17. Meneylyuk, A., Chernov, I., Lobakova, L. (2014). Vybor effektivnyh modeley realizatsii proektov v usloviyah izmenyayushcheysya finansovoy situatsii. Visnyk Natsionalnoho tekhnichnoho universytetu "KhPI". Seriya: Stratehichne upravlinnia, upravlinnia portfeliamy, prohramamy ta proektamy, 2 (1045), 71–75. Available at: http://nbuv.gov.ua/UJRN/vntux_ctr_2014_2_13
18. Nikiforo, A. L., Menejlju, I. A. (2016). Efficient reconstruction of engineering buildings in conditions of organizational constraints. Automation of Technological and Business Processes, 8 (1), 60–65. doi: https://doi.org/10.21691/atbp.v8i1.24
19. Bose, R., Conno, W. (1960). Analysis of fractionally replicated 2"'-3" designs. Bull. L'lnst. Intern. Stat., 37, 141–160.
20. Cox, D. (1958). Planning of Experiments. John Wiley, 320.
21. Kalmus, H. (1952). The Design and Analysis of Experiments. By Oscar Kempthorne. New York. Annals of Eugenics, 17 (1), 96–97. doi: https://doi.org/10.1111/j.1469-1809.1952.tb02500.x
22. Brodskiy, V. Z., Brodskiy, L. I., Golikova, T. I., Nikitina, E. P., Panchenko, L. A. (1982). Tablitsy planov eksperimenta. Dlya faktornyh i polinomial'nyh modeley. Moscow: Metallurgiya, 753. Available at: https://www.twirpx.com/file/789483/

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CHOOSING THE RATIONAL MANAGEMENT OF HIGH-RISE BUILDING CONSTRUCTION PROJECTS

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Розроблено підхід до вибору раціонального управління проектами спорудження висотних будівель, який забезпечує ефективне використання ресурсів. Такий підхід спрямований на забезпечення економічності, енергоощадності, якості, безпечності та екологічності висотних будівель.

Запропоновано вирішувати такі завдання на основі пошуку раціональних рішень, що найбільше відповідають бажаним (заданим) техніко-економічним характеристикам (показникам), на основі застосування статистичного моделювання проектів як керованих процесів. Разом із цим доцільно враховувати вплив визначальних організаційно-технологічних, технічних та управлінських факторів. Для оцінювання рішень відносно цих факторів необхідно відшукати раціональне значення критерію ефективності управління. З позиції замовника (інвестора) в якості одного з таких критеріїв доцільно розглядати мінімум вартості спорудження висотних будівель.

Запропоновано враховувати вплив факторів якості, безпечності, енергоефективності, екологічності, оптимальної експлуатації висотної будівлі. Достатність і суттєвість впливу цих факторів на прийняття раціональних рішень при управлінні проектами висотного будівництва обгрунтовано результатами експертного опитування.

Отримано математичні моделі, які засновані на врахуванні системного впливу визначальних факторів. Ці моделі надають можливість кількісного оцінювання рівня досягнення заданого результату, зокрема за критерієм вартості спорудження висотних будівель, на різних етапах управління проектом.

Одержані результати є актуальними, оскільки дозволяють досягати раціональних значень бажаних показників у конкретних умовах виконання будівельно-монтажних робіт та в межах заданих ресурсних обмежень. Оперуючи прогнозованими оцінками очікуваних результатів, інвестори мають можливість відкоригувати свої цілі та обрати найбільш раціональний варіант реалізації інвестиційно-будівельного проекту

Ключові слова: проект, раціональне управління проектом, критерій ефективності управління, висотне будівництво, ефективне використання ресурсів, організаційно-технологічні, технічні та управлінські фактори

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1. Introduction

The development of modern cities is characterized by high population density, a shortage of land plots for the construction of the sites for different functional purposes, which, in turn, raises the cost of vacant sites in cities. It causes an increase in the number of stories in buildings and density of the city development, and in combination with measures of the economy, caused by the increasing scale of construction of buildings, makes high-rise buildings a viable alternative to modern development. Along with this, there arises the problem of finding territorial reserves for construction. In most major cities, these reserves can include degraded industrial zones, during the reconstruction of which with the change of their functional purpose, one can obtain modern buildings [1–3].

The modern concepts of sustainable development and compact cities determine the tendencies of a further increase in the number of floors in buildings [4].

Management of the project of high-rise building construction can be considered as the process of transition from the initial state (the state of unsatisfied needs in the premises for a certain functional purpose with specific quantitative and qualitative characteristics) to the final state (the state of satisfied needs regarding quantity and quality) under conditions of assigned resource restrictions.

In this case, a project of high-rise building construction as an object of control is under the following actions and influences:

– requirements for results, as well as the ways to achieve them;

– conditions of project implementation;

– resource restrictions;

– risks;

– external influences;

– internal influences.

Taking into account the specific features of high-rise building construction, planning, and implementation of such projects takes place under conditions of a changeable external environment, the impact of which on the state of projects complicates rational decision making.

2. Literature review and problem statement

Management of high-rise building construction projects involves making rational decisions aimed at reducing the cost of high-rise building construction. This is achieved by increasing the efficiency of resource use while meeting the requirements for efficiency, energy saving, safety, quality, and ecological friendliness of high-rise construction.

Paper [5] focuses on designing and constructing high-rise buildings. The city construction and architectural-structural aspects of designing high-rise buildings were considered. The effect of the functional purpose and the multi-story factor on the choice of the form and the structure of a high-rise building was determined. However, the author did not study the problem of organization and management of high-rise building construction projects.

The research, covered in paper [6], deals with the theory and practice of sustainable design of high-rise buildings, but considers mainly architectural and technological components of high-rise building construction, leaving the management processes beyond consideration.

The results of research into the used schemes of implementation of investment-construction processes are reported in paper [7]. The inconsistency of many solutions, some violation of technology, and organization of production works, safety, a significant excess of the actual cost, and time indicators of investment projects over the planned ones were revealed. The reason for this may be the poor quality of pre-project research and surveys. That is why it is expedient to improve methodological approaches to the design and operation of the system of managerial decision-making regarding the construction of high-rise buildings with a high-reliability level.

The application of a systemic approach to the development and implementation of construction projects is presented in article [8] in the context of the complexity of managing the projects related to stakeholders, and projects' sustainability in the context of resource supply. A new look at effective project management is given in study [9], which focuses on the principles of green construction and ecologically friendly buildings.

Article [10] deals with the substantiation of organizational and managerial decisions under conditions of the changeable external environment, taking into consideration the risk of a project. The difference of the proposed approach is refusal from a priori assumptions about the stochasticity of the studied processes and magnitudes, as well as in the application of the measurement theory. However, this approach involves the use of sufficiently complex analytical models, which do not exclude the subjectivity factor. That is why it is necessary to apply other approaches to the substantiation and the choice of managerial decisions, in particular, statistical modeling.

Paper [11] presents the author's approach to project management, which is based on the development of appropriate tools for the conditions of specific design-oriented enterprise. It is aimed at ensuring obtaining maximum results of a project under certain resource restrictions. Attention is paid to the management of influences in order to minimize their possible negative effect on a project. It is proposed to apply expert estimates to the assessment of priority parameters of a project (temporal, cost, qualitative). However, it is necessary to expand the set, taking into account the impact factor. In addition, determining the project quality requires specification.

The approach to the evaluation of the managerial implementation of the calendar plans of construction sites projects, taking into consideration the probabilistic nature of impact factors was formed in study [12]. However, only the organizational and technological processes of construction of residential facilities, which influence the level of managerial implementation of calendar plans, are taken into consideration. The systemic impact of determining factors in the management of project costs and resources is not taken into account.

Paper [13] proposed the methodological principles of the formation, evaluation, substantiation, and selection of organizational and technological decisions for the construction of high-rise multifunctional complexes under conditions of compacted urban areas. The impact of the factors of the building height, design complexity, construction, and management of investment and construction projects was taken into consideration in the substantiation of decisions in terms of costs and duration criteria. These decisions are aimed at ensuring the commissioning of facilities with the assigned technical and economic characteristics. However, the issues related to energy efficiency and environmental friendliness of high-rise buildings remained unresolved.

Article [14] focuses on the development of the applied toolset of the organization of biosphere compatible construction, implemented in the format of modern construction development based on the principles of environmental friendliness and energy saving. The determining components of the organization of the biosphere compatible construction were identified. However, in article [14], the management object is sports and health complexes, which do not take into consideration the specific characteristics of high-rise buildings and peculiarities of their technology and construction organization. Accordingly, this approach requires further improvement.

Paper [15] considers the task of assessing the investment attractiveness of construction projects in terms of risk and uncertainty. It was proposed to apply the methods of mathematical statistics in determining the project efficiency indicators. The possibility to evaluate the project effectiveness under various scenarios of risky events was taken into account. However, the proposed approach does not make it possible to compare simultaneously the alternative options of a project at different values of its key parameters, in particular, such as cost-effectiveness, energy efficiency, and environmental friendliness.

In paper [16], the advantages and disadvantages of various methodological approaches to the assessment of the risk level, related to a construction project are analyzed. However, the considered approaches involve the use of the standard mathematical apparatus. Ensuring the rational management of high-rise building construction project is a complex problem, the solution of which requires a systemic approach, based on consideration of a set of impact factors with the appropriate substantiation of the methods for determining quantitative values of these factors, in particular, by expert estimates.

Research [17] gives the analytical review of the studies of the selection of rational decisions in the field of civil engineering using multi-criteria optimization. It was proposed to create an integrated decision-making system combining the advantages of both BIM-technologies and subject-oriented design. Along with this, the issue of the relationship between different criteria at an increase in the number of criteria, setting the criteria hierarchy remains unresolved. The specific features of the management of high-rise building construction processes under conditions of uncertainty were not considered either.

Research [18] deals with the improvement of the green building assessment system. It was proposed to take into consideration the comprehensive influence of factors such as internal environment, materials, and intelligent systems when assessing the ecological friendliness of buildings. The interrelation of criteria, by which environmental friendliness of buildings is assessed, was taken into consideration. However, the obtained results are not balanced when it comes to the interests of all stakeholders.

In paper [19], the approaches to a preliminary assessment of investment-construction projects taking into account the stochastic nature of the processes were analyzed, which indicates the relevance of the task, considering the steady tendency towards an increase in the volume of high-rise construction. However, the issue of prediction and substantiation of the indicators of the effectiveness of organizational and technological solutions requires a systemic approach given a significant number of determining factors. Such factors are the magnitudes of different dimensionality, and that is why determining their influence requires a relevant mathematical apparatus. For this purpose, it is possible to use, for example, the theory of expert estimates, which is used in cases of problem complexity, its novelty, insufficiency of the existing information, or impossibility of formalization of the decision-making process. Thus, paper [20] gives an example of the application of the theory of expert estimates in determining the most expedient methods of repair and restoration of water supply networks. It seems also possible to spread the proposed approach to research into the choice of rational management of high-rise building construction projects. However, when applying the theory of expert estimates, it is advisable to consider the experience of the projects that are most successful and similar by basic indicators.

Thus, today there is no unified approach to the selection of the rational management of high-rise building construction, both in terms of consideration of impact factors, and in terms of the choice of management efficiency criterion. That is why it is proposed to consider a task of management of high-rise building construction as a task of searching for rational solutions, which best meet the desired (assigned) technical and economic characteristics (indicators), based on the application of statistical modeling of projects as manageable processes. At the same time, it is advisable to take into consideration the influence of determining organizational-technological, technical, and managerial factors in compliance with the requirements on cost-effectiveness, energy-saving, safety, quality, and ecological friendliness, when choosing a rational decision. To assess decisions regarding these factors, it is necessary to find a rational value of the management efficiency criterion. It will characterize the quality of the made decision and represent the extreme value of the objective function, as well as serve to compare alternative options and the selection of the most rational of them. From the customer's (investor's) position, it is appropriate to consider the minimum of the cost of high-rise building construction as one of the criteria.

3. The aim and objectives of the study

The aim of this study is to develop the approach to the selection of rational management of high-rise building construction, which ensures efficient use of resources. This approach is aimed at ensuring cost-effectiveness, energy-saving, quality, safety, and environmental friendliness of high-rise buildings.

To achieve the set aim, the following tasks have been solved:

– to systematize determining organizational-technological, technical and managerial factors, which characterize the specific requirements to cost-effectiveness, energy efficiency, quality, safety and environmental friendliness of high-rise buildings during their life cycle (design, construction, and maintenance);

– to formalize the factors that exert a significant influence on making rational decisions in the management of high-rise building construction project;

– to develop mathematical models, which are based on taking into account the systemic influence of determining factors and are intended for quantitative estimation of the level of achievement of the assigned result, in particular, by the cost criterion of high-rise building construction, at different stages of project management.

4. Materials and methods to study the rational management of high-rise building construction projects

25 projects were analyzed to research the rational management of high-rise building construction projects. Information about these projects was provided by the municipal organization "Institute of General Plan of Kyiv". The explored buildings of the height up to 150 m combine residential, entertaining, office, trade functions and are equipped with underground parking lots. These high-rise buildings belong to the frame ones, with the stiffness diaphragms and frame-tying, with monolithic reinforced concrete frames and brick non-bearing external walls, having a rectangular shape.

The following research methods were applied to solve the set tasks:

– a method of expert estimates – for the selection of factors that perform a determining influence on making rational decisions in the management of high-rise building construction projects;

– methods from the theory of probability and mathematical statistics, correlation-regression analysis – to select, process and analyze the source data, development of mathematical models that provide an opportunity to obtain quantitative estimates of the level of achievement of the assigned result, in particular, in terms of the cost of high-rise building construction, at various project management stages.

The appropriateness of the application of the method of expert estimates for making a reasonable decision on the selection from the composite list of determining factors is caused by the lack of statistical data on priority their impact on the studied indicators.

To identify the set of potential experts in the field of high-rise building construction, it is advisable to apply the most common and effective "snowball" method. The "snowball" method is effective because it makes it possible to identify a rather wide range of specialists, contains rich latent information, which can be detected as a result of additional analysis.

The method for assessing professional competence based on questionnaire self-assessment is rather productive to assess the competence of specialists. According to this method, the competence of experts is evaluated by the competence coefficient, calculated based on the subjective judgment of an expert about the degree of awareness about the problem solved and specification of the typical sources of reasoning of their ideas [21, 22].

To be able to use the results of problem-solving confidently, one must have reliable source data. The only way to obtain information in such cases is to collect the necessary data on other similar sites and their treatment by the methods of mathematical statistics.

The estimation and substantiation of authenticity, the uniformity of collected information and its obedience to the law of normal distribution are carried out by means of the root mean square deviation, variation factor, asymmetry index, and excess indicator.

The most difficult issue when creating mathematical models is to choose a communication form, that is, an analytical function that connects the elements of the explored system.

To model the relationships between the factor and resultant features, that is the selection of the appropriate regression equation, the systematized factors are subjected to correlation-regression analysis after their presenting in the form of paired and of multifactor models.

In order to assess the quality (reliability) of the chosen regression equation, the Fischer criterion [23] and the determination coefficient [23] are used.

5. Results of the systematization of influence factors in the rational management of high-rise building construction projects

In making rational decisions on the management of high-rise building construction, aimed at ensuring the efficient use of resources, it is necessary to take into account such factors as the space lack of a construction site, methods for construction organization, availability of storage areas for structures, reliability of organizational-technological solutions, and technological design solutions. That is why these factors were not considered in the study.

When forming the list of determining factors, the specific features of the design, construction, and maintenance of high-rise buildings and the fact that high-rise buildings belong to the sites with the increased level of responsibility were taken into account. The topical concepts of sustainable development of settlements, green construction, and compact cities were considered, literary sources were studied [24–28], and design and executive construction documentation of several high-rise facilities were analyzed. Based on the above, we formed the list of organizational-technological, technical and managerial factors, which to a large extent determine the character of high-rise construction and influence making rational decisions in the management of high-rise building construction projects:

1) organizational-technological factors:

– reliability of a construction organization (f_r);

– quality of a high-rise building (f_q);

2) technical factors:

– safety of a high-rise building (f_s);

– the energy efficiency of a high-rise building (f_{en});

– ecological friendliness of a high-rise building (f_{ec});

– labor productivity (f_{lp});

– harmonization of a high-rise building with the environment (f_{he});

– rational urban land use (f_{lu});

3) managerial factors:

– qualification of construction personnel (f_{qp});

– competence of administrative and management staff (f_c);

– staff motivation (f_{sm});

– optimal maintenance of a high-rise building (f_{om}).

In this study, the reliability of the construction organization implies the possibility of realizing the interests of the participants of high-rise construction.

The quality of a high-rise building is determined by its reliability, durability, technological efficiency, utility, and aesthetics.

The safety of a high-rise building implies its capacity not to pose threats to life and health of people, as well as for the environment during its maintenance.

The energy efficiency of a high-rise building is its property that is characterized by the amount of energy needed to ensure normal vital activity of people.

The ecological friendliness of a high-rise building implies minimizing its impacts on the environment.

Labor productivity is characterized by the ratio of the volume of works and the amount of labor spent to execute them.

Harmonization of a high-rise building with the environment implies that the building should not destroy the environment, but rather improve it.

Rational urban land use means effective, safe, investment-attractive, and sustainable land use, taking into consideration the value of urban areas.

Qualification of construction personnel is determined by the average tariff coefficient of brigades involved in high-rise building construction.

Competence of administrative and managerial staff is determined by the existence of communication skills, creativity, innovativeness, result-based orientation, flexibility, adaptability, availability of work experience, professionalism, leadership, organization and control over activity, motivation, and development of personnel.

Staff motivation is the impact on workers to form the need for high-performance work, increased interest in improving the final performance. It can be done by material, labor, and status motivation.

Optimum maintenance of a high-rise building involves minimizing capital investments and current costs for its maintenance.

20 experts were involved in the expert estimation of the degree of influence of the above-mentioned factors on the level of achievement of the assigned result of a project by the chosen criterion of management efficiency. The experts included scientists of higher education institutions of the construction profile and specialists of design and construction organizations. The number of experts was determined according to the recommendations [21, 22].

The results of the expert survey are consolidated in Table 1.

Based on the data of Table 1, we determined the coefficient of concordance of experts' opinions, which equals 0.75, which indicates a high concordance of experts' opinions.

To assess the significance of the concordance coefficient, we apply Pierson criterion (χ^2-criterion), which is equal to χ^2=165.

The table value of χ^2-criterion for $P(\chi^2)$=0.05 and the number of degrees of freedom $d.f.$=12–1=11 is $\chi^2_{tab}=19.68$.

According to Table 1, the diagram of the total ranks of the studied factors was plotted (Fig. 1).

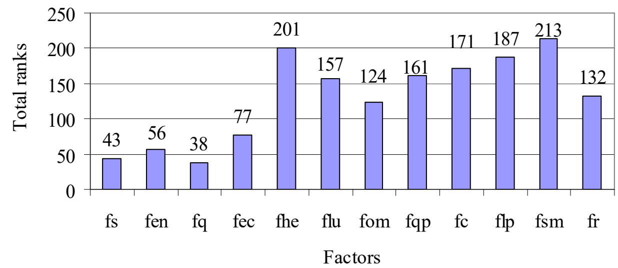

Fig. 1. Diagram of the total ranks of the studied factors by the results of expert estimation

According to the data in Fig. 1, taking into consideration the value of the average rank, which is equal to 130, we concluded that the factors that exerted determining influence on the level of achievement of the given project result by the criterion of costs of construction of high-rise buildings. From the studied 12 factors, the greatest influence on the cost of construction of high-rise buildings was made by factors f_q, f_s, f_{en}, f_{ec}, f_{om}, since the total ranks of these factors are minimal.

Table 1

Results of the expert survey regarding the influence of systematized factors on the level of achievement of the assigned project result

Experts	Factors												Total
	f_s	f_{en}	f_q	f_{ec}	f_{he}	f_{lu}	f_{om}	f_{qp}	f_c	f_{lp}	f_{sm}	f_r	
1	1	4	2	3	12	5	9	7	8	11	10	6	78
2	1	3	2	5	10	7	8	12	6	9	11	4	78
3	3	2	1	6	7	4	8	9	11	10	12	5	78
4	1	3	2	4	12	9	8	5	6	11	10	7	78
5	4	3	1	2	11	12	7	6	8	10	9	5	78
6	2	4	1	3	12	7	6	9	8	10	11	5	78
7	5	2	1	3	11	4	6	8	7	12	10	9	78
8	5	1	2	4	12	8	3	6	9	7	11	10	78
9	5	2	1	3	7	12	4	9	10	6	11	8	78
10	3	4	1	2	12	10	5	9	6	11	8	7	78
11	1	4	2	3	10	12	7	6	9	11	8	5	78
12	2	4	1	3	11	9	8	7	10	6	12	5	78
13	1	3	2	4	11	6	5	7	8	10	12	9	78
14	2	1	4	3	6	5	7	8	9	10	12	11	78
15	1	2	3	6	11	12	5	10	9	7	8	4	78
16	1	2	3	4	6	7	5	12	11	8	10	9	78
17	1	3	2	5	11	8	9	7	6	10	12	4	78
18	1	3	4	2	11	7	5	8	9	10	12	6	78
19	2	3	1	6	11	9	4	7	10	8	12	5	78
20	1	3	2	6	7	4	5	9	11	10	12	8	78
t_j	43	56	38	77	201	157	124	161	171	187	213	132	1,560
Δ_j	–87	–74	–92	–53	71	27	–6	31	41	57	83	2	0
Δ_j^2	7,569	5,476	8,464	2,809	5,041	729	36	961	1,681	3,249	6,889	4	42,908

Thus, organizational-technological, technical and managerial factors that have a decisive influence on the cost of construction of high-rise buildings are: among the organizational-technological factors – the quality of a high-rise building (f_q), among technical factors – the safety of a high-rise building (f_s), the energy efficiency of a high-rise building (f_{en}), the environmental friendliness of a high-rise building (f_{ec}), among the management factors – the optimal maintenance of a high-rise building (f_{om}).

6. Results of the formalization of influence factors in the rational management of high-rise building construction projects

For quantitative estimation of the above factors, it is advisable to use dimensionless factors, the values of which vary from 0 to 1.

With this regard, the factors that exert a decisive influence on the cost of high-rise construction were formalized.

Thus, the cost of high-rise building construction (C) depends on the quality, safety, energy efficiency, environmental friendliness, optimal maintenance of a high-rise building:

$$C = f\left(f_q, f_s, f_{en}, f_{ec}, f_{om}\right), \quad (1)$$

where f_q is the factor of quality of a high-rise building; f_s is the factor of safety of a high-rise building; f_{en} is the factor of energy efficiency of a high-rise building; f_{ec} is the factor of environmental friendliness of a high-rise building; f_{om} is the factor of ensuring the optimal maintenance of a high-rise building.

These characteristics are formed and consumed throughout all stages of the life cycle of high-rise buildings.

Determining the values of each of the factors (quality, safety, energy efficiency, environmental friendliness, optimal maintenance) throughout the entire life cycle (designing, construction, operation) of a high-rise building is carried out using the method of expert estimates.

The quality of a high-rise building is determined from the following formula:

$$f_q = \frac{\sum_{j=1}^{m} f_{q_j}}{m}, \quad (2)$$

where f_{q_j} is the j-th component of the factor of quality of a high-rise building (Fig. 2); m is the number of components of the factor of the quality of a high-rise building.

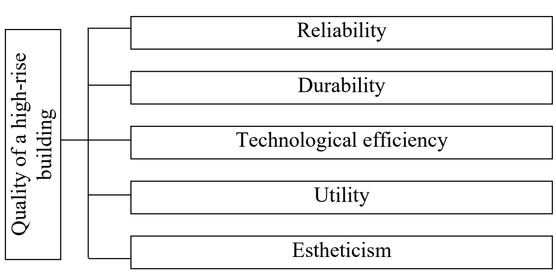

Fig. 2. Components of the factor of quality of a high-rise building

Safety of a high-rise building is determined from the following formula:

$$f_s = f_{s_t} \cdot w_{s_t} + f_{s_b} \cdot w_{s_b}, \quad (3)$$

where f_{s_t}, f_{s_b} are the components of the territory safety and safety of a building itself, respectively; w_{s_t}, w_{s_b} are the weight coefficients of the components of territory safety and safety of a building itself, respectively.

The values of weight coefficients of the components of the territory safety $\left(w_{s_t}\right)$ and safety of a building itself $\left(w_{s_b}\right)$ are determined by the methods of expert estimates, in this case $w_{s_t} + w_{s_b} = 1$.

The components of territory safety and safety of a building itself are shown in Fig. 3 are determined from the following formulas:

$$f_{s_t} = \frac{\sum_{i=1}^{n} f_{s_{t_i}}}{n}, \quad (4)$$

where $f_{s_{t_i}}$ is the i-th component of safety of the territory of a high-rise building; n is the number of components of the safety of the territory of a high-rise building.

$$f_{s_b} = \frac{\sum_{z=1}^{w} f_{s_{b_z}}}{w}, \quad (5)$$

where $f_{s_{b_z}}$ is the z-th component of a high-rise building itself; w is the number of components of the safety of a high-rise building itself.

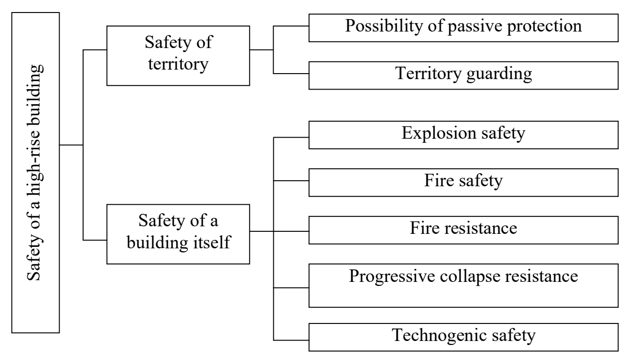

Fig. 3. Components of the safety factor of a high-rise building

To calculate the factor of energy efficiency of a high-rise building, the formula is proposed:

$$f_{en} = f_{en_1} \cdot w_{en_1} + f_{en_2} \cdot w_{en_2}, \quad (6)$$

where f_{en_1} is the component of the energy efficiency factor that characterizes the improvement of thermotechnical indicators of enclosing structures (Fig. 4); f_{en_2} is the component of the energy efficiency factor that characterizes consumption of power resources by engineering systems (Fig. 4); w_{en_1} is the weight factor of the component of the energy efficiency factor that characterizes the improvement of thermotechnical indicators of enclosing structures; w_{en_2} is the weight factor of the component of the energy efficiency factor that characterizes the consumption of power resources by engineering systems.

The values of weight factors of the components of the energy efficiency factor are determined by the method of expert estimates, in this case $w_{en_1} + w_{en_2} = 1$.

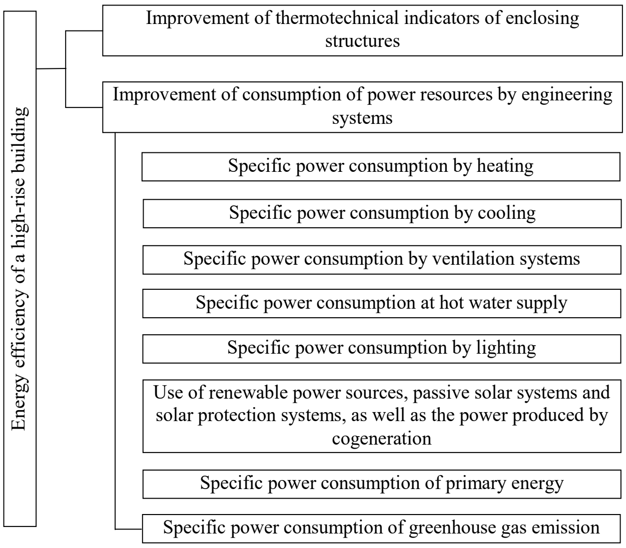

Fig. 4. Components of the energy efficiency factor of a high-rise building

The value of the component of the energy efficiency factor, which characterizes the improvement of thermotechnical indicators of enclosing structures, is calculated from the following formula:

$$f_{en_1} = \frac{\sum_{k=1}^{l} f_{en_{1_k}}}{l}, \tag{7}$$

where $f_{en_{1_k}}$ is the k-th element of the component of the energy efficiency factor, which characterizes the improvement of thermotechnical indicators of enclosing structures (Fig. 4); l is the number of elements of the components of the energy efficiency factor, which characterizes the improvement of thermotechnical indicators of enclosing structures.

The value of the component of the energy efficiency factor, which characterizes the consumption of energy resources by engineering systems, is calculated from the following formula:

$$f_{en_2} = \frac{\sum_{g=1}^{h} f_{en_{2_g}}}{h}, \tag{8}$$

where $f_{en_{2_g}}$ is the g-th element of the component of the energy efficiency factor, which characterizes consumption of power resources by engineering systems (Fig. 4); h is the number of elements of the component of the energy efficiency factor, which characterizes consumption of power resources by engineering systems.

It is proposed to determine the environmental friendliness of a high-rise building as follows:

$$f_{ec} = f_{ec_1} \cdot w_{ec_1} + f_{ec_2} \cdot w_{ec_2}, \tag{9}$$

where f_{ec_1} is the component of the factor of environmental friendliness of a high-rise building exterior (Fig. 5); f_{ec_2} is the component of the factor of environmental friendliness of a high-rise building interior (Fig. 5); w_{ec_1}, w_{ec_2} are the weight factors of components of the factor of environmental friendliness of a high-rise building exterior of interior.

The values of weight factors of the components of the factor of environmental friendliness of a high-rise building exterior $\left(w_{ec_1}\right)$ and interior $\left(w_{ec_2}\right)$ are determined by the method of expert evaluation, in this case

$$w_{ec_1} + w_{ec_2} = 1.$$

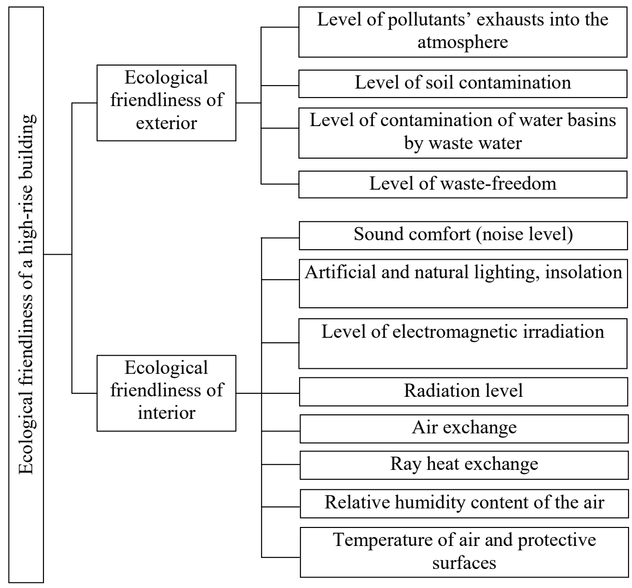

Fig. 5. Components of the factor of environmental friendliness of a high-rise building

The value of the component of the factor of environmental friendliness of the exterior of a high-rise building is calculated from the following formula:

$$f_{ec_1} = \frac{\sum_{p=1}^{q} f_{ec_{1_p}}}{q}, \tag{10}$$

where $f_{ec_{1_p}}$ is the p-th element of the component of the factor of the environmental friendliness of a high-rise building exterior; q is the number of elements of the component of the factor of the environmental friendliness of the high-rise building exterior.

The value of the component of the factor of the environmental friendliness of the high-rise building interior is calculated from the formula that is similar to formula (10).

The factor of ensuring the optimal maintenance of a high-rise building is calculated from the following formula:

$$f_{om} = \frac{\sum_{u=1}^{v} f_{om_u}}{v}, \tag{11}$$

where f_{om_u} is the u-th component of the factor of ensuring the optimal maintenance of a high-rise building (Fig. 6); v is the number of components of the factor of ensuring the optimal maintenance of a high-rise building.

These factors should be taken into consideration during rational management of the high-rise building construction projects.

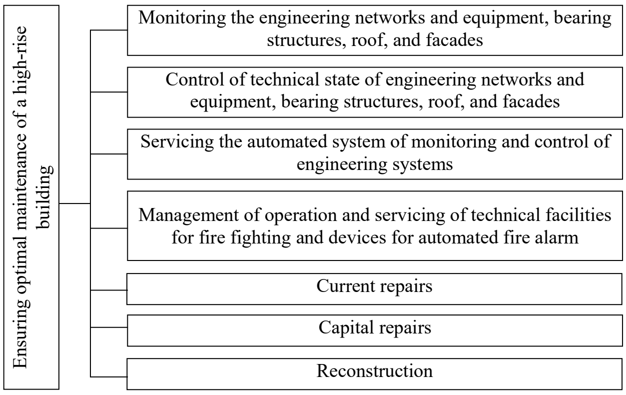

Fig. 6. Components of the group of factors for ensuring efficient maintenance of a high-rise building

7. Results of development of the mathematical models for the rational management of high-rise building construction projects

As a result of collecting and evaluating the source information, it was established that the value of the cost of high-rise building construction and determining factors changed within the following range (Table 2).

Table 2

Statistical characteristics of the studied indicators and determining factors

Statistical characteristics	Name of indicators and factors					
	C, USD/m^2	f_q	f_s	f_{en}	f_{ec}	f_{om}
Minimal value	900	0.79	0.85	0.78	0.7	0.72
Maximal value	2.400	0.9	0.94	0.91	0.88	0.86
Mean value	1,869.2	0.822	0.9	0.847	0.781	0.775
Root mean square deviation	356.757	0.027	0.032	0.038	0.046	0.031
Variation coefficient	19.086	3.3087	3.579	4.435	5.908	4.063
Asymmetry indicator	−1.177	1.134	−0.298	−0.027	0.25	1.029
Excess indicator	0.948	1.412	−1.59	−0.778	−0.566	1.678
A/m_a	−2.4	2.315	−0.609	−0.055	0.51	2.101
E/m_e	0.96787	1.441	−1.623	−0.794	−0.578	1.713

Note: A is the asymmetry indicator, E is the excess indicator, m_a is the asymmetry error, m_e is the excess error

According to the data given in Table 2, we can conclude that the source information is reliable and homogeneous, it obeys the law of normal distribution and can be used in the process of modeling the relations between the factor and resulting features.

According to the results of all types of dependences of the cost of high-rise building construction on the determining factors, the models, which rank first by the quality of experimental research approximation, were selected (Table 3).

With the purpose of clarification of obtaining the paired models and taking into consideration the mutual complex influence of determining organizational-technological, technical, and managerial factors on the level of achievement of the assigned result according to the cost of high-rise building construction, the multifactor models were analyzed.

Table 3

Paired models for rational management of the high-rise building construction projects

Type of dependence	R	R^2, %	Value of the Fisher criterion	
			actual value, F_{act}	tabular value, F_{tab}
$C = 11{,}182.0 - \frac{7{,}649.99}{f_q}$	−0.83	69.99	53.64	4.28
$C = 2{,}823.06 + 8{,}983.46 \cdot \ln f_s$	0.906	82.15	105.86	4.28
$C = 3{,}120.57 + 7{,}508.6 \cdot \ln f_{en}$	0.935	87.51	161.22	4.28
$C = 3{,}263.66 + 5{,}596.55 \cdot \ln f_{ec}$	0.923	85.25	132.92	4.28
$C = 3{,}868.41 + 7{,}817.21 \cdot \ln f_{om}$	0.875	76.6	75.28	4.28

Note: R is the correlation factor; R^2 is the determination factor

According to the results of the analysis of all types of dependences of costs of high-rise building construction of the organizational-technological, technical, and managerial factors, the models which rank first place by the quality of the experimental research approximation were selected (Table 4).

The proposed mathematical models are based on taking into account the systemic influence of determining factors and give an opportunity for quantitative evaluation of the level of achievement of the assigned result, in particular, by the criterion of the cost of high-rise building construction, by the information existing at a certain stage project management stage.

Upon receipt of additional information, in particular, concerning the conditions of high-rise building construction and resource restrictions, the expected costs may be specified at the following stages of high-rise building construction.

For example, in the case of a change in the investment dynamics, resource supply conditions, market conditions, etc., there can be corrective influences, in particular, in the form of changes in the duration of stages, which, in turn, will affect the cost of high-rise building construction.

Table 4

Multifactor models for rational management of high-rise building construction projects

Type of dependence	R^2, %	F_{act}	F_{tab}
$C = -7{,}225 + 6{,}861.5 \cdot f_s + 3{,}767.81 \cdot f_{om}$	84.63	60.6	3.44
$C = -1{,}095.94 - 6{,}617.37 \cdot f_q + 10{,}766.8 \cdot f_{ec}$	85.59	65.3	3.44
$C = -4{,}028.38 + 8{,}933.98 \cdot f_{en} - 9{,}579.04 \cdot f_q + 8{,}006.39 \cdot f_{om}$	88.4	53.2	3.07
$C = -298.872 - 15{,}532.8 \cdot f_q + 9{,}409.18 \cdot f_{ec} + 9{,}799.58 \cdot f_{om}$	88.4	53.3	3.07
$C = -5{,}000.55 + 8{,}418.66 \cdot f_s - 15{,}423.7 \cdot f_q + 15{,}455.7 \cdot f_{om}$	89.8	61.7	3.07
$C = -2{,}657.5 + 5{,}556.65 \cdot f_s - 16{,}886.1 \cdot f_q + 4{,}897.17 \cdot f_{ec} + 12{,}373 \cdot f_{om}$	91.6	54.6	2.87

8. Discussion of results regarding the selection of the rational management of high-rise building construction projects

According to the research results, the approach to the selection of rational management of high-rise building construction, which ensures effective use of resources, was developed.

The results of research into the systematization of the influencing factors, presented in Table 1, show that according to the results of the expert survey, the factors of quality, safety, energy efficiency, environmental friendliness, and optimal maintenance of a high-rise building have the decisive influence. Such results are explained by the orientation of design and construction organizations to the greening of the investment and construction projects and energy-efficient construction.

These results caused the need to continue research, specifically, those that focus on formalization of determining influence factors under rational management of high-rise building construction projects, shown in Fig. 2–6 and in formulas (2) to (11). Their existence makes it possible to obtain quantitative values of influence factors, which is a prerequisite of their application in statistical modeling.

According to the results of modeling of the relations between the factorial and resulting features, the most statistically reliable paired (Table 3) and multifactor models (Table 4) for the rational management of high-rise building construction projects were established. Assessment of the established dependences of costs of high-rise building construction on the determining factors by Fischer criterion, as well as practical approbation in the design and construction organizations proved their adequacy of the actual process of management of high-rise building construction projects. The developed models, thanks to taking into consideration of the systemic influence of determining factors, enable quantitative assessment of the level of achievement of the assigned result, in particular, by the criterion of costs of high-rise building construction. This is explained by the fact that cost is a manageable parameter, by which the ultimate results are estimated from the point of view of the compliance of the actual state of a project with the planned one, the compliance of the obtained result of a project with the investor's requirements.

The main feature of the developed approach is that controlling the changes in the values of influence factors within given resource restrictions, we obtain different variants of solutions with corresponding values of the cost of high-rise building construction. A customer (investor) will choose the most rational solution from the obtained variants, depending on the possibilities and desires.

A controversial issue of the conducted study is a change in the cost over time, however, this drawback can be eliminated by the application of the coefficient determined based on the indicators of the indirect cost of housing in the regions; inflation indices; changes in the cost of construction and mounting works.

Restrictions on the application of this research results lie in the fact that they relate only to the frame buildings with stiffness diaphragms and frame-tying buildings with a monolithic reinforced concrete frame of 150 m in height.

The development of the above-mentioned research implies the expansion of the set of the considered influence factors, based on which decisions on the choice of the rational management of high-rise building construction, are formed.

9. Conclusions

1. To choose the rational management of the high-rise building construction projects, it is proposed to apply the approach based on the search for solutions that best correspond to the desired (assigned) technical and economic characteristics (indicators), based on the use of statistical modeling of projects as manageable processes. At the same time, when choosing a rational decision, it is advisable to take into consideration the influence of determining organizational-technological, technical, and managerial factors in compliance with the requirements on cost-effectiveness, energy-saving, safety, quality, and environmental friendliness. The structure of the organizational and technological factors include: reliability of a construction organization, the quality of a high-rise building. The examined technical factors include: the safety of a high-rise building, energy efficiency of a high-rise building, environmental friendliness of a high-rise building, labor productivity, harmonization of a high-rise building with the external environment, rational urban land use. The management factors included: qualification of construction personnel, the competence of administrative and managerial staff, staff motivation, optimal maintenance of a high-rise building. The assessment of decisions concerning these factors requires the search for the rational value of the management efficiency criterion. It will characterize the quality of the taken decision and will represent the extreme value of the objective function, as well as will serve to compare alternative options and choose the most rational of them. From the customer's (investor's) position, it is advisable to consider the minimum cost of high-rise building construction as one of these criteria.

2. Using the methods of expert estimates, we selected a set of factors that characterize the specific features of the process of high-rise building construction and significantly affect the level of achievement of the assigned project result, in particular, by the cost criterion. The factors that make the greatest influence on the cost of construction of high-rise buildings were formalized: the quality of a high-rise building, safety of a high-rise building, energy efficiency of a high-rise building, environmental friendliness of a high-rise building, and optimal maintenance of a high-rise building.

3. According to the results of modeling, the statistically reliable models, based on consideration of the systemic influence of the influence factors and provide quantitative estimates of the level of achievement of the assigned result at different stages of project management, were obtained. These models do not contradict to regulatory procedures for the development and approval of the project documentation. They create the preconditions for the formation of design decisions, determining the direction of the achievement of the set goal, and if there are alternative variants, they are scientifically substantiated toolset for choosing among them of the rational one using the cost criterion. The application of the developed approach makes it possible to reach rational values of predicted indicators under specific conditions of execution of construction and mounting works within the specified resource restrictions. By operating predictive estimates of the expected results, investors have the opportunity to adjust their goals and choose the most rational variant of project implementation.

References

1. Goncharenko, D. F., Karpenko, Yu. V., Meersdorf, E. I. (2013). Vozvedenie mnogoetazhnyh karkasno-monolitnyh zdaniy. Kyiv: A+S, 128.
2. Beedle, L. S., Ali, M. M., Armstrong, P. J. (2007). The skyscraper and the city: design, technology, and innovation. Lewiston: Edwin Mellen Press.
3. Tamboli, A. R. (2014). Tall and supertall buildings: planning and design. McGraw-Hill.
4. Kravchunovska, T. S., Bronevytskyi, S. P., Kovalov, V. V., Danylova, T. V., Tkach, T. V. (2019). Planuvannia rozmishchennia i orhanizatsiya budivnytstva ta rekonstruktsiyi obiektiv dostupnoho zhytla z urakhuvanniam mistoformuiuchykh osoblyvostei terytoriy velykykh mist. Dnipro: Litohraf, 228.
5. Maklakova, T. G. (2008). Vysotnye zdaniya. Gradostroitel'nye i arhitekturno-konstruktivnye problemy proektirovaniya. Moscow: ASV, 160.
6. Yeang, K. (Ed.) (2011). Green design: from theory to practice. London: Black Dog, 144.
7. Mlodetskiy, V. R., Tyan, R. B., Popova, V. V., Martysh, A. A. (2013). Organizatsionno-tehnologicheskaya i ekonomicheskaya nadezhnost' v stroitel'stve. Dnepropetrovsk: Nauka i obrazovanie, 194.
8. Walker, A. (2015). Project management in construction. New Jersey: Wiley-Blackwell, 352.
9. Levy, S. M. (2012). Project management in construction. New York: McGraw-Hill, 496.
10. Zaiats, Y. I., Kravchunovska, T. S., Kovalov, V. V., Kirnos, O. V. (2018). Risk level assessment while organizational-managerial decision making in the condition of dynamic external environment. Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu, 2, 123–129. doi: https://doi.org/10.29202/nvngu/2018-2/24
11. Teslia, I., Yehorchenkov, O., Khlevna, I., Khlevnyi, A. (2018). Development of the concept and method of building of specified project management methodologies. Eastern-European Journal of Enterprise Technologies, 5 (3 (95)), 6–16. doi: https://doi.org/10.15587/1729-4061.2018.142707
12. Zaiats, Ye. I., Mlodetskyi, V. R., Tkach, T. V., Martysh, O. O. (2019). Metody zabezpechennia upravlinskoi realizovanosti kalendarnykh planiv zvedennia obiektiv budivnytstva. Dnipro: Aktsent-PP, 148.
13. Zaiats, Ye. I. (2015). Zvedennia vysotnykh bahatofunktsionalnykh kompleksiv: orhanizatsiyno-tekhnolohichni aspekty. Dnipropetrovsk: PDABA, 208.
14. Chernyshev, D. O. (2017). Metodolohiya, analitychnyi instrumentariy ta praktyka orhanizatsiyi biosferosumisnoho budivnytstva. Kyiv: KNUBA, 294.
15. Sizova, N., Starkova, O., Solodovnik, G., Dolgova, N. (2019). Development of a computer model for evaluating the alternative options of an investment and construction project under conditions of uncertainty and risk. Eastern-European Journal of Enterprise Technologies, 6 (3 (102)), 66–76. doi: https://doi.org/10.15587/1729-4061.2019.184376
16. Lytvynenko, O. V. (2015). Risk assessment and organizational-technological reliability of construction projects. Shliakhy pidvyshchennia efektyvnosti budivnytstva v umovakh formuvannia rynkovykh vidnosyn, 33, 184–190.
17. Zavadskas, E., Antucheviciene, J., Vilutiene, T., Adeli, H. (2017). Sustainable Decision-Making in Civil Engineering, Construction and Building Technology. Sustainability, 10 (2), 14. doi: https://doi.org/10.3390/su10010014
18. Shao, Q.-G., Liou, J., Weng, S.-S., Chuang, Y.-C. (2018). Improving the Green Building Evaluation System in China Based on the DANP Method. Sustainability, 10 (4), 1173. doi: https://doi.org/10.3390/su10041173
19. Kovalov, V. V., Kirnos, O. V. (2018). Modern approaches to the preliminary assessment of investment-building projects with the stochasticity of processes. New Technologies in Construction, 34, 39–42.
20. Goncharenko, D. F., Veveler, H., Aleynikova, A. I. (2015). Ekspluatatsiya, remont i vosstanovlenie truboprovodov vodosnabzheniya. Kharkiv: Raritety Ukrainy, 280.
21. Kryuchkovskiy, V. V., Petrov, E. G., Sokolova, N. A., Hodakov, V. E. (2011). Introspektivniy analiz. Metody i sredstva ekspertnogo otsenivaniya. Kherson: Grin' D.S., 168.
22. Orlov, A. I. (2011). Organizatsionno-ekonomicheskoe modelirovanie. Ch. 2: Ekspertnye otsenki. Moscow: Izd-vo MGTU im. N.E. Baumana, 486.
23. Ershova, N. M., Skripnik, V. P. (2011). Ekonomiko-matematicheskie metody i modeli prinyatiya resheniy v usloviyah opredelennosti, neopredelennosti i riska. Dnepropetrovsk: PGASA, 350.
24. Kovalov, V. V., Danylova, T. V., Yepifantseva, S. V. (2018). Systemization of organizational and technological and other factors affecting the cost of building objects, with the requirement for their energy efficiency and environmentality. Bulletin of Prydniprovs'ka State Academy of Civil Engineering and Architecture, 6, 57–64. doi: https://doi.org/10.30838/j.bpsacea.2312.261218.57.448
25. Kovalov, V. V., Kravchunovska, T. S., Danylova, T. V., Yepifantseva, S. V. (2019). Formuvannia vymoh do obiektiv budivnytstva protiahom yikh povnoho zhyttievoho tsyklu. Shliakhy pidvyshchennia efektyvnosti budivnytstva v umovakh formuvannia rynkovykh vidnosyn, 39 (1), 179–186.
26. Kobeleva, S. (2013). The scenarios of housing in view of the influence of the environmental factors. Stroitel'stvo i rekonstruktsiya, 3 (47), 33–38.
27. Lapteva, A. Y., Chervona, A. O. (2015). Reliability of the construction company and its evaluation (example of public company «Makrocap Development Ukraine»). Scientific Bulletin of Civil Engineering, 1, 248–251.
28. Savytskyi, M., Benderskyi, Y., Babenko, M. (2014). Assessment of environmental parameters of object construction. Academic Journal. Industrial Machine Building, Civil Engineering, 1 (3 (42)), 144–149. Available at: http://znp.nupp.edu.ua/files/archive/ua/2014/42_1/144-149.pdf