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Assessment of technical and economic security risks protection at the stages of the life cycle of real estate objects

Introduction. An innovative approach to the sustainable development of real estate objects based on a comprehensive analysis of the requirements of resource conservation, technical and economic protection and safe operation is presented. The shortcomings of the current standards for the design of corrosion protection measures are identified, which do not allow modelling the calculation of the life cycle cost (LC). It is shown that it is necessary to expand the calculation and analytical indicators of the expertise of design solutions in order to prevent negative consequences in case of corrosion failure.
Materials and methods. The object of the study is a regulatory management system for which algorithms for making effective decisions on corrosion protection construction projects are developed. A technique for reserving technical and economic protection based on computational models of quality, reliability and safety of structures and structures is proposed. Functional and temporary redundancy of resistance to aggressive influences is carried out taking into account the requirements for operation and safety of the ISO/TC 267 Facility Management (FM) standard. A holistic perception of the criteria of technical and economic protection is achieved with the help of indicators of the expertise of design solutions and the regulations of the housing and communal services for a given level of corrosion hazard (KI – KV) or protection (ZI – ZIV).
Results. The approbation of the principles and conditions of the regulatory reservation of technical and economic protection measures was carried out by setting direct and inverse survivability tasks. The programme of definitive tests included monitoring, risk diagnostics and management of indicators for calculating the cost of housing and communal services. The risk assessment was carried out on the basis of the HAZOP (Hazard and Operability Study) method. The proposed approach provides a scenario analysis of the possibilities and identification of threats to the use of new materials and technologies in accordance with the provisions of the *Lean Six Sigma* concept of “lean management”.
Conclusions. The theoretical and experimental substantiation of the principles of the regulatory management system for corrosion protection and survivability of real estate objects contributes to the promotion of digital technologies and platform solutions for technical and economic protection based on target indicators of quality, reliability and safety of structures and structures.
Keywords: *sustainable development, real estate, life cycle, parametric design, technical and economic protection, monitoring, risk-oriented management*

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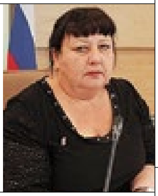

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INTRODUCTION

Current trends in sustainable real estate management are represented in international agreements that form the basic principles of the 2030 Agenda for Sustainable Development, as well as the UN Geneva Charter on Sustainable Housing[1]. Among the priority tasks, it is necessary to highlight the development of building codes and technical standards for the application of regulations that contribute to the sustainability of the life cycle (LC), the implementation of technical and economic protection measures based on an assessment of the risks of negative impacts.

In accordance with the requirements of regulatory legal acts, the National Association of Designers of the Russian Federation has prepared recommendations, according to which LC determines the time period during which engineering surveys, design, construction (including conservation), operation (including ongoing repairs), modernization, reconstruction, major repairs, demolition of the building are carried out or structures. In accordance with the provisions of the methodology [1], the main task of calculating the cost of LC is to estimate the total cost of design solutions, justify the choice of effective materials and technologies, and reduce operating costs. At the same time, the planned period of operation (service life T = 30 years) is set before the start of the first major renovation of the building. The final criterion for evaluating an effective construction project is the present cost of ownership, equal to the ratio of the total cost to its planned period of operation.

The need to introduce and develop a management system for LC of capital construction facilities using information modelling technologies is defined in the Strategy for the Development of the construction industry until 2030[2]. Taking into account the presence of a certain discrepancy between quality indicators (input control), reliability and safety (construction control and supervision), measures are envisaged for digital transformation in the field of sustainable design, operation and management, the creation of an integrated system for evaluating

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1 Policy Framework for Sustainable Real Estate Markets Geneva, 2019. A principle-based framework for the development/ECE/HBP/202 United Nations Economic Commission for Europe. Real Estate Market Advisory Group, Geneva, 2019 United Nations. P. 42. URL: https://unece.org/DAM/hlm/documents/Publications/2019_Policy_Framework_for_Sustainable_Real_Estate_Markets.pdf

2 Strategy for the development of the construction industry and housing and communal services of the Russian Federation for the period up to 2030 with a forecast up to 2035. URL: trategiia-razvitiia-stroitelnoi-otrasli-i/ (date of request: 02.15.2024).

technical solutions at various stages of LC (especially at the operational stage).

The purpose of the paper is to substantiate the expert assessment of life cycle indicators for the selection of effective materials and technologies for managing the corrosion protection of construction facilities.

In the context of contradictions, the search for rational criteria for technical and economic protection, taking into account the safety of technical solutions, resource conservation and minimization of operating costs, is carried out by considering the following research objectives:

- develop principles of regulatory management based on balanced life cycle indicators;
- systematize the structure of the information description and data models that determine the protection and stability of construction facilities under negative impacts;
- perform an analysis of the effectiveness of design solutions for the routine reservation of technical and economic protection measures.

The research paradigm is based on managing the risks of technical and economic protection by reserving, as a universal method of ensuring reliability, to achieve the sustainability of LC of real estate objects [2–4].

MATERIALS AND METHODS

Studies aimed at timely identification and prevention of modern challenges and threats that impede the effective use of funds involved in the investment and construction cycle, saving resources and increasing the durability of real estate objects are devoted to the problem of sustainable development of the construction sector of the economy [5, 6]. Issues of introducing technological innovations are inextricably linked with the improvement of methods are technical and economic assessment (TEA) and Life Cycle Cost Analysis (LCCA) [7, 8]. Sustainable efficiency of construction projects implies responsible consumption and production, according to the set of technical and economic protection measures (Sustainable Development Goal 12).

The key aspects of the examination of construction projects are related to the transition to the parametric method of rationing [3, 9], information modelling of indicators of LC stability [10, 11], comprehensive justification of technical and economic protection [12], risk-oriented management of design solutions [13–15].

In accordance with the developed approach, the technical and economic protection of construction facilities, along with the requirements of structural safety (passive barrier), is determined by technological safety measures (active barrier). Activated barriers are installed on the basis of five DMAIC principles (Define, Measure, Analyze, Improve, Control), which allow monitoring and risk diagnostics of the technical condition of structures. Technological safety management includes justification, planning, provision, improvement and maintenance of operational parameters of structures and structures that affect the stability of real estate facilities LC.

The strategy of technological safety measures is based on the five principles of DMAIC and includes:

- risk-taking, monitoring, maintenance on the actual condition of structures and structures;
- risk minimization, the use of risk diagnostics and the effect of risk diversification.

It is proposed to consider means and methods of ensuring technological safety as a unifying platform for a comprehensive analysis of the problem of corrosion hazard and measures of effective protection against corrosion.

As is known, technological protection characterizes the degree of protection of a person, society, objects and the environment from threats associated with the unjustified creation or non-creation of technical systems, technological processes and materials that ensure the achievement of the main national interests of the state. As an important structural element, the technological safety of an enterprise characterizes a system of measures to maintain operability, improve the operational properties of structures and structures that have completely or largely exhausted their regulatory resource. Such facilities are considered as sources of potential danger during modernization (technical re-equipment), reconstruction and extension of their service life.

The formed approach was adopted to determine the signs of technical and economic protection:

- corrosion hazard — a condition or situation (threat) in which the probability of damage or that which may affect the amount of damage increases;
- corrosion protection — the ability of the anticorrosive protection system of constructions (APSC) to meet specified quality, reliability and safety requirements based on organizational and technical measures established for a sustainable LC of a construction facility.

It is proposed to carry out the justification of technical and economic protection measures based on the use of principles that determine the requirements of durability (a systematic approach) and regulatory survivability (a process approach).

The principle of durability. Corrosion protection is determined by the parameters of the calculation model of quality and reliability level of APSC.

The principle of survivability. The operability of structures depends on the criteria of corrosion protection (danger), qualimetric monitoring of risks (threats and vulnerabilities), the calculated situation of risk diagnostics of buildings and structures LC.

The subject of the study includes the management of technical and economic risks of corrosion protection of structures by reserving reliability (mechanical safety) and operational suitability (functional safety). The formation of a system of regulatory management of technical and economic protection measures is carried out on the basis of the requirements for the operation and safety of real estate objects in accordance with GOST R ISO 41001–2023[3].

RESULTS

The task of modelling the cost of LC in the scenario justification of technical and economic protection options is formulated as follows. The costs ΔC_1 are estimated of option $S(R1)$ of implementing secondary protection measures. For option $S(R2)$, the costs ΔC_2 for primary and secondary protection measures are set. For each option, the cost of LC and the possible risks associated with negative impacts are assessed. Out of all the options, the least expensive one is chosen, which ensures the established level of APC APSC reliability with an acceptable risk value throughout the LC of the construction object.

3 GOST R ISO 41001–2023. Management of real estate objects.

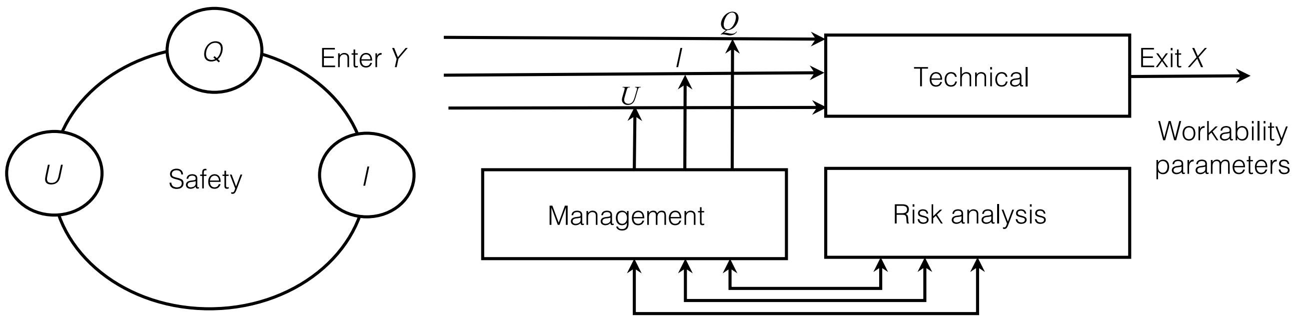


Fig. 1. LC sustainability management scheme for construction facilities: technical Q, information I and management U components

The stability and continuity of business processes under negative impacts is ensured by the conditions of economic protection, which can be represented as:

$$\begin{cases} \sum_{i=1}^{N} U_i \geq \sum_{i=1}^{N} \left(S_{d,i} + S_{c,i}\right); \\ \sum_{i=1}^{N} U_i = \sum_{j=1}^{M} f\left(T_{v,j}\right) \Rightarrow \min, \end{cases} \quad (1)$$

where U_i — the cost of maintaining the i-th structural element of the sample (N) in working condition, ensuring acceptable risk requirements, ₽/year; $S_{d,i}$ — losses caused by physical wear, ₽/year; $S_{c,i}$ — losses as a result of moral aging, ₽/year; $T_{v,j}$ — the maintainability indicator, which determines the period of time (year) to restore operability at minimum cost of the j-th structural element of the sample (M), with a risk level higher than the permissible damage value.

The amount of damage associated with the risk of implementing primary and secondary protection measures is determined by the formula:

$$R_c = \sum_{i=1}^{n} \sum_{j=1}^{m} g_{ij}(V) P_j P_i(j, z_j) X_i, \quad (2)$$

where $g_{ij}(V)$ — the probability of choosing an LC model, with the probability of an unfavourable situation P_j and the law of loss distribution $P_j(j,z_j)$; $P_i(j, z_j)$ — the conditional probability of possible damage X_i(₽) upon the occurrence of a negative event of type j, taking into account the costs z_j(₽) of protective measures to eliminate it.

The developed regulation of balanced life cycle indicators (Fig. 1) combines the capabilities of a systematic analysis of design data (input parameters of durability) and a process approach to managing the operational characteristics of a technical condition (survivability criteria).

A comparative analysis of the means of technical and economic protection is proposed to be carried out in accordance with the methodology [5] of assessing the readiness coefficient (K_g). At the same time, the task of determining the K_g coefficient is formulated as the calculation of structures according to the limit conditions for durability and survivability according to risk diagnostics of primary and secondary protection options for a given level of corrosion protection (hazard).

Functional redundancy of LC stability under the conditions of primary and secondary protection is achieved by setting the required level of reliability of the construction object, taking into account the data in Table 1, 2.

Time redundancy includes the regulation of reliability and operational suitability using the results of the calculation of indicators and the cost of LC of technical and economic protection measures (Fig. 2).

The availability coefficient K_g has been adopted as a comprehensive indicator of reliability and maintainability for scenario analysis of technical and economic protection measures. The K_g coefficient reveals the variability of redundancy conditions in terms of corrosion hazard (KI – KV) or corrosion protection (ZI – ZIV), as well as the possibilities of scenario iterative control of structures and objects LC.

Table 1. Generalized reliability level matrix of APSC

Identification of impacts	Interval estimates of the coefficient of readiness of anticorrosive protection K_g and the degree of aggressiveness of impacts C, mm/year				
	$0 < K_g \leq 0.1$	$0.1 < K_g \leq 0.3$	$0.3 < K_g \leq 0.5$	$0.5 < K_g \leq 0.7$	$0.7 < K_g \leq 1.0$
MA	Mildly aggressive $0.01 < K \leq 0.05$				
	KI	ZIV	ZIII	ZII	ZI
LA	Low aggressive $0.05 < K \leq 0.15$				
	KII	KI	ZIV	ZIII	ZII
HA	Highly aggressive $0.15 < K \leq 0.30$				
	KIII	KII	KI	ZIV	ZIII
VHA	Very highly aggressive $0.30 < K \leq 0.50$				
	KIV	KIII	KII	KI	ZIV
VA	Very aggressive $K > 0.50$				
	KV	KIV	KIII	KII	KI

Table 2. Classification of signs of technical and economic protection of construction objects LC

APSC condition	Hazard class	Name of the risk	Loss characteristics	Risk level (R_i, mark)	The amount of damage, minimum wage
Corrosion hazard	1	Catastrophic	Partial or complete destruction of structures and constructions	9–10	> 72,500
	2	Critical	The losses exceed the estimated gross income of the restoration of facilities	7–8	25,000–72,500
Corrosive protection	3	Allowable	Losses do not exceed the estimated amount of profit when extending the resource and technological renovation of facilities	5–6	2,500–25,000
	4	Acceptable	The losses do not exceed the cost of maintaining quality during the life of the facility	1–4	< 2,500

The choice of effective materials and technologies for corrosion protection management is based on balanced LC indicators, the determination of which requires the accumulation and processing of a significant amount of experimental data reflecting the requirements for the quality of materials, reliability and safety of capital construction facilities.

Balanced indicators represent a set of system-structured indicators to achieve sustainable LC under negative impacts. Two groups of technical and economic indices should be distinguished, representing characteristics established by measuring the required quality indicators of primary and secondary protection, as well as management indicators that form criteria for choosing calculation models and situations for assessing reliability and safety, depending on a given cycle of sustainable development of technical and economic protection measures.

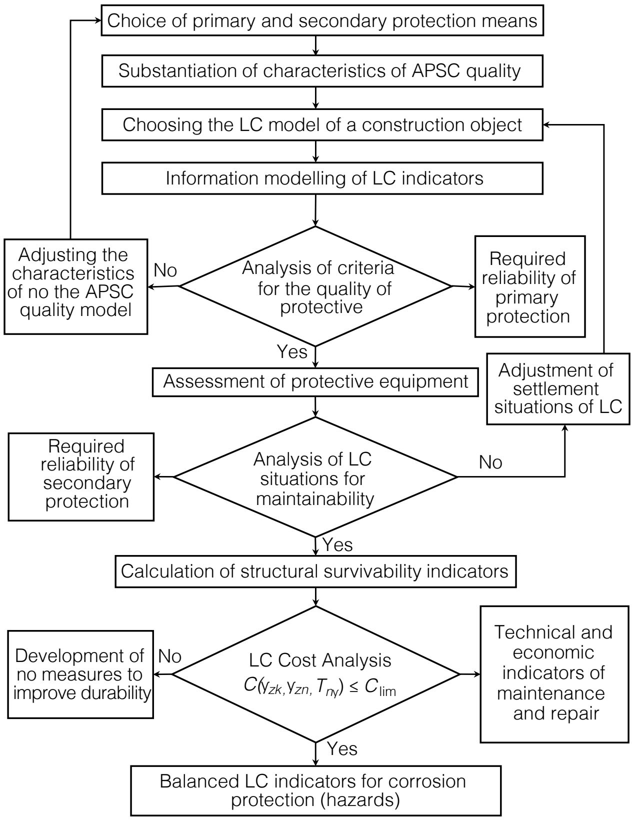


Fig. 2. Parametric modelling of balanced indicators of constructions LC

In the period from 2009 to 2018, bench and accelerated corrosion tests of reference samples and fragments of structures with protective coatings were performed (Fig. 3) to create a database of operational parameters of APSC durability:

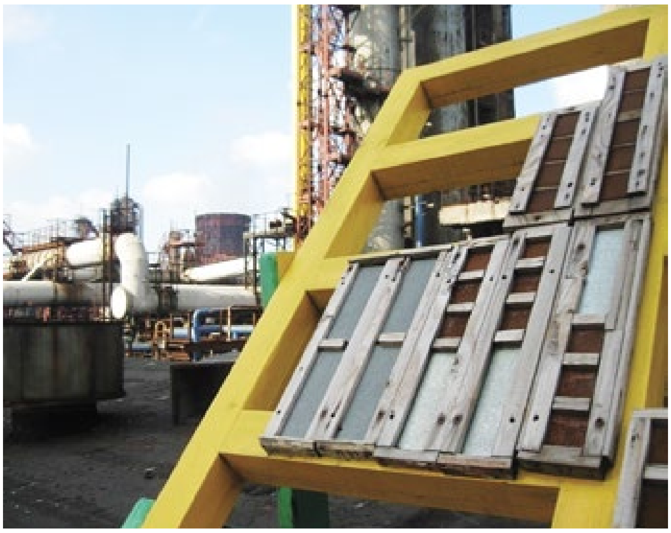
- at the Southeastern Research Station for zoning the coastal territory and zoning enterprises of the Donetsk region according to signs of corrosion hazard (protection) according to the requirements GOST 9.905–82[4], GOST 9.906–83[5];
- in the testing laboratory (TL) "Antikor-Don" of the Donbass Centre for Technological Safety (DONTSTB) LLC Ukrinstalcon named after V.N. Shimanovsky, accredited according to the ISO/IEC17025 standard.

With the participation of PSTU, interested enterprises and organizations, technical regulations for risk-based safety management of a number of mining, metallurgical, chemical enterprises of production facilities have been developed, taking into account the increase in the level of corporate social responsibility of business. The risk assessment is carried out in accordance with the requirements of ISO/IEC 31010[6] based on the HAZOP (Hazard and Operability Study) method, aimed at identifying threats and opportunities of planned measures to maintain the operational state of APSC.

Regulatory requirements for the stability of cycles of development of technical and economic protection and experimental data of definitive tests allowed, based on the results of monitoring and risk diagnostics of construction facilities, to form a unified system of LC indices for corrosion protection management.

The theoretical and experimental approbation of the principles of durability and survivability allowed us to formulate the conditions for direct and inverse tasks of technical and economic protection. The direct task reflects the requirements of structural safety: according to the specified indicators of the APSC reliability matrix (see Table 1) determine the resistance to negative influences. The principle of durability allows you to adjust the level of corrosion protection, provides the possibility of scenario selection of alternative means of primary and secondary protection. Constructive safety management is carried out by justifying the maximum redundancy of technical and economic protection resources. The justification of the design indicators of the durability of structures is carried out according to the developed methodology, taking into account the reliability coefficients of primary γ_{zk} and secondary protection γ_{zn}, the specified service life of the object $T_{\gamma n}$.

4 GOST 9.905–82. A unified system of protection against corrosion and aging. Corrosion testing methods.
5 GOST 9.906–83. Climate testing stations. Unified system of corrosion and ageing protection. Test climatic stations. General requirements.
6 ISO/IEC 31010:2009. Risk management — Risk assessment techniques.



a

b

Fig. 3. Justification of LC stability indicators during definitive tests: a — bench corrosion tests; b — bench strength tests

Survivability defines a system of measures to counteract degradation processes until partial or complete restoration of working condition to ensure the stability of LC of construction facilities. The inverse problem forms the criteria of technological safety: according to the expert assessment of monitoring indicators and risk diagnostics (see Table 2) to justify the routine reservation of corrosion protection. The principle of survivability establishes performance limitations, provides an assessment of technical and economic protection measures based on an acceptable level of risk in case of corrosion failure.

The economic feasibility of regulatory corrosion protection management throughout LC is associated with the sustainable development of the real estate market. The determining factor in the creation of an effective technological safety management system is the extraction of profit and an increase in the capital return coefficient of the functioning of infrastructure facilities.

To structure the input data in assessing the risks of technical and economic protection, an integral indicator is needed that determines the basic basis for analysis and decision-making. The complex criterion of the indicator of the level of risk of corrosion protection (LRCP) has the form:

$$\text{LRCP} : \text{CCPS} / \text{CCCL}, \tag{3}$$

where CCPS — the cost of a corrosion protection system, ₽; CCCL — a compensatory component of corrosion losses, ₽.

The CCPS and CCCL indicators (in monetary units) are calculated on a single natural unit of measurement characterizing the compared structures (pcs., t, m^3, m^2, m). The LRCP index varies from zero to one, above which the risk is not justified. The analysis of the LRCP allows you to normalize its interval values by groups of objects.

It is proposed to consider corrosion protection management based on risk analysis in accordance with the size of the rate of return of innovations:

$$\text{RR} = (\text{CCCL} - \text{CCPS}) / \text{CCPS} = \text{CEPE} / \text{CCPS}, \tag{4}$$

where CEPE — cost-effectiveness of protective equipment, ₽.

The indicator approach is primarily related to the need to assess the effective use of materials and technologies. The essence of LC stability management through risk analysis of corrosion protection is determined by the justification of the required CCPS, taking into account the definition of CCCL and LRCP. By adopting the LRCP as a basis, we get the opportunity to increase the effectiveness of technical and economic protection for the main classification groups of real estate objects.

The expert assessment of LC indicators is aimed at reserving technical and economic protection measures, changing the assessed state of corrosion hazard (KI – KV) and switching to the corrosion protection regime of a construction facility (ZI – ZIV). Functional redundancy involves the management of primary and secondary protection measures. Time redundancy includes the regulation of durability and survivability using calculation and measurement methods.

A balanced application of the technical and economic protection measure, depending on the required level of reliability, is carried out by substantiating (coordinating) the index coefficient of the combination of corrosion protection elements (CCPE):

$$\text{CCPE}_{\text{I, (II)}} = \text{CCPS}_{\text{I, (II)}} / \text{CCCL}, \tag{5}$$

where $\text{CCPS}_{(\text{I})}$ — cost of the primary corrosion protection system, ₽; $\text{CCPS}_{(\text{II})}$ — cost of a secondary corrosion protection system, ₽.

The development of index characteristics in the parametric design of technical and economic protection ensures cost management of LC of capital construction facilities with minimal operating costs.

CONCLUSIONS

The improvement of the sustainable LC management system reflects the need to create a unified system of balanced indicators for the expert assessment of the required measures of technical and economic protection of real estate. The formulated principles of substantiation of durability and survivability in conditions of negative impacts are aimed at improving regulatory and technical requirements, providing new opportunities for expert evaluation of design solutions, reserving technical and economic protection measures.

The theoretical justification of the methodology of system analysis and the process approach in assessing the cost of LC opens up new opportunities for building an information data structure and digital modelling of resource conservation tasks, technical and economic protection and safe operation of construction facilities. The results of the work are aimed at implementing the requirements of the ISO/TC 267[7] Facility Management standard, contribute to the improvement of parametric design methods based on balanced LC indicators, the creation of laboratories for input quality control, examination of compliance with reliability and safety indicators, digitalization of the tasks of estimating the value of LC of real estate.

The essence of the justification of technical and economic protection measures is revealed, including the conditions for regulatory confirmation of compliance with quality indicators and risk-oriented management of functional and temporary redundancy of LC stability indicators of structures and objects.

The introduction of the procedure for reserving technical and economic protection into technical regulations and norms will reduce the cost of repairing fixed assets by 5–15 % and reduce the risks of emergency situations. The regulatory management system provides information modelling of LC cost according to the provisions of the *Lean Six Sigma* concept.

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[7] ISO/TC 267. Facility Management Technical Committee.

Оценка рисков технико-экономической защищенности на этапах жизненного цикла объектов недвижимости

Введение. Представлен инновационный подход к устойчивому развитию объектов недвижимости на основе комплексного анализа требований ресурсосбережения, технико-экономической защиты и безопасной эксплуатации. Выявлены недостатки действующих норм проектирования мер защиты от коррозии, не позволяющие производить моделирование расчета стоимости жизненного цикла (ЖЦ). Показана необходимость расширения расчетно-аналитических индикаторов экспертизы проектных решений с целью предотвращения негативных последствий при коррозионном разрушении.

Материалы и методы. Объект исследования представляет систему регламентного управления, для которой разработаны алгоритмы принятия эффективных решений строительных проектов по защите от коррозии. Предложена методика резервирования технико-экономической защищенности на базе расчетных моделей качества, надежности и безопасности конструкций и сооружений. Функциональное и временно́е резервирование устойчивости к агрессивным воздействиям осуществляется с учетом требований к эксплуатации и безопасности стандарта ИСО/ТК 267 Фасилити менеджмент (ФМ). Целостное восприятие критериев технико-экономической защиты достигается с помощью индикаторов экспертизы проектных решений и регламента ЖЦ для заданного уровня коррозионной опасности (KI – KV) или защищенности (ZI – ZIV).

Результаты. Апробация принципов и условий регламентного резервирования мер технико-экономической защиты выполнена путем постановки прямой и обратной задач живучести. Программа определительных испытаний включала мониторинг, риск-диагностику и управление индикаторами расчета стоимости ЖЦ. Оценка рисков осуществлена на основе метода HAZOP (Hazard and Operability Study). Предложенный подход обеспечивает сценарный анализ возможностей и идентификацию угроз применения новых материалов и технологий согласно положениям концепции «бережливого хозяйствования» *Lean Six Sigma*.

Ключевые слова: *устойчивое развитие, объекты недвижимости, жизненный цикл, параметрическое проектирование, технико-экономическая защита, мониторинг, риск-ориентированное управление*

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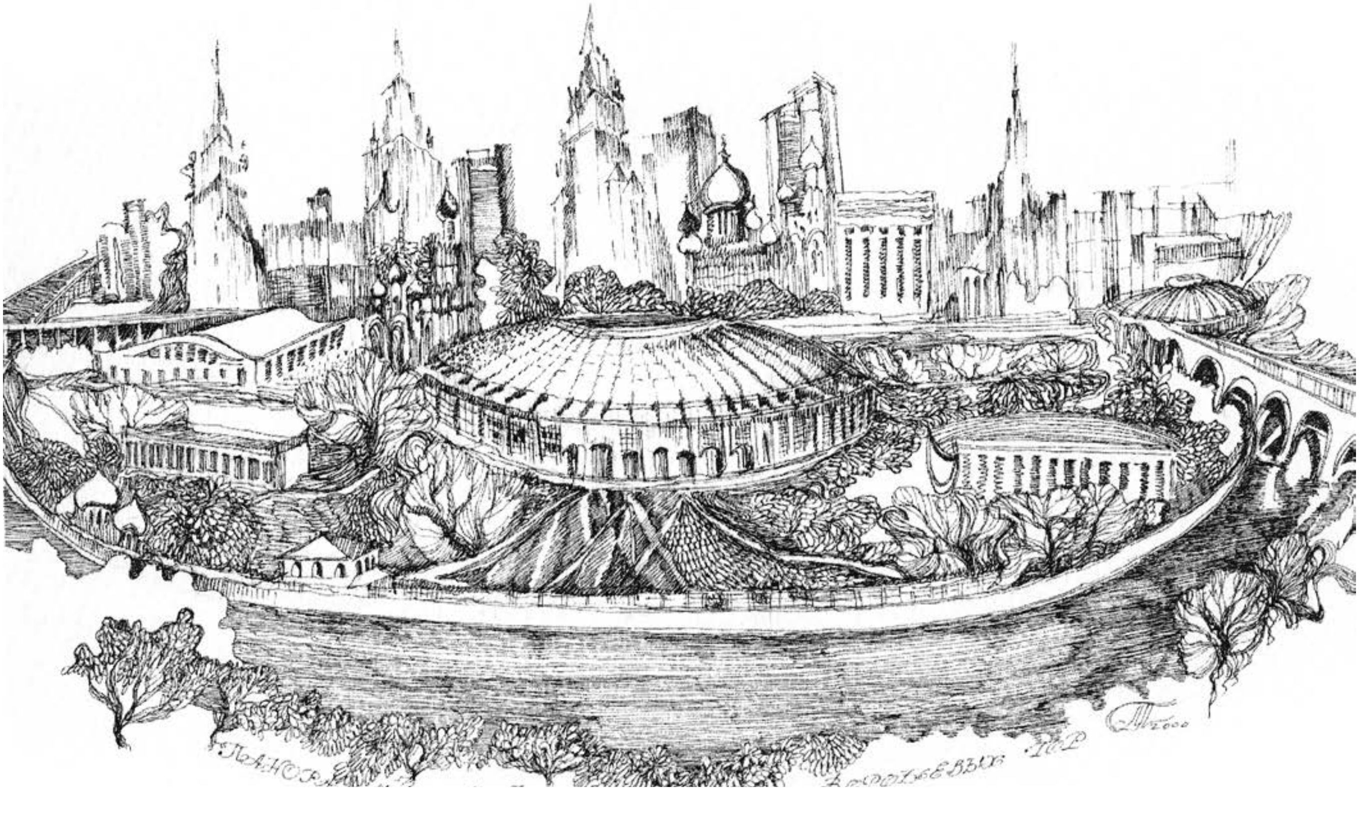

Л.И. Павлова. Панорама Москвы с Воробьевых гор. Рисунок, тушь, перо.