METHOD FOR REDUCING THE LIFE CYCLE COSTS OF OBJECTS AT THE PRE-PROJECT STAGE OF CONSTRUCTION BASED ON RISK AND SUITABILITY FACTOR MANAGEMENT WITH BIM AND GIS INTEGRATION

Azariy Lapidus, Roman Samsonov, Maksim Kuzmich

National Research Moscow State Construction University (NIU MSCU); Moscow, RUSSIA
maksadvs@gmail.com

Abstract

The article proposes a methodology for reducing the life cycle cost of construction projects at the early pre-design stage through risk management and site suitability assessment using the integration of building information modeling (BIM) and geographic information systems (GIS) technologies. The pre-design stage is characterized by a high degree of uncertainty and risk, which has a significant impact on the subsequent stages of the project. The article describes an approach in which GIS data (relief, geological and climatic conditions, land use restrictions, etc.) are integrated into a BIM model for spatial analysis of the site. The calculation of risk (R) and suitability (S) indices is based on the normalization and weighting of influencing factors. The territory is then classified according to the S-index level. The results of this process are the generation of a "site passport", which is a document that summarizes the conditions and includes engineering recommendations for risk reduction. The method enables the identification of optimal sites at the conceptual planning stage, as well as the anticipation of engineering solutions in advance. This process serves to reduce uncertainty and costs throughout the life cycle of the facility.

Keywords: BIM, GIS, pre-project stage, life cycle, suitability and risk coefficients, multi-criteria assessment, sensitivity analysis.

I. Introduction

The pre-project (pre-investment) stage of a construction project's life cycle determines strategic decisions that largely influence subsequent construction and operating costs. This period is characterized by the greatest uncertainty in the initial data and conditions for project implementation. Nevertheless, it is at this early stage that the key factors for project success are established, and there is the greatest potential to influence costs and risks before the decisions made become difficult to reverse. The principle of life cycle cost management assumes that investments in research and risk analysis at early stages can pay off many times over by preventing costs associated with eliminating problems during construction and operation. For example, construction in permafrost areas without proper consideration of geocryological risks can lead to serious damage to infrastructure and high repair costs [1][2]. Thus, reducing uncertainty at the start of a project through effective risk management is a critical task.

In modern conditions, digital technologies such as Building Information Modeling (BIM) and Geographic Information Systems (GIS) are increasingly being used to solve this problem. BIM models are traditionally used for project detailing and 3D visualization during the design and construction stages, but when integrated with GIS, they become a powerful tool for analyzing sites in a geospatial context [3][4]. GIS, for its part, provides extensive spatial data on site conditions (relief, soils, climate, ecology, infrastructure, etc.) and tools for multi-criteria analysis of the territory. The combination of these technologies (BIM+GIS) allows the creation of a digital twin of the territory with engineering data linked to the geography of the area, which significantly improves the validity of decisions made at an early stage [5]. Research shows that the integration of BIM and GIS at the planning and design stages provides decision-makers with multi-scale, semantically rich information about the project and allows them to evaluate schedules, costs, and sustainability in a virtual environment before construction begins. As a result, this reduces risks, optimizes costs, and improves safety and environmental performance throughout the entire life cycle of the facility [6].

This paper aims to describe a methodology that allows for the systematic consideration of risks and the suitability factor of a territory when selecting a site and making early design decisions. The suitability factor is understood as a comprehensive criterion that reflects the degree to which a site meets construction requirements, taking into account a combination of geographical, engineering-geological, environmental, and regulatory factors [7]. The idea is to calculate an integral suitability index (S) to compare alternative sites or planning options, while simultaneously assessing the risk index (R), which characterizes potential adverse effects. The methodology uses GIS data to quantitatively assess factors (such as terrain relief, soil type and condition, presence of permafrost, groundwater level, proximity to water bodies, etc.), which are then integrated into a BIM model of the site's relief. By normalizing the indicators and assigning weighting coefficients to them, the S and R indices are calculated, on the basis of which the territory is classified into categories of suitability. The final result is the creation of a "site passport" — a document containing all key information about the site, identified risks, and recommendations for engineering measures to mitigate them. It is expected that the application of this method will reduce uncertainty and the total life cycle cost of the facility through early risk identification and optimization of design choices.

II. Methods of risk analysis and calculation

The first stage is the collection and integration of spatial data. At this stage, a digital model of the site is formed, combining a BIM model of the terrain with geoinformation data layers. The following data is used as source data: a digital terrain model (e.g., based on topographic surveys or remote sensing data), engineering and geological surveys (maps of soil types, bearing capacity, seasonal frost depth, and permafrost distribution), hydrogeological data (groundwater levels, flooding), climatic data (e.g., presence of permafrost, depth of seasonal thaw), as well as information about the environment and land use restrictions (proximity to watercourses and depressions, protected areas, sanitary gaps, existing buildings and communications) (see Fig. 1). Data is collected from various sources, including engineering survey results, open spatial data, and industry GIS databases. All spatial data is converted to a single coordinate system and uploaded to a GIS platform for further processing. At the same time, based on topographic data in a BIM environment (Autodesk Revit, Archicad, etc.), a three-dimensional information model of the site's relief is created, into which GIS layers can be imported. This integration provides a 3D visualization of the engineering and geographical conditions and links attribute data to spatial objects in the model. The result is an integrated BIM+GIS model of the territory, containing both geometric information (relief, objects on the ground) and semantic data for each element (soil type, risk factor value, etc.).

The second stage involves identifying and quantitatively assessing risk and suitability factors. Based on an integrated model, key factors affecting the suitability of the site for construction and the level of risk involved in implementing the project are identified. In this method, risk factors (R-factors) are understood as characteristics of conditions that can cause negative consequences, such as the presence of permafrost (risk of loss of foundation stability during thawing), high groundwater levels (risk of flooding and foundation complications), steep slopes (risk of landslides or increased cost of earthworks), proximity to a river or low-lying area (risk of flooding), unstable or weak soils (risk of subsidence, need to reinforce foundations), the presence of underground voids or karst (risk of sinkholes), seismicity of the area, environmental restrictions, etc. Suitability factors (S-factors), on the contrary, characterize the positive aspects of the site — for example, strong stable soils, flat terrain, absence of adverse geological processes, developed infrastructure nearby (which reduces connection costs), etc. It should be noted that the same factor can be presented both as a risk and as a contribution to suitability, the difference being only in the sign of the influence. In the proposed methodology, all factors are normalized so that a higher numerical value corresponds to a more favorable condition (i.e., greater suitability and/or lower risk). For example, for the "permafrost" factor, areas without permafrost are assigned a high score (close to 1), and areas with permafrost are assigned a low score (close to 0). Similarly, for the "relief (slope)" factor, flat areas receive a high score (as more suitable), while steep slopes receive a low score. For continuous quantitative parameters (e.g., surface slope angle, distance to the river, groundwater depth), normalization is performed—conversion to a dimensionless scale, usually from 0 to 1. Normalization can be performed linearly, relative to the minimum and maximum permissible values or standards. Thus, for a slope of 0°, suitability 1 (maximum) is set, and for a slope of, say, >15°, suitability 0 is set, with intermediate values interpolated linearly. The formula for normalizing criteria (1).

$$S_i^j = \frac{x_i^j - x_{min}^j}{x_{max}^j - x_{min}^j} \quad (1),$$

where x_i^j is the value of the j-th factor for the i-th section (or cell of the territory) x_{min} and x_{max} are the minimum and maximum favorable values of this factor. After calculation and normalization, the indicators become comparable on a scale.

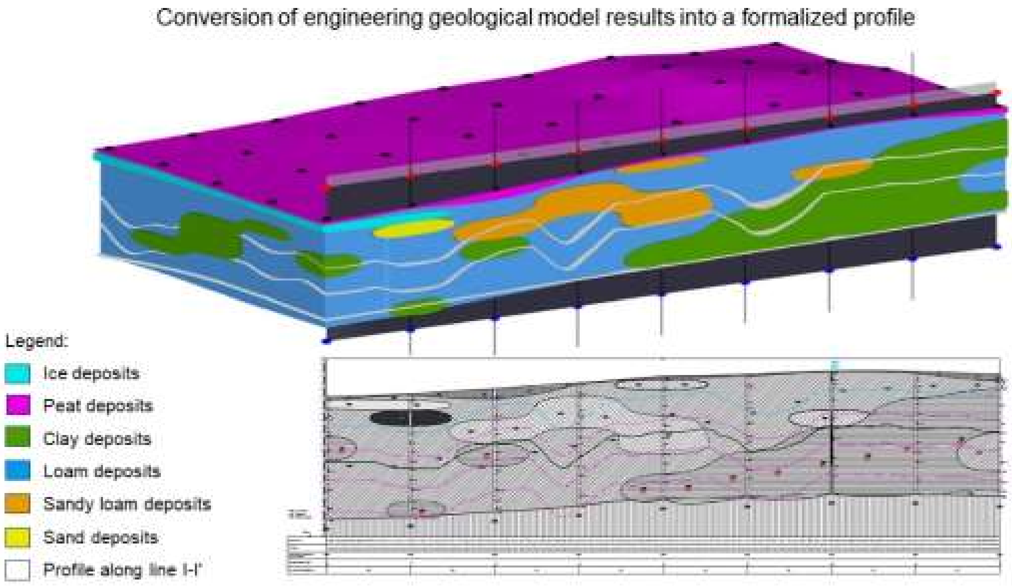

Fig. 1: *Conversion of engineering geological model results into a formalized profile*

The third stage involves weighing factors and calculating integral indices. Since different factors have varying degrees of influence on the overall success of the project, they are assigned weighting coefficients wj according to the importance of the factor for the suitability of the site. The sum of all weights is normalized to 1: ∑jwj=1. Weights can be determined by experts (for example, using the paired comparison method or the rank sorting method). Experts compare factors in pairs according to their importance, on the basis of which priorities are calculated; in the ranking approach, factors are ordered, and weights are calculated based on the ranks. For example, if the soil factor has the greatest impact on cost (foundation task), it can be assigned a weight wgr = 0.3. Next in importance are the presence of permafrost wfz = 0.25, terrain slope wsl = 0.2, flood risk wfl = 0.15, and other factors collectively wothers = 0.1. These weights reflect the expert assessment of each aspect's contribution to the overall risk of the project. After that, for each site under consideration (or for each elementary zone of the territory), the suitability index S (2) is calculated as the weighted sum of normalized indicators

$$S_i = \sum_j w_j S_i^j \quad (2),$$

where Si is the normalized assessment of the i-th suitability factor (for site j). The higher S (closer to 1), the more suitable the site is in terms of the set of conditions [8]. In parallel, the integral risk index R can be calculated, which is either directly opposite to the suitability index (for example, R=1-S if all important factors are taken into account in S), or calculated separately as the weighted sum of only negative risk factors. In some cases, it makes sense to separate these concepts: for example, two sites may have a similar low risk (R) but differ in suitability (S) due to different advantages—proximity to infrastructure, more convenient location, etc. However, in general, with a competent choice of factor system, the S index correlates with risk.

The fourth stage is site classification and sensitivity analysis. The calculated S values are used to rank alternative sites or to zone the territory into suitability classes. In the simplest case, threshold values can be set: for example, $S>0.7$ – high suitability (low risk) site, $0.4<S\leq0.7$ – moderate suitability, $S\leq0.4$ – site unsuitable for construction [9]. When assessing large areas with a continuous distribution of S values, it makes sense to perform clustering or classification, for example, using natural breaks (Jenks) or quantiles, to identify the areas most and least suitable for development. The classification results are clearly presented in the form of thematic suitability maps, where the territory is marked by categories (for example, from green – favorable, to red – extremely unfavorable). In addition, it is useful to perform a sensitivity analysis to check how changes in weight coefficients or initial assumptions affect the distribution of S. This analysis identifies which factors are critical for site selection and allows you to justify the reliability of the recommendation [10].

The fifth stage involves creating a “site passport” and recommendations. For the selected (or each considered) site, a report is compiled that includes: a summary table of values for all factors (e.g., slope – 3°, soil – loam, bearing capacity – 3 kg/cm², permafrost – intermittent at a depth of 1.5 m, groundwater level – 1.2 m, distance to the river – 200 m, protected areas – none, etc.), calculated R and S indices, suitability class, as well as a list of potential risks and recommendations for their mitigation [11]. Engineering recommendations are developed based on the identified risk factors: for example, if there are permafrost soils on the site, it is recommended to provide a special foundation solution (pile field to a depth below the seasonal thawing boundary, soil thermostabilization using thermosiphons or a ventilated subsoil zone) [12]. If the groundwater level is high, a drainage system or raising the planning level is recommended. For sloping sites, shore reinforcement measures, terracing, or refusal to build on the steepest sections. If the site is in a potential flood zone, provide embankments or hydraulic protection, or move the building site to a higher area. At the same time, the recommendations include measures to increase overall reliability and reduce operating costs: for example, insulating foundations and pavements on frozen ground to maintain the temperature regime, using prefabricated monolithic foundations on complex soils to reduce the cost of work, etc. In addition to technical measures, alternative management solutions may be proposed, such as additional surveys in areas of greatest uncertainty (drilling wells to clarify soil conditions), revising the configuration of the planned facility to take into account identified limitations (moving the building outside the area with poor soil), insurance against certain risks, etc. As a result, the site passport serves as a guide for designers and investors: it provides a clear understanding of the strengths and weaknesses of the site even before the design phase begins, and the recommendations proposed will form the basis of the technical design specifications. This ensures proactive risk management: problems are not ignored, but are solved in advance on paper, which is always cheaper than on the construction site.

III. Discussion

The study showed that integrating BIM and GIS with a focus on risk management provides significant advantages in the pre-investment stage. The resulting 3D BIM+GIS model of the site will serve as a common platform for analysis: it will allow for the joint visualization of terrain, geological layers, and potential hazards, facilitating risk identification and communication between specialists (geotechnical engineers, designers, economists) (see fig. 2, 3) [13]. Previously, in practice, engineers often assessed factors separately, in different reports, and it was not easy to link them together for decision-making. The digital approach provides clarity and a quantitative basis for comparing scenarios. It should be noted that such ideas of multi-criteria assessment of territories are not new and have been developed in the field of urban planning and hydraulic engineering surveys [14]. Many authors have successfully applied weighted linear combination and AHP methods to select sites for dams, waste disposal sites, residential development, etc. Thus, in the work of Rodriguez and Mokrova (2020), an approach combining multi-criteria analysis and GIS methods was implemented to support reservoir planning, proving the objectivity and rationality of decisions [15]. The approach under consideration develops this direction as it applies to construction tasks, adding BIM as a means of simulation modeling and cost accounting at the concept stage. In addition, the integrated model facilitates the involvement of experts in the decision-making process: visualizing risks on a map is much clearer for investors or authorities than dry text reports.

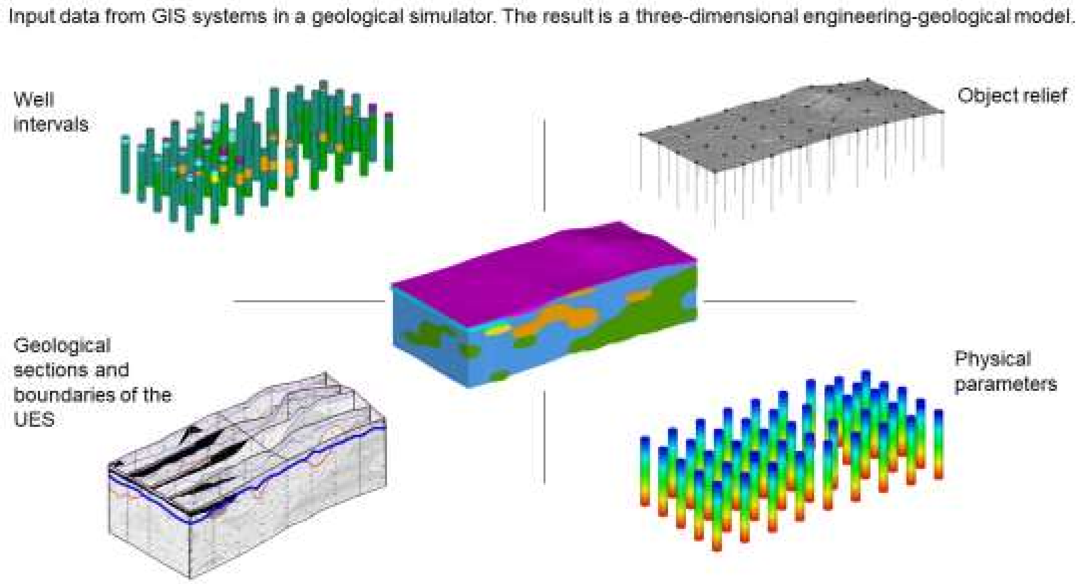

Fig. 2: *Composition of the resulting BIM + GIS terrain model*

The economic effect of the proposed method should also be discussed. The reduction in life cycle costs is achieved not by directly reducing the price of construction work, but indirectly—through more rational planning, prevention of rework and accidents, and optimization of technical solutions. It is well known that making changes to a project during the construction phase is an order of magnitude more expensive than during the documentation phase. The proposed approach essentially minimizes the likelihood of late changes: problems are identified and solved "on paper." In a potential example, the difference in the projected cost between the options reached 10–15%. According to industry data, the introduction of BIM into design reduces direct capital costs by ~5–10% and reduces the likelihood of overspending [16]. The addition of GIS analytics extends these savings by optimizing site selection and land development plans. The effect on project timelines is noteworthy: early detection of problems reduces downtime and delays, which means that the life cycle is implemented faster, which also translates into cost savings [17].

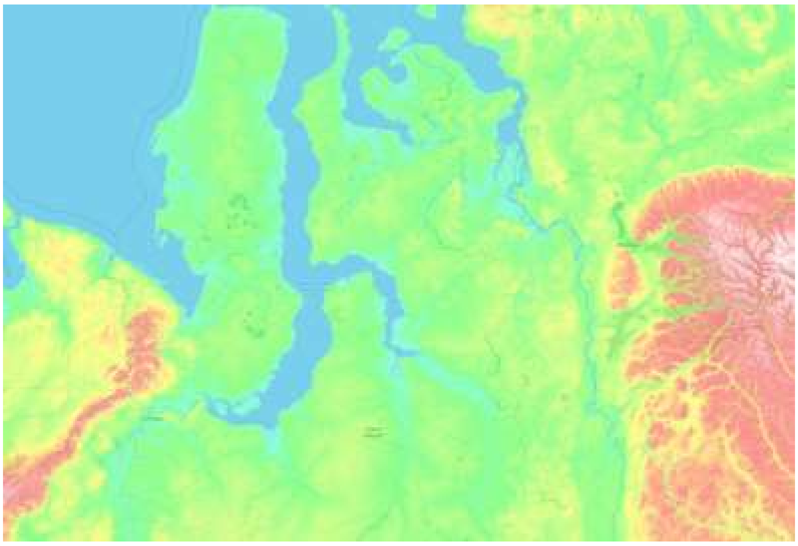

Fig. 3: *Example of analyzed relief with a range of suitable areas*

Additional prospects for developing the method are linked to the use of dynamic and forecast data. In particular, in permafrost regions, it is extremely important to forecast changes in soil conditions in connection with climate trends. Integrating climate change models into GIS would allow us to assess risks not only for the present moment, but also for decades to come—for example, how the depth of seasonal thawing will change by the middle of a building's service life and whether additional measures will be required. Similarly, probabilistic scenarios can be included to estimate the distribution of possible S values instead of deterministic ones. This will provide an understanding of the reliability of the solution: if, despite variations in parameters, the site still maintains a high S, then the choice is justified.

Finally, an important area is the implementation of this approach in regulatory and practical terms. The possibility of creating a “territory passport” with an integrated suitability assessment could be used in complex development, territorial planning, and the selection of sites for public facilities (schools, hospitals) from the perspective of maximum investment efficiency. The tool can form the basis of a decision support system for developers and investors, increasing the transparency and validity of land asset selection.

IV. Conclusion

The presented methodology demonstrates how the combination of modern digital technologies and classic risk management principles can significantly improve the process of preparing construction projects at the earliest stage. The integration of GIS and BIM data provides a comprehensive overview of the site's characteristics in a visual form, while the calculation of suitability (S) and risk (R) indices transforms heterogeneous information into quantitative metrics for comparing alternatives. The end result is the achievement of the main goal: reducing life cycle costs by reducing uncertainty and managing risks in advance.

The main results of the work include: (1) developing a sequence of steps for collecting and integrating spatial data about the territory into a unified BIM+GIS model; (2) proposing a system for standardizing and weighting factors with the calculation of an integral suitability index S for the site; (3) calculation of S and subsequent classification of the territory, allowing for the objective identification of the most advantageous areas for construction; (4) presentation of the results in the form of a “site passport” with recommendations that directly translate the results of the analysis into design solutions. The practical application of this approach contributes to more informed decision-making: instead of intuitive choices, there is a measurable suitability metric; instead of reacting to problems, there is prevention. The integrated BIM+GIS environment provides a common information base for all participants, reducing the risk of communication gaps and errors.

In the future, the method could be expanded to assess areas for linear infrastructure (roads, pipelines), where early detection of unfavorable sections of the route is also critical. Another direction is the inclusion of sustainability criteria in the S-index, such as carbon footprint or impact on ecosystems, which will allow projects to be optimized according to environmental and social parameters, in addition to purely technical ones. In conclusion, we would like to emphasize that the described method of reducing life cycle costs at the pre-project stage is in line with the general trend of digitalization in construction and the transition to data-driven project management. Its implementation will help make the project preparation process more transparent, scientifically sound, and cost-effective, which will ultimately benefit both investors and society.

CONFLICT OF INTEREST.

Authors declare that they do not have any conflict of interest.

References

[1] Manos E, Witharana C, Liljedahl AK. Permafrost thaw-related infrastructure damage costs in Alaska are projected to double under medium and high emission scenarios. // Communications Earth & Environment. 2025;6(1). doi:10.1038/s43247-025-02191-7

[2] US ARC of T. ARCUS. Arctic Research Consortium of the U.S. https://www.arcus.org/search-program/arctic-answers/permafrost-and-infrastructure/briefs.

[3] Song, Y.; Wang, X.; Tan, Y.; Wu, P.; Sutrisna, M.; Cheng, J.C.P.; Hampson, K. Trends and Opportunities of BIM-GIS Integration in the Architecture, Engineering and Construction Industry: A Review from a Spatio-Temporal Statistical Perspective. // ISPRS Int. J. Geo-Inf. 2017, 6, 397. https://doi.org/10.3390/ijgi61203977

[4] Karimi S, Iordanova I. Integration of BIM and GIS for construction automation, a Systematic Literature Review (SLR) combining bibliometric and qualitative analysis. Archives of Computational Methods in Engineering. 2021;28(7):4573-4594. doi:10.1007/s11831-021-09545-2

[5] Liu, X.; Wang, X.; Wright, G.; Cheng, J.C.P.; Li, X.; Liu, R. A State-of-the-Art Review on the Integration of Building Information Modeling (BIM) and Geographic Information System (GIS). // ISPRS Int. J. Geo-Inf. 2017, 6, 53. https://doi.org/10.3390/ijgi6020053

[6] Sheina, Svetlana & Chubarova, Karina & Dementeev, Dmitry & Kalitkin, Andrey. (2022). Integration of BIM and GIS Technologies for Sustainable Development of the Construction Industry. 10.1007/978-3-031-11058-0_132

[7] Malczewski, J. (2006). GIS-based multicriteria decision analysis: a survey of the literature. // International Journal of Geographical Information Science, 20(7), 703–726. https://doi.org/10.1080/13658810600661508

[8] Saaty TL. Decision making with the analytic hierarchy process. // International Journal of Services Sciences. 2008;1(1):83. doi:10.1504/ijssci.2008.017590

[9] Figueira, J., Greco, S., & Ehrgott, M. (Eds.). (2005). Multiple Criteria Decision Analysis: State of the Art. Springer.

[10] Eastman, J.R. (2005). Multi-criteria evaluation and GIS. 35, 493-502.

[11] Chen Y, Yu J, Khan S. Spatial sensitivity analysis of multi-criteria weights in GIS-based land suitability evaluation. // Environmental Modelling & Software. 2010;25(12):1582-1591. doi: 10.1016/j.envsoft.2010.06.001

[12] CSA S500:21. Thermosyphon foundations for buildings in permafrost regions. (2021) https://www.csagroup.org/store/product/2428776/

[13] Wang, H., Pan, Y., Luo, X. (2019). Integration of BIM and GIS in sustainable built environment: A review and bibliometric analysis. // Automation in Construction, 103, 41–52.

[14] Armanuos, A. M., Elgaafary, K. A., & Gado, T. A. (2023). Landfill site selection using MCDM methods and GIS in the central part of the Nile Delta, Egypt. // Environmental monitoring and assessment, 195(12), 1407. https://doi.org/10.1007/s10661-023-11946-8

[15] Rodriguez V.S., Mokrova N.V. (2020). Multi-criteria assessment of territorial planning alternatives using geographic information system technologies for dam construction. // Russian Journal of Resources, Conservation and Recycling, 1(7). Available at: https://resources.today/PDF/11INOR120.pdf (in Russian) DOI: 10.15862/11INOR120

[16] Gharaibeh, L., Eriksson, K., Lantz, B. (2024). Quantifying BIM investment value: a systematic review. // Journal of Engineering, Design and Technology. http://dx.doi.org/10.1108/JEDT-06-2023-0259

[17] Alnaser, A. A., Alsanabani, N. M., & Al-Gahtani, K. S. (2023). BIM Impact on Construction Project Time Using System Dynamics in Saudi Arabia's Construction. // Buildings, 13(9), 2267. https://doi.org/10.3390/buildings13092267