domclick case mainly covers multi-apartment residential developments and may not fully covey the individual housing construction sector; nevertheless, the general trend is evident.

To overcome the current imbalance, it is important to identify which financing models are currently used–and which of them can ensure synchronization. Russian and international practice distinguishes three main models: budget financing, developer financing, and mechanisms based on public-private partnerships (PPP). Their comparative characteristics are presented in Table 2. The budgetary model remains dominant in the vast majority of constituent

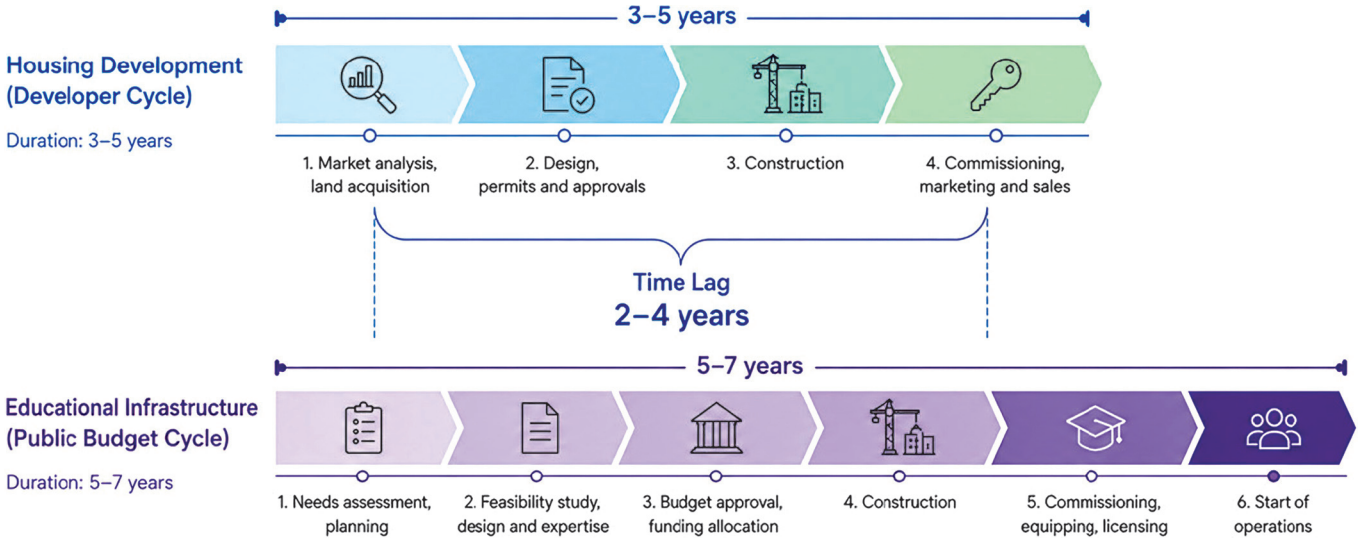

Fig. 1. Comparison of investment and construction cycles for housing and educational facilities (conceptual diagram)

Note: the figure shows the differences in cycle duration and stages that lead to the time lag. Stage durations are indicative and may vary depending on specific regional conditions.

Table 1. Provision of new residential buildings with nearby schools and kindergartens in selected constituent entities of the Russian Federation (2025)

Region	Provision with nearby schools, %	Provision with nearby kindergartens, %
Kaliningrad Region	53.2	50.6
Nizhny Novgorod Region	52.5	53.2
Republic of Tatarstan	49.3	55.8
Tyumen Region	47.9	45.1
Omsk Region	44.6	47.6
Omsk Region	14.2	14.2
Republic of Bashkortostan	14.9	14.9
Samara Region	18.8	20.1

Source: compiled by the authors based on Domclick data, 2025.

Table 2. Comparison of financing models for educational infrastructure

Model	Source of funds	Advantages	Disadvantages	Examples
Budgetary (classical)	Federal/regional budget, targeted investment programs	Direct quality control; compliance with standards	High budget burden; long lead times (5–7 years); risk of underfunding	Most regions of the Russian Federation
Developer-based (developer obligations under CTD contracts)	Developer's own funds	Synchronization with the housing commissioning schedule; reduced budget burden	Increase in housing cost; risk of transferring a low-quality facility to the municipality	Moscow (renovation), Rostov Oblast (since 2025)
PPP (concessions, infrastructure bonds)	Off-budget investment with returns through operation or the budget	Risk sharing; accelerated construction; introduction of innovations	Complex structuring; long-term budget obligations	Saint Petersburg (5 schools, 13.3 billion rubles), DOM.RF projects

Source: compiled by the authors based on data from [5–8].

entities of the Russian Federation; however, its potential is limited: according to the Ministry of Finance of Russia, more than 60 % of consolidated regional budgets are in deficit [5]. The developer-based model, developed in Moscow within the renovation program, has proved effective in terms of schedule synchronization, but it requires significant financial resources from developers and can increase the cost per square meter of housing by 8–12 % [6]. The PPP model, including the use of infrastructure bonds, is considered the most promising in terms of balancing the interests of the parties. Bond issues of "SOPF DOM.RF" have a ruAAA credit rating, which confirms their reliability and makes them an attractive instrument for investors [7].

Valuable experience in synchronization has also been accumulated internationally. In the United Arab Emirates, the general plans of the emirates establish obligations for master developers to commission schools and kindergartens before completion of the first

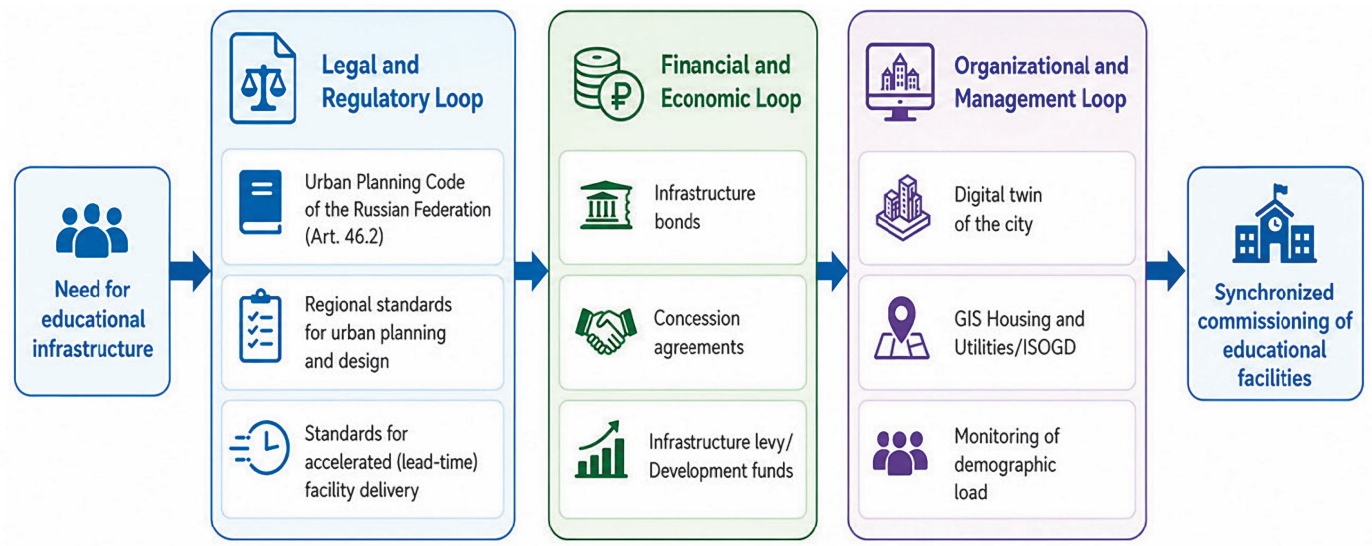

Fig. 2. Conceptual model of the organizational and economic mechanism for synchronizing educational infrastructure construction in CTD projects

phase of housing. Compliance is ensured through escrow account mechanisms and substantial penalties [9]. As a result, in Dubai in 2023–2024, an average of 87 % of educational facilities in new districts were commissioned synchronously with occupancy. In Saudi Arabia›s NEOM megaproject, educational infrastructure is designed as an integral part of the smart city simultaneously with engineering networks and residential areas [10]. In European Union countries, approaches based on targeted fees from developers are common. In the United Kingdom, under Section 106 Agreements, developers transfer contributions to the municipal budget, which are then centrally allocated to the construction of schools within walking distance of new housing [11]. A similar mechanism is beginning to be implemented in Russian legislation through comprehensive territorial development agreements; however, in practice, payments for removing infrastructure constraints often do not cover the actual cost of constructing social facilities [12].

Taking into account these models and international experience, it is possible to propose a holistic structure that consolidates disparate tools into a single system. Fig. 2 presents a conceptual three-loop model of the organizational and economic synchronization mechanism. The first regulatory and legal loop involves introducing standards for anticipatory commissioning at the level of constituent entities of the Russian Federation; under these standards, housing cannot be commissioned without the availability of places in educational organizations within walking distance. This will require amendments to the Town Planning Code of the Russian Federation and to regional urban planning standards. The second financial and economic loop includes expanding the use of the “infrastructure menu” mechanism, subsidizing interest rates on loans to developers that undertake school construction, and creating regional social infrastructure development funds that accumulate targeted fees and budget transfers. The third organizational and managerial loop is based on the implementation of a city digital twin using the GIS Housing and Communal Services and the information system for ensuring urban development activities. This enables real-time forecasting of shortages of school places based on data on issued construction permits and demographic forecasts. All three loops should function within a unified logic, exchanging data and ensuring end-to-end control from the planning stage to facility commissioning.

Implementation of the described model involves some risks that must be considered in practice. For developers, the main risk is an increase in project cost due to the need for simultaneous financing of residential and social construction. For the public partner, the risk lies in receiving a facility that does not meet educational standards or requires significant maintenance costs. One effective way to minimize these risks is to use standard design documentation (SDD). However, according to available data, only 21.7 % of new schools and 19.6 % of kindergartens are currently built using SDD [13]. Increasing this share can reduce design time by 30–40 % and construction costs by up to 15 % [14]. In addition, the development of turnkey concession agreements with predetermined technical and economic parameters is a promising direction, as it can simplify the entry of private investors into projects [15].

Thus, the analysis confirms that synchronization between housing construction and the commissioning of educational infrastructure is a key factor in forming a full-fledged urban environment in CTD projects. Existing financing models are limited in effectiveness; however, their combination, primarily on the basis of PPP and supported by regulatory requirements, can provide the necessary balance. The proposed three-loop conceptual model establishes a holistic framework for the practical transition from “catch-up” to “anticipatory” planning. Its implementation will require improvement of the regulatory framework, expansion of the practice of issuing infrastructure bonds, and large-scale digitalization of urban planning data. Further research by the authors will focus on developing a detailed methodology for assessing the economic efficiency of various forms of PPP for school construction within CTD projects.

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Организационно-экономические механизмы синхронизации строительства образовательной инфраструктуры в проектах комплексного развития территорий

В статье исследуется проблема дисбаланса между темпами жилищного строительства и созданием образовательной инфраструктуры в рамках проектов комплексного развития территорий (КРТ). Целью работы является систематизация и развитие организационно-экономических механизмов, обеспечивающих синхронизацию ввода жилья и объектов образования. На основе анализа данных Росстата и Минпросвещения РФ показано, что, несмотря на выполнение целевых ориентиров национального проекта «Образование», значительная часть новых учебных заведений работает с превышением проектной мощности из-за отставания их ввода от заселения микрорайонов. Выявлены три базовые модели финансирования: бюджетная, девелоперская и на основе государственно-частного партнерства (ГЧП), проведен их сравнительный анализ по критериям сроков, нагрузки на бюджет и качества объектов. Рассмотрен международный опыт стран Персидского залива и Европейского союза, демонстрирующий эффективность нормативного закрепления обязательств застройщиков и применения механизма инфраструктурных облигаций. Предложена концептуальная трехконтурная модель организационно-экономического механизма синхронизации, включающая нормативно-правовой, финансово-экономический и организационно-управленческий блоки. Определены ключевые риски участников и пути их снижения, в том числе за счет расширения использования типовой проектной документации (ТПД) и цифровых двойников городов. Практическая значимость работы заключается в возможности применения предложенных мер для перехода от «догоняющего» к «опережающему» планированию социальной инфраструктуры в проектах КРТ.

Ключевые слова: *комплексное развитие территорий, образовательная инфраструктура, синхронизация строительства, государственно-частное партнерство, организационно-экономический механизм, инфраструктурные облигации*

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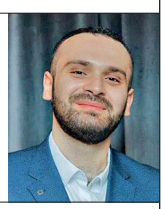
Investment Mechanisms for the Modernization of Utility Infrastructure within Comprehensive Territorial Development

This article examines a comprehensive approach to modernizing public utility infrastructure within the framework of integrated territorial development (ITD). The study focuses on the combined use of investment instruments and life-cycle-based performance indicators, including life cycle cost (LCC) and total cost of ownership (TCO), as a means of improving the efficiency, financial sustainability, and institutional coordination of infrastructure modernization projects. The purpose of the research is to identify and systematize the legal, financial, and organizational instruments available under the Russian legislation for the integrated development of territories and related utility sectors, with particular attention to fiscally subsidized regions. The methodology includes an analysis of the regulatory framework, including Federal Law No. 494-FZ and housing and utilities modernization programs; a review of ITD projects implemented in subsidized regions; and a comparative assessment of investment mechanisms such as concessions, public-private partnerships, infrastructure budget loans, infrastructure bonds, subsidies, grants, and long-term management contracts. The study classifies modernization mechanisms by funding source and risk level, develops an applicability matrix for different stages of the infrastructure life cycle, and proposes an organizational model for a regional project office with a mechanism for the distribution of responsibilities among stakeholders. The findings demonstrate the priority of portfolio-based financing, the need for long-term tariff regulation, and the importance of improving the regulatory framework to scale effective modernization practices. The practical significance of the research lies in substantiating the relationship between investment mechanisms and institutional coordination towards regional infrastructure development.

Keywords: *infrastructure modernization, comprehensive territorial development, utility infrastructure, investment mechanisms, public-private partnership, concessions, life-cycle cost, tariff regulation*



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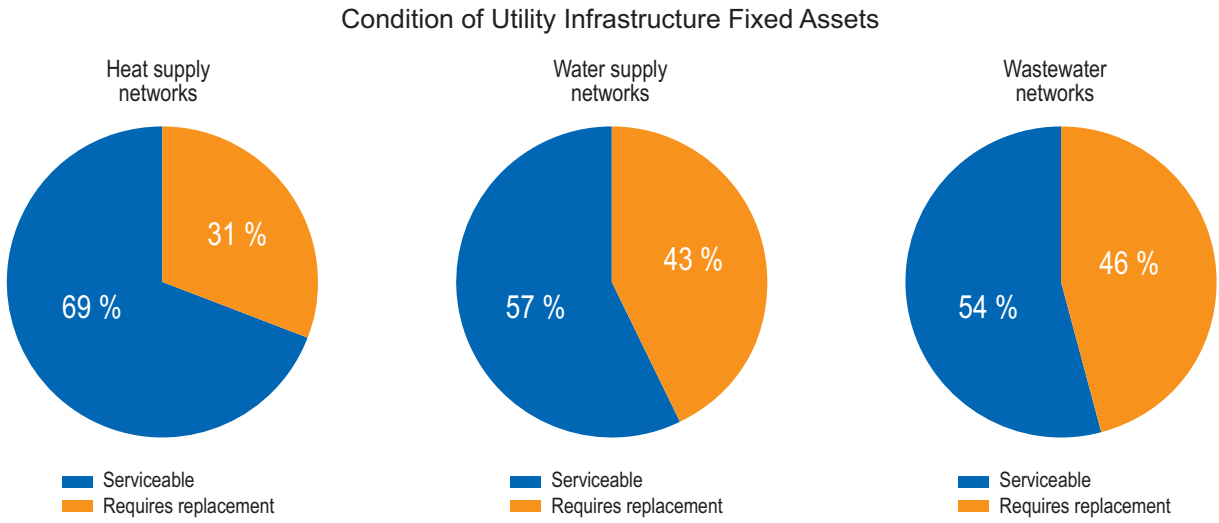
INTRODUCTION

Utility infrastructure in Russian cities is affected by chronic deterioration, largely caused by substantial underfinancing, which negatively affects the quality of the urban environment and living standards. According to the estimates made by the Federal State Statistics Service cited in the article, 43–46 % of water supply and wastewater networks require complete renewal. In some regions, the situation reaches a critical level: in the Republic of Tuva, up to 95 % of water supply networks are considered worn out, while in several North Caucasian regions, including the Republic of Dagestan, the Republic of Ingushetia, and the Kabardino-Balkarian Republic, more than half of heating networks require replacement [1]. This condition produces a large number of emergency situations. In 2024–2025, roughly 220–230 serious utility accidents were registered daily on average. Such frequency of incidents highlights the urgent need to raise additional funding for the modernization of the housing and utilities sector (Fig.).

Although the housing and utilities sector performs an important social function, its investment attractiveness remains low. Private investment in utility infrastructure is limited because project payback periods are long and tariff regulation is strict. As a result, by the end of 2023 the total value of concession agreements in heat supply was about RUB 830 billion, significantly below the initial forecast of RUB 2 trillion [2]. Private companies are reluctant to enter the housing and utilities market because of low margins and material risks related to tariffs, political factors, and institutional constraints. By the end of 2025, accumulated household debt for utility services reached almost RUB 900 billion, and together with organizational debt approached RUB 1.5 trillion, worsening the financial position of resource-supplying organizations [2]. The main research task, therefore, is to develop effective financial instruments capable of attracting investment into utility infrastructure modernization without causing excessive tariff growth for households.

Comprehensive territorial development (CTD) is an innovative approach to the urban environment modernization. It combines housing construction, the resettlement of dilapidated and emergency housing, and the development of infrastructure facilities. Federal Law No. 494-FZ of 30 December 2020 established the legal foundations for CTD projects by replacing earlier approaches based on point development and the development of already built-up areas. CTD projects involve not only the construction of new housing to replace emergency housing, but also the creation of social facilities and the modernization of engineering infrastructure. By the end of 2024, decisions had been approved to implement more than 1,100 CTD projects in 86 constituent entities of the Russian Federation. The total construction area involved in these projects is estimated at 76.3 million square meters of new housing, and by 2030 the CTD potential is expected to rise to approximately 198 million square meters. CTD is therefore a promising mechanism for renewing urban infrastructure, but its effectiveness depends directly on the availability of sufficient financing for utility infrastructure and related facilities.



Condition of fixed assets of utility infrastructure

Russian scholarly and policy discussions offer different views on attracting investment into the housing and utilities sector. A number of studies emphasize the importance of public-private partnership (PPP) as a modernization instrument. In particular, concession agreements in water supply and heat supply can attract extra-budgetary resources and address long-term infrastructure problems. A concession gives the investor a long-term revenue basis and a mechanism for recovering invested funds, while the region receives network renewal financed by private capital. However, critical reviews of PPP practice show that substantial results are difficult to achieve without public support in the form of guarantees and auxiliary measures such as co-financing and subsidies. For example, DOM.RF has implemented an infrastructure bond mechanism which, from 2021 to September 2025, attracted more than RUB 45 billion to finance 14 projects. Some experts also argue for targeted financing of housing and utilities modernization programs from the federal budget and for the creation of special funds for these purposes [3].

MATERIALS AND METHODS

The analysis is based on public official sources and specialized publications issued by government bodies. The regulatory framework includes federal acts and program documents that define investment mechanisms in housing and utilities and CTD, including legislation on CTD, concessions and PPP, the Budget Code, and the passports of the national project Infrastructure for Life and the federal project Modernization of Utility Infrastructure. Statistical data were collected from the Ministry of Construction of the Russian Federation, Federal State statistics Service, Russian Government portals, development institutions including the Territorial Development Fund, regional authorities, and specialized media.

The research design includes three analytical blocks. First, regulatory and program analysis was used to examine current laws and subordinate acts and to classify investment instruments by type, including budget investments, infrastructure loans and bonds, concessions, and subsidies. Second, quantitative analysis was used to summarize official statistics on wear, accident rates, commissioning and repair of facilities, and financing volumes. Third, a case study was carried out for Zabaykalsky Krai, where declared program targets were compared with the actual progress of heat-supply and water-supply works.

RESULTS

1. Investment mechanisms available for CTD projects. Current legislation offers a variety of investment mechanisms to support and finance infrastructure development within CTD projects. Federal Law No. 494-FZ, which introduced Chapter 10, Comprehensive Territorial Development, into the Urban Planning Code of the Russian Federation, does not list specific federal financial mechanisms. In practice, regions and municipalities are empowered to conclude territorial development agreements with flexible conditions and obligations for investors. Such projects have revealed the need for public support, implemented through the special federal mechanism known as the infrastructure menu, designed to stimulate developer interest. The menu has infrastructure bonds, infrastructure budget loans, subsidies for low-margin projects, and the use of the National Welfare Fund.

In 2021–2022, the Ministry of Construction issued low-interest infrastructure loans to regions in a total amount exceeding RUB 483 billion. The interest rate was 3 % per year and the repayment period was 15 years. Importantly, access to these loans required at least 50 % co-financing from the regions [4]. The funding mission was to create engineering infrastructure, including water supply, wastewater systems, and roads, in new residential districts. Repayment was expected to come from tax revenues and payments from residents of the new districts. DOM.RF has issued infrastructure bonds through a special project arm that offers them in the financial market. The funds thus raised go to regional operators under the guarantee of the constituent entity of the Russian Federation. Regional operators are obliged to develop local infrastructure. Investors receive bonds with a high rating, while regions obtain financing with payment deferral of 15–20 years.

Concession agreements in housing and utilities, governed by Federal Law No. 115-FZ On Concession Agreements, are also important. This mechanism is used to transfer utility infrastructure facilities to private investors for modernization and operation purposes. In CTD projects, concessions can be used both for the construction of new nodal facilities and for the reconstruction of individual networks within renovated neighborhoods [5]. Under a concession agreement, the investor contributes cash and expects repayments through a pre-set tariff and, if necessary, an additional concession-grantor payment from the budget. Presently, concessions are the most common form

of PPP in housing and utilities: more than 2,700 agreements have been concluded with a total value of about RUB 1.2 trillion [6]. They cover heat supply, water supply, and wastewater facilities across Russia. Nevertheless, in large CTD projects concessions are used selectively, primarily for water and heat supply facilities.

Direct budget investment is implemented through the federal project Modernization of Utility Infrastructure, launched in 2024 within the Infrastructure for Life project. The project provides for an annual federal contribution of at least RUB 150 billion for network reconstruction. The total amount to be invested into housing and utilities modernization by 2030, including private investment, is expected to reach RUB 4.5 trillion. In addition to budget allocations, the program requires about RUB 750–800 billion annually from regional and private sources. Regions draft comprehensive modernization plans for housing and utility infrastructure up to 2030. These plans contain detailed measures, such as the replacement of boiler houses and pipelines, and identify financing sources for each measure. According to the Ministry of Construction, by September 2025, 37 regions had approved their comprehensive modernization plans, while 9 projects were still in the process of approval. This combination of a modernization plan and federal-investor financing functions as a new instrument.

Existing mechanisms do not apply to the whole infrastructure life cycle. Capital repair and network renovation continue to be financed mainly through depreciation included in tariffs and through consumer payments, which are insufficient [6]. At the same time, legislation allows the necessary instruments to be introduced gradually. In 2023, amendments were made to the PPP and concession legislation to simplify the implementation of housing and utilities projects. Among other things, these changes allow investors to propose projects on their own initiative and simplify the conversion of lease agreements into concessions.

2. Case study: Zabaykalsky Krai. Zabaykalsky Krai, know for its low budget revenues, faces acute problems of dilapidated housing and network wear. By 2024, more than 1,400 buildings had been registered as emergency housing, while the deterioration of heating networks reached up to 70 %. The region was among the first to adopt a regional law on CTD in 2022. In Chita, 34 renovation sites have been identified, and the program is expected to cover approximately 97 % of the emergency housing stock. Developers are required to resettle residents and improve territories. In 2026–2027, seven sites are expected to be launched, with the resettlement of about 20,000 square meters of emergency housing and approximately 1,140 people.

The key to success is the modernization of external engineering networks in older residential districts, many of which were built in the 1970s. Private developers usually do not invest into mains because of high costs and vague payback prospects, so public investment is required. In 2022, the region received a RUB 1.3 billion infrastructure budget loan for a new boiler house and a main heat pipeline for one of the pilot CTD sites. Under the federal housing and utilities modernization project for 2024–2025, RUB 2.4 billion was allocated, including at least RUB 1 billion for Chita. The financing scheme is combined: developers build housing and courtyard networks, while the region and the federation finance the mains infrastructure, including boiler houses and main pipelines. In-kind compensation is also involved: investors build apartments for resettled residents and, in return, receive land plots for commercial development and the right to sell the remaining floor area.

A concession was also involved: the city concluded a 15-year agreement for the reconstruction of the water utility. The concessionaire is to invest approximately RUB 600 million in treatment facilities and water supply networks, which will increase the reliability of water supply at CTD sites. Payback is secured through an increase in the water tariffs: the regional regulator committed to raising the tariff by 15 % over five years. The case shows that even a subsidized region can attract private resources if regulatory support and predictable tariff policy are in place.

Interim results as of mid-2025 are moderate but significant. Design documentation was prepared for seven CTD sites, about 5 % of emergency housing stock was resettled, one modular boiler house was commissioned, and about three kilometers of heating networks were modernized. An effective financial model has been created by combining federal grants and low-interest loans, regional co-financing, concessions, and investments from developers and utility operators. Projects become unstable without any one of these elements. By comparison, in the Amur Region, the launch of CTD is delayed because of a shortage of funds for the engineering site preparation: developers cannot start without the infrastructure in place, while the region cannot finance it.

3. Comparative assessment of instruments. The analysis identified the full set of investment mechanisms applicable to utility infrastructure modernization in CTD projects and assessed their comparative effectiveness. Direct budget financing, including subsidies and capital investments, is advantageous because it does not create a debt burden and guarantees the receipt of funds. For example, the resettlement program supported by the Housing and Utilities Fund ensures transfers for new housing and infrastructure. Its disadvantages are limited amounts and narrow targeting: in 2022, only about 5 % of the Russian regions obtained support for housing and utilities modernization, and the amounts were often only sufficient for partial repair. The new federal program up to 2030, with a total amount of RUB 4.5 trillion, expands coverage, but the federal contribution is about RUB 150 billion per year, with the rest being expected from investors [7]. Consequently, subsidies are necessary but insufficient, and a combined approach is required.

Infrastructure budget loans are in high demand: by 2022, applications totaling RUB 483 billion had been approved. Their advantages are a 3 % rate and a long repayment period. They are used to construct social facilities and mains required for housing development. Their disadvantages are the 50 % co-financing requirement, which forces poorer regions to raise debt funding, and the future repayments from the budget, with repayment peaks after 2032. Nevertheless, in 2021–2024 these loans became a key CTD driver, and in 2023 the instrument was extended.

DOM.RF infrastructure bonds remain relatively small in scale, but they have demonstrated a strong potential. The 2021 pilot amounted to RUB 30 billion for 12 regions to finance infrastructure for housing projects [8]. Their advantage is flexibility: market funds are raised under public guarantees without direct growth of regional debt, because obligations are formally assumed by DOM.RF. The rate for regions is below market level, approximately 7 % compared with more than 10 %. The limitation is the need to create a regional subsidiary and organize interaction with DOM.RF, so not all regions have been able to use the instrument. By 2023, the Moscow Region and Tatarstan were leaders, each attracting more than RUB 10 billion. For small subsidized regions, the mechanism is used rarely, often because they lack large housing programs; therefore, a standard road map for the instrument would be useful.

PPP and concessions are the classic channel for private investment. At the beginning of 2024, 2,763 concessions were in force, ranging from large city water utilities, such as in Rostov-on-Don, to

boiler houses in district centers. Their effect is to reduce losses and optimize expenditure by combining investment and operation functions in one private operator. A standard result is a reduction in network accidents after modernization. Problems include the requirement of tariff payback, which limits access to regions with low tariffs unless subsidies are available; fragmentation, because a concession often covers only one subsystem while CTD requires a comprehensive solution; and a lengthy preparation period, usually one to two years. However, over the last five years private operators have invested about RUB 1 trillion in housing and utilities [6], confirming the effectiveness of the mechanism. Concessions remain appropriate for large systems with stable payment flows, such as the heat or water supply of a new CTD micro-district.

Although interest-rate subsidies for developers are not direct investments in networks, they indirectly influence infrastructure. In 2020, Government Resolution No. 629 launched the subsidization of loan rates for developers in low-profitability regions [9]. In 2020–2022, around 1,800 projects were supported, which helped start construction in lagging regions. As a result, previously unprofitable projects became feasible and new housing was added to modernized networks. Zabaykalsky Krai serves as an example: several residential facilities in Chita were financed and later included in CTD [10]. Further, this mechanism could be supplemented with direct infrastructure grants for low-payback projects, which is being considered in the reform of developers' investment quotas.

Additional instruments include targeted regional infrastructure funds, municipal bonds, and project financing through infrastructure bonds. Moscow, Saint Petersburg, and Tatarstan use tariffs and budget funds to launch utility infrastructure development funds, whereas such funds are unavailable or poorly financed in subsidized regions, where municipalities have difficulty accessing cheap capital [11]. There are individual cases: in 2022, Khanty-Mansi Autonomous Area issued green bonds to finance boiler-house modernization and conversion to gas. In 2022, access to proceeds from the National Welfare Fund was simplified: its resources can be contributed to infrastructure, including housing and utilities, through investments in bonds or loans. The mechanism has been used to modernize heating in the new regions of the Russian Federation; in 2023, about RUB 50 billion from the National Welfare Fund was allocated to utility facilities there. No cases of this kind have been registered in the older regions, but the instrument has potential as a source of equity funding if access to debt financing is limited.

According to the Ministry of Construction, in 2025–2030 more than 50,000 kilometers of engineering networks and about 2,000 water supply and wastewater facilities are planned to be built or reconstructed to improve services for about 20 million people. Achieving the target network renewal rate of 2.5 % per year by 2030, compared with the current rate of about 1 %, is possible only through large-scale investment: hundreds of billions of rubles can be raised annually through loans and bonds, combined with tariff policies that stimulate concessionaire investment [12].

In CTD projects, investment mechanisms accelerate implementation and increase project completeness. Moscow and the Moscow Region, as donor regions, implement comprehensive neighborhood development projects aimed at comprehensive replacement of utilities; they renew dozens of kilometers of networks. The North Caucasus Federal District and the Far East cannot implement major renovation programs without federal support. In 2023, all North Caucasus regions approved housing and utilities modernization plans to 2030, including more than 1,700 actions worth about RUB 200 billion. The sources are subsidies, infrastructure loans, and concessions involving corporations; T Plus stated its readiness to participate if public support was available [13]. For depressed regions, public financing is a triggering mechanism that reduces risks and attracts private investors.

The first public assessments of the new instruments and their effectiveness have emerged. According to the Government of the Russian Federation, in 2019–2025 more than 12,000 kilometers of utility networks and about 5,500 facilities were built or modernized. These projects were supported by the national project Housing and Urban Environment and the launch of the infrastructure menu. Forty five kilometers of water supply networks were modernized in 16 municipal districts of Primorsky Krai in 2019-2023; financing was 60 % budgetary and 40 % from concessionaires, and water quality was improved for approximately 123,000 residents.

The socio-economic effects of CTD are impressive. Infrastructure loans totaling RUB 483 billion will create dozens of thousands of jobs and about 130 million square meters of housing by 2030. Improved housing conditions are a key value: according to the Ministry of Construction, in 2023–2024, 4.4 million families improved their living conditions, also through CTD. Not all effects are directly attributable to utility infrastructure, but its modernization is a necessary foundation for housing commissioning.

Overall, the set of instruments is broad, but each instrument has limitations. Maximum effect is achieved through a combination of budget leverage, borrowed sources, and private investment. Large-scale modernization of utility infrastructure within CTD is impossible without public involvement, including incentives and regulatory support, especially in subsidized regions.

DISCUSSION

The findings are consistent with publications on the chronic underfinancing of housing and utilities and the need for an active role of the state. The share of worn networks remains high and accident rates are significant. The analysis clarifies the balance of sources: even if tariff constraints are relaxed, private capital covers only about 20 % of the need, while about 80 % is covered by budgets and households. This corresponds to the parameters of the federal project, with approximately RUB 150 billion per year from the budget against roughly RUB 750 billion from other sources. The role of the state is therefore broader than direct investment: it creates an environment that attracts the remaining resources.

A comprehensive approach encompasses borrowing successful practices from adjacent sectors, including long-term life-cycle contracts, permanent funds, and service-oriented agreements, similar to approaches used in the European Union, where the grant component in water supply may cover 10–30 % of non-repayable costs. The Zabaykalsky Krai case confirms that subsidized resettlement and mains infrastructure make projects profitable; a combination of grants and debt instruments is required.

Concerns about the efficiency of expenditure can be mitigated through a project filter: key performance indicators, program passports, quantitative effects in loan applications, profitability requirements for infrastructure bonds combined with mandatory technology effects, such as lower heat losses. Background risks include household solvency and import pressure caused by sanctions [14]. These factors make the integration of financial mechanisms a necessary condition for closing the investment gap; the sector's deficit of approximately RUB 970 billion confirms the scale of the task [3].

CONCLUSIONS

The proposed comprehensive financing mechanism for modernizing utility infrastructure in CTD projects combines budget investments, low-interest loans, bonds, PPP, concessions, and targeted subsidies linked to the stages of the facility life cycle. The study shows that current instruments are effective if used in a coordinated manner: isolated use, such as concessions alone or subsidies alone, does not close the investment gap. The proposed scheme distributes roles by stage: planning involves requirements for developers; construction relies on infrastructure loans and bonds; operation requires long-term tariff regulation; capital repair uses accumulative funds and innovations; and renewal launches a new CTD cycle.

Practical results are aimed at federal and regional authorities as well as investors. The subsidized-region case of Zabaykalsky Krai shows that combined federal and private resources can successfully launch CTD even when regional earnings are small. For broader dissemination, this model should be integrated into the regulatory framework and program-level solutions.

The main instruments are as follows. Firstly, each CTD project should have a uniform investment passport with a utility infrastructure constituent, including the list of facilities, estimated costs, financing sources, and risk sharing models. Secondly, raising the required RUB 2 trillion of private investment for network renewal requires flexible tariff models that account for payback periods; without tariff indexation, such investment amounts cannot be raised. Third, the powers of the Housing and Utilities Fund should be expanded or a separate infrastructure modernization fund should be launched, with mechanisms for concessionaire participation and targeted grants for network development, including resources from the National Welfare Fund. Fourth, a pilot programme of municipal infrastructure bonds supported by DOM.RF should be launched for financially stronger municipalities to disseminate tested regional issuance practices. Fifth, regulatory acts governing lifecycle management of utility facilities should be introduced through amendments to strategic federal planning; this would include mandatory assessment of asset life, incorporation of depreciation into the tariff system, and reservation of funds for renewal.

To assess the effectiveness of the proposed scheme, pilot projects should be implemented in five cities representing different types of territories, including donor regions, subsidized regions, and medium-sized centers. Combining CTD with housing and utilities modernization within these pilot projects would provide empirical data for subsequent scaling. Regional financial stability, including the accumulation of debt under low-interest loans and bonds, requires continuous co-financing rather than single-time injections. The relevance of these proposals is confirmed by stronger budget support and investment control in resource-supplying organizations planned for 2025–2026.

Utility infrastructure modernization becomes feasible when policy moves from separate single-time actions to an integrated, life-cycle-oriented strategy. Such an approach can not only improve network reliability, but also reduce total operating costs and accelerate the commissioning of housing, creating a multiplier effect for the economy and improving the quality of the urban environment. Its application will support the achievement of national goals in housing and urban development and contribute to the sustainable development of Russian regions.

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Инвестиционные механизмы модернизации коммунальной инфраструктуры в рамках комплексного развития территорий

В данной статье исследуется комплексный подход к модернизации коммунальной инфраструктуры, рассматриваемый в рамках концепции комплексного развития территорий (КРТ). Особое внимание уделяется применению комбинированных инвестиционных стратегий и учету таких показателей, как стоимость жизненного цикла (СЖЦ) и совокупная стоимость владения (ССВ), с целью повышения эффективности модернизационных процессов. Целью данного исследования является выявление и систематизация инструментов, предусмотренных российским законодательством, для комплексного развития территорий и взаимосвязанных с ними отраслей. Также будут разработаны рекомендации по комбинированному применению этих инструментов с учетом особенностей дотационных регионов. В ходе реализации данной методологии будут осуществлены следующие шаги: изучение нормативно-правовой базы (в частности, Федерального закона № 494-ФЗ и программы модернизации ЖКХ), проведение статистического обзора действующих проектов КРТ в субъектах с дотационным финансированием, а также сравнительный анализ существующих инвестиционных механизмов (концессии, государственно-частное партнерство, инфраструктурные бюджетные кредиты, инфраструктурные облигации, бюджетные субсидии и гранты, долгосрочные контракты управления). Будет осуществлено изучение реализуемых проектов КРТ. В ходе работы были определены классификации механизмов по источникам финансирования и уровням риска, разработана матрица применимости для разных этапов жизненного цикла, а также предложена организационная структура проектного офиса и распределение ответственных сторон. Выводы подтвердили приоритет портфельной модели финансирования, необходимость долгосрочного тарифного подхода и важность совершенствования нормативно-правовой базы для масштабирования эффективных практик. Важность данного научного исследования состоит в обосновании взаимосвязи между инвестиционными инструментами и институциональной координацией на региональном уровне.

Ключевые слова: *модернизация инфраструктуры, комплексное развитие территорий, инвестиционные механизмы, государственно-частное партнерство, концессии*

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Problems in selecting durability indicators for elements of buildings and structures at the design, construction, and operation stages

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Using residential buildings erected during the period of mass industrial housing construction as a case study, the article examines the impact of selecting an optimal combination of standard and design service lives for structural components, individual elements, engineering systems, and the building as a whole on ensuring its reliability throughout the entire life cycle. It is shown that a mismatch between the service lives of load-bearing and enclosing structures, finishing layers, internal engineering systems, and equipment leads to a premature decline in the facility's operational performance, an increased need for repairs, higher total costs, and reduced efficiency in the use of the housing stock. The necessity of an integrated assignment of durability indicators already at the design stage is substantiated, taking into account construction conditions, operational features, maintainability, accessibility of technical servicing, and the economic feasibility of the decisions made. Methodological approaches are proposed for selecting rational technical, organizational-technological, and economic solutions that ensure the required level of reliability of buildings and structures at the design, construction, and operation stages. A theoretical framework is presented that makes it possible to relate the durability of individual elements to the integral reliability of the building, assess the influence of service life on its functional stability, and provide a basis for improving design practice, regulatory requirements, and strategies for housing stock operation. Particular attention is paid to buildings of the first mass-produced series as the facilities that most clearly demonstrate the consequences of errors in assigning service lives. The practical significance of the results lies in the possibility of using them to substantiate major repairs, modernization, and reconstruction of the existing housing stock under current conditions.

Keywords: *life cycle, reliability, durability, construction, technical operation, reliability indicators*

In the second half of the twentieth century, the USSR launched housing construction on an unprecedented scale, which continued until the early 1990s. At the first stage, from the late 1950s to the mid-1960s, the task was to relocate citizens from basements and barracks. At the second stage, from the mid-1960s to the mid-1980s, mass housing construction was used to resettle residents of communal apartments. Finally, beginning in the mid-1980s, the main objective of housing construction was to increase the provision of comfortable and well-equipped housing for citizens.

At all stages, inexpensive and short-lived materials and products were used in the construction of residential buildings. This can be explained by two circumstances.

First, the pace and volume of housing construction were so high that extensive savings in financial resources became necessary. This was achieved through the use of simplified and unreliable engineering solutions in the design process and the application of construction materials with minimum cost.

Second, the construction of buildings and structures relied exclusively on products manufactured by domestic construction industry enterprises, whose technological base was largely archaic. This predetermined the production of a limited range of products, their low quality and, consequently, poor durability.

During the years of industrialized housing construction, a sufficiently large number of residential buildings were erected according to various standard designs, which combined both successful solutions in terms of operational reliability and extremely unsuccessful technical solutions. Examples of completely unsuitable technical solutions include three-layer reinforced concrete wall and roof panels with insulation layers made of reed boards (design service life: 10 years) and cement-fiber boards (design service life: 15 years). Another striking example of disregard for maintainability is heating panels, which are reinforced concrete blocks with heating system pipelines cast into them.

In Moscow, between 1959 and 1976, 5,081 prefabricated five-storey residential buildings were constructed, with a living area of 10.7 million sq m (approximately 15 million sq m of total floor area), which, at the time the renovation programme was launched, accounted for about 10 % of the city's housing stock [1]. In recent decades, Moscow has been implementing a large-scale renewal of residential development dating from the 1960s and 1970s, involving the demolition of five-storey apartment buildings and the construction of modern residential buildings in their place within the framework of the renovation programme [2, 3].

In buildings of the standard series P-32, P-35, and K-7, the external wall panels are self-supporting and have different structural designs. In P-35 series buildings, they are made of rolled thin-walled ribbed shell slabs assembled in pairs with 100 mm mineral wool slab insulation. In P-32 series buildings, vibrobrick panels with a thermal insulation layer of large-porous expanded clay concrete were used. In K-7 series buildings, suspended three-layer panels were

applied, consisting of two layers of cement-sand mortar and an intermediate thermal insulation layer made of foam glass or mineral wool slabs.

The intermediate floors in buildings of the P-35 and P-32 series are made of two reinforced concrete shells, with the upper shell supported along its longitudinal sides by the lower shell, with sound-insulating gaskets laid along the entire length of bearing. To improve the sound insulation properties of the floors, the lower shells were filled with quartz sand.

The external walls, sized to a single room, were made either of three-layer panels consisting of reinforced concrete layers and insulation, for which mineral wool slabs and cellular concrete were commonly used, or of single-layer panels made of concrete with lightweight aggregates, such as expanded clay, thermozite, and others.

From the standpoint of operational reliability, prefabricated buildings of the overwhelming majority of standard series cannot be regarded as efficient and reliable. This applies primarily to interpanel and interblock joints and seams, as well as to the thermal insulation properties of external enclosing structures, which deteriorate significantly during operation due to the ageing of thermal insulation materials. Initially, extremely short-lived cement-reed and cement-fibre boards were used as insulation; these were later replaced by semi-rigid mineral wool slabs, and only in the 1980s did insulation layers in three-layer reinforced concrete panels begin to be made of foam plastic materials with substantially greater durability [4, 5].

Since a significant part of the currently existing housing stock was erected during the period of mass housing construction, the problem of the reliability of the apartment buildings comprising this stock is particularly acute today. In the course of major repairs, this problem should be addressed by minimizing the discrepancy between the residual service life of structures, elements, and systems that are not replaced during overhaul and the standard service lives of newly installed elements.

Over the years, domestic industry has mastered the mass production of a wide range of durable structures, materials, and products for construction, which makes it possible, in the design of buildings and structures, to focus on selecting their optimal combinations from the standpoint of durability. It should also be noted that the domestic market for construction materials still offers a sufficiently wide range of imported products.

Ensuring the normative values of individual reliability indicators and their rational combination makes it possible to adopt, in the design process, solutions that fully comply with the established reliability requirements. This can be achieved provided that alternative design solutions are developed using modern technical means and technologies.

An analysis of architectural and construction design practice makes it possible to assert that ensuring the required reliability of structures, elements, systems, equipment, as well as buildings and structures as a whole at the design stage is possible only if all evaluation indicators characterizing reliability are taken into account, various technical solutions are developed on their basis, and these solutions are comprehensively assessed, optimized, and subsequently selected.

At the same time, the formation of a set of evaluation indicators ensuring the reliability of buildings at the design stage is a conceptual issue of fundamental importance. The difficulty of solving this problem lies in the fact that all reliability evaluation indicators taken into account are deterministic, equally significant, and partially contradictory.

The deterministic nature of evaluation indicators means that their values may vary only within the permissible ranges established by regulatory documents.

Their equal significance implies mandatory compliance of all evaluation indicators, without exception, with the established regulatory requirements.

Contradictoriness is inherent not in all evaluation indicators, but only in some of them. At the same time, contradictions between indicators may be either strict, that is, antagonistic, or non-strict. An example of an antagonistic contradiction is the requirement contained in the design brief to ensure the minimum cost of constructing a building while simultaneously achieving the maximum level of comfort, including space-planning solutions, the quality of interior finishing, the level of engineering amenities, and other characteristics.

An example of a non-antagonistic contradiction between evaluation indicators is the relationship between the indicator characterizing the insolation of the internal spaces of the building being designed and the indicator characterizing its energy efficiency.

In the case where contradictions among all evaluation indicators without exception are non-strict, the formation and selection of the optimal (rational) solution are carried out within the area of agreement. This area is characterized by the fact that any solution chosen within it can be improved without reducing the values of the remaining evaluation indicators [6–9]. However, in the assessment and selection of reliable technical solutions in the design of buildings and structures, such a situation generally does not arise. Therefore, the task is not to choose the option that is best from the standpoint of reliability across the entire set of evaluation indicators, but rather to determine a solution that satisfies reliability requirements through an optimal combination of the values of these indicators.

In other words, each evaluation indicator, while remaining within the permissible range in quantitative terms, does not necessarily attain its absolutely best value; however, the combination of all indicators in their interrelation proves to be the most preferable for a particular project. In this formulation, the problem of selecting the best solution is addressed within the area of compromise, which is characterized by the principle of optimality according to which solution a is preferable to solution *a′* if the conditionx (*a*) ≥ *x*(*á*) is satisfied. The mathematical model for selecting the best solution in the area of compromise is as follows [10]:

$$x^0 = \{x/x \in X, \{x^1/x^1 \geq x\} \cap X \neq \varnothing\}. \quad (1)$$

The search for the best solutions in the area of compromise is carried out on the basis of a specific algorithm and the corresponding principle of optimality [11].

To select the best solution at the design stage while taking into account the values of all reliability assessment indicators, we have proposed two methods, referred to as the computational method and the material method.

The computational method is based on varying the quantitative values of reliability assessment indicators within the intervals established by regulatory documents, taking into account constraint indicators in order to obtain their optimal combination. For example, the load reliability factor is successively varied within the range from 1.05 to 1.10 with a step of 0.01 while the values of the remaining assessment indicators are kept unchanged. In a similar manner, the material reliability factor is varied within the range from 1.15 to 1.50 using the same increment. The search for the best combina-

tion of assessment indicators is carried out using one of the well-known mathematical methods of combinatorics.

Combinatorics is a branch of mathematics that studies discrete objects, finite sets, and the operations of selecting, ordering, and enumerating their elements, including combinations, permutations, and arrangements.

Combinatorial problems are characterized by the fact that all objects under consideration, which in the present study are rational design options, consist of individual discrete elements, that is, reliability assessment indicators of design solutions, while the sets of these elements are finite.

In the course of combinatorial analysis, two main types of operations are performed: the selection of subsets and the ordering of the elements of a set [12]. This fully corresponds to the essence of the proposed method, which is based on the successive enumeration of admissible combinations of assessment indicators and the selection of the most preferable design solution.

The material-based method of ensuring the reliability of design solutions is based on the purposeful selection of such materials as make it possible, already at the design stage, to achieve high reliability indicators for structures, elements, and systems while simultaneously minimizing labor, financial, and material-technical costs. One example is the manufacture of reinforced concrete structures under both factory and on-site conditions using reinforcement made of different materials.

For conventional steel reinforcement (classes A400, A500, A600, and higher in accordance with CP 63.13330[1]), the material-based method is implemented through the use of reinforcement of higher strength classes, which makes it possible to increase the design resistance and reduce the stress level under given loads; the use of reinforcement with improved ductility and crack-resistance characteristics, ensuring more reliable structural behavior in limit states; the introduction of anti-corrosion protection measures for reinforcement, including epoxy coatings, hot-dip galvanizing, and the use of stainless reinforcement, which significantly reduces the rate of corrosion damage during operation in aggressive environments; as well as an increase in durability due to a lower probability of corrosion-related damage.

The use of high-quality metallic reinforcement makes it possible to improve structural reliability without increasing dimensions and weight; however, it requires strict quality control of the material and compliance with technological requirements during fabrication and installation.

The use of composite reinforcement in design solutions (glass-fiber-reinforced polymer, basalt-fiber-reinforced polymer, and carbon-fiber-reinforced polymer reinforcement), regulated by CP 295.1325800.2017[2], represents one of the clearest examples of the implementation of the material-based method for improving reliability. The main advantages of composite reinforcement include high corrosion resistance, which prevents reinforcement deterioration in aggressive environments; low density, reducing the self-weight of structures; high tensile strength exceeding the corresponding values for steel reinforcement; and electromagnetic inertness.

Another illustrative example of the material-based method for selecting design solutions optimal from the standpoint of reliability assurance is the consideration of alternative uses of different concrete classes in the manufacture of reinforced concrete structures under both factory and on-site conditions. In this case, concretes of different classes, substantially differing in properties and cost, may be used for the production of the same structure.

The long-term experience of constructing and technically operating prefabricated buildings erected during the period of mass industrial housing construction should be thoroughly analyzed, first, in the design of new buildings and structures and, second, in the technical operation of existing facilities in the course of repair works.

In the design of new construction projects, efforts should be made to minimize deviations of the standard (design) service lives of structures, elements, and systems from their average value by selecting the most durable elements subject to replacement during operation, while simultaneously providing a justified reduction in the standard service lives of non-replaceable elements.

Within the framework of current or major repairs, when replacing elements that are in an unsatisfactory technical condition or have exhausted their service life, it is necessary to take into account the residual service life of those elements whose replacement is not envisaged. In cases where the technical condition of non-replaceable elements in the repaired buildings does not comply with the regulatory requirements for technical operation, remedial measures should be provided for their rehabilitation without replacement.

The reliability of complex technical systems, which include buildings and structures, at all stages of the life cycle is determined by the durability of their constituent elements. In mathematical form, the reliability of a system consisting of m elements may be represented as follows [13]:

$$P(t) = \prod_{i=1}^{m} P_i(t)dt. \quad (2)$$

This reliability function is associated with the point indicator T and the integral indicator $\hat{T}$ of the durability of a building (structure), as well as with the γ-percent service life T_γ, which are determined by expressions (3)–(5):

$$T = \int_0^\infty \prod_{i=1}^{m} P_i(t)dt; \quad (3)$$

$$\hat{T} = \int_0^\infty \prod_{i=1}^{m} P_i(t)dt; \quad (4)$$

$$T_\gamma : \prod_{i=1}^{m} P_i(T_\gamma) = \gamma. \quad (5)$$

In principle, the relationship between the reliability of a complex system and the durability of its constituent elements raises no doubt. However, in cases where, at certain stages of the life cycle, requirements are imposed to ensure reliability in the form of specified quantitative parameters, the durability indicators of the elements must be determined analytically.

With a certain degree of approximation, it may be assumed that, provided the regulatory operating conditions of buildings and structures are observed, the service lives (durability) of their constituent elements follow a normal distribution.

In this case, if the parameters of the normal distribution are denoted by μ_i and σ_i, and their estimates by $\hat{\mu}_i$ and $\hat{\sigma}_i$, then the point estimate of the probability of failure-free operation of the system may be determined from expression (6) [14, 15]:

$$\hat{P}(t) = \prod_{i=1}^{m} \Phi\left[h_i(t)\right], \quad (6)$$

[1] SP 63.13330. Concrete and reinforced concrete structures.

[2] SP 295.1325800.2017. List of rules. Concrete structures reinforced with polymer composite reinforcement. Design rules. URL: https://www.minstroyrf.gov.ru/docs/15269/

where the Laplace function is given by:

$$\Phi(x) = \frac{1}{\sqrt{2n}} \int_{-\infty}^{x} \exp\left(-\frac{t^2}{2}\right) dt; \quad (7)$$

$$h_i(t) = \frac{\hat{\mu}_i - t}{\hat{\sigma}_i}, \quad i = \overline{1, m}. \quad (8)$$

The minimum reliability value of the system (building, structure), taking into account the durability of its constituent elements, is determined by expression (9):

$$P_q(t) \cong \Phi\left\{h(t) - u_q\sqrt{\left[1 + \frac{1}{2}h^2(t)\right]}\right\}, \quad (9)$$

where u_q and $h(t)$ are tabulated values of the quantiles of the normal distribution corresponding to the levels q and $\hat{P}(t)$.

The above theoretical approaches should be taken as the basis for selecting optimal (rational) technical, organizational-technological, and economic solutions at all stages of the life cycle of buildings and structures. Their application makes it possible, already at the design stage, to substantiate such combinations of structural, technological, and operational solutions as ensure the required level of reliability, durability, maintainability, and economic efficiency of facilities. This approach is of particular importance during the construction of buildings and structures, when the quality of implementation of design solutions directly affects the achievement of the calculated reliability indicators and service life. Equally important is the application of these approaches in the course of technical operation, major repair, modernization, and reconstruction, since it is precisely at these stages that it becomes necessary to reconcile the residual service life of existing structures and systems with the standard service lives of newly introduced elements, materials, and engineering equipment. This creates the methodological prerequisites for making well-founded decisions aimed at improving the operational reliability of facilities, extending their effective service life, and reducing total costs throughout the entire life cycle.

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Проблемы выбора показателей долговечности элементов зданий и сооружений при проектировании, возведении и эксплуатации

В статье на примере жилых зданий, возведенных в период массового индустриального жилищного строительства, рассматривается влияние выбора оптимального сочетания нормативных и расчетных сроков службы строительных конструкций, отдельных элементов, инженерных систем и здания в целом на обеспечение его надежности в течение всего жизненного цикла. Показано, что несогласованность сроков службы несущих и ограждающих конструкций, отделочных слоев, внутренних инженерных систем и оборудования приводит к преждевременному снижению эксплуатационных качеств объекта, увеличению потребности в ремонтах, росту совокупных затрат и уменьшению эффективности использования жилищного фонда. Обоснована необходимость комплексного назначения показателей долговечности уже на этапе проектирования с учетом условий возведения, особенностей эксплуатации, ремонтопригодности, доступности технического обслуживания и экономической целесообразности принимаемых решений. Предложены методологические подходы к выбору рациональных технических, организационно-технологических и экономических решений, обеспечивающих требуемый уровень надежности зданий и сооружений на стадиях проектирования, строительства и эксплуатации. Приведен теоретический аппарат, позволяющий увязать долговечность отдельных элементов с интегральной надежностью здания, оценить влияние сроков службы на его функциональную устойчивость и сформировать основу для совершенствования проектной практики, нормативных требований и стратегий эксплуатации жилищного фонда. Особое внимание уделено зданиям первых массовых серий как объектам, наиболее наглядно демонстрирующим последствия ошибок в назначении сроков службы.

Практическая значимость результатов заключается в возможности их использования при обосновании капитального ремонта, модернизации и реконструкции существующего жилищного фонда в современных условиях.

Ключевые слова: *жизненный цикл, надежность, долговечность, возведение, техническая эксплуатация, показатели надежности*

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Requirements management in construction

The article examines key changes in the regulatory and technical framework of the construction industry driven by the transition to the Registry of Requirements, which applies to engineering surveys, design, construction, and demolition. Based on a study of the interconnectedness between the registry-based principle, digital transformation, and performance-based (parametric) regulation, the paper reveals the revised objectives of the Registry of Requirements as an end-to-end verification mechanism. This mechanism is designed to govern design, monitoring, and compliance verification processes across all stages of an asset's lifecycle. The authors analyze the reasons behind delaying the official launch of the Registry of Requirements, and synthesize early feedback from the professional community — for whom operating the Registry will become a routine professional activity — alongside critical assessments from specialized IT developers. Special attention is paid to the challenges and prospects of translating regulatory requirements into machine-readable and machine-understandable formats, as well as defining the conditions for the further advancement of this approach.
The paper substantiates the need to modify the format for extracting and amending existing requirements. A shortage of software services designed to manage requirement systems is highlighted. The authors propose a collaborative approach to developing and practically implementing corporate and local registries of requirements within the operations of construction companies. Furthermore, the study analyzes the rules approved by the Government of the Russian Federation for developing and publishing requirements in the Registry, as well as mechanisms for resolving conflicts between them. As a systemic solution, the importance of integrating the registry-based principle with the performance-based (parametric) regulation method is argued. The authors present a new concept for a Parametric Requirement Management System in construction (PRMS). Finally, new definitions of core terms are formulated, reflecting the general concept and structural principles of the proposed System.
Keywords: *register of requirements, digital transformation, automation of processes, machine-readable format, Parametric Requirements Management System (PRMS) in construction, parametric rationing*

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INTRODUCTION

The digital transformation of the construction industry and the development of its technical regulation system are gaining momentum every year. New resources, information systems are emerging, document formats are being updated, etc. Administrative and professional transformations are not lagging behind the digital one. All this contributes to an increase in the volume of housing, industrial, and road construction, improves the quality of the urban environment, and forms the economic and technological sovereignty of our country. Against the background of budget financing, extra-budgetary sources of these transformations are becoming more common. In addition to these changes, norms, rules, and regulatory documents in general are being actively updated and reworked. For almost two years, the information system "Register of Requirements to be applied when performing engineering surveys, carrying out architectural and construction design, conducting an examination of project documentation and (or) examining the results of engineering surveys, construction, reconstruction, major repairs, operation and demolition of capital construction facilities" has been operating [1] (hereinafter referred to as the Register of Requirements), posted on the Stroykompleks.RF portal. According to the creators, the Register of Requirements should ensure synchronization of the entire volume of requirements of various departments in the construction industry, provide a unified approach to their purpose and application. With the introduction and development of the Register of Requirements, the industry receives a single clear mechanism on the basis of which compliance will be designed, monitored and verified at all stages of the facility's life cycle. It will be possible to switch to automation of design processes, as well as to remove existing conflicts and inaccuracies in the regulatory and technical framework [2].

THE RESULTS OBTAINED

According to some information, the Register of Requirements already contains more than 170,000 requirements from more than 1,000 documents. The Ministry of Construction of Russia, together with FAU "FCS" and other interested departments, are optimizing and reworking the requirements, preparing them for translation into machine-readable and machine-understandable formats. The transition to the application of the Register of Requirements determines that, for example, when preparing and examining project documentation, it is necessary to work not just with current regulatory documents, but with the current requirements of the Register [3]. The new format of work will require a revision of the usual approaches to the selection of regulatory documents, and the importance of correctly documenting the justifications for design decisions will increase. At the same time, responsibility for such decisions becomes more personalized and formalized.

In accordance with Federal Law No. 653-FZ dated December 25, 2023. The Register of Requirements will enter into force on March 1, 2026 [4]. In particular, this is the launch date of a new format for the examination of project documentation. But contrary to

expectations, the entry into force of the Register of Requirements did not take place on the specified date. But on the contrary. Long before this date, Federal Law No. 507 of 12/28/2025 [5] postponed the application of the provisions of the Register of Requirements during the examination of project documentation to March 1, 2027. And already this year, the Government of the Russian Federation amended the relevant by-laws by Resolution No. 179 dated February 21, 2026 [6]. Why did this happen? Some open sources analyze the reasons for such a transfer and note that the implementation of such large-scale digital tools as the Register of Requirements requires quite a lot of debugging time. And the extra time in the preparatory period helps to reduce the number of failures and errors during the application period. Due to the postponement, participants in the construction industry also get time to refine their systems and corporate solutions, as the transition to working with the Register of Requirements will require major changes in the practice of specialists and the architecture of IT systems. According to IT industry experts developing digital solutions for construction, the primary task is to create such digital registers that will contain all the information necessary for a specialist, understandable application services for working with it [7]. In this case, we can already talk about full-fledged digital technology, and this is not currently available in the current version of the Register of Requirements.

There are also criticisms of the Requirements Registry: long loading of search results, the relationship between requests and the data provided is not always clear, difficulties with searching by requirement ID or document number, significant differences in search results from the results obtained in the usual “manual” way, lack of instructions for working with the Registry. As a result, there is a lack of trust in this information system.

When selecting and interpreting regulatory and technical documentation, the specialist performs the following actions:

- extracts specific mandatory requirements (norms, conditions) from the text;
- highlights the requirements relevant to the current stage of the facility's life cycle (design, construction, operation);
- uses them as source data for engineering calculations, performance verification, and development of technical and design solutions;
- aligns requirements with CIM;
- compares the prepared results and reporting materials with the previously identified requirements, which ensures the passage of expertise.

But there are significant limitations at each of these stages:

- requirements are extracted primarily based on the personal experience and qualifications of a specialist;
- there is no systematic fixation of references to specific paragraphs and provisions of regulatory documents;
- structured registers of requirements suitable for reuse and control are not being formed;
- references in the accounting documentation are usually given to regulatory documents in general, without precise reference to the requirements;
- there is no integration with CIM in any form (for example, in the form of links);
- conformity assessment is performed either expertly (based on experience) or through reinterpretation of the original regulatory documents, which increases labor costs and the risk of discrepancies.

NEW PERSPECTIVES

Due to the fact that the entry into force of the Register of Requirements has been postponed for a year, there is time to finalize and eliminate most of the technical problems. However, there is a possibility that technological and functional issues will remain. In the case when the only source of requirements is the Registry, a number of issues arise related to the possibility of integration with the TIM, with convenience and flexibility of application, with the prospects of translating requirements into a machine-readable format. At the moment, these tasks can only be solved manually with high resource costs.

In Fig. 1, you can clearly see that today's work with requirements is, in fact, limited by the available formats for working with regulatory documents. That is, the small task of updating several requirements entails at least an annual decision on the release of a new standard, for example.

At the same time, the introduction of the Register of Requirements is designed to ensure the transition from working with Registers of Documents to working with requirements. Since it is the marking of requirements, not documents, that will automate the process of examining project documentation and information model (IM), and in the future automate the design process. However, if the work remains in alternating “Document – Requirement – Document – etc.”, then difficulties will arise even when integrating requirements with the Construction Information Classifier (CIC). Even now, specialists in the field of construction and design are working with regulatory requirements, but this process remains largely unsystematic and non-automated. Due to the fact that in the Register of requirements on the Stroykomplex portal. In the Russian Federation, it is not

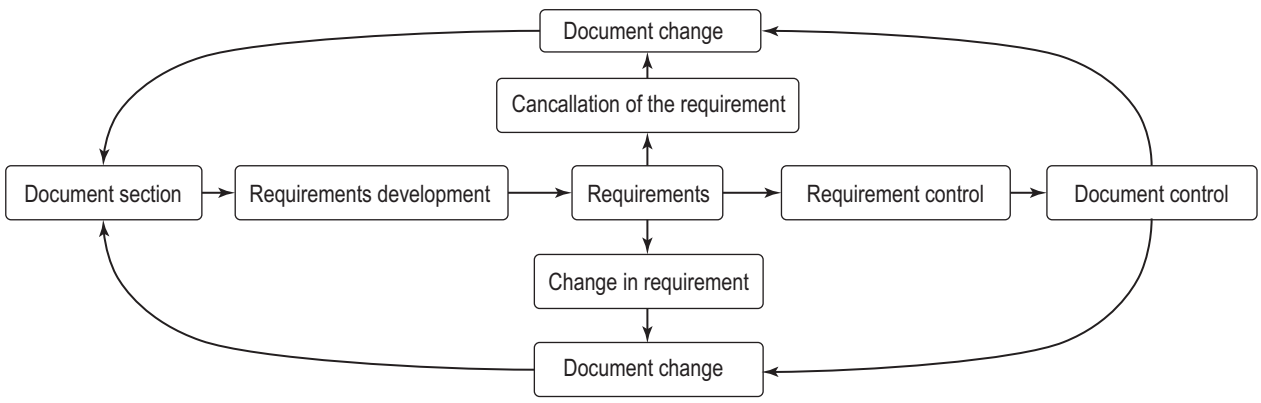

Fig. 1. The existing format for working with requirements

possible to create thematic collections of requirements in the user's personal account. In previous publications, the authors proposed and justified a separate tool for working with requirements — Corporate registers of requirements. The authors defined them as databases in which the regulatory requirements that the company applies and fulfills within the framework of its specific activities are structured and systematized [8]. By analogy, if we exclude the "corporate" nature, these may be Local registers of requirements, which can be defined as databases in which regulatory requirements are structured and systematized, which an individual specialist applies and fulfills within the framework of his specific activities. It should be noted that the format of local registries was successfully applied by the authors during the development of the SRT series last year. But these proposals will only help builders in the transition period to reduce time losses, improve the accuracy of working with requirements and allow the use of additional services that will inevitably appear in the near future. However, there remains a problem due to the fact that the procedure for introducing and replacing requirements in the Registry takes a considerable amount of time. In accordance with the new version of the Decree of the Government of the Russian Federation No. 1417 dated August 31, 2023 (as amended on April 4, 2025) [9], the Ministry of Construction, the Federal Agency for Technical Regulation and Metrology will need to be involved in identifying and eliminating contradictions between the requirements of the Register and, for example, the draft standard planned for inclusion. The developer of the standard, the Government Commission for Regional Development, as well as the authority that approved the standard. At the same time, the organization of interaction between these associations must be implemented within up to 70 working days.

There are already hundreds of thousands of requirements in the Register of Requirements at the moment, and their number is constantly increasing. As a result, the amount of responsible and complex work will increase many times in the future. Obviously, without systemic changes, this approach to norm transformation will not be much more promising than the traditional approach, in which regulatory documents were updated entirely and gradually. There is another direction for the transformation of the regulatory system in the construction industry — the transition to a parametric method of rationing. The integration of the two stated approaches can provide productive changes. The authors justified the organizational possibility of such integration in previous publications in the form of an algorithm according to which regulatory requirements are collected in local registries, divided into qualitative or quantitative parameters for more convenient operation and for the possibility of configuring checklists to facilitate automation of the conformity assessment process [10]. This approach can facilitate the transition to requirements management. Due to the fact that only the requirements necessary for the work (both mandatory requirements and requirements from the company's service station) will be used, updated and monitored, and not the entire documents. By analogy with the standardization tools in other industries, the authors propose to develop a System of Parameterized Requirements Management in construction (SPTS). It should be noted that management is proposed to be given a "parameterized" character, that is, focused on interaction with the components of requirements. This feature cannot be identified with the elements of the introduction of the parametric method of normalization. Fragments of the conceptual framework of such a system were proposed by the Engineering Division of the State Atomic Energy Corporation ROSATOM in 2018 [11]. But at that time, there was no need to switch to a parametric method of rationing, structuring requirements, or switching to automated processes and typescript formats. Therefore, the conceptual framework considered each requirement as something indivisible, regardless of the form of presentation, volume and structure of the content. The system of parameterized requirements management in construction proposed by the authors is based on deeper approaches. Some proposed provisions for the current content of the satellite are listed below.

PARAMETERIZED MANAGEMENT OF REQUIREMENTS IN THE FIELD OF CONSTRUCTION

The first step is to define the term "requirement". In accordance with CP 555.1325800.2025, a requirement is a provision (regulatory document) containing quantitative and (or) qualitative criteria that must be met [12]. A regulation is defined as a logical unit of the content of a regulatory document in construction. There are no definitions for "logical unit" and "criteria" in the document, so it is difficult to say what should be understood by them and what properties they possess. GOST R 59194–2020, used in the development of the aforementioned joint venture, contains the following definition of the requirement: This is the required (expected) quantitative or qualitative characteristic or property of an object, as well as related restrictions and conditions [13]. The ISO/IEC/IEEE 29148:2018 standard states the following: requirements are statements that identify the operational, functional parameters, characteristics, or limitations of a product or process. In addition, it is determined that they must be: unambiguously measurable; verifiable and suitable for acceptance of the product or process by the customer [14]. The latter definition seems precise and succinct, and it also traces a connection with the basics of the parametric method of normalization. However, there is a problem related to the multilevel nature of the industry's rationing system, according to which almost half of the requirements contain references to other regulatory and technical documents. Therefore, it will be impossible to apply the definition from ISO/IEC/IEEE 29148:2018 without appropriate adaptation. The definition from GOST R 59194–2020 is not suitable for use in the construction sector, as it contains assumptions focused on the engineering industry.

According to the authors of the article, the definition from CP 555.1325800.2025 could be supplemented and clarified: a requirement is a provision of a regulatory document containing logically interrelated criteria, conditions and parameters that must be fulfilled (provided). In the context of the proposed approach (PRMS), when the appearance of requirements will not necessarily occur "through a document", it is possible to give a shorter definition. For example: a requirement is a logically interrelated application conditions, criteria, and parameters that must be fulfilled (provided). In this context, a parameter can be defined as a feature, usually quantitative, on the basis of which an assessment, classification, and determination of the measurable characteristics of the system are performed. Criteria can be defined as a set of indicators for identifying parameters. a condition is an integral part of a requirement that indicates the circumstances or events under which the requirement applies. It is also necessary to separate the concept of "parameter", which is used in the definition of the term "requirement", from the concept of "parameter", which is used in the context of parametric normalization. In the first case, a parameter is a sign of any requirement. In the second case, the parameter is a sign of a requirement for the functional (operational) characteristics of an object or process. Next, it is necessary to define the term "requirements management". In the context of the introduction of parametric rationing, the following definition can be proposed: requirements management is a set of types of

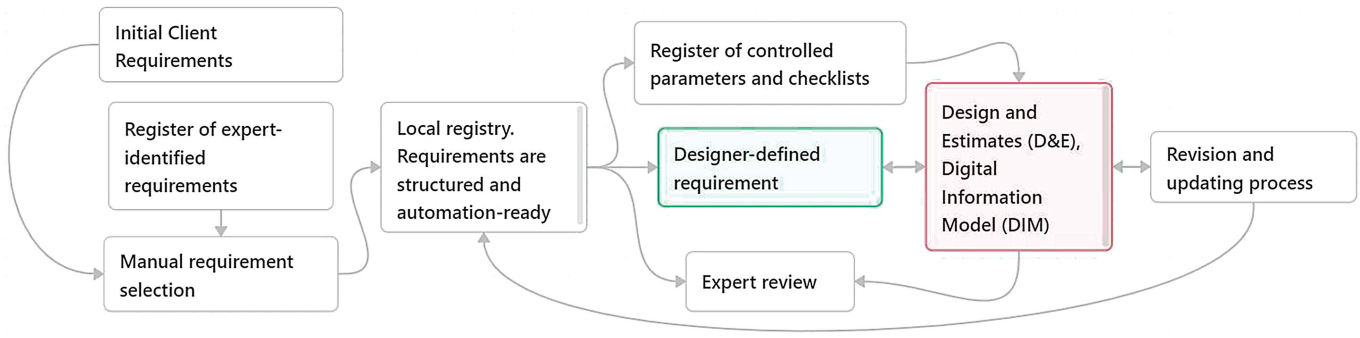

Fig. 2. The proposed algorithm for working with requirements

engineering and management activities for the formation, analysis, structuring, parameterization (markup), validation, updating, documentation, cross–linking, changing requirements for standardization objects. It should be noted that the requirements under the operating conditions of the system will be heterogeneous. Within the framework of the preliminary classification, it is already possible to distinguish the initial and design requirements. The initial requirements can be understood as the requirements obtained as a result of an analysis of the needs of an interested party, for example, a functional construction customer. Separating the initial requirements into a separate category may be a good solution in order to combine the approach to the transformation of rationing, namely the approach to working with the Register of Requirements and the method of parametric rationing, in its functionally oriented understanding.

By design requirements, the authors propose to understand the requirements obtained as a result of the decomposition and analysis of the initial requirements in the preparation of the design assignment and the preparation of project documentation. Even now, in a qualitative way, PRMS will be able to separate and process “parent” and “child” requirements. This, in turn, will ensure the traceability of the requirements. This is a property of requirements that determines the ability to trace the sources of their formation and all their child requirements. a mandatory function of the system should be to work with checklists. With their help, it will be possible to select requirements for a specific section of the project documentation or for one of the tasks of the technical customer. Checklists can serve two important roles. The first is the role of a structured set of agreed and interrelated initial requirements and constraints for the facility under construction, formulated by the stakeholders. The second is the role of a structured set of coordinated and interrelated design requirements for an object, its elements, operating conditions, etc. Using the same checklist, you can quickly and accurately monitor accounting and compliance with requirements. And if the requirement is parameterized, then it can be implemented in an automated mode, without complex manual markup, as it is found today, and without the use of trained neural networks, as many see it tomorrow. When working with checklists, it is possible to assign statuses of their fulfillment to requirements. This status can be determined based on the results of verification or validation of an object for compliance with these requirements. The use of structured aggregates corresponds to the provisions of GOST R 21.101–2026 [15] regarding the control of requirements and parameters. It follows from the above that new standards need to be developed in new digital formats. Otherwise, there is a risk that requirements will be isolated from existing standards, and new ones will appear, from which requirements will also need to be manually isolated. The optimal solution available today may be the following combination: development of GOST + parallel development of a local registry of requirements for this GOST + parallel development of a local registry of criteria and parameters for requirements. an abbreviated algorithm for working with requirements in this case is shown in Fig. 2.

This will be a real mechanism for translating regulatory documents into a more convenient digital format for work and automation. This also allows for a faster and more balanced transition to parametric normalization in a natural way.

CONCLUSIONS

In the context of the transformation of the rationing system, aimed, among other things, at automating the design and construction processes, taking into account the promising development of information technology, an important task is to change the approach to requirements management when working with the Register of Requirements. At the same time, management should include both the collection, monitoring of relevance and changing requirements, as well as the development of new documents, taking into account the subsequent possibility of working with specific requirements. The proposed PRMS does not involve restructuring or completely changing the usual patterns of action and appears to be a tool to begin to systematize the work already being done and prepare opportunities for simple automation at the first stages, in the future — to provide prospects for the transition to parametric standardization, integration of requirements into information models, the development of algorithms for automating more complex tasks related to regulatory regulation in the construction sector.

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Управление требованиями в строительстве

В статье рассмотрены ключевые изменения в нормативно-техническом регулировании строительной отрасли, обусловленные переходом к работе с Реестром требований, подлежащих применению при выполнении инженерных изысканий, проектировании, строительстве и сносе. На основе исследования взаимосвязи реестрового принципа, цифровой трансформации и параметрического нормирования раскрыты скорректированные задачи Реестра требований как сквозного механизма контроля, на основании которого будут осуществляться процессы проектирования, контроля и проверки соответствия на всех этапах жизненного цикла объекта. Проанализированы причины переноса сроков официального введения в действие Реестра требований, обобщены первые отзывы профессионального сообщества, для которого в будущем работа с Реестром станет повседневной профессиональной практикой, а также критические оценки профильных IT-разработчиков. Особое внимание уделено проблемам и перспективам перевода нормативных требований в машиночитаемый и машинопонимаемый форматы, а также определению условий для дальнейшего развития этого подхода.

Обоснована необходимость изменения формата выделения и корректировки существующих требований. Отмечен дефицит сервисов по работе с системами требований. Предложен авторский подход к формированию и практическому применению корпоративных и локальных реестров требований в деятельности строительных компаний. Проанализированы принятые Правительством РФ правила разработки и размещения требований в Реестре требований, а также механизмы устранения противоречий между ними. В качестве системного решения аргументирована важность интеграции реестрового принципа с методом параметрического нормирования. Представлена авторская концепция Системы параметризированного управления требованиями в строительстве (СПУТС). Сформулированы авторские определения базовых терминов, отражающие общую концепцию и принципы построения предлагаемой Системы.

Ключевые слова: *реестр требований, цифровая трансформация, автоматизация процессов, машинопонимаемый формат, Система параметризированного управления требованиями в строительстве (СПУТС), параметрическое нормирование*

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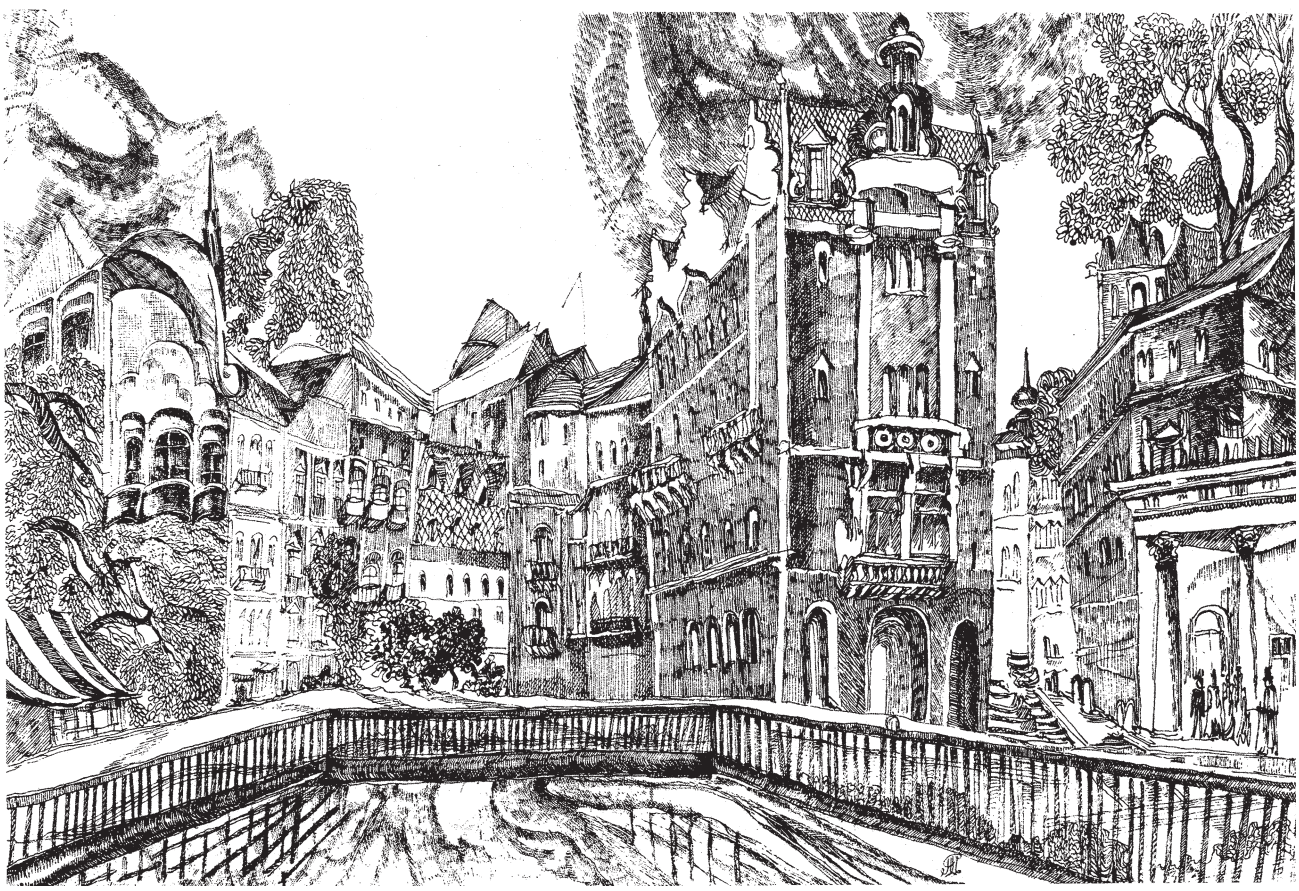

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Approaches to Parametric Configuration Modeling and End–to–End Digital Identifier Generation in Industrial Modular Housing Systems

To meet the national target of commissioning 120 million square metres of housing annually, the Russian construction industry is transforming its technological approaches. Traditional construction methods, characterized by high labour intensity on-site and unpredictable processes, are giving way to industrial prefabrication. Large-scale modular housing construction represents one of the most promising technologies in construction, allowing up to 80 % of labour to be transferred to controlled factory conditions. However, the widespread adoption of this technology is hampered by issues associated with information gaps at different stages of the building lifecycle. This paper presents a scientific and methodological toolkit aimed at eliminating existing gaps through the use of parametric modelling of building configurations and an end-to-end digital object identification system. The study develops a mathematical model for generating architectural planning solutions based on constraint vectors that include geospatial, regulatory, production, and business requirements. The structure of a unique digital identifier designed for use as a key element of end-to-end management is presented. Research has shown that the transition to algorithmic design and digital certification of building system modules improves their organizational and technological reliability by reducing the risk of interface conflicts and optimizing production and logistics processes.
Keywords: *modular construction, parametric modelling, digital identifier, building life cycle, information modelling (BIM), organizational and technological reliability, prefabrication, industrial development*

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Currently, the investment and construction sector is facing a depletion of resources previously utilized in extensive management models [1, 2]. The current paradigm, which views construction as a sequence of loosely coupled stages, is ineffective for large-scale residential construction projects [3]. In light of the Russian Construction Development Strategy to 2030, which prioritizes industrialization and modular technologies to increase productivity, the relevance of this problem has increased significantly [4].

Large-scale modular construction (LSMC) is currently going beyond simple prefabricated building elements. It is a special type of industrialized construction in which the building is perceived as a product created using mechanical engineering principles. Modern factory production conditions allow for precision of up to 2 mm, significantly exceeding the capabilities of currently common monolithic technologies on construction sites. Despite the enormous technological potential, the implementation of modular construction projects is often hampered by issues arising from the interaction of rigid, immutable modules with imperfections in the foundation or adjacent structures. In this research paper, these issues will be referred to as “interface conflicts”.

These conflicts may arise due to the lack of a unified digital system and synchronization that could conceivably connect the design concept with the production pipeline and installation stages. Existing building information modelling (BIM) typically relies on the creation of 3D models, which can lose their accuracy and information completeness when transferred between different software environments used by various project participants. To overcome these obstacles, it is necessary to transform the static model into a dynamic parametric function. This function will be controlled by a comprehensive digital identifier system that will ensure continuous and flexible control over the object (Table 1) [5].

MATERIALS AND METHODS

A parametric modelling approach to modular building configurations

This study proposes a design system that utilizes mathematical modelling to find the optimal solution in a space with multiple constraints. a distinctive feature

Table 1. Comparative analysis of the life cycle of building systems

Life cycle stage	Monolithic construction technology	Modular construction technology
Design	Discrete creation of drawings and the possibility of modifications at later stages	Parametric modelling, fixing the module configuration at an early stage
Production	Delivery of building materials to the site	Manufacturing of high-readiness modules at the factory
Logistics	Flow of supplies of various building materials	Synchronized delivery of prefabricated large-sized modules
Installation	Long wet processes, weather dependent	High speed of module assembly (1 floor in 3–4 days)
Data management	Fragmented management, resulting in a predominance of paperwork	End-to-end digital identification, digital technical data sheets of module elements

of this methodology is its form, which is not limited to functional requirements but also takes into account the capabilities of the manufacturing process [6].

Mathematical model of constraint vectors

For the design system to function, a clear definition of four constraint vectors is necessary, which form a corridor of feasible solutions [7].

1. Geospatial and physical constraint vector (C_{env}).

Formalizes the context of the construction site:

$$C_{env} = \{G_{site}, S_{soil}, L_{gw}, A_{seis}, R_{clim}\}, \quad (1)$$

where G_{site} is the geometry of the site;

S_{soil} is the bearing capacity of the soil, which determines the maximum mass of the building;

L_{gw} is the estimated groundwater level;

A_{seis} is the seismicity, which dictates the requirements for the rigidity of the module frame;

R_{clim} are the climatic parameters that determine the thickness of the enclosing structures [8].

2. Vector of urban planning and regulatory restrictions (C_{reg}).

This vector allows us to ensure the legality of the project within the framework of current legislation:

$$C_{reg} = \{H_{max}, K_{dens}, K_{ins}, F_{class}\}, \quad (2)$$

where H_{max} is the maximum permissible height of the object according to land use and development regulations;

K_{dens} is the coefficient of the maximum permissible development density of the site;

K_{ins} is the regulatory requirements for the duration of insolation of residential premises;

F_{class} is the functional fire hazard class of the building, dictating the requirements for materials and evacuation routes.

All requirements of the Land Use and Development Regulations (L&D) regarding the height and density of development are taken into account.

3. Vector of production and logistics constraints (C_{prod}).

The vector sets the boundaries of technological feasibility:

$$C_{prod} = \{Dim_{max}, W_{mod}, T_{cycle}, Tr_{limit}\}, \quad (3)$$

where Dim_{max} is the maximum overall dimensions of one module (length, width, height) that the plant can produce;

W_{mod} is the maximum mass of the module, limited by the capacity of the crane equipment;

T_{cycle} is the cycle time of the production line (the time it takes to produce one finished product);

Tr_{limit} is the overall restrictions along the delivery route (the height of bridges, the turning radii of roads).

At this stage, the maximum dimensions of the module are determined, which are determined by the dimensions of the molds at the plant (for example, up to 15.5 × 7.5 m), as well as the weight, limited by the capacity of the crane equipment.

4. The vector is related to the economic part and reflects business requirements (R_{biz}).

The target performance function is formed for the developer:

$$R_{biz} = \{CAPEX_{target}, S_{sell}, Mix_{flat}, ROI_{min}\}, \quad (4)$$

where $CAPEX_{target}$ is capital expenditure;

S_{sell} is the required useful (sellable) area of the building;

Mix_{flat} is the specified apartment layout structure;

ROI_{min} is the minimum acceptable level of return on investment.

At this stage, the desired apartment layout, budget and profitability of the project are determined [9].

Algorithm for optimized generative design and scenario-based alternative modelling

Specific optimization algorithms are used to synthesize a space-planning solution. The objective function is aimed at maximizing the saleable area while minimizing deviations from the target apartment matrix and complying with all constraints $F(X)$ [10]:

$$F(X) \rightarrow \max(w_1 \cdot S_{sell}(X) - w_2 \cdot \Delta Mix(X) - w_3 \cdot C(X)/CAPEX_{target}), \quad (5)$$

where w — project priority weighting factors.

This system can generate various layout options, depending on the initial conditions provided automatically:

- "investment" option: the goal is to quickly sell properties. The selection primarily includes studios and 1–2-bedroom apartments;
- "balanced" option: the selection includes a balanced and optimal combination of 1–2–3-bedroom apartments. This satisfies mass market demand;
- "family" option: in this case, the selection includes a large number of spacious 2–3-bedroom apartments.

It should be noted that a key step in this system is the configuration locking stage. This is a defined point of no return, after which the possibility of changing the geometry is blocked. This is necessary for a stable production flow.

End-to-end digital identification system for elements

To ensure an uninterrupted flow of information throughout the entire lifecycle of an object, a universal digital identifier system must be implemented. Under these conditions, the module becomes a unique element of the digital structure, containing a comprehensive data summary.

STRUCTURE AND SEMANTICS OF A DIGITAL IDENTIFIER

The digital identifier of a module is not just a serial number, but a semantically rich data structure integrated into the TIM model (Table 2) [11].

RESULTS

As a result of modelling the target state of the lifecycle management system using the developed methodology, the following predicted performance indicators were obtained:

1. Increased organizational and technological reliability (OTR). This is achieved by enhancing reliability at all stages of the lifecycle (design, production, installation, logistics). Design and production collisions are eliminated through parametric control and the implementation of digital identifiers.

2. Reduction of the investment cycle. Using an algorithm for recording the configuration of elements and end-to-end identification, the construction period for a 10,000 sq. m facility is reduced to 17 months [12, 13]. This acceleration occurs primarily at the design and installation stages of the aboveground portion due to the elimination of downtime and rework [14, 15].

3. Cost reduction. The synergistic effect of implementing the methodology ensures a reduction in project costs by approximately 10.35 % (Table 3).

Table 2. Proposed structure of five functional blocks

Data block	Composition of parametres	Function in the management system
Metadata	GUID, project code, module type (corner/row), production series	Clear link to the TIM model and the plant's ERP system
Spatial data	Global coordinates (*X*, *Y*, *Z*), floor, cardinal direction, installation zone index	Control of positioning accuracy, elimination of errors in installing the module in the design position
Technical parametres	Dimensions, weight, centre of gravity, design loads, fire resistance limit	Automatic selection of a transport trailer and calculation of the slinging scheme
Engineering saturation	Equipment specifications, network routing, article numbers of finishing materials	Control of plant assembly and support of operational processes
Dynamic status	Current phase (Project/Plant/Logistics/Installation), quality check log	Synchronization of flows, predictive monitoring of deadlines, activation of works

Table 3. Forecast of cost reduction

Cost item	Optimization factor	Forecast of reduction in expenditure item, %
Materials (supplied mainly to the plant)	Production of blocks using parametric cutting, taking into account precise specifications	1.35
Logistics	Improving the efficiency of transport loading and deliveries	1.50
Construction and installation works (carried out at the construction site)	Reduced lead times, no rework	3.00
Overheads	Reducing the site maintenance period	2.00
Finance (As part of the payment of interest on the loan)	Acceleration of the turnover period of funds	2.50
TOTAL	Complex effect	~10.35

CONCLUSIONS

As a result of the conducted scientific study, the following conclusions can be drawn:

1. The considered parametric design system, under constraint vectors, can enable high-level implementation of technical solutions with the ability to resolve conflicts during the assembly stage of modular units.

2. Digital identification of modular unit elements enables the creation of a sufficiently comprehensive information system from interconnected elements.

3. The considered algorithm allows for predicting the economic efficiency of the system.

4. The considered system of end-to-end identification and parametric design meets current requirements for the introduction of digital technical passports (DTP) starting March 1, 2026.

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Подходы параметрического моделирования конфигурации и генерации сквозных цифровых идентификаторов в системе индустриального модульного домостроения

Для выполнения национальной задачи по ежегодному вводу 120 млн м² жилья строительная отрасль России проходит через процесс трансформации своих технологических подходов. Традиционные методы строительства, отличающиеся высокой трудоемкостью на площадке и непредсказуемостью процессов, уступают место индустриальной префабрикации. Крупногабаритное модульное домостроение представляет собой одну из самых перспективных технологий в строительстве, позволяя переместить до 80 % рабочих усилий в контролируемые заводские условия. Тем не менее широкое распространение этой технологии сдерживается проблемами, связанными с информационными разрывами на разных этапах жизненного цикла здания. В данной статье представлен научно-методический инструментарий, направленный на устранение существующих разрывов за счет применения подходов параметрического моделирования конфигурации здания и системы сквозной цифровой идентификации объектов. В исследовании разработана математическая модель для генерации архитектурно-планировочных решений, которая основывается на векторах ограничений, включающих геопространственные, нормативные, производственные и бизнес-требования. Представлена структура уникального цифрового идентификатора, предназначенного для использования в качестве ключевого элемента сквозного управления. Исследования показали, что переход к алгоритмическому проектированию и цифровой паспортизации модулей строительных систем повышает их организационно-технологическую надежность за счет снижения рисков конфликтов на интерфейсах и оптимизации производственно-логистических процессов.

Ключевые слова: *модульное строительство, параметрическое моделирование, цифровой идентификатор, жизненный цикл здания, информационное моделирование (ТИМ), организационно-технологическая надежность, префабрикация, промышленный девелопмент*

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Evaluation of the Effectiveness of Lean Construction Tools Implementation during the Execution Phase of a Construction Project in Moscow

The paper addresses the problem of persistent cost escalation in the Russian construction industry, which, under conditions of macroeconomic instability, inflation, and rising logistics costs, has become a critical factor reducing the competitiveness of construction companies. The necessity of implementing management technologies aimed at reducing production waste without significant capital investment is substantiated. Lean construction, which adapts the principles of lean manufacturing to the specifics of construction projects, is proposed as such an approach.
The study examines the application of 5S, Value Stream Mapping (VSM), and standardized work methodologies in a residential development project in Moscow, together with supplementary tools including 4M, 5W+1H, and the one-piece flow principle. The research methodology comprised time-motion studies, photographic documentation, employee interviews and questionnaires, and a comparative assessment of key performance indicators before and after implementation.
Key types of waste on the construction site are identified: waiting for materials and equipment, unnecessary worker movements, excess inventory, defects and rework. The implementation of lean construction tools in three pilot areas (finishing works, installation of engineering systems, and installation of a ventilated facade) resulted in a 66 % reduction in tool search time, a 50 % decrease in equipment downtime frequency, and a 60 % reduction in schedule deviations. Economic effects are estimated: savings on labour costs, reduced equipment rental expenses, and lower overheads.
Barriers limiting the scaling of lean practices are identified (staff resistance, lack of digital monitoring tools, the need to adapt foreign methods). Directions for scaling the experience are proposed, including the development of industry standards and training programmes. The paper is intended for specialists in construction management and project management.
Keywords: *lean construction, production costs, 5S, VSM, 4M, 5W+1H, one-piece flow, efficiency, construction project, Moscow*

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The construction industry in the Russian Federation is currently experiencing a period of high uncertainty and cost volatility. These problems are particularly acute in major cities such as Moscow, where the combined impact of high labour costs, logistics and inflation on building materials leads to a constant rise in the cost of construction projects. In these circumstances, there is a need to introduce modern management technologies aimed at reducing waste and increasing process transparency.

The vast majority of construction projects are characterized by unique features, which precludes the direct application of the assembly-line principles of classical lean manufacturing. One promising approach is lean construction, which builds on the principles of lean manufacturing and adapts them to the specific nature of construction projects. A shift towards this approach is enshrined in the Strategy for the Development of the Construction Industry and Housing and Utilities Sector of the Russian Federation. The aim of this paper is to assess the applicability and effectiveness of implementing key lean construction tools at a specific site in Moscow.

In pursuit of the stated objective, the following tasks were accomplished:

- a description of the practical tools of lean construction was provided;
- models for the business diagnosis of a construction company were defined in the context of improving the efficiency of production operations, as well as the implementation, maintenance and evolution of lean construction methods and philosophy;
- a matrix of tools for the philosophy of lean construction was developed;
- organizational schemes for construction project management, based on the principles of lean construction, were described.

The progressive development of the construction industry is inconceivable without the adoption of advanced management methods. The improvement of administrative activities in construction is shifting towards the rationalization of financial, material, technical, human and other resources, the use of innovative building materials and the implementation of breakthrough technologies. Modern lean technologies integrate all these aspects, which are utilized across a wide range of industries.

Researcher T. Abdelhamid emphasizes that classical methods such as the critical path, the earned value method and similar approaches do not guarantee a high probability of achieving targets within the specified timeframe [1].

Lean technology is rightly considered one of the most dynamically scalable systems for strengthening a business's competitive position. Its origins are linked to the Japanese corporation Toyota Motor and are widely known as the Toyota Production System (TPS).

Lean manufacturing focuses on the efficient use of available resources and the elimination of processes that consume resources without adding value to the final product. Such operations are identified as waste (muda). Their elimination shortens the production cycle and reduce the final cost of the product.

The approach is based on the principles of systematic waste elimination, the immersion of staff in a process of continuous improvement, and the synchronization of all links in the production chain. Unlike traditional construction management, the Lean approach involves the decentralization of management decisions, the active involvement of front-line production units, the standardization of operations, and the visualization of technological processes.

In total, the Lean production paradigm classifies seven categories of waste [2]:

1. Unnecessary staff movement — effort caused by the absence or irrelevance of production standards, poor work discipline and an inefficient workplace layout.

2. Unnecessary transport — excessive movement of raw materials, semi-finished products and components.

3. Overproduction — the production of volumes exceeding actual demand.

4. Idle time — inactivity of staff and equipment whilst awaiting work.

5. Excess inventory — capital tied up in the form of the company's working capital.

6. Defects and rework — the manufacture of products whose parameters do not meet customer requirements, necessitating corrections to the process, product or service.

7. Over-processing — endowing a product with properties or characteristics that are excessive from the customer's perspective [2].

A highly effective approach to problem-solving is the One-piece flow method. This is a step-by-step algorithm for resolving production incidents: first, the nature of the problem is identified, after which measures are implemented to eliminate it and prevent future recurrences.

The starting point in the One-piece flow method is a clear definition of the problem. For this purpose, the 4M Matrix and 5W+1H tools are used.

According to the logic of the 4M Matrix, the entire pool of potential sources of problems and losses is grouped into four clusters: personnel (Man), machinery (Machine), materials (Material) and methodology (Method). Breaking things down into these categories allows the essence of the problem to be articulated with the utmost clarity.

The 5W+1H toolkit enables the deviation to be analyzed in detail. When identifying root causes, one must answer the following set of questions: "who?", "what exactly?", "where?", "when?", "to what extent?" and "how often?".

The next stage is identifying the root cause of the failure. Techniques such as the Ishikawa diagram and the 5 Whys method are used here.

The Ishikawa diagram visualizes a systematic approach to identifying the root causes of a problem. Factors are classified into groups and listed under each group. Graphically, the model resembles a fish skeleton.

The 5 Whys method aims to identify the fundamental causes of emerging difficulties. Its essence lies in repeatedly (usually five times) asking "why?" to find the root cause. The number of iterations may vary; the key is to identify the root cause itself.

The third stage is the selection of a method to resolve the problem. At this stage, it is necessary to generate corrective actions and select from them the most effective and least costly ones. The key steps in implementation are reaching consensus with the implementers and drawing up an implementation roadmap.

Step four: implementation of corrective measures. This involves carrying out the approved plan in strict accordance with the timetable and conducting ongoing monitoring of progress in collaboration with the parties involved.

Phase five: managing the outcomes. It is necessary to analyze how the implemented measures have affected the future frequency of problems and what preventive mechanisms can be put in place for the future.

The final stage is the development or updating of the standard. Ultimately, to resolve the problem, it is necessary to draw up new regulations or amend existing ones [3, 4].

Another significant tool for radically reducing the volume of losses occurring on a construction site is the 5S system. The methodology is structured into five phases[1]:

1. Sorting — separating critical tools and documentation from unnecessary items and removing the latter from the work area.

2. Order — assigning strictly defined and clearly marked locations to essential items.

3. Cleanliness — developing cleaning procedures, providing staff with the necessary equipment, and monitoring adherence to the schedule.

4. Standardization — formalizing rules to systematically support organization, order and hygiene.

5. Improvement — the continuous evolution of existing standards.

The method is founded on the principle that every employee has the right to propose initiatives for improvement[1] [5].

The use of Lean Construction tools can significantly streamline operations not only directly on the construction site, but also in factory-based house-building workshops. Optimized processes help to reduce costs, improve quality and eliminate unnecessary movements.

These tools provide the opportunity to analyze all technological processes on site and transform the sequence of operations, technological equipment and resource base to multiply productivity.

It is also worth noting other tools that are quite important when implementing lean construction tools in the construction sector.

One of these is Value Stream Mapping. This tool allows all operations to be visualized. It can be applied from the design stage right through to the operation of the building. The tool enables the description of both business processes and construction and installation works on the building site[2].

It helps to identify inefficient areas, bottlenecks and redundant processes that do not add value. On a construction site, this may include processes such as the delivery of materials, the movement of workers and the handover between contractors.

Standardized work is a method focused on identifying waste and continuous improvement. Its purpose is to provide a detailed representation of processes and their step-by-step improvement[3].

It involves a fixed sequence of actions, clear time standards and quality control. Standardization is particularly important when

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[1] National Standard of the Russian Federation GOST R 56906–2016. Lean production. Workspace organization method (5S). Effective January 2016. URL: https://docs.cntd.ru/document/1200133736 (rus.).

[2] GOST R 57524–2017. Lean production. Value stream mapping. Introduced 2018-07-01. Moscow, Standartinform, 2018; 22. (rus.).

[3] National Standard of the Russian Federation GOST R 56908–2016. Lean production. Work standardization. Effective January 2016. URL: https://docs.cntd.ru/document/1200133738 (rus.).

carrying out repetitive tasks (such as plastering or installing partitions), where consistent quality and predictable completion times are required.

An advantage of the method is the ability to assess the workload of all operators, which in the construction industry is most applicable to the existing organization of work by teams and brigades. This makes it possible to increase the productivity of the entire brigade by redistributing work between teams and operators, as well as through the effective organization of these tasks.

The main trend in the evolution of lean construction tools is primarily linked to the synchronization of participants and beneficiaries of the investment project.

The application of lean construction tools makes it possible to identify and eliminate bottlenecks more quickly, achieve a sustained increase in efficiency and quality, and reduce time and financial losses.

The subject of the study is a residential complex of varying storeys, being developed by a major construction company in the South-Eastern Administrative District of Moscow. The project is characterized by a tight schedule, a significant number of contractors and complex logistics on the construction site. The choice of this particular site is justified by its typicality for the conditions of large-scale urban construction.

Methods of data collection:

- time and motion studies;
- analysis of work schedules;
- interviews with workers, foremen and site supervisors;
- photographic documentation of the construction site;
- staff surveys on working conditions and the effectiveness of collaboration.

To assess the impact of the implemented tools, both qualitative and quantitative analysis methods were used, including a comparative measurement of indicators before and after the tools were applied.

Lean construction tools were implemented between June and August 2025. Three pilot areas were selected:

1. Finishing works in common areas.
2. Installation of building services.
3. Installation of a rainscreen cladding.

At each stage, the current status was recorded, losses were identified, improvements were formulated, and the results were assessed using metrics for time, losses and staff satisfaction (Table).

Prior to implementation, the following issues were observed:

- delays in material deliveries of up to two days;
- up to 30 minutes per day were wasted searching for tools;
- a high proportion of work in progress;
- a lack of coordination between contract units;
- overcrowded storage areas and frequent disruptions to material supply routes.

After the implementation of the tools:

- delays were reduced by 40 %;
- time lost was reduced to 10 minutes;
- deviations from standard times were reduced from 35 to 10 %;
- discipline and safety in work areas improved;
- adherence to delivery schedules improved;
- the number of unfinished tasks in finishing areas decreased.

The results demonstrate the high sensitivity of construction processes to the implementation of even basic elements of lean construction. It is important to emphasize that the implementation of these tools is possible without significant financial outlay — the main resources required are organizational effort and staff skills.

However, certain limitations and challenges were identified during the implementation process:

- a low level of motivation among contractors to transition to new forms of collaboration;
- a lack of digital monitoring and control tools;
- the need to adapt foreign methodologies to the realities of Russian regulations;
- time-related costs associated with retraining staff and adjusting established working habits.

To achieve sustainable results, it is important to secure support from project management, conduct regular status audits, and implement visual control tools at all stages of the project lifecycle.

The selection and application of lean construction tools must take into account identified and potential systemic losses.

The research findings can be applied in the development of regulatory recommendations and standards at the federal level. Lean construction tools can be particularly effective within state-funded capital construction programmes, as well as in renovation and infrastructure renewal projects.

Projects involving innovative clusters and world-class campuses based at federal universities could serve as one of the most promising avenues for implementing a hybrid construction management model.

It is recommended that:

- a set of rules (SR) entitled “Lean Construction: Key Provisions” be developed and approved;
- lean assessment be introduced into the system for reviewing design and working documentation;
- regional and federal training programmes be implemented to teach engineering and technical staff lean management methods;
- the provision of pilot projects with the mandatory application of Lean tools (particularly 5S and VSM);
- the creation of standard VSM charts and standard operating procedures adapted to Russian construction practice.

The systematic implementation of lean construction principles requires a package of measures aimed at integrating the new paradigm into the existing management structure. Without changing the current operational algorithm, in which Lean tools become an integral part of the system, the effect will be fragmented.

Regular meetings must be introduced: weekly and daily sessions at which identified issues will be discussed in detail and a set of preventive and corrective measures will be developed. Each week constitutes a reporting cycle, beginning with a joint site inspection by

Key performance indicators

Indicator	Before	After	Change, %
Time spent searching for tools	30 min	10 min	– 66
Frequency of equipment downtime	4 times/week	2 times/week	– 50
Deviations from schedule	1.5 days	0.6 days	– 60

all project members and a parallel management meeting. In addition, a daily morning briefing is held to update the decisions recorded during the site walk-around. Its purpose is to set priorities for those responsible and develop strategies for tackling current tasks. Peak efficiency is achieved through the standardization of the meeting room: the latest information is displayed on the walls in an optimal layout. A daily morning operational meeting is also held to adjust the decisions made during the site walk-through. Its aim is to identify the most urgent tasks for those responsible and discuss ways to resolve them. Maximum efficiency is achieved because the meeting room is arranged to a standard — the necessary materials are displayed on the walls in the most effective order.

Every evening, a meeting is held with subcontractors to assess the actual progress of work and any losses incurred, and to approve the work plan for the following day using production analysis sheets.

Participants also carry out daily site inspections independently to assess the effectiveness of the improvements and measures being implemented.

If there is a deviation from the work plan, a work analysis is initiated. If a single type of work deviates from the plan, the standardized work tool is applied. In the event of a deviation from the plan for a set of works, a project is launched which involves analyzing all types of work with the aim of implementing measures to address the root causes of the problem.

To implement these tools at the initial stage, staff will need to be trained in the basics of lean construction and a motivation system will need to be established.

Thus, the implementation of lean construction tools is possible at any stage of construction in any organization.

The implementation of lean construction tools at a site in Moscow has shown that even limited measures yield tangible results in the form of reduced costs, shorter lead times and increased staff satisfaction. For systematic implementation, methodological, regulatory and educational support must be developed. The data presented can be used both within the framework of the thesis and in the development of practical recommendations for the Ministry of Construction of the Russian Federation.

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Оценка эффективности внедрения инструментов бережливого строительства на этапе реализации строительного проекта в г. Москве

В статье рассматривается проблема устойчивого роста себестоимости строительства в Российской Федерации, которая в условиях макроэкономической нестабильности, инфляции и удорожания логистики становится критическим фактором снижения конкурентоспособности строительных компаний. Обосновывается необходимость внедрения управленческих технологий, направленных на сокращение производственных потерь без значительных капитальных затрат. В качестве такого подхода предлагается бережливое строительство (Lean Construction), адаптирующее принципы бережливого производства к специфике строительных проектов.

На примере жилого комплекса в г. Москве проводится анализ применения методик 5S, VSM, стандартизированной работы, а также дополнительных инструментов, таких как 4M, 5W+1H и принцип «одна за одной» (Onepiece flow). Методика исследования включала хронометраж, фотофиксацию, интервьюирование и анкетирование персонала, а также сравнительный анализ показателей «до» и «после» внедрения.

Выявлены ключевые виды потерь на строительной площадке: ожидание материалов и техники, лишние перемещения рабочих, избыточные запасы, дефекты и переделки. Внедрение инструментов бережливого строительства в трех пилотных зонах (отделочные работы, монтаж инженерных систем, устройство навесного вентилируемого фасада) позволило сократить время на поиск инструмента на 66 %, снизить частоту простоев техники на 50 % и уменьшить отклонения от графика работ на 60 %. Оценены экономические эффекты: экономия фонда оплаты труда, сокращение затрат на аренду техники и снижение накладных расходов.

Выявлены барьеры, ограничивающие масштабирование Lean практик (сопротивление персонала, отсутствие цифровых инструментов мониторинга, необходимость адаптации зарубежных методик). Предложены направления масштабирования опыта, включая разработку отраслевых стандартов и программ обучения. Статья предназначена для специалистов в области организации строительства и управления проектами.

Ключевые слова: *бережливое строительство, себестоимость, 5S, VSM, 4M, 5W+1H, one-piece flow, эффективность, строительный проект, Москва*

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Application of the Distressed Asset Securitization Mechanism in the Implementation of Housing Construction Projects

The construction industry of the Russian Federation faces a serious problem: the accumulation of a significant volume of construction in progress and illiquid distressed assets constrains investment activity and creates risks for equity holders, creditors, and budgets at all levels. Traditional restructuring methods, such as bankruptcy proceedings, asset substitution, or rehabilitation with investor involvement, do not fully restore the housing reproduction cycle and require large-scale budget injections. As an alternative, the securitization of distressed assets is proposed, enabling the transformation of pools of rights of claim under Equity Participation Agreements (EPA), collateral land plots, and project finance portfolios into liquid marketable securities. a structural model of securitization adapted to the specifics of the investment and construction cycle has been developed, including the stages of pool formation, creation of a Special Purpose Vehicle (SPV), tranching, credit enhancement, and servicing administration. The advantages of the mechanism are substantiated for developers (balance sheet relief, reduced funding costs), banks (improvement of capital adequacy ratios), institutional investors (a new class of high-quality assets), and regional budgets (reduction of expenditures for completing long-term construction projects). The scientific novelty lies in the integration of a cyclical approach to construction asset management with securitization tools, allowing the structure of issuance and payments to be synchronized with the phases of the facility life cycle. The practical significance consists in the possibility of applying the proposed model to reduce the volume of "dead capital" in the construction sector and to implement pilot transactions with the participation of development institutions (DOM.RF, Territorial Development Fund).

Keywords: *construction industry, construction in progress, distressed assets, securitization, investment and construction cycle, project finance, refinancing*

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The construction complex of the Russian Federation traditionally belongs to the number of systemically important sectors of the economy. Its share in the gross domestic product is steadily in the range of 6–7 %, and the total number of employed persons, according to Rosstat, exceeds 5 million people. The industry provides multiplicative demand for the products of metallurgy, the cement industry, mechanical engineering, and logistics, forming up to 15 % of the total investment demand in the country. In recent years, despite external shocks and sanctions pressure, the construction sector has demonstrated relative stability, largely due to the implementation of the national project "Housing and Urban Environment" [1]. However, systemic problems are simultaneously accumulating: the growth of construction in progress, an increase in distressed assets, and the dependence of developers on short-term credit resources.

One of the key factors that changed the landscape of housing construction financing was the transition from 2019 to the mechanism of project finance using escrow accounts. This measure significantly reduced the risks for citizens participating in shared-equity construction, practically eliminating the possibility of losing their funds in the event of the developer's bankruptcy. However, the flip side was a significant increase in the burden on the banking system and a sharp rise in developer's dependence on credit resources. Under the conditions of tightening monetary policy and the subsequent increase in the key rate (to 16–18 % in 2024–2025), the cost of project finance has risen substantially. As a consequence, a significant portion of initiated projects has faced cash flow gaps, which negatively affects the potential increase in the volume of construction in progress (including facilities whose construction is suspended or terminated) due to the impossibility of fulfilling obligations under Equity Participation Agreements (EPA) because of inefficient project finance [2].

According to data from the register of problematic facilities of DOM.RF, the number of problematic facilities at the end of 2025 exceeds 130 buildings, and the total area of construction in progress is estimated at one million square meters (Fig. 1).

Distressed assets in construction are understood to include rights of claim under Equity Participation Agreements (EPA) and pledged land plots [3].

Distressed assets in housing construction can be divided into three categories. The first category includes rights of claim under EPA transferred to creditor banks or funds after the developer is declared bankrupt; they are characterized by legal complexity and uncertainty regarding realization timelines.

The second category includes collateral assets: land plots and facilities under construction pledged to banks; their book value often exceeds market liquidity.

The third category includes project finance portfolios with disrupted servicing schedules, against which banks are forced to create reserves. The accumulation of these assets leads to a chain of negative consequences: a decrease in the investment attractiveness of the industry, the diversion of capital from circulation, increased social tension (defrauded equity holders), and an increased burden on

Statistics	Regions	Developers	Buildings	Residential area, thousand m²
Bankruptcy proceedings initiated in accordance with Federal Law of October 26, 2002 No. 127-FZ[1]	16	30	39	395
Another bankruptcy procedure introduced in accordance with Federal Law No. 127-FZ[1]	—	—	—	—
Construction completion deadlines exceeded by more than 6 months	9	11	23	106
Deadlines for transfer of shared-equity construction units exceeded by more than 6 months	4	4	6	43
Total	**21**	**44**	**68**	**544**
Including cases requiring restoration of the rights of citizens participating in shared-equity construction	19	41	65	542

Fig. 1. Statistics of Problematic Facilities as of the End of 2025

regional budgets forced to complete construction at their own expense [4].

In Russian practice, three main approaches to handling distressed assets in construction have emerged:

- bankruptcy proceedings of the developer lead to the sale of property at auction; however, the sale price is usually significantly below market value (discounts reach 40–60 %), and the procedure timelines extend over 2–3 years; furthermore, it is not always possible to complete construction, and facilities remain unfinished [5];
- asset substitution through the transfer of facilities to the Territorial Development Fund (formerly the Fund for the Protection of Equity Holders' Rights) allows for the completion of some projects but requires significant budget co-financing. Over the period 2019–2024, more than 300 billion rubles were allocated from the federal budget for these purposes, while the number of problematic facilities decreased by only 40 %. The cost efficiency averages approximately 7.5 billion rubles per completed facility;
- rehabilitation involving an investor-developer is possible if there is an economically attractive residual potential of the facility; however, investors often demand substantial preferences (additional land plots, changes to urban planning parameters, tax incentives), which entails administrative and legal complications. According to expert estimates, no more than 15 % of problematic facilities have investment-attractive parameters [6].

[1] On Insolvency (Bankruptcy) : Federal Law of October 26, 2002 No. 127-FZ.

A common drawback of the listed approaches is that they do not solve the problem of involving “dead capital” in market circulation without significant budget expenditures. A tool is needed that would allow the conversion of pools of distressed assets into liquid resources, attracting private investors and distributing risks [7]. Securitization can become such a tool.

Securitization is a financial mechanism whereby illiquid assets (loans, rights of claim, collateral) are pooled together, transferred to a specially created legal entity (SPV), which issues securities (bonds) backed by these assets. The key elements of classic securitization include: isolation of assets from the originator's balance sheet, bankruptcy remoteness (true sale), credit enhancement (guarantees, reserves, subordination), and tranche rating [8]. Several established schemes have emerged in global practice (Fig. 2–5).

Assets are sold to the SPV, the SPV issues securities, and payments are made from asset proceeds; first applied in the USA in 1970 (GNMA, Ginnie Mae).

Assets remain on the originator's balance sheet; bonds such as Pfandbrief (Germany) or Obligations Foncиres (France) are issued.

Under this model, investment units are issued, and a real estate pool is formed.

Under this scheme, assets remain on the balance sheet, but risks are transferred via Credit Default Swaps (CDS); applied since 1997–1998. As noted by A. Rachkevich (Bank of Russia Analytical Note, 2025), the term “securitization” is often attributed to Lewis Ranieri, and its essence lies in “involving assets in the issuance and servicing of securities”.

Global issuance volumes of securitized securities remain significant. According to S&P Global (2024), issuance volume in 2023

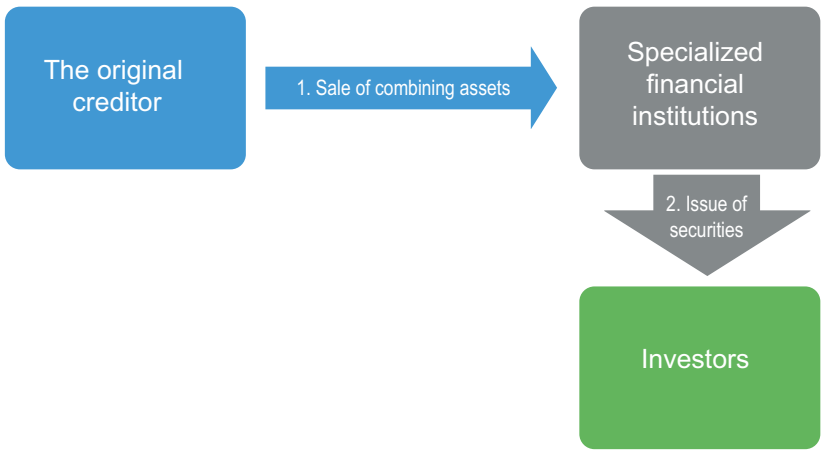

Fig. 2. Scheme 1 (Classic Off-Balance Sheet)

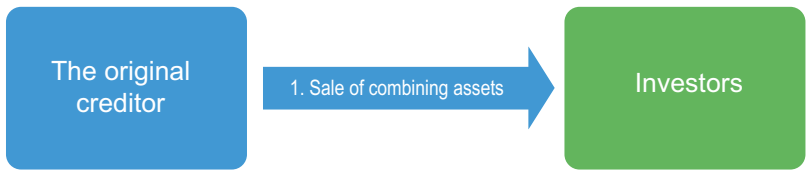

Fig. 3. Scheme 2 (On-Balance Sheet)

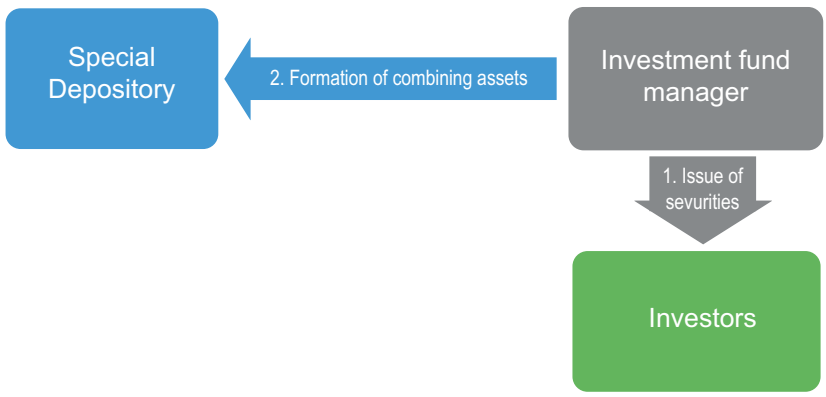

Fig. 4. Scheme 3 (Using REITs)

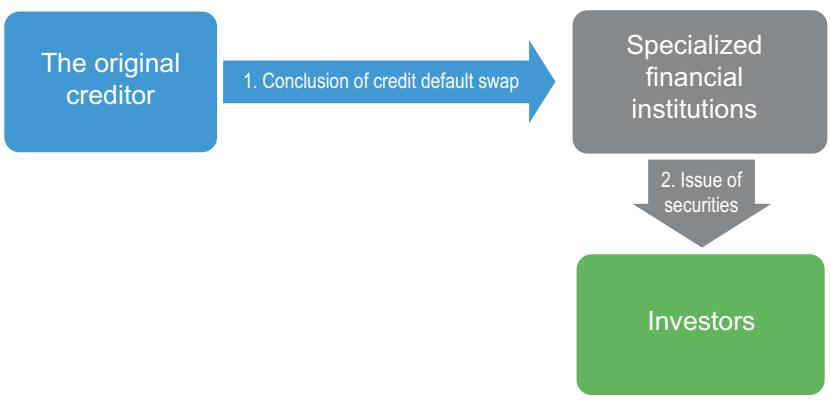

Fig. 5. Scheme 4 (Synthetic)

amounted to USD 510 billion in the USA, USD 19 billion in Canada, USD 104 billion in Europe, USD 264 billion in China, USD 40 billion in Japan, and USD 31 billion in Australia. The US market structure is dominated by mortgage-backed securities (RMBS and CMBS — about 70 %), followed by ABS (auto loans, credit cards) and CLOs (Collateralized Loan Obligations). It is important to note that securitization actively develops only in countries with market-based mortgage lending and solvent demand. As Rachkevich points out, the dominance of subsidized mortgage programs in Russia (over 50 % of new issuances) complicates securitization and increases risks.

Regarding housing construction, the specifics of securitization are determined by three factors. First, cash flows from assets are distinctly uneven, depending on the stage of completion of the facilities. At initial stages (documentation preparation, obtaining a construction permit), there are no receipts; at the excavation and monolithic frame erection stage, the attraction of funds under equity participation agreements begins, but their intensity depends on sales rates and marketing activity. After completion of construction and receipt of the commissioning permit, the bulk of revenue is generated from the sale of remaining apartments, as well as commercial spaces and parking places. The cash flow profile has an S-shape with a long ramp-up period and a peak during the finishing works stage. Second, the assets that can be included in the pool are heterogeneous in their legal and economic nature: rights of claim under EPA transferred to the mortgagee bank after the developer's alienation; mortgages on land plots held as collateral; project finance loan agreements with disrupted servicing schedules; as well as unsold residential and non-residential premises in completed buildings. Each asset type has its own liquidity, realization timeline, and legal specifics. Third, asset realization timelines are inextricably linked to the life cycle of capital construction facilities, which can range from 2 to 5 years or more, with potential delays caused by shifts in commissioning deadlines, changes in urban planning conditions, or litigation. Consequently, classic securitization based on stable, uniform payments (e.g., mortgage loans) cannot be mechanically transferred to the construction sector without substantial adaptation.

To account for these specifics, an adapted securitization model is proposed, based on the principle of phased pool formation and synchronization of cash flows with construction phases [9]. The model envisages not a one-time aggregation of all assets, but the formation of the pool as facilities pass critical life cycle stages. This reduces uncertainty and enhances the predictability of cash flows for investors.

The proposed model includes the following stages.

Stage One — Aggregation and Structuring of the Pool. The originator (a bank, the Territorial Development Fund, a major developer, or a specialized management company) conducts an inventory of distressed assets, forming a pool based on the principle of economic homogeneity. For example, a pool may be created consisting exclusively of rights of claim under EPAs for facilities with an actual completion level of at least 50 %, for which a construction permit has already been obtained and there are no legal disputes over land rights. Alternatively, a pool of collateral land plots located in areas with confirmed demand. a key requirement is that assets must have a predictable residual cash flow that can be assessed and discounted. At this stage, an independent appraiser and auditor are engaged to perform due diligence, verify the legal integrity of the assets, and calculate the discounted value of future receipts considering default probability and liquidation timelines. The result is a pool passport including a forecast schedule of receipts broken down by quarter.

Stage Two — Creation of a Special Purpose Vehicle (SPV). The SPV is registered as an independent structure, typically in the form of a joint-stock company or fund, whose charter capital is formed from the transferred assets. The originator sells the asset pool to the SPV at market or discounted price, thereby removing them from its balance sheet. This is critically important for risk isolation: the bankruptcy of the originator does not affect the SPV's rights to the assets, and investors receive protection from "contamination" by the originator's problems. The SPV finances the purchase of assets through the issuance of bonds placed among investors. The SPV has no other activity besides managing this pool and servicing the issued securities, which complies with international practice standards.

Stage Three — Tranching and Rating. The issued bonds are divided into several tranches (classes) with different priority of repayment and, accordingly, different levels of risk and yield. The senior tranche (Class "A") constitutes up to 70–80 % of the total issuance volume. It is assigned an investment grade rating (e.g., ruAA or ruA on the Expert RA or ACRA scale) due to credit enhancement and conservative cash flow forecasts. Senior tranches are acquired by institutional investors — pension funds, insurance companies, asset management companies — which are legally permitted to invest only in highly reliable instruments. The mezzanine tranche (Class "B") — 10–20 % of the volume — offers higher yield but also higher risk; it can be purchased by qualified investors or the originator itself. The subordinated (junior) tranche (Class "C") — 5–10 % of the volume — absorbs the first losses and is usually retained by the originator or sold to a strategic investor (e.g., a development institution). Such a structure allows risks to be distributed according to the risk appetite of different investor groups.

Stage Four — Credit Enhancement. In order for senior tranches to receive an investment grade rating, a safety margin must be ensured. The model provides for the following mechanisms: a reserve fund amounting to 3–5 % of the issuance volume, formed from part of the bond placement proceeds or from originator funds; this fund serves to cover cash flow gaps during temporary shortfalls in receipts. Guarantees from regional guarantee organizations — constituent entities of the Russian Federation interested in completing long-term construction projects can provide guarantees up to a certain amount, enhancing the credit quality of the securities. Insurance against construction non-completion risks — specialized insurance companies ensure the risk that construction will not be completed on time or that a commissioning permit will not be obtained; the insured amount covers the volume of shortfalls. Overcollateralization — the nominal value of assets in the pool exceeds the bond issuance volume by 15–25 %, creating a buffer against depreciation or realization delays. Subordination of tranches – subordinated tranches absorb losses first, protecting senior holders.

Stage Five — Servicing and Administration. The servicer (a management company with experience in the construction and financial sectors) performs operational management of the asset pool. Its functions include: monitoring the progress of completing construction (if assets include facilities under construction), interacting with contractors and technical customers, accounting for receipts from housing sales (under EPA or direct sale-purchase agreements), collecting debt from obligors, forming an accumulation account for payments to investors, preparing reports, and disclosing information [10]. The servicer also monitors covenant compliance — for example, maintaining the reserve fund level and adherence to construction schedules. In case of deviations, the servicer notifies investors and initiates the application of credit enhancement mechanisms.

A key distinction of the proposed model is the consideration of the cyclical dynamics of the investment and construction process. During the active construction phase (from excavation to completion of monolithic works), cash flows are forecast based on actual EPA conclusion rates, which in turn depend on the stage of completion, marketing, and market conditions. For this purpose, simulation modeling is applied at the pool structuring stage: several scenarios are constructed (optimistic, base, stress), and critical points of potential cash gaps are identified. At the final stage (after the facility is put into operation), cash flows are generated from the sale of finished apartments and non-residential premises, characterized by higher certainty but potentially stretched over time (realization of remaining stock can take 12–24 months). In the proposed model, the bond amortization structure (principal repayment and coupon payment schedule) is synchronized with forecast cash flows: at early stages, only coupon payments are envisaged, while principal repayment is tied to construction completion and mass realization milestones. This approach reduces refinancing risk and enhances the stability of the entire structure.

The implementation of the distressed asset securitization mechanism yields a multiplicative effect for all participants. For developers and banks, it primarily means unloading balance sheets from distressed debt, which improves capital adequacy ratios (for banks — reducing provisions for loan impairment), as well as obtaining additional funding at a rate 2–3 percentage points lower than project finance rates (due to the higher rating of bonds compared to the individual credit rating of the developer). Released resources can be reinvested in new projects, accelerating capital turnover. For institutional investors, the emergence of a new class of high-quality assets with predictable yields and collateral in the form of real construction assets expands portfolio diversification opportunities. Senior tranche bonds, possessing investment grade ratings and credit enhancement mechanisms, can be included in the Bank of Russia Lombard List and used for REPO operations, increasing their liquidity. For regional budgets, securitization reduces direct expenditures on completing long-term construction projects, as projects receive funding from private investors. Moreover, the commissioning of problematic facilities increases the tax base (property tax, personal income tax from buyers, profit tax from developers) and solves the social problem of defrauded equity holders without attracting budget funds. For the financial system as a whole, securitization contributes to reducing the volume of "dead capital" — assets that do not participate in value creation — developing a secondary

Features of the Securitization Process: Purpose, Risks, and Control Methods

Secutitization Feature	Purpose of the Feature	Risk Associated with the Feature	Methods for Controlling Risks Related to the Feature
Assets generating cash flow are involved in issuing securities	Proceeds from assets are used to make payments to security holders	Fluctuations in market interest rates increase the risk of cessation of asset-generated cash flows due to early repayment or defaults	Formation of a reserve fund from "excess spread" to cover losses from fluctuations in market interest rates
Assets used when issuing securities are combined into a pool	Avoid violations in payment schedule on securities in case of stoppage of proceeds from individual assets	The volume of pooled assets and limited access to information for external participants help maintain their real value	Creation of centralized state registry of assets applied as source of payments under issued securities
Initiator transfers its assets to the pool through "real sale"	Ensure protection of assets constituting the pool against claims by third parties in case of bankruptcy of original owner (initiator)	Quick release of issued assets leads to weakening criteria for creditworthiness assessment	Delegating rights to independent party regarding decisions on refinancing loan initially granted by initial creditor

market for construction bonds, and enhancing the resilience of the entire project finance system.

At the same time, the application of securitization is associated with a number of risks that require careful monitoring [11]. As shown in the analytical note by A. Rachkevich (2025), securitization according to the American model carries systemic risks. The first risk is the weakening of credit standards (the "originate to distribute" phenomenon). Banks, planning to sell loans, lower requirements for borrowers. Control method: delegating the right to make loan refinancing decisions to an independent party (e.g., a specialized rating committee). The second risk is information asymmetry: investors cannot adequately assess asset quality due to the large pool volume and limited access. Control method: creating a centralized state register of assets used in securitization with differentiated access (full — for the regulator, anonymized — for investors) [12]. The third risk is the loss of supervisory control when using true sale: banks dispose of distressed debt without consequences. Control method: mandatory retention by the originator of a subordinated tranche (at least 5 % of the volume) and the introduction of a "clawback period" for transactions with low-quality assets. The fourth risk is interest rate risk: fluctuations in market rates can lead to early repayments or borrower defaults, disrupting the payment schedule. Control method: forming a reserve fund from "excess spread" (the difference between asset rates and issuance servicing costs). Table systematizes the features of securitization, associated risks, and control methods.

Minimizing the listed risks is most effective with the participation of development institutions — DOM.RF and the Territorial Development Fund. DOM.RF can act as a guarantor for senior tranches (providing suretyship), as well as a co-investor in subordinated tranches, assuming part of the risks. The Territorial Development Fund, possessing competencies in completing problematic facilities, can perform the functions of servicer and technical customer, ensuring control over construction. Such a hybrid public-private partnership format in structuring securitization allows combining the advantages of market financing with the administrative and guarantee resources of the state.

The strategic targets set by the national project "Housing and Urban Environment" and the Construction Industry Development Strategy until 2030 envisage annual housing commissioning of at least 120 million sq. m [13]. Achieving these indicators requires not only increasing the volume of new construction but also effectively completing already initiated projects, releasing frozen resources. Securitization of distressed assets can become one of the tools for implementing the "roadmap" to reduce the volume of construction in progress, approved by the Ministry of Construction of Russia [14]. The most promising directions for further development are: creating a specialized securitization operator based on DOM.RF with the ability to purchase pools of distressed assets from banks and subsequently refinance them through bond issuance; developing standardized contracts and rating models for construction assets, which will unify procedures and reduce transaction costs (estimated potential reduction of 15–20 %); amending Federal Law No. 214-FZ[1] and the Federal Law "The Securities Market"[2] regarding simplifying procedures for transferring rights of claim under EPA to an SPV, recognizing such bonds as secured, and establishing tax specifics for SPV (exemption from profit tax on income from the pool) [15].

The conducted research has shown that the accumulation of a significant volume of construction in progress and distressed assets is a systemic challenge for the Russian construction industry. Traditional restructuring methods — bankruptcy proceedings, asset substitution, rehabilitation — do not fully return "dead capital" to economic circulation without substantial budget expenditures. The proposed mechanism for securitizing distressed assets, adapted to the specifics of the investment and construction cycle, ensures the transformation of pools of rights of claim and collateral assets into marketable securities, attraction of long-term investments from institutional investors, distribution of risks among participants through tranching and credit enhancement, and a reduction of the burden on budgets at all levels by 30–40 % compared to direct financing.

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Применение механизма секьюритизации проблемных активов при реализации проектов жилищного строительства

Строительная отрасль Российской Федерации сталкивается с серьезной проблемой: накопление значительного объема незавершенного строительства и низколиквидных проблемных активов сдерживает инвестиционную активность и создает риски для дольщиков, кредиторов и бюджетов всех уровней. Традиционные методы реструктуризации, такие как конкурсное производство, замещение активов или санация с привлечением инвестора, не позволяют в полной мере восстановить цикл воспроизводства жилья и требуют масштабных бюджетных вливаний. В качестве альтернативы предложена секьюритизация проблемных активов, позволяющая трансформировать пулы прав требований по договорам долевого участия, залоговые земельные участки и портфели проектного финансирования в ликвидные рыночные ценные бумаги. Разработана адаптированная к специфике инвестиционно-строительного цикла структурная модель секьюритизации, включающая этапы формирования пула, создания специального юридического лица (SPV), транширования, кредитного усиления и сервисного администрирования. Обоснованы преимущества механизма для застройщиков (разгрузка балансов, снижение стоимости фондирования), банков (улучшение нормативов достаточности капитала), институциональных инвесторов (новый класс качественных активов) и региональных бюджетов (сокращение расходов на завершение долгостроя). Научная новизна состоит в интеграции циклического подхода к управлению строительными активами с инструментарием секьюритизации, что позволяет синхронизировать структуру выпуска и выплат с фазами жизненного цикла объектов. Практическая значимость заключается в возможности применения предложенной модели для сокращения объема «мертвого капитала» в строительной сфере и реализации пилотных сделок с участием институтов развития (ДОМ.РФ, Фонд развития территорий).

Ключевые слова: *строительная отрасль, незавершенное строительство, проблемные активы, секьюритизация, инвестиционно-строительный цикл, проектное финансирование, рефинансирование*

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Enhancing the Investment Attractiveness of Construction Projects Using Green Technologies

The subject of the study is the influence of modern green technologies on the investment attractiveness of real estate. The aim of the work is to identify mechanisms for increasing the investment value of investment and construction projects through the introduction of environmentally sustainable solutions in the current market conditions. The methodology includes an analysis of scientific and analytical sources, the regulatory framework of the Russian Federation, as well as a comparative analysis of the practice of introducing green technologies in office and residential real estate. The empirical base consists of cases of Russian developers implementing the principles of sustainable construction. The results of the study demonstrate the complex impact of green technologies on the investment attractiveness of real estate. It has been established that their implementation: reduces operating costs due to increased energy efficiency, increases the profitability of facilities, stimulates demand from tenants and buyers, prolongs the service life of buildings and preserves their value. In office real estate, this is reflected in an increase in rental rates and a decrease in vacancy rates, in residential real estate — in an increase in liquidity and an acceleration in the pace of sales. The scope of the results is the activity of developers and investors in the development and implementation of investment and construction projects. Examples and arguments are given, proving that green technologies serve as an effective tool for increasing the investment attractiveness of real estate properties, ensuring their long-term sustainability and competitiveness.

Keywords: *investment attractiveness, green technologies, sustainable development, energy efficiency, operating costs, development, green construction*

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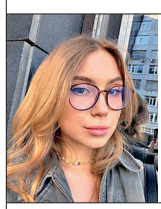

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Current conditions in the property market are transforming existing approaches to the implementation of development projects and the assessment of a property's investment appeal. Increased competition, high base rates, expensive project financing and, consequently, stagnation in the property market are inevitably pushing both investors and developers to seek new strategic solutions and directions, one of which is sustainable development. Thus, in addition to the project's financial indicators — which have long remained the primary criteria for project evaluation — new characteristics are being introduced that reflect operational efficiency, environmental sustainability, uniqueness, and the resilience of properties.

Currently, the consideration of ESG factors (environmental, social and governance) is gaining particular prominence, becoming an integral part of investment analysis. Investors are focusing on assets that provide a stable income whilst minimizing long-term risks, such as the consequences of operation and the obsolescence of real estate properties. In these circumstances, it is necessary to apply tools aimed at improving the quality and sustainability of properties.

One of the key areas is the implementation of green technologies, which reduce resource consumption, improve energy efficiency and enhance environmental quality. Such solutions have a significant impact not only on the operational aspects of buildings, but also on their market value, liquidity and demand among buyers and tenants.

The relevance of this paper stems from the need to identify the mechanisms through which green technologies influence the investment attractiveness of real estate properties [1].

In a climate of economic instability and rapidly changing factors that determine investment attractiveness, investors are placing higher demands on the quality of investment assets capable of maintaining value and returns in the long term [2].

Increasing attention is being paid to the environmental characteristics of properties, their energy efficiency and compliance with modern environmental quality standards. Properties with such characteristics demonstrate lower operating costs and are more resilient to market fluctuations.

Among tenants and property buyers, there is a growing trend towards properties that provide comfortable conditions for living, working and leisure, whilst minimizing operating costs. Environmental friendliness, energy efficiency and the quality of the indoor climate are becoming significant factors in property selection [1, 3].

A key factor is the rising cost of energy resources, which leads to increased costs and reduced competitiveness for inefficient properties. In these circumstances, the importance of measures aimed at reducing resource consumption and optimizing operating costs is growing.

Consequently, the investment appeal of property developments now depends not only on financial factors, but also on operational, environmental and market factors that directly influence the preferences of end-users.

Modern green technologies are used as a tool to directly enhance investment attractiveness. Let us consider the main technologies and their impact on an investment and construction project (ICP).

One of the green technologies with the fastest payback is energy efficiency. LED lighting, heat recovery, cogeneration and other energy-saving methods

reduce operational energy costs. In real-world conditions, such reductions save up to 40 % of energy consumption. Reducing energy costs even during the construction phase already means an increase in free cash flow for the investor. Furthermore, lower energy intensity means reduced dependence on fluctuating electricity tariffs and, consequently, a reduction in market risk and the application of a lower discount rate when evaluating the project.

The longest phase of an ICP project is its operational phase. During this phase, it is crucial to continuously monitor the condition of the facility and promptly address any issues that could lead to significant costs.

IoT systems are currently in widespread use: sensors for occupancy, lighting and temperature. Even air quality is monitored. The practice of continuous IEQ (Indoor Environmental Quality) monitoring is employed — maintaining temperature, humidity and carbon dioxide levels. Modern sensors enable the rapid detection of leaks and the monitoring of water consumption. Not only is the main water supply monitored, but also stormwater and greywater systems.

For investors, these metrics signify increased automation, reduced equipment downtime, and transparency regarding energy and emissions KPI. Real-time data enables investors to avoid "greenwashing" — the practice whereby companies merely pretend their operations are environmentally friendly, misleading investors and consumers.

Investment appeal is also enhanced by the scalability of IoT systems, which reduces the subsequent costs of implementing them in new ICP.

"Green" building materials are characterized by reusability, low toxicity, durability and local production.

The use of recyclable, low-carbon materials (such as replacing traditional Portland cement with its polymer-based alternatives), recycled raw materials (metal, glass, recycled plastic) and biodegradable composites reduces dependence on virgin raw materials. Local production helps avoid logistical problems and sanctions, which is particularly relevant at present.

One example is the work of scientists at Novosibirsk State University, who have developed a building material based on coal ash (industrial waste from coal, ash and peat). This material fully replaces high-grade cement, whilst being cheaper and ensuring complete waste utilization.

The use of such materials solves the problem of construction waste disposal for developers and reduces costs for primary materials. The carbon footprint is reduced, which enhances the prestige of the investment project. Thanks to these effects, the project's NPV increases and the payback period is reduced.

One of the key challenges in Russia is water conservation. According to the Centre for Strategic Research, around 45 % of water supply and drainage networks require replacement, whilst the annual rate of network replacement stands at 0.9–1.1 % [4].

In these circumstances, the use of water-saving technologies is justified and delivers tangible benefits for ICP. Closed-loop water supply systems, leak detection, water consumption monitoring, and the treatment of stormwater and greywater enable any issues to be resolved quickly and without wastage, whilst also reducing dependence on municipal networks and lowering operational costs for water supply and wastewater management.

Water risks are taken into account when assessing creditworthiness. If ICP has high water efficiency, this improves its ESG rating, which directly reduces the cost of debt capital.

The use of green roofs and facades, the planting of protective tree belts and reforestation, and landscape optimization are technologies that are not yet widely adopted in Russia but which hold significant investment potential. Comprehensive land development enhances the environmental sustainability of areas and also enables a project to achieve a high level of environmental certification and access preferential financing.

For development projects, the presence of green spaces increases the value per square metre by up to 15 %. Green roofs reduce air-conditioning costs in summer and heating costs in winter, whilst also extending the roof's service life by 1.5–2 times [5]. For commercial and residential property, greening and a high-quality environment increase the rental rate by up to 20 %.

It is important to understand that all the methods and technologies listed work best within a well-structured system. They hold great potential for the Russian market. The competent, systematic implementation of energy efficiency, eco-friendly materials, water conservation and IoT systems provides investors with a sustainable competitive advantage and lays the groundwork for future projects and expansion as "green" financing develops (Fig. 1).

In terms of the impact of introducing green technologies into an investment and construction project, the following main categories can be identified: financial, investment, market and operational effects.

During its operations, an organization incurs operating expenses (OPEX). Reducing these expenses is one of the benefits achieved through energy-efficient and water-saving technologies, as well as the use of recycled building materials.

This leads to the second key performance indicator for ICP: growth in net operating income (NOI). This metric is calculated as the gross income from the asset minus OPEX, before deduction of taxes and interest. NOI can be influenced by reducing OPEX, as well as by increasing operating income through higher rental rates. The ability to set higher rental rates arises from the demand for environmental awareness. By obtaining eco-certification, an investment project automatically enhances its prestige among tenants and, consequently, the rental rate [6].

Growth in NOI directly increases the value of the asset. If operating income increases by 10 % whilst the capitalization rate remains unchanged, the value of the asset rises by 10 %.

By opting for "green" construction, the company achieves a reduction in regulatory charges. The adoption of green technologies minimizes environmental fines and charges for exceeding emission limits.

The investment benefits stem from changes in the terms for securing financing, as well as shifts in the attitudes of capital providers.

Growing awareness of ESG construction has led to an expansion of the pool of potential investors. One example is the BPI Fund "RSHB – Moscow Exchange Index – RSPP Sustainable Development Vector", whose portfolio includes companies such as PhosAgro, Sberbank, Tatneft, MMK. Since its inception, the fund has delivered a return of 18.16 %, which is a strong performance and attracts new investors to green construction [7].

For investors, a company applying "green" and ESG principles is now associated with reduced risks. This allows for the application of a lower discount rate in the internal rate of return (IRR) calculation, thereby increasing the present value of the asset. Combined with growth in NOI, this effect is amplified and results in a significant increase in the property's value.

Competitiveness is a key factor in the market. As a competitive landlord with green certification, you can charge a premium rent (10–20 % higher than the standard rate). In Russia, energy-efficient

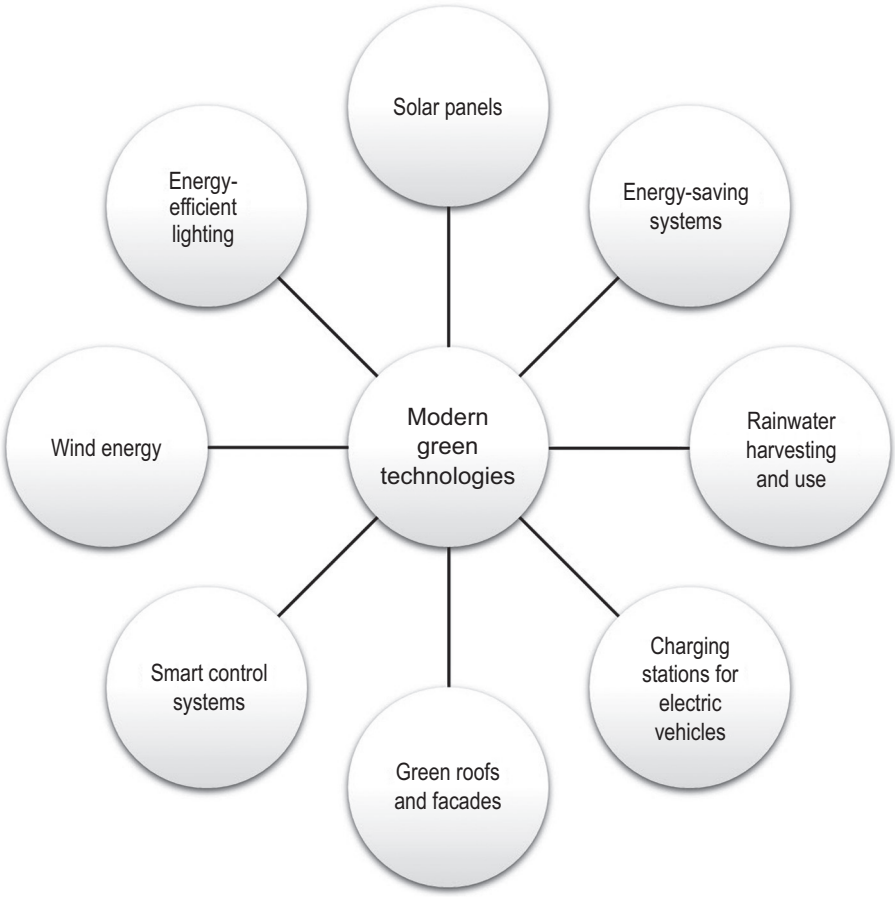

Fig. 1. Types of green construction

technologies and methods for reducing environmental pollution are often difficult for competitors to replicate, so companies that use them have a huge advantage. Major tenants are willing to pay a premium for energy-efficient buildings with a low carbon footprint and a strong environmental reputation [8].

During the operation of a green building, operational efficiency is key for investors. IoT technologies enable the rapid and accurate identification of systems requiring repair or replacement, helping to prevent breakdowns and the costs associated with emergency repairs, whilst reducing equipment downtime. Improved operational efficiency lowers OPEX, thereby enhancing the investment appeal.

The use of eco-friendly and durable materials, green roofs and facades, high-precision sensors and other green building methods extends the building's lifespan, both physically and economically. Greening the building envelope increases the interval between routine and major repairs, reducing operating costs. Tenants prefer properties with a longer remaining service life, as this reduces the risks of breakdowns and relocations; consequently, owners of such buildings can charge higher rents and attract more loyal, large-scale tenants.

Current trends in the adoption of green technologies demonstrate a shift towards the systematic application of such approaches across various property sectors. The greatest impact on investment appeal is evident in the development of office and residential properties (Fig. 2).

Thus, in the office segment, the most significant benefits of applying green technologies are improved energy efficiency, optimized operations and an enhanced working environment.

A prime example is the development of Sberbank's "green" offices [9]. Energy-efficient engineering systems, automation systems and solutions aimed at reducing resource consumption and improving conditions for employees are being implemented. In particular, Sberbank's offices have been awarded certification under the green building standard rating system and also comply with modern environmental standards. Regional offices have repeatedly won industry-specific competitions for the implementation of solutions in the fields of energy efficiency and water conservation.

From the perspective of investment attractiveness, such solutions ensure a reduction in operating costs, increased productivity and employee engagement, and growing interest among tenants in high-quality office spaces.

In the residential sector, the introduction of green technologies is primarily aimed at improving the quality of the living environment and reducing housing maintenance costs.

A prime example is the work of the developer Brusnika. The company is delivering a new standard of housing, setting new benchmarksIn 2021, according to the Unified Resource of Developers (ERZ.RF), the company was recognized as an innovation-oriented developer in the Russian Federation.

One of the most recognizable and unique projects in Brusnika's portfolio is Urban Villa 17, part of the "European Quarter" development in Tyumen. This building was the first in Russia to receive the BREEAM "Excellent" international environmental certification. As part of this project, a range of engineering and analytical solutions were applied to improve residents' health and the quality of the environment [10].

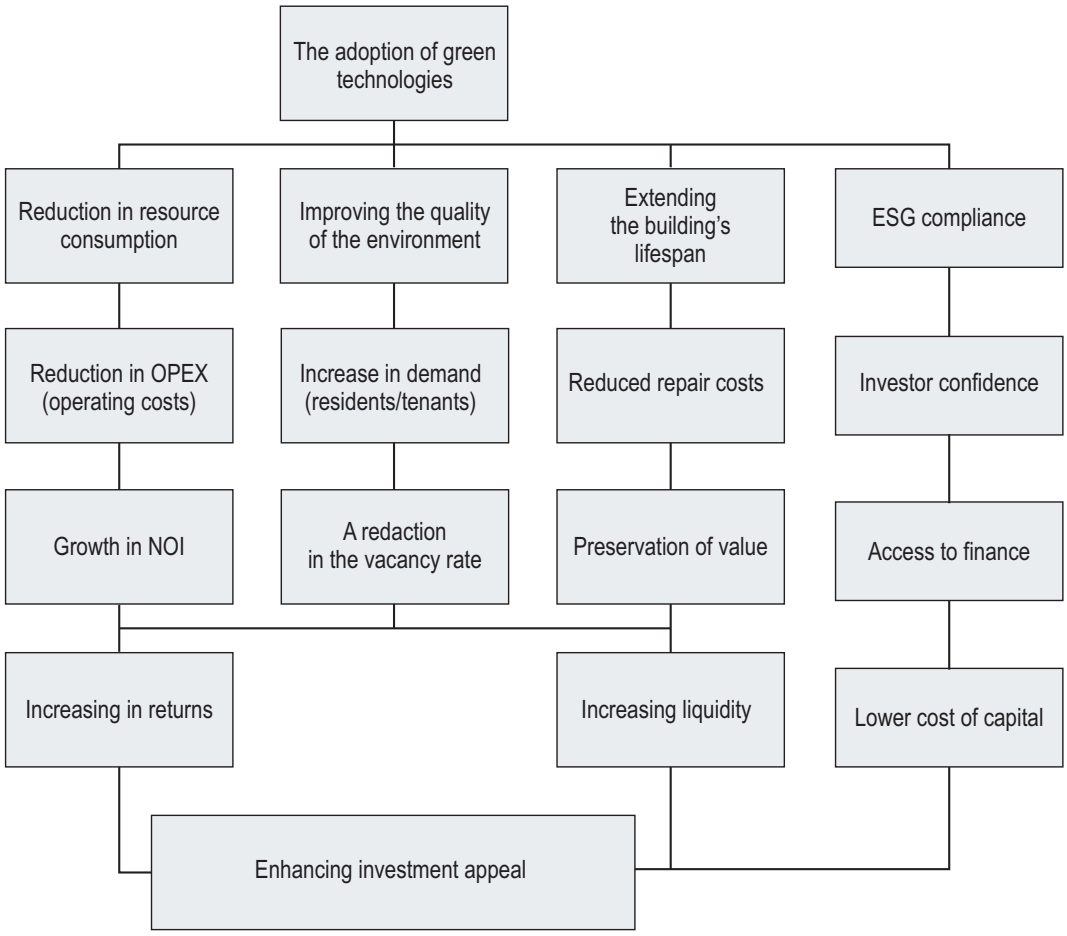

Fig. 2. The green technologies effect on real estate investment attractiveness

The use of energy modelling and the results of acoustic studies made it possible to determine the optimal parameters for engineering and technical solutions and to reduce the building's energy consumption. As a result, the energy performance coefficient was 0.69 — this indicates a significant reduction in energy consumption compared to typical residential buildings in Russia. Analysis of heat flows enabled a comfortable indoor climate to be achieved without the use of additional engineering equipment.

Photovoltaic solar panels have been installed on the roof of the urban villa; the electricity they generate is used to power the lighting in communal areas, storage rooms and the car park. The building is fully automated — to save energy, motion sensors have been installed in communal areas, the apartments feature a "smart home" system, and a telemetry system connects the apartment to the control centre, enabling meter readings to be transmitted in real time. And although the construction costs are significantly higher than for standard projects, the developer has purposefully implemented this concept, earning a reputation in the market as a pioneer in the application of all possible cutting-edge technologies and gaining invaluable experience and the opportunity to reduce costs by implementing proven solutions in future developments.

From an investment perspective, these solutions ensure lower operating costs, increased appeal of the property to buyers, and improved liquidity and value stability over time.

Thus, in residential property, green technologies also enhance investment appeal by creating a high-quality product that is in demand on the market.

In recent years, the active development of the ESG agenda has become a significant element of strategic corporate management. This is driven by the government's focus on sustainable development, as well as stricter requirements regarding corporate environmental and social responsibility.

The development of a regulatory framework has been a key factor in the growth of "green" construction. In 2021, Russia developed a classification system for "green" projects (a taxonomy) [11], passed a law on reducing greenhouse gas emissions, and issued recommendations from the Bank of Russia on the disclosure of non-financial environmental information by companies [12].

A new inter-state standard for "green" multi-family residential buildings (MFRB) has been approved in Russia. The document will come into force on 1 July 2026 [13] and will replace the national "green" GOST R standard for new buildings, which has been in force since 2022 [14].

The standard contains both mandatory and general criteria. Mandatory criteria include, for example: a high energy efficiency class for the building (not lower than A), landscaping of the surrounding area, the creation of a barrier-free environment for people with reduced mobility, and improved sound insulation and natural lighting in the apartments.

In parallel, a national standard for "green" construction is being developed for offices, warehouses and shopping centres.

CORE.XP conducted a study of the office sector, analyzing over a hundred certified properties, and concluded that rental rates in "green" offices are 16 % higher, whilst sale prices are 4 % higher [15].

The new standard will outline the methodology for assigning energy efficiency ratings to commercial buildings. Thanks to this tool, developers gain access to tax incentives — under Article 381 of the Tax Code of the Russian Federation, properties with a high energy efficiency rating are exempt from property tax for three years [16].

As green technologies develop, the scope of financial instruments focused on sustainable development is also expanding. In particular, Bank DOM.RF has secured market financing for projects by the developer "Pioneer" through exchange-traded "green" bonds. This demonstrates the emergence of new sources of capital for ICP that comply with ESG principles [17].

The development of the regulatory framework and the establishment of evaluation criteria for "green" projects are making the market more transparent and increasing interest among investors, tenants and residents alike. The growing investment appeal of real estate properties is driven by the introduction of specialized financial instruments and government support measures.

In today's climate, the investment appeal of real estate assets is determined not only by financial indicators, but also by operational efficiency and the quality of the environment. The growing importance of the ESG agenda and rising resource costs necessitate the adoption of new approaches in investment and construction projects.

Analysis has shown that green technologies are an effective tool for enhancing investment appeal: they reduce operating costs, increase returns, demand and liquidity of properties, extend their service life and preserve their value over time.

Practice in Russian office and residential property projects confirms that green technologies influence both the technical characteristics of buildings and user behaviour, creating added value and enhancing competitiveness; the regulatory framework, national standards for "green" construction and financing instruments increase market transparency and reduce investment risks.

Thus, the implementation of green technologies represents a strategic direction for the development of the property sector, ensuring long-term sustainability and growth in investment attractiveness.

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Повышение привлекательности инвестиционно-строительного проекта путем внедрения современных «зеленых» технологий

Предметом исследования выступает влияние современных «зеленых» технологий на инвестиционную привлекательность объектов недвижимости. Цель работы — выявить механизмы повышения инвестиционной ценности инвестиционно-строительных проектов за счет внедрения экологически устойчивых решений в текущих рыночных условиях. Методология включает анализ научных и аналитических источников, нормативно-правовой базы РФ, а также сравнительный анализ практики внедрения «зеленых» технологий в офисной и жилой недвижимости. Эмпирическую базу составили кейсы российских девелоперов, реализующих принципы устойчивого строительства. Результаты исследования демонстрируют комплексное воздействие «зеленых» технологий на инвестиционную привлекательность недвижимости. Установлено, что их внедрение: снижает эксплуатационные затраты благодаря росту энергоэффективности, повышает доходность объектов, стимулирует спрос со стороны арендаторов и покупателей, продлевает срок службы зданий и сохраняет их стоимость. В офисной недвижимости это выражается в росте арендных ставок и снижении вакантности, в жилой — в повышении ликвидности и ускорении темпов реализации. Область применения результатов — деятельность девелоперов и инвесторов при разработке и реализации инвестиционно-строительных проектов. Приведены примеры и аргументы, доказывающие, что «зеленые» технологии служат эффективным инструментом повышения инвестиционной привлекательности объектов недвижимости, обеспечивая их долгосрочную устойчивость и конкурентоспособность.

Ключевые слова: *инвестиционная привлекательность, «зеленые» технологии, устойчивое развитие, энергоэффективность, эксплуатационные затраты, девелопмент, «зеленое» строительство*

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