Vol. 15, 2026, 7-14

DOI: 10.17512/bozpe.2026.15.01

Construction of optimized energy potential

Budownictwo o zoptymalizowanym potencjale energetycznym

ISSN 2299-8535 e-ISSN 2544-963X

Integration of risk assessment methods in construction with BIM technology – an innovative approach

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Abstract: The article under discussion herein sets forth a discussion of the utilisation of the BIM model in the context of risk management on construction sites. The authors present the use of information contained in the model for the identification and analysis of risk, as well as for graphical visualisation of risk responses in the form of equipment or collective protection measures. The article demonstrates the potential for automating risk analysis activities through the utilisation of If/Then analyses, Monte Carlo simulations and Python programming.

Keywords: BIM, risk identification, risk analysis

Please, quote this article as follows:

Zima, K., Plebankiewicz, E. & Rueda, J. (2026) Integration of risk assessment methods in construction with BIM technology – an innovative approach. *Construction of Optimized Energy Potential* (*CoOEP*), 15, 7-14. DOI: 10.17512/bozpe.2026.15.01

Introduction

It is an acknowledged fact that contemporary construction projects are characterised by increasing complexity and multifaceted risks. These risks extend to financial, technical, environmental and occupational safety aspects. Construction is also a high-risk sector due to the complexity of projects, the large number of participants in the construction process and variable environmental conditions. Conventional risk management methodologies are frequently constrained by static reports and retrospective analyses, which often result in delays, cost overruns and accidents (Almashhour et al., 2025). Conventional risk assessment methodologies, including

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FMEA (Failure Mode and Effects Analysis) and the Delphi method, frequently prove inadequate in delivering dynamic, real-time risk management.

One potential solution to this issue is to utilise the Building Information Modelling (BIM) process for the purpose of conducting risk analysis and implementing risk control measures. The BIM approach facilitates an integrated approach in which risks are monitored and analysed in real time, and information about hazards is available to all project participants and across all collaborating disciplines fostering proactive risk management. The integration of risk assessment methodologies with BIM technologies represents a major area of research in civil engineering and construction project management, exhibiting rapid growth in scope and significance. Research indicates that the quantitative evidence from prior studies highlights the positive impacts of BIM adoption for enhancing construction risk management across the project lifecycle (Numan, 2024), which means that BIM has the potential to enable better identification, analysis, response planning and monitoring of risks.

Building Information Modelling (BIM) has evolved in recent years as an innovative technology with the potential to transform risk management in construction (Salman, 2011). A BIM model is a digital representation of a building that contains a wealth of key and useful information on both the geometry of the building (visualised in 3D) and non-geometric information (technologies, material properties, costs, etc.). It can thus be posited that BIM is synonymous with the evolution of intelligent three-dimensional (3D) models. These models are replete with detailed information about a project and facilitate a plethora of analyses and simulations (Sacks et al., 2018). The visualisation of building elements, in conjunction with the capacity to present collective protection measures in three dimensions, accompanied by comprehensive descriptions, facilitates the exploration of dynamic security design methodologies. For instance, in the study (Ali et al., 2022) the utilisation of BIM for the purpose of visualising project risks and communicating risk information to relevant stakeholders was analysed. Furthermore, BIM facilitates risk analysis throughout the entire design and construction cycle of a building. Consequently, the implementation of BIM has been shown to enhance risk management during the various phases of risk identification, analysis, and mitigation (Zou et al., 2017).

1. Brief literature review

Firstly, it is important to emphasise the growing interest in BIM and the need to regulate it and adapt information processes to Polish investment conditions. The implementation of BIM signifies the initial and pivotal phase in the digitalisation of construction processes. Three classes of methodologies, which are often integrated with BIM, dominate the literature:

- Qualitative methods (e.g. risk matrices, checklists, cause and effect analysis) – useful for quick identification and prioritisation of risks.
- Semi-quantitative methods (e.g. scoring, probability and impact indicators).
- Quantitative methods (e.g. probabilistic models, Monte Carlo simulations) – used where data is available and there is a need to estimate distributions of effects

and uncertainties. In empirical work, probabilistic models combined with BIM are used to simulate schedule risks and health exposures (Zou et al., 2017).

1.1. Qualitative methods

The article (Grzyl & Kristowski, 2016) points to the possibility of eliminating significant differences in the calculation of investment costs by the contracting authority and bidders through the use of BIM technology and the application of uniform and consistent data by the participants in the investment project.

Based on existing risk models, (Abanda et al., 2020) examined and developed a BIM-based framework for risk management in construction project scheduling. The authors in (Kim et al., 2020) found that traditional safety reviews (checklists) are subjective, while BIM enables automated, repeatable hazard detection. Thus, automation and partial replacement of subjective checklists with BIM-supported hazard identification were demonstrated.

In turn, in (Bockstael & Issa, 2016), the authors explicitly propose the use of FMEA for collision groups extracted from the BIM model. This study proposes the use of failure mode and effects analysis as part of a methodology for collision detection using building information modelling (BIM) and assessing its impact on the feasibility of commercial projects and return on investment for contractors. It was applied to a case study of a commercial construction project designed using BIM.

Attention is currently being drawn to the practical benefits of BIM in the context of collision detection (Pubanz et al., 2022), hazard visualisation and work planning, which facilitates the identification of risks at the design and construction stages. A review of practical articles and industry guides indicates that Building Information Modelling (BIM) facilitates the identification of potential risks and collisions during the preliminary feasibility study and planned stages.

1.2. Semi-quantitative methods

Semi-quantitative methods, such as probability and impact scoring, are increasingly used in studies where a BIM model can be used to automatically identify risks and attempt to describe the parameters for their assessment. Specifically, the risk rating for each item is calculated by multiplying its severity (the extent of impact or consequences if the risk event occurs) and by its frequency of occurrence (Kim et al., 2020). For example, in (Lee et al., 2020), the authors present a BIM-based risk assessment methodology consisting of BIM-based hazard extraction, assessment of requirements information, selection of evaluation items, and use of an evaluation system in a safety design review. To calculate the risk assessment, disasters that could occur on the construction site were identified, and then severity and probability coefficients were calculated for a given risk class. In order to automate the safety review of the model, IFC-based hazard extraction and risk assessment estimation were performed. The IRI (Improved Risk Index) method presented in (Zhang et al., 2025) is another example where indicators and indices were introduced, combining the weight of various aspects of evacuation risk with BIM data. The authors presented a fire model and an evacuation model based on BIM information. They then defined a safety index (SI) as a comprehensive index, as well as an IRI (Safety Index) to assess the safety of escape routes for fire evacuation model.

1.3. Quantitative methods

Quantitative methods, using probabilistic and simulation tools, allow for a more accurate representation of uncertainty in construction processes than qualitative and semi-quantitative. The literature increasingly emphasises that the integration of quantitative risk analysis with BIM technology enables both the forecasting of schedule delays and the modelling of costs and safety parameters (Numan, 2024).

The integration of BIM with simulation tools allows for the automatic extraction of input parameters for simulation (e.g. deadlines, quantities of work, exposure parameters), followed by the execution of probabilistic (Monte Carlo) scenarios for the assessment of schedule risk, potential cost escalation or occupational exposure. The literature describes implementations that combine BIM models with simulation engines to model schedule and cost uncertainty. In addition to classic Monte Carlo methods, more complex probabilistic approaches are also emerging. The authors in (Lu et al., 2021) have developed a risk assessment method integrated with BIM at the design stage, based on three indices: Likelihood, Consequence and Exposure. This approach enables quantitative analysis of safety risks based on design parameters encoded in BIM models.

It should also be noted that the possibilities for implementing safety risks have also been formally defined. The formal implementation of BIM in the field of health and safety (H&S) was achieved, among other things, by the BS PAS 1192-6:2018, which introduced the structuring of health and safety information in the construction context using BIM technology (Kaczorek, 2023). In turn, the ISO 19650-6 standard is mainly dedicated to information management in the field of occupational health and safety. This standard defines information relating to health and safety hazards at all stages of a building's life cycle.

2. Risk identification and analysis in the BIM model

2.1. Identifying risk levels in the BIM model

Integrating design data, schedules, cost and health and safety information in a BIM model enables automated risk identification. Key data sources include:

- Design data – 3D geometry, technical parameters, material specifications.
- Schedules (4D BIM) – linking elements to time, allowing simulation of construction sequences.
- Cost estimates (5D BIM) – connecting design data with cost databases for budget control.
- H&S risk data – assigning potential hazards and protective measures to tasks and elements.

This integration transforms BIM into a knowledge base for the entire project. Combining data enables rules and algorithms to automatically detect risks, e.g.:

- Assembly of heavy elements at height → system flags high risk and prompts safety measures.
- Materials requiring special protection → model issues H&S warnings.
- Detected 3D collisions → potential on-site hazards.

For example, when installing heavy components at height, H&S attributes (e.g. weight > 500 kg, height > 3 m, use of cranes) are added as Properties in the BIM model (Table 1).

Table 1. Fragment of the properties for the selected prefabricated element (*own research*)

Type	Heavy Prefab Element
Weight	500 kg
Installation Height	> 3 m
Installation Method	Crane
Risk Level	Height

If the model contains relevant information assigned to individual elements, IF/THEN rules can be created in tools such as Solibri Model Checker, Navisworks Clash Detective or in specialised plug-ins. For example, a saved rule may look like this:

IF (Weight > 500 kg) AND (InstallationHeight > 3 m)
THEN RiskLevel = 'High'
AND RequiredSafety = 'Use safety nets + safety belts + lifting plan'

Executing the rule will cause a prefabricated element that meets the conditions (e.g. Heavy Prefab Element 500 kg installed at a height of 4 m) to be automatically marked as 'High Risk' (Fig. 1). Based on the results, a risk report can be generated, e.g.: 'Day 15: installation of ceiling beams – high risk – additional safety measures required'. The report can be exported to an Excel file, PDF or directly to the health and safety management system. In more advanced implementations, the system can also automatically update the HS Plan (Health and Safety Plan).

2.2. Risk response strategies and solution modelling in the BIM model

In the BIM model, you can also vary your response strategies in reaction to risk. The result of risk analysis should be the presentation of a strategy for action. Strategies that require the use of equipment and machinery can be modelled in BIM. For example, when analysing the risk of joint or spine damage and tendonitis, one of the elements of a specific strategy is investment in mechanical equipment. The BIM model includes a winch, shown in Figure 1, designed to reduce the workload on employees and ensure greater comfort at work. The element properties related to risk analysis, which were additionally implemented in the model, are shown in Figure 1.

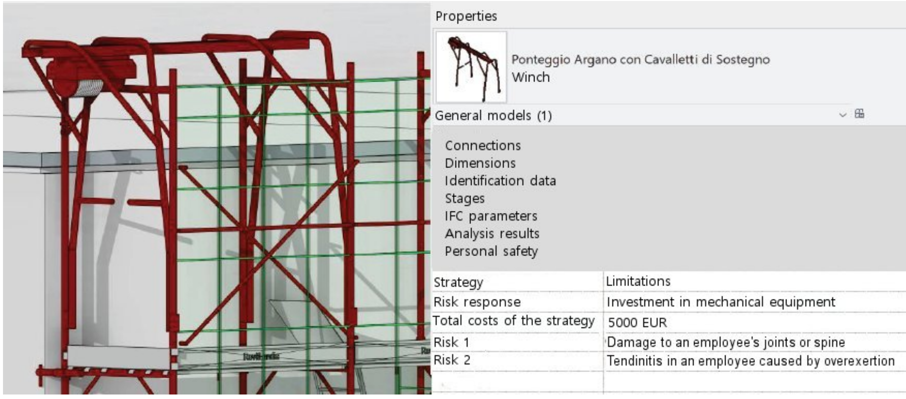

Fig. 1. A winch modelled in BIM with a properties field describing the risk (*own research*)

The use of BIM opens up a new era in safety and risk management in construction. Thanks to the ability to automatically identify potential hazards at the planning stage, those involved in the construction process can make more informed decisions, reduce the number of accidents and minimise financial losses. In the future, with the development of artificial intelligence and machine learning, such models will support the safe and effective implementation of investments even more effectively.

2.3. Simulations in BIM-based risk analyses

The information collected in the BIM model (Fig. 2) can be combined with historical or empirical data and used for risk analysis and simulations. The Monte Carlo method can be used to simulate various design and construction scenarios and calculate the probability of risks occurring and their potential impact on costs and schedules.

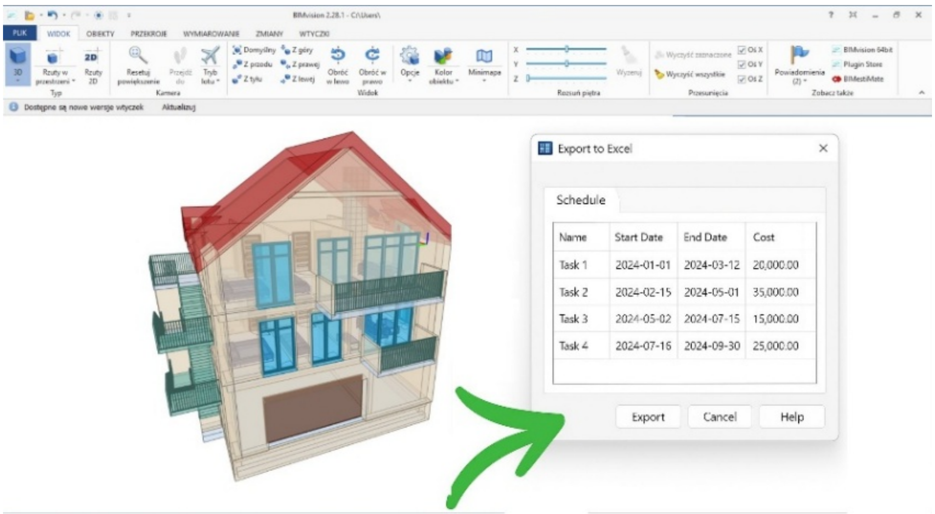

Fig. 2. Export of important information from BIM model (*own research*)

When working with BIM models, there is an increasing need to extract information, including costs and schedules, from IFC files in a format such as MS Excel. One tool that enables such export is BIM Vision. This IFC viewer allows you to create and save summaries in XLSX or CSV format thanks to additional plugins. To export data, the relevant plugins must be installed; for example, BIM Quantity Takeoff is used for quantity summaries. The following example illustrates a rudimentary Monte Carlo algorithm in Python, utilising this to simulate the financial implications of delay in a construction project, as well as the associated risk.

```
import numpy as np
p_risk = 0.1
impact_cost = 50000
simulations = 10000
# we generate all simulations at once
costs = np.random.rand(simulations) < p_risk
total_costs = costs * impact_cost
expected_cost = np.mean(total_costs)
print(f" Expected cost of risk: {expected_cost} EUR")
```

The application performs 10,000 simulations and calculates the predicted risk cost for the given values based on the probability p_risk and the cost impact_cost. The random.rand() function is employed to generate a random number within the range of [0,1]. In the event of a random number falling below p_risk, the im-pact_cost value is added to the simulation value. An assessment of available historical and/or empirical data can be used to define the level of uncertainty for the simulation process. In conclusion, the total costs are obtained, which represent the mean anticipated cost for a single iteration (the predicted risk cost) taking into consideration market and construction uncertainties. It is evident that the scope of the simulation can be expanded to encompass not only the calculation of the expected average cost, but also that of its variance and confidence interval, for instance, at the 95 % level of confidence. The simulation results can be visualised using a histogram. This enables the observation of the frequency of occurrence of different costs and the manner in which risk is distributed.

Conclusions

The article shows that BIM models can and even should be used in risk analyses, as they create a platform that integrates all design elements and project systems. This integration allows complex interdependencies to be factored into the risk management process. By definition, models are used to collect data, so this data can be processed to identify risks and perform analyses (including simulations, e.g. Monte Carlo). Data from the model can be exported to files such as MS Excel, be supplemented by historical or empirical data, and be used in analyses, automating actions and calculations using, for example, the Python programming language. Data from the analyses can be saved in the BIM model, thus creating a model integrated with identified and quantified schedule, cost, and safety risks. In the graphic layer, collective safeguards or devices can be designed to reduce or eliminate certain types of risks. The use of BIM modelling has many advantages related to the visualisation of safeguards against certain risks and provides a risk database integrated with the BIM model and thus accessible to participants in the construction project.

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