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Models for technical and economic justification of the feasibility of reconstruction in the construction industry

_Oleksandr Pidodnia_*

Postgraduate Student
Ukrainian State University of Science and Technologies
49010, 2 Lazarian Str., Dnipro, Ukraine
https://orcid.org/0009-0006-2156-0682

Abstract. The study aimed to develop a system of models for the technical and economic justification of the feasibility of reconstructing enterprises in the construction industry, considering technical, investment, resource and energy, life-cycle and risk parameters. As a result, normative-methodological, parametric, structural, scenario-based and calculation-integral models for evaluating refurbishment decisions were developed. It was established that the feasibility of renovation cannot be determined solely by the estimated cost or payback period, as it depends on the interplay of technical suitability, economic impact, investment performance, resource and energy sustainability, and risk exposure. The scenario-based model made it possible to compare alternatives not only in terms of initial costs, but also in terms of long-term effect, energy efficiency, life-cycle cost and risk level. A comparison of the scenarios showed that maintaining the current status quo has the lowest capital expenditure index – 0.15 – but is characterised by the lowest operational benefit – 0.05 – low energy efficiency – 0.20 – and the highest risk level – 0.78. The scenario involving comprehensive refurbishment with a digital and energy component demonstrated the highest methodological feasibility: the technical renewal index was 0.92, the operational benefit index – 0.86, the energy efficiency index – 0.89, the life-cycle cost index was 0.76, the net present value index was 0.39, and the risk load fell to 0.34. Integral ranking confirmed the superiority of this scenario, which received a reconstruction feasibility index of 0.54. This demonstrated that the most sound scenario is one in which technical modernisation is combined with digital control, energy management, reduced life-cycle costs and a managed level of risk uncertainty. The practical significance is determined by the possibility of using the proposed system of models for the preliminary selection of a feasible reconstruction scenario for enterprises in the construction industry of Ukraine

Keywords: life-cycle cost; return on investment; risk exposure; integrated ranking; payback period

Introduction

The renovation of enterprises in the construction sector has become a strategic priority in the context of increasing requirements for resource efficiency, environmental sustainability and the resilience of production systems. Unlike

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*Corresponding author (oleksandrpidodnia@outlook.com)

conventional refurbishment projects aimed solely at restoring the technical condition of facilities, contemporary renovation involves the comprehensive modernisation of buildings and engineering infrastructure, the integration of energy-efficient technologies and digital tools, and the optimisation of long-term operating performance. Under conditions of economic uncertainty and post-war recovery, the justification of renovation decisions requires integrated approaches capable of balancing technical, economic, environmental and risk-related considerations. The urgency of renovating Ukraine's building stock is underscored by the scale of the renovation needs: according to a World Bank estimate (2026), Ukraine's total renovation and reconstruction needs for the period 2026-2035 amount to USD 588 billion. An additional factor is the introduction in Ukraine, from 1 April 2025, of requirements for nearly zero-energy buildings, which highlights the need to incorporate energy-efficient solutions when planning renovations (State Agency on Energy Efficiency and Energy Saving of Ukraine, 2025).

The issue of the economic effectiveness of innovative solutions in the activities of construction companies was examined by O. Malykhina *et al.* (2023), who demonstrated the correlation between the choice of innovation strategy and the economic performance of a company's operational system. This approach demonstrated that the restructuring of a construction enterprise cannot be assessed solely based on the volume of capital investment, as its feasibility is linked to the impact of restructuring measures on production productivity, the stability of the operational system, process costs and long-term economic returns. The environmental dimension of modernising enterprises in the construction industry was explored by U. Andrusiv *et al.* (2024), where environmental modernisation is interpreted as an innovative production and management technology. This provides grounds for including in the technical and economic justification not only financial indicators but also parameters of resource conservation, energy efficiency, environmental impact and the reduction of production's impact on the environment. Digital approaches to evaluating renovation decisions are actively developing in connection with the use of Building Information Modelling (BIM). O. Doukari *et al.* (2023) proposed a BIM-oriented technical and economic framework for comparing building renovation strategies, which was used to assess options in terms of cost, timeframes, energy efficiency and operational parameters. For companies in the construction sector, this approach is particularly relevant, as the refurbishment of production and ancillary facilities requires not only cost estimates but also digital validation of refurbishment scenarios. K. Lu *et al.* (2023) systematised the relationship between building life-cycle cost analysis and BIM, demonstrating that the combination of these tools enhances the soundness of decisions during the planning, design, operation and renovation stages of a facility. This has reinforced the need to incorporate life-cycle indicators into renovation assessment models for construction industry enterprises. In the study by M. Gubert *et al.* (2023), traditional and industrialised scenarios for deep renovation were compared, demonstrating the differences between renovation options in terms of costs, technological complexity and expected outcomes. This approach is relevant for developing the scenario-based logic of a technical and economic justification, within which renovation can be viewed not as a single fixed project, but as a set of alternatives: minimal refurbishment, partial modernisation, comprehensive renovation, or renovation incorporating digital and energy-efficient solutions. Y. Alsalem *et al.* (2023), using the example of the modernisation of an engineering system, demonstrated the importance of technical and economic evaluation in determining the effectiveness of reconstruction measures. Their findings confirmed that decisions regarding the upgrading of equipment or engineering infrastructure should be based on a comparison of the initial investment, operating costs, energy efficiency and payback period.

The multi-criteria nature of selecting renovation solutions was explored by Y. Shi *et al.* (2024), where energy-efficient renovation strategies were evaluated based on energy, economic and comfort parameters. Although the study targeted buildings with a different functional purpose, its methodological logic is relevant for enterprises in the construction sector, as the renovation of industrial facilities also requires a balance between costs, technical performance, operating conditions and long-term effects. D. Macek & S. Vitásek (2024) focused on risk analysis in building renovation and strategies for investors, which is particularly relevant for technical and economic justification in conditions of uncertainty. In the renovation of construction industry facilities, risks may be associated with cost overruns, changes in material costs, delays in work completion, insufficient return on investment, technical limitations of existing facilities, and incomplete input data. Approaches to sustainable building renovation are increasingly based on a combination of economic, environmental and social criteria. M. Caruso *et al.* (2024) proposed an updated multi-criteria decision-making method for sustainable renovation, which incorporates environmental, economic and social life-cycle metrics. This logic implies that the model for justifying a plant refurbishment must go beyond simple payback and encompass a broader set of criteria relating to the durability, resource efficiency, operational stability and adaptability of the production system. In a critical review of methods for analysing the costs and benefits of sustainable building renovations, S. Sharbaf & P. Schneider-Marin (2024) demonstrated that the financial assessment of renovation requires consideration not only of direct investment but also of future savings, operational effects, maintenance costs and long-term benefits. This is directly consistent with the need to develop a technical and economic model capable of demonstrating not only the cost of refurbishment but also its viability over a longer time horizon.

An analysis of academic literature has shown that the renovation of buildings and industrial facilities is examined through the interplay of an enterprise's innovation strategy, environmental modernisation, digital modelling, life-cycle cost analysis, scenario comparison, technical and economic evaluation of engineering systems, multi-criteria selection and risk analysis. At the same time, in the existing literature, these areas are mostly considered separately: some studies focus on digital modelling, others on life-cycle costs, energy efficiency, risks or the sustainability of renovation solutions. An integrated model for technical and economic justification remains underdeveloped; such a model would be suitable specifically for assessing the feasibility of refurbishing enterprises in the construction sector and would combine the technical condition of the facility, the scale of investment, operating costs, energy efficiency, risks, payback period, life cycle and the strategic effectiveness of the refurbishment.

The study aimed to develop a system of models that provides a comprehensive technical and economic justification for the feasibility of renovating enterprises in the construction sector, considering the technical condition of the facilities, investment returns, resource and energy efficiency, life-cycle costs and risk exposure. Achieving this aim involved the development of normative-methodological and parametric models for the technical and economic justification of reconstruction; the construction of structural and scenario-based models of the interaction between technical, economic, investment, resource-energy and risk parameters; the development of a computational-integral model for ranking scenarios for the reconstruction of enterprises in the construction industry based on a reconstruction feasibility index.

Materials and Methods

The study was theoretical and modelling-based, combining an analytical review of regulatory and methodological sources with scenario-based, calculation- and assessment-based, and risk-oriented modelling. The material basis of the study consisted of cost, design, construction, energy, life-cycle, environmental and risk-oriented sources, which were processed using various methods in accordance with their hierarchy and functional purpose. In Order of the Ministry of Community and Territorial Development of Ukraine No. 281 (2021), a regulatory-cost analysis was applied, which made it possible to determine the role of the cost estimate base in shaping initial investment costs, the structure of reconstruction costs and the financial prerequisites for technical and economic evaluation. DBN A.2.2-3:2014 (2014) was examined using the normative-design analysis method, as this document defines the composition of design documentation, initial data, technical specifications and the stages of preparing reconstruction solutions. DBN V.2.2-9:2018 (2018) was analysed using a functional and planning analysis to consider the requirements for administrative, auxiliary, service and production support components of enterprises in the construction industry.

The energy module of the model was developed through energy audits and structural-functional analysis. DSTU EN 16247-3:2015 (2015) was used to determine the baseline energy consumption parameters of industrial processes, identify potential losses, and establish performance indicators for energy modernisation. ISO 50001:2018 (2018) was used as a basis for addressing energy consumption management, monitoring energy performance and reducing operational losses. ISO 15686-5:2017 (2017) was used within the framework of life-cycle analysis, as this standard provides a basis for considering not only initial costs but also operational, ongoing, discounted and final costs over the calculation horizon. ISO 14044:2006 (2006) was applied using the environmental and resource analysis method to incorporate resource efficiency parameters, reduce environmental impact and assess the consequences of technical upgrades throughout the life cycle. ISO 31000:2018 (2018) was used within the framework of risk-based analysis to categorise cost, schedule, technical, market and regulatory risks that may affect the cost, implementation timeline, return on investment and overall viability of the refurbishment scenario.

The structural-systemic method was applied to identify five interrelated groups of parameters for the technical and economic feasibility study: technical suitability, economic impact, investment effectiveness, resource and energy sustainability, and risk exposure. Technical suitability covered physical wear and tear, obsolescence, structural reliability, the condition of engineering networks, technological compatibility of equipment, and the ability to adapt buildings to new production needs. Economic effect included capital expenditure, changes in production costs, expected resource savings, productivity gains, and reductions in operational losses. Investment performance was determined by payback period, net present value, discounted cash flows, and the sensitivity of the result to changes in the cost of works or the expected effect. Resource and energy sustainability covered energy efficiency, reduced resource consumption, controllability of energy processes, and a reduction in life-cycle impact. Risk exposure considered cost, technical, schedule, market, and regulatory risks.

Comparative and scenario-based methods were used to compare alternative options for the restructuring of a hypothetical production and construction system at a construction industry enterprise. The study did not analyse a specific enterprise; the model was developed for an enterprise whose activities are related to construction production, storage of materials, operation of repair areas, administrative and amenity premises, engineering networks and energy infrastructure. Within the framework of scenario modelling, four hypothetical reconstruction scenarios were identified: maintaining the current state, partial modernisation, comprehensive reconstruction, and comprehensive reconstruction with a digital-energy component. These were selected as typological options reflecting varying degrees of reconstruction intervention, ranging from no systematic renewal to local, comprehensive, and comprehensive digital-energy renewal of the production and construction system.

A normalised model scale ranging from 0 to 1 was used to quantitatively compare the renovation scenarios. The indices were calculated using the following algorithm: first, the parameters to be assessed were determined for each scenario, specifically technical upgrades, capital expenditure, operational benefits, life-cycle cost, net present value, energy efficiency and risk exposure; next, each parameter was assigned a level of manifestation on a scale of 0.00-0.20 (minimum), 0.21-0.40 (low), 0.41-0.60 (moderate), 0.61-0.80 (high), and 0.81-1.00 (very high). For positive parameters, an increase in the index indicated a greater contribution to the feasibility of the refurbishment, whereas for capital expenditure, life-cycle costs and risk exposure, it indicated higher costs or a greater level of constraints. As the study was not tied to a specific enterprise, the normalised values were used as model calculation and assessment indicators to demonstrate the algorithm for the preliminary comparison of refurbishment scenarios.

The calculation and evaluation method was used to formalise the indicators used to determine the financial and operational viability of the refurbishment scenario. The input data for calculating the payback period, life-cycle cost and net present value are the initial investment costs, projected cash flows or cost savings following refurbishment, operating costs, the discount rate, the duration of the calculation horizon and costs in the final period. In practical application, these data can be determined based on a preliminary refurbishment estimate, project documentation, energy audit results, the enterprise's financial plan, a forecast of operating costs, and assumptions regarding the cost of capital. Within the scope of this study, these indicators were used as model calculation parameters for comparing hypothetical refurbishment scenarios, rather than as actual data for a specific enterprise. The payback period for the refurbishment project was defined as the ratio of the initial investment costs to the average annual increase in cash flow or cost savings following the refurbishment (1):

$$PP = \frac{I_0}{\Delta CF}, \quad (1)$$

where PP – payback period for the refurbishment; I_0 – initial investment costs, covering the costs of construction and installation works, upgrading of utility networks, equipment, project preparation and supervision of the refurbishment; ΔCF – the average annual increase in cash flow or cost savings following refurbishment, resulting from reduced energy consumption, operational losses and maintenance costs, and improved production efficiency.

Life-cycle costs were used to estimate the total costs associated with the construction and subsequent operation of the refurbished facility (2):

$$LCC = C_0 + \sum_{t=1}^{n} \frac{C_t}{(1+r)^t} + \frac{C_d}{(1+r)^n}, \quad (2)$$

where LCC – cost of a lifecycle; C_0 – initial renovation costs; C_t – operating costs during the period t, in particular, costs relating to energy, upkeep, repairs, maintenance and the management of the facility; r – discount rate, reflecting the cost of capital and the time value of money; C_d – costs incurred during the final period relating to the dismantling, disposal, replacement of equipment or final refurbishment; – duration of the projection horizon.

The investment performance of the refurbishment solution was assessed using the net present value (3):

$$NPV = \sum_{t=1}^{n} \frac{CF_t}{(1+r)^t} - I_0, \quad (3)$$

where NPV – net present value; CF_t – cash flow during the period t; r – discount rate; I_0 – initial investments. The values obtained for PP, LCC and NPV were incorporated into the composite index K_{rec} by normalising the relevant calculated indicators on a scale of 0-1. The payback period and net present value formed the investment component of the model, as they reflected the rate of return on investment and the financial performance of the refurbishment. The life-cycle cost was used in the resource-energy and operational components, as it showed not only the initial costs but also the long-term financial burden following the implementation of the refurbishment scenario. A lower value of PP and LCC after normalisation corresponded to a higher feasibility of the scenario, whilst a higher value of NPV increased the investment rating.

To summarise the technical, economic, investment, resource and energy, and risk parameters, a comprehensive index of the feasibility of the refurbishment was developed (4):

$$K_{rec} = w_T T + w_E E + w_I I + w_S S - w_R R, \quad (4)$$

where K_{rec} – comprehensive feasibility index for reconstruction; T – technical suitability of the property for renovation; E – economic effect; I – return on investment; S – resource and energy sustainability; R – risk load; w_T, w_E, w_I, w_S, w_R – weighting factors for relevant blocks. As part of the model-based ranking of scenarios, an equilibrium distribution of weighting coefficients was applied: $w_T = w_E = w_I = w_S = w_R = 0.2$. This approach was used to demonstrate the basic logic of an integrated comparison of scenarios without prioritising any particular evaluation component.

A risk-based analysis was used to refine the constraints of the integrated model and to determine the risk exposure index . Risks were grouped into five categories: cost, schedule, technical, market and regulatory. For each risk group, a standardised scale from 0 to 1 was used, where 0.00-0.20 indicated minimal risk, 0.21-0.40 – low, 0.41-0.60 – moderate, 0.61-0.80 – high, and 0.81-1.00 – critical risk levels. Cost risk reflected the probability of exceeding the planned cost of the refurbishment; schedule risk – a possible deviation from the implementation deadlines; technical risk – incomplete information about the actual condition of structures, utility networks and equipment; market risk – changes in demand, resource costs or the company's operating conditions; regulatory risk – changes in requirements for design, operation, energy efficiency and environmental safety. The overall risk load index was determined as the weighted average of the five risk components (5):

$$R = w_c R_c + w_t R_t + w_{tech} R_{tech} + w_m R_m + w_{reg} R_{reg}, (5)$$

where R – overall risk exposure index; R_c – budget risk; R_t – calendar risk; R_{tech} – technical risk; R_m – market risk; R_{reg} – regulatory risk; w_c, w_t, w_{tech}, w_m, w_{reg} – weighting factors for the relevant risk groups. In the baseline model assessment, equal weighting was applied, with each risk group assigned a weight of 0.20. The resulting value was included in the overall index of the feasibility of reconstruction as a limiting factor; consequently, an increase in this value reduced the scenario's overall score.

To facilitate decision-making within the conceptual model, threshold criteria for scenario selection were established. A renovation scenario was considered methodologically acceptable if the technical suitability index was at least 0.40, as a lower value indicated that the facility lacked sufficient structural, engineering or technological suitability for refurbishment. An acceptable level of risk was defined as up to 0.60; for a value of $R > 0.60$, the scenario required further review of the budget, timelines, technical solutions or organisational conditions for implementation. The integrated reconstruction feasibility index K_{rec} was used as the final ranking criterion: a value below 0.30 indicated low feasibility of the scenario, 0.30-0.49 – conditional acceptability, 0.50-0.69 – sufficient feasibility, and a value of 0.70 and above – a high level of technical and economic justification. A limitation of the study is that the proposed scenarios, normalised indices and calculated indicators are of a model nature and are not based on empirical data from a specific enterprise, the actual reconstruction cost estimate or real cash flows.

Results

The regulatory, methodological and parametric framework for the technical and economic justification of the refurbishment

An analysis of the regulatory and methodological framework has shown that the technical and economic justification for the refurbishment of enterprises in the construction sector has a multi-component structure and encompasses cost, design, spatial planning, energy, life-cycle, environmental and risk-oriented parameters. This approach makes it possible to evaluate a reconstruction decision not only in terms of initial investment costs, but also in terms of technical feasibility, expected operational benefits, energy consumption management, changes in life-cycle costs and the level of risk exposure. The functional breakdown of these components is presented in Table 1.

Table 1. Regulatory and methodological sources for developing a model for the technical and economic justification of the reconstruction of enterprises in the construction industry

Regulatory and methodological basis	Scope of regulation	Section on the technical and economic feasibility study	Outcome for assessing the feasibility of the refurbishment
Order of the Ministry of Community and Territorial Development of Ukraine No. 281	Cost standards for the construction industry in Ukraine	Asset and investment unit	Determining the initial cost of the refurbishment, the cost structure and the basis for further investment appraisal
DBN A.2.2-3:2014	Composition and content of the project documentation	Design and documentation unit	Alignment of the renovation proposal with the initial data, technical specifications, design stages and the scope of design documentation
DBN V.2.2-9:2018	Requirements for public buildings and structures	Spatial planning unit	Consideration of structural and functional constraints for the administrative, ancillary, service and public-industrial components of the enterprise
DSTU EN 16247-3:2015	Energy audits of industrial processes	Energy audit unit	Determining baseline energy data, identifying energy losses and identifying areas for improving energy efficiency
ISO 50001:2018	Energy management systems	Energy management and performance monitoring	Incorporating energy performance indicators into the model and ensuring that energy consumption can be managed following the refurbishment
ISO 15686-5:2017	Life-cycle cost of buildings and structures	Life-cycle module	Assessing not only the initial cost, but also the operational, ongoing and final costs over the forecast period
ISO 14044:2006	Life cycle environmental assessment	Environmental unit	Consideration of the resource, energy and environmental implications of the refurbishment solution
ISO 31000:2018	Risk management	Risk-based module	Adjustment of the final valuation to account for uncertainties regarding value, timing, technical condition, market conditions and regulatory conditions

Source: compiled by the author

The data in Table 1 demonstrate that the regulatory and methodological framework for technical and economic justification has a hierarchical structure. Its basic level is formed by cost estimates and design requirements, as it is impossible to proceed to the investment appraisal of the refurbishment without determining the cost of the works, the composition of the documentation and the technical specifications. The second level consists of spatial planning and energy requirements, which correlates the renovation with the functional adaptation of buildings, the condition of engineering systems and the potential for reducing energy consumption. The third level encompasses life-cycle, environmental and risk assessments, which can be used to analyse the renovation not only as a one-off investment project, but as a long-term change to the production and construction system. The systematisation revealed the functional distribution of regulatory sources within the integrated model. Order of the Ministry of Community and Territorial Development of Ukraine No. 281 (2021) establishes the cost estimation and valuation framework for renovation; DBN A.2.2-3:2014 (2014) defines design and documentation requirements; DBN V.2.2-9:2018 (2018) specifies the spatial planning and functional constraints for the administrative, auxiliary and service components of the enterprise; DSTU EN 16247-3:2015 (2015) and ISO 50001:2018 (2018) provide the energy assessment section; ISO 15686-5:2017 (2017) is used for life-cycle cost assessment, ISO 14044:2006 (2006) – for accounting for resource and environmental impacts, and ISO 31000:2018 (2018) – for the risk-oriented module of the model. The budgetary framework defines the initial financial scope of the refurbishment; the design framework establishes the link between economic decisions and technical implementation; the energy framework demonstrates the potential for reducing energy losses; the life-cycle framework broadens the scope of assessment; the environmental framework takes resource implications into account; and the risk-oriented framework adjusts the overall feasibility to account for uncertainty. This provided the basis for a transition from a prescriptive list to a structural model of parameters, in which each source is linked to a corresponding group of indicators. Thus, the results of the normative and methodological systematisation have made it possible to establish that the model for the technical and economic justification of the reconstruction of enterprises in the construction industry should be structured as an integrated system, in which estimated cost, project preparation, spatial and planning constraints, energy efficiency, life-cycle cost, environmental impact and risk exposure are considered as interrelated components. This framework facilitates the transition to the further systematisation of five groups of parameters for the feasibility of reconstruction: technical suitability, economic effect, investment performance, resource and energy sustainability, and risk exposure.

The technical and economic feasibility of renovating enterprises in the construction sector has been structured into five components, with each group of parameters reflecting a separate aspect of the decision-making process regarding renovation. Technical suitability determines the feasibility of upgrading existing buildings, utility networks and technological equipment; economic effect characterises the expected change in costs, productivity and operational losses; investment performance indicates the financial return on investment over the forecast horizon; resource and energy sustainability reflects the ability of the refurbishment to reduce resource consumption and maintain the manageability of energy processes; risk exposure identifies constraints that may reduce the expected outcome due to uncertainty regarding cost, timing, technical condition or market conditions. The resulting framework showed that the feasibility of refurbishment cannot be determined by a single dominant indicator. A low estimated cost does not guarantee the rationality of a scenario if it does not eliminate technical constraints, reduce operating costs or ensure an acceptable level of resource and energy sustainability. At the same time, a scenario with higher initial investment may receive a better overall assessment due to a longer economic effect, lower life-cycle costs, greater adaptability of the facility and a lower risk burden. The relationship between these groups of parameters is presented in Table 2.

Table 2. Groups of parameters relating to the technical and economic feasibility of renovating enterprises in the construction sector

Parameter group	Assessment content	Key indicators	Impact on the comprehensive index of the feasibility of reconstruction
Technical suitability	Determines the feasibility and practicality of refurbishment based on the current condition of the buildings, utility networks, technical equipment and spatial layout	Physical wear and tear; obsolescence; structural integrity; condition of utility networks; technological compatibility of equipment; adaptability of buildings to new operational requirements	Increases the index provided the property is sufficiently suitable for refurbishment; reduces the feasibility if the property is heavily worn or cannot be adapted
Economic impact	Describes the expected changes in costs, productivity and operational performance following the refurbishment	Capital expenditure; changes in production costs; resource savings; productivity gains; reduction in operational losses; lower maintenance costs	Increases the index when there is an improvement in cost savings, productivity and a reduction in operating costs; decreases the index when the operational impact is insufficient

Table 2, Continued

Parameter group	Assessment content	Key indicators	Impact on the comprehensive index of the feasibility of reconstruction
Investment performance	Reflects the financial viability of the refurbishment over the forecast period and the project's ability to generate a return on investment	Payback period; net present value; discounted cash flows; sensitivity to changes in the cost of works, the discount rate and the expected return	Improves the index in terms of positive return on investment, an acceptable payback period and the resilience of the results to changes in initial conditions
Resource and energy sustainability	Assesses the long-term ability of a refurbishment solution to reduce resource consumption, energy costs and the company's operational dependence	Energy efficiency; reduced resource consumption; controllability of energy processes; lower life-cycle costs; stability of operating parameters	Improves performance by reducing energy consumption, lowering resource usage and enhancing operational control
Risk exposure	Determines the degree of uncertainty that may reduce the expected impact of the redevelopment or complicate the implementation of the chosen scenario	Cost risks; technical risks; schedule risks; market risks; regulatory risks; uncertainty regarding the actual condition of the facility	Has a negative impact on the index; reduces the overall viability of the scenario where there is a high probability of cost overruns, delays or failure to achieve the intended effect

Source: developed by the author based on the estimated cost, design, energy, life-cycle and risk-based approaches to evaluating the refurbishment

The data in Table 2 show that the parameters of the technical and economic feasibility of the refurbishment affect the final assessment differently. Technical feasibility serves as a prerequisite for the model, since even an economically attractive scenario cannot be justified if there is no structural, engineering or technological possibility of its implementation. Economic impact and investment performance form the financial core of the assessment, yet they have different focuses: economic impact captures expected changes in costs and productivity, whilst investment performance indicates whether these changes can offset the initial investment within the projection horizon. Resource and energy sustainability extends the assessment beyond short-term savings, as it considers the long-term manageability of energy consumption, the reduction in resource costs, and the impact of the refurbishment on the enterprise's future operations. In this context, what is relevant is not only the reduction in energy costs, but also the enterprise's ability to maintain controlled operational parameters after the refurbishment is complete. In contrast to other factors, risk does not increase the feasibility of refurbishment but serves a corrective function. Its inclusion in the model demonstrates that the overall effectiveness of a refurbishment scenario depends not only on expected benefits but also on the likelihood of cost overruns, implementation delays, technical complications, or changes in market and regulatory conditions. High technical viability without sufficient economic benefits does not justify the investment, and a positive net present value may lose its significance if there is a high implementation risk or high life-cycle costs. The systematisation of parameters has made it possible to develop the internal structure of a model for assessing the technical and economic feasibility of renovating enterprises in the construction sector. The study established that such a model must combine an assessment of technical condition, expected economic benefit, financial performance, resource and energy sustainability, and risks. This provides the basis for constructing a structural model for justifying reconstruction, in which these groups of parameters interact with one another and form a final decision regarding the choice of a scenario for the enterprise's modernisation.

A structural-scenario model for evaluating reconstruction alternatives

The structure of the technical and economic feasibility study revealed that the feasibility of renovating a construction company is determined not by isolated indicators, but by the interaction of several functionally linked components, which collectively influence the final decision. At the heart of this system lies an integrated assessment of the feasibility of reconstruction, which synthesises technical, economic, investment, resource-energy and risk parameters into a single analytical framework. This approach treats reconstruction not as a separate construction project, but as a comprehensive management and investment decision formed at the intersection of the technical condition of the facility, the expected benefits of the refurbishment, and implementation constraints. The structural model of the technical and economic justification for the feasibility of reconstructing a construction industry enterprise is presented in Figure 1. As shown in Figure 1, at the centre of the model lies an integrated decision regarding the feasibility of renovating a construction industry enterprise. This decision is formed through the interaction of five parametric blocks: technical suitability, economic impact, investment effectiveness, resource and energy sustainability, and risk exposure. Within the model, technical suitability reflects the actual condition of buildings, engineering networks, technological equipment and spatial planning structure, and also sets the technical limits of the reconstruction decision, considering the requirements for the composition of project documentation in accordance with DBN A.2.2-3:2014 (2014). The economic effect reflects the expected reduction in costs, increase in productivity, reduction in operational losses and the formation of the cost estimate basis for the renovation in accordance with Order of the Ministry of Community and Territorial Development of Ukraine No. 281 (2021). Investment performance shows the relationship between the volume of investment and the expected financial return, and is therefore linked to the payback period, discounted cash flows and net present value.

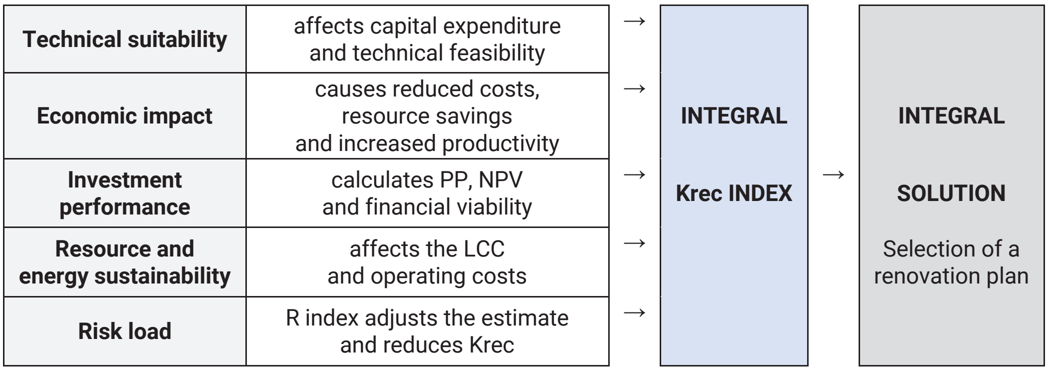

Figure 1. Structural model for the technical and economic justification of the feasibility of a construction company's refurbishment

Source: compiled by the author based on a systematisation of cost, design, energy, life-cycle, environmental and risk-based parameters of the refurbishment

Resource and energy sustainability refers to the ability of a refurbishment project to reduce energy consumption, resource use and life-cycle costs. This module combines the results of energy audits of industrial processes, energy management and life-cycle assessment, in accordance with the provisions of DSTU EN 16247-3:2015 (2015), ISO 15686-5:2017 (2017) and ISO 50001:2018 (2018). The environmental dimension of this part of the model relates to the resource and energy impacts of the refurbishment solution throughout its life cycle, following ISO 14044:2006 (2006). The risk factor serves a corrective function, as it accounts for the probability of cost overruns, delays, technical complications, market changes or regulatory requirements; this logic is consistent with the risk-based approach of ISO 31000:2018 (2018). All blocks of the model form a closed-loop assessment system, within which a change in one parameter affects other components of technical and economic feasibility. For example, a high level of technical wear and tear may increase capital expenditure, extend the payback period and heighten implementation risks, whilst improving resource and energy sustainability can enhance the economic impact, reduce life-cycle costs and improve investment performance. The structural model shows that the choice of a refurbishment scenario should not be based on a single dominant criterion, but rather on a balance between technical feasibility, economic benefits, return on investment, energy stability and an acceptable level of risk. The presented structural model for assessing the feasibility of reconstructing a construction industry enterprise reflects an interrelated system of parameters, in which technical suitability determines the possibility of reconstruction, economic effect and investment performance determine its financial feasibility, resource and energy sustainability characterise the long-term operational effect, and the risk burden adjusts the final assessment. The output of the model is the selection of a reconstruction scenario that best meets the criteria of technical and economic feasibility and ensures a balance between investment returns, operational stability and a controlled level of uncertainty.

A scenario-based comparison of refurbishment alternatives has shown that the choice of the most appropriate option for upgrading a construction industry enterprise cannot be based solely on minimising initial capital expenditure. Each scenario involves a different level of technical complexity and has a different impact on operating costs, energy efficiency, return on investment and risk exposure. Therefore, maintaining the current state, partial modernisation, comprehensive refurbishment and comprehensive refurbishment with a digital-energy component differ not only in the scale of construction and technical changes, but also in the enterprise's long-term ability to reduce costs, maintain productivity and manage risks. The summarised results of the scenario comparison are presented in Table 3. The data in Table 3 show that the "maintain current status" scenario has the lowest capital expenditure index – 0.15, but is characterised by the lowest operational efficiency – 0.05, low energy efficiency – 0.20, a zero-payback index and the highest risk load – 0.78. This indicates that reducing the initial investment does not eliminate technical, energy and operational constraints. Partial modernisation yields intermediate values: the technical upgrade index is 0.45, the operational effect is 0.38, energy efficiency is 0.48, the normalised payback index is 0.56, and the risk load is reduced to 0.52. This scenario provides a local effect but does not comprehensively transform the production and construction system. Comprehensive reconstruction increases the technical renewal index to 0.78, the operational efficiency index to 0.72 and the energy efficiency index to

0.71, although it has a higher capital intensity of 0.76 and a lower normalised payback index of 0.48. The comprehensive refurbishment scenario with a digital-energy component has the highest values for technical renewal – 0.92, operational efficiency – 0.86, and energy efficiency – 0.89; the lowest LCC index – 0.76; the highest NPV index – 0.39; and the lowest risk load – 0.34. Thus, the scenario comparison demonstrated that the feasibility of the refurbishment is determined not by the minimum initial costs, but by the balance between technical modernisation, operational efficiency, energy efficiency, life-cycle costs, investment performance and risk.

Table 3. A scenario-based comparison of alternatives for the restructuring of a construction company

Scenario	Technical update index	Capital expenditure index	Operational effect index	Standardised payback period	LCC index	NPV index	Energy efficiency index	Risk exposure index	Methodological appropriateness of the application
Saved current status	0.10	0.15	0.05	0.00	1.00	0.00	0.20	0.78	Base scenario for comparison; does not provide a system update
Partial modernisation	0.45	0.42	0.38	0.56	0.92	0.18	0.48	0.52	Suitable for locally addressing technical limitations
Comprehensive refurbishment	0.78	0.76	0.72	0.48	0.84	0.31	0.71	0.44	Suitable for the systematic modernisation of the industrial and construction infrastructure
Comprehensive refurbishment with a digital and energy component	0.92	0.88	0.86	0.43	0.76	0.39	0.89	0.34	Suitable for strategic renewal and long-term sustainability

Source: developed by the author as a standardised model for evaluating reconstruction scenarios on a 0-1 scale, using formulas (1-3) and considering cost, design, energy, life-cycle and risk frameworks

Calculational and integrative assessment and ranking of reconstruction scenarios

The results of the functional comparison showed that each indicator has a distinct zone of analytical sensitivity. The payback period is most informative for scenarios with a relatively rapid return on investment, but may underestimate long-term operational losses. Life-cycle cost highlights the difference between scenarios with low initial costs and those with higher initial investments but lower subsequent costs. Net present value reflects financial performance over time, whilst the integrated index can be used to compare financial indicators with technical, energy and risk components. The generalised role of these indicators in the feasibility model for the refurbishment is presented in Table 4.

Table 4. The functional role of calculation indicators in the model for justifying the feasibility of reconstruction

Indicator	Evaluated aspect	Management significance	Scenarios in which the indicator is critical
Payback period, PP	Payback period based on increased cash flow or cost savings	Can be used to determine the rate of return on investment and compare scenarios in terms of short- and medium-term financial attractiveness	Partial modernisation; comprehensive refurbishment; comprehensive refurbishment with a digital and energy component
Life-cycle cost, LCC	Total costs for implementation, operation and the final phase over the forecast period	Can be used for a shift from assessing the initial cost to assessing the total cost of ownership of a refurbished production and construction system	Comprehensive refurbishment; comprehensive refurbishment with a digital and energy component
Net present value, NPV	Discounted financial result of the reconstruction scenario, incorporating the initial investment	Indicates the investment performance of the scenario and its ability to generate a positive economic return over the forecast period	Partial modernisation; comprehensive refurbishment; comprehensive refurbishment with a digital and energy component
Comprehensive reconstruction feasibility index, Krec	Overall assessment of technical suitability, economic impact, investment performance, resource and energy sustainability, and risk exposure	Ranks scenarios and selects the option that offers the best balance of effectiveness, cost, sustainability and risk	All scenarios, including the baseline scenario of maintaining the current status quo

Source: compiled by the author based on the calculation and estimation logic of the technical and economic justification for the reconstruction, using equations (1-4)

The data in Table 4 showed that each calculated indicator served a specific management purpose. The payback period was used for a quick comparison of scenarios in terms of the time taken to recoup the investment, but did not incorporate subsequent costs after the payback period had ended. Therefore, the scenario with the shortest payback period was not necessarily the most appropriate in the long term. This situation could arise when a local upgrade required lower initial costs but did not eliminate systemic operational losses. The life-cycle cost indicator expanded the assessment, as it can be used to consider costs not only during the implementation phase of the refurbishment but also during the subsequent operational period. This indicator revealed the difference between scenarios with a lower initial cost and those with higher capital intensity, but which ensured cost reductions over a longer period. Net present value complemented this logic with an investment dimension, as it showed whether a scenario generated a financial return after accounting for initial investments and discounting future cash flows.

The comprehensive index of the feasibility of reconstruction served as a summary indicator for the model, as it combined parameters that could not be fully captured by payback period, life cycle or net present value alone. Its significance stemmed from the fact that it was used for the simultaneous consideration of the technical suitability of the facility, economic impact, investment performance, resource and energy sustainability, and risk exposure. In this context, the risk component served as a corrective factor and could lower the final assessment even when the scenario demonstrated positive economic indicators. A comparison of the functions of the indicators showed that the isolated use of a single calculation criterion did not provide a complete assessment of the refurbishment. A short payback period did not always mean the best long-term viability, and a lower initial cost could be accompanied by higher operating costs, a weaker resource and energy efficiency, or higher implementation risks. Therefore, the calculation and evaluation model demonstrated the need to combine the PP, LCC, NPV and Krec indicators into a single system, where each indicator performs a separate function, and the final decision is formed through their mutual interpretation.

An integrated ranking of the scenarios showed that the overall feasibility of the refurbishment did not vary in proportion to the level of initial expenditure, but depended on the balance between technical suitability, economic impact, investment performance, resource and energy sustainability, and risk exposure. Within the model assessment, scenarios involving a greater extent of technical upgrading achieved better rankings only when the increase in capital expenditure was offset by lower life-cycle costs, higher energy efficiency, better investment performance and reduced risks during the subsequent operational period. The integrated ranking of scenarios was performed using formula (4), in which the risk burden had a negative impact on the final index. Table 5 presents the model ranking of the four refurbishment scenarios.

Table 5. Model-based ranking of reconstruction scenarios using the Krec integral index

Scenario	T – technical suitability	E – economic impact	I – investment performance	S – Resource and energy sustainability	R – Risk exposure	K_{rec}	Relevancy rank
Saved current status	0.10	0.05	0.00	0.20	0.78	-0.09	IV
Partial modernisation	0.45	0.38	0.18	0.48	0.52	0.19	III
Comprehensive refurbishment	0.78	0.72	0.31	0.71	0.44	0.42	II
Comprehensive refurbishment with a digital and energy component	0.92	0.86	0.39	0.89	0.34	0.54	I

Source: calculated by the author using the integrated model for the technical and economic feasibility study of the reconstruction, in accordance with equations (4-5)

The data in Table 5 showed that the “maintain current status” scenario received the lowest overall score – $K_{rec} = -0.09$. This result was explained by the fact that the minimal current costs did not compensate for the low technical suitability, lack of investment returns, weak resource and energy efficiency, and the highest risk load – 0.78. The obtained value indicated that foregoing reconstruction may appear less costly only in the short term; however, in the longer term, it exacerbates the enterprise's technical, operational and energy constraints. The partial modernisation scenario received an integral index of $K_{rec} = 0.19$ and a third-place ranking in terms of feasibility. It demonstrated better values compared to the baseline option in terms of technical suitability, economic effect and resource-energy sustainability, but remained limited due to the localised nature of the upgrade. A risk load of 0.52 indicated that partial modernisation reduces certain technical and operational risks but does not eliminate the systemic constraints of the production and construction system. Comprehensive reconstruction was ranked second with a K_{rec} value of 0.42. Its advantage was determined by higher values for technical suitability (0.78), economic efficiency (0.72) and resource and energy sustainability (0.71). This scenario provided for a more comprehensive refurbishment of buildings, utility networks, equipment and the spatial layout. At the same time, the risk score of 0.44 remained significant due to the greater complexity of implementation, the larger scope of work and the need to coordinate several of the enterprise's subsystems. The highest overall score was awarded to the scenario involving comprehensive refurbishment with a digital-energy component – $K_{rec} = 0.54$, which secured it first place in terms of feasibility. Its advantage was linked to the highest values for technical feasibility – 0.92, economic effect – 0.86, and resource and energy sustainability – 0.89. The inclusion of digital monitoring, energy management and control of operational parameters enhanced the scenario's ability to reduce life-cycle costs and maintain the enterprise's manageability after the completion of the reconstruction. The lower risk load – 0.34 – indicated that, in the long term, the digital-energy component not only improves operational performance but also reduces the uncertainty of managing the reconstructed system. A comparison of the scenarios demonstrated that the overall feasibility of modernising enterprises in the construction sector was not determined by a single indicator. The scenario with the lowest initial costs had the worst overall outcome due to weak economic and resource-energy effects and a high-risk load. Partial modernisation brought about local improvements but did not ensure sufficient systematicity. Comprehensive refurbishment yielded the highest technical and economic performance, whilst comprehensive refurbishment incorporating a digital and energy component demonstrated the best balance between technical modernisation, economic benefits, investment returns, resource and energy sustainability, and risk management. The results of the integrated ranking made it possible to refine the overall logic behind the choice of reconstruction scenario. The most comprehensive assessment was provided by a combination of cost, design, energy, life-cycle, investment and risk-oriented logic. The K_{rec} integrated index made it possible to compare scenarios not only in terms of costs, but also in terms of their ability to ensure the long-term sustainability of the enterprise, reduce operational burden and maintain an acceptable level of risk. Therefore, the scenario in which technical modernisation was combined with energy management, life-cycle cost control and the reduction of risk uncertainty was deemed to have the highest methodological merit.

A summary of the findings showed that the technical and economic justification for the feasibility of renovating enterprises in the construction sector should be viewed as a system of interrelated models: regulatory and methodological, parametric, structural, scenario-based, and computational-integral. The normative-methodological model defined the assessment framework by combining cost, design, energy, life-cycle, environmental and risk-oriented requirements. The parametric model made it possible to identify five key factors determining the feasibility of reconstruction: technical suitability, economic impact, investment performance, resource and energy sustainability, and risk exposure. A scenario comparison showed that minimal initial costs do not guarantee the best outcome, as the "maintain current status" scenario had the highest risk load and the lowest long-term effect. Calculated-integral ranking demonstrated the advantage of a comprehensive refurbishment with a digital-energy component, which received the highest K_{rec} index due to the combination of technical upgrading, energy management, life-cycle cost control, and reduced risk uncertainty. The results confirmed that the choice of renovation scenario should be based not on a single indicator, but on a balanced combination of cost, return on investment, operational sustainability, energy efficiency and an acceptable level of risk.

Discussion

A comparison of the results obtained with current research showed that the proposed system of models expanded the traditional interpretation of renovation as a standalone investment or cost-estimation decision. In the present study, the feasibility of renovation was demonstrated through the interaction of regulatory-methodological, parametric, structural, scenario-based, and computational-integral models. This result was consistent with the findings of S. Cova *et al.* (2021), who, when assessing economically optimal investments in building retrofits, demonstrated the importance of combining the cost of measures with long-term outcomes. At the same time, the resulting model differed in its broader scope, as it transferred the logic of investment feasibility from the level of an individual building to the level of the construction industry as a production-construction system. A similar temporal dimension of renovation was evident in the study by I. Maia *et al.* (2021), where a step-by-step retrofit model was proposed, incorporating the optimal timing for implementing measures. The results presented complemented this approach, as they showed that the choice of scenario depended not only on the timing of implementation but also on a combination of technical feasibility, economic impact, investment performance, resource and energy sustainability, and risk exposure. The findings of P. Palma *et al.* (2021), which emphasised the cost of energy-efficient refurbishment of the housing stock, were also consistent with the conclusions reached: in the presented model, the initial cost did not act as an independent criterion of optimality, as the "maintain current state" scenario had the lowest capital expenditure index of 0.15, but received the worst overall ranking due to its poor operational performance and high-risk burden. The life-cycle logic of the results obtained was consistent with the direction of research in which renovation was considered in terms of total costs, environmental impacts and long-term operational performance. O. Fahlstedt *et al.* (2024), in a review of studies on building refurbishment and life-cycle assessment, demonstrated that the benefits of refurbishment cannot be accurately determined without considering the consequences throughout the entire period of the building's use. This was consistent with the result obtained, according to which the life cycle cost index became one of the key indicators in the scenario comparison. The conclusions of G. Maselli *et al.* (2024) regarding the use of Life Cycle Costing in structural analysis and design were consistent with the finding that, in the calculation and evaluation model, the life cycle cost indicator was used for the short-term cost-effectiveness of a scenario to be distinguished from its long-term viability. A similar issue regarding the limits of applying Life Cycle Costing in decision-making processes was examined by S. Gil *et al.* (2025). The results obtained confirmed their conclusion that the life-cycle approach must be integrated into a broader assessment framework, as it does not independently address technical suitability, return on investment and implementation risks. The findings of L. Gustavsson & C. Piccardo (2022) regarding the optimisation of energy retrofits across different materials, economic scenarios and energy supply systems were also consistent with a scenario-based model, in which the top ranking was not awarded to the cheapest option, but to the scenario offering the best balance of energy efficiency, life-cycle costs and risk manageability. The conclusions of H. Zhang *et al.* (2021) on the application of Pareto optimisation in the assessment of energy retrofits using life-cycle logic were similar to the integral ranking obtained, as in both cases optimality was determined not by a single indicator but by a balance between several criteria. The review by M. Papangelopoulou *et al.* (2025), dedicated to the financial evaluation of energy retrofits, confirmed the importance of combining investment and technical indicators, as reflected in the combination of payback period, net present value, life-cycle cost and the integrated retrofit feasibility index.

The parametric and scenario-based components of the results obtained were conceptually similar to studies in which renovation solutions were evaluated using multi-criteria models. J. Amorocho & T. Hartmann (2022) proposed a multi-criteria approach to the renovation of residential buildings using pairwise comparisons and the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method. The obtained results were consistent with this logic, as the parametric model also involved comparing several groups of indicators, but was adapted to enterprises in the construction industry and supplemented with a risk module. The study by P. Spūdys *et al.* (2025), in which payback was combined with embodied carbon costs and stakeholder priorities, supported the study's conclusion that renovation cannot be assessed solely based on the payback period. In the study's model, a shorter payback period did not guarantee higher overall feasibility if the scenario retained high risks or failed to ensure resource and energy sustainability. K. Theilig *et al.* (2025), comparing multi-criteria decision-making methods for energy renovation, showed that the ranking result depends on the structure of the criteria and the method of their weighting. This was directly relevant to the integrated ranking in this study, where the balanced distribution of weighting coefficients made it possible to demonstrate the underlying logic of scenario selection without reference to the priorities of a specific enterprise. At the same time, the obtained results expanded upon the approaches outlined by incorporating not only energy and financial parameters, but also technical suitability, operational resilience and risk exposure. A separate section of the comparison focused on the digitalisation of renovation solutions. S. Jiang *et al.* (2023) identified gaps and requirements for the application of automated architectural design in building renovation. The study's findings aligned with this direction, as the comprehensive renovation scenario with a digital-energy component received the highest overall rating precisely due to the combination of technical upgrades, digital monitoring of operational parameters and energy management. The bibliometric review by S. Adekunle *et al.* (2021) demonstrated the growing role of digital transformation in the construction industry, which was consistent with the results obtained: the digital-energy component reduced the risk load to 0.34 and enhanced resource and energy sustainability to 0.89. The conclusions of R. Charef & S. Emmitt (2020) regarding the use of BIM to overcome barriers to the circular economy were also relevant to the structural model obtained. In the study, digital support was not considered merely as a design tool, but was incorporated into a broader assessment system, where it influenced operational manageability, life-cycle cost control and the reduction of uncertainty in the refurbishment scenario. Thus, the findings complemented previous research in that digitalisation was linked not only to design accuracy but also to the overall feasibility of the plant's refurbishment. A comparison with works on the circular economy and sustainability in the construction sector showed that the proposed system of models corresponded to the broader trend of moving from one-off refurbishment solutions to long-term, balanced renewal strategies. B. Guerra & F. Leite (2021) identified stakeholders' awareness, barriers and factors influencing the implementation of the circular economy in construction, which aligned with the conclusion that it is necessary to take into account not only technical and financial parameters, but also organisational and risk-related factors. E. Gasparri *et al.* (2023) highlighted gaps in research on the circular economy in construction, particularly regarding the need for new integrated research frameworks. The resulting normative-methodological and parametric models partially met this need, as they combined cost, design, energy, life-cycle and risk logic within a single assessment framework. B. Dams *et al.* (2023) showed in an analysis of the scaling of bio-oriented construction that sustainable solutions require simultaneous consideration of technical capabilities, the market, resources and regulatory constraints. A similar pattern emerged in the present study: a high level of resource and energy sustainability would not provide an overall advantage without technical suitability, investment efficiency and controlled risk. This confirmed that the restructuring of enterprises in the construction sector should be assessed as a multi-factor process, rather than as a set of individual modernisation measures. The risk-oriented set of results was consistent with contemporary research on risk management in sustainable construction. R. Almashhour *et al.* (2025) examined the transition from traditional to sustainable risk management in the construction industry, which corresponded to the study's conclusion regarding the corrective role of risk exposure in the integrated model. In the present study, risk was not an external add-on to financial calculations, but directly reduced the final feasibility index of the refurbishment. Therefore, the "maintain current state" scenario received the lowest score of $K_{rec} = -0.09$ with a high-risk load of 0.78, despite a low capital expenditure index. A systematic review by F. Wang *et al.* (2025) on risk management in sustainable construction projects also confirmed the need to link risks to environmental, economic and technical parameters. The obtained results built on this logic by establishing a scenario ranking, in which a reduction in risk exposure became one of the criteria favouring a comprehensive refurbishment incorporating a digital and energy component. Thus, the risk module in the model served not a descriptive function but a computational and corrective one, thereby strengthening the rationale for selecting the refurbishment scenario.

A summary of the results showed that the proposed model system was consistent with the main trends in contemporary research on renovation, whilst at the same time expanding upon them by shifting the focus from an individual building, energy measure or financial indicator to the construction industry as a whole, viewed as an integrated production and construction system. Unlike approaches focused primarily on retrofit costs, energy renovation, life-cycle assessment or multi-criteria selection, this study combined regulatory-methodological, parametric, structural, scenario-based and integrated logic. The results obtained showed that the scenario of comprehensive renovation with a digital-energy component had the highest methodological feasibility, as it provided the best balance between technical modernisation, economic effect, investment performance, resource and energy sustainability, and risk exposure. This provided grounds for considering the integrated reconstruction feasibility index as a tool for the preliminary ranking of alternatives, which can be further refined based on actual data from specific enterprises in the construction industry in Ukraine.

Conclusions

The study has resulted in the development of a system of models for the technical and economic justification of the feasibility of renovating enterprises in the construction sector. It has been established that reconstruction cannot be assessed solely based on estimated cost, payback period or individual energy efficiency. Its feasibility is determined through the interaction of normative-methodological, parametric, structural, scenario-based and calculation-integral models. The normative-methodological systematisation made it possible to identify seven interrelated assessment dimensions: cost, design, spatial planning, energy, life cycle, environmental and risk-oriented. This facilitated a shift from viewing renovation as a separate cost-intensive measure to interpreting it as a comprehensive management and investment decision. The parametric model covered five key blocks: technical suitability, economic effect, investment performance, resource and energy sustainability, and risk exposure. The study determined that technical suitability determines the feasibility of reconstruction, economic effect and investment performance form financial viability, resource and energy sustainability reflect long-term operational effect, and risk exposure adjusts the final assessment. A comparison of the scenarios showed that the lowest initial costs do not guarantee the best outcome. The "maintain current status" scenario had the lowest capital expenditure index – 0.15 – but was characterised by the lowest operational benefit – 0.05, low energy efficiency – 0.20 – and the highest risk load – 0.78. The most balanced scenario was the comprehensive refurbishment with a digital-energy component: the technical upgrade index was 0.92, the operational benefit index – 0.86, energy efficiency was 0.89, LCC was 0.76, NPV was 0.39, and the risk load fell to 0.34. Integral ranking based on the K_{rec} index confirmed the superiority of comprehensive refurbishment with a digital-energy component, which received the highest Krec value of 0.54. Comprehensive refurbishment was second with Krec = 0.42, partial modernisation third with Krec = 0.19, whilst maintaining the current state received the lowest rating – K_{rec} = -0.09. The main limitation of the study is the theoretical nature of the standardised indices, which demonstrate the logic of the technical and economic justification without reference to the actual financial statements of a specific enterprise. Further research should verify the model on real enterprises in Ukraine's construction sector, refine the weighting coefficients for different types of enterprises, incorporate actual data on energy consumption, capital expenditure, cash flows and risks, and expand renovation scenarios to account for digital monitoring, BIM support and energy management systems.

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Моделі техніко-економічного обґрунтування доцільності реконструкції підприємств будівельної галузі

Олександр Підодня

Аспірант

Український державний університет науки і технологій

49010, вул. Лазаряна, 2, м. Дніпро, Україна

https://orcid.org/0009-0006-2156-0682

Анотація. Метою дослідження було розроблення системи моделей техніко-економічного обґрунтування доцільності реконструкції підприємств будівельної галузі з урахуванням технічних, інвестиційних, ресурсно-енергетичних, життєво-циклових і ризикових параметрів. У результаті сформовано нормативно-методичну, параметричну, структурну, сценарну та розрахунково-інтегральну моделі оцінювання реконструкційних рішень. Встановлено, що доцільність реконструкції не може визначатися лише кошторисною вартістю або строком окупності, оскільки вона залежить від взаємодії технічної придатності, економічного ефекту, інвестиційної результативності, ресурсно-енергетичної стійкості та ризикового навантаження. Сценарна модель дала змогу зіставити альтернативи не лише за початковими витратами, а й за довгостроковим ефектом, енергоефективністю, вартістю життєвого циклу та рівнем ризику. Сценарне порівняння показало, що збереження поточного стану має найнижчий індекс капітальних витрат – 0,15, але характеризується мінімальним експлуатаційним ефектом – 0,05, низькою енергоефективністю – 0,20 і найвищим ризиковим навантаженням – 0,78. Найвищу методичну доцільність продемонстрував сценарій комплексної реконструкції з цифрово-енергетичним компонентом: індекс технічного оновлення становив 0,92, експлуатаційного ефекту – 0,86, енергоефективності – 0,89, індекс вартості життєвого циклу – 0,76, індекс чистої приведеної вартості – 0,39, а ризикове навантаження знизилося до 0,34. Інтегральне ранжування підтвердило перевагу цього сценарію, який отримав індекс доцільності реконструкції 0,54. Це засвідчило, що найбільш обґрунтованим є сценарій, у якому технічне оновлення поєднується з цифровим контролем, енергоменеджментом, зниженням життєво-циклових витрат і керованим рівнем ризикової невизначеності. Практична значущість полягає у можливості використання запропонованої системи моделей для попереднього вибору доцільного сценарію реконструкції підприємств будівельної галузі України

Ключові слова: вартість життєвого циклу; інвестиційна результативність; ризикове навантаження; інтегральне ранжування; строк окупності