Open Access
Original paper

Budownictwo i Architektura / Civil and Architectural Engineering 25(3) (2026) 26047
https://doi.org/10.35784/bud-arch.9314

BIM-based investment risk management framework in construction projects

Urszula Kwast-Kotlarek[1], Mariusz Szóstak[2,*]

[1] *University of Wroclaw, plac Uniwersytecki 1, 50-137 Wrocław; urszula.kwast-kotlarek@uwr.edu.pl*
[2] *Department of Building Engineering, Faculty of Civil Engineering, Wroclaw University of Science and Technology, Wybrzeże Stanisława Wyspiańskiego 27, 50-370 Wrocław; mariusz.szostak@pwr.edu.pl*

[*] *Corresponding Author*
Received: 05.03.2026; Revised: 20.07.2026; Accepted: 07.08.2026; Available online: 15.09.2026

Abstract:
The article addresses risk management in building construction projects amid increasing technical, organisational, and informational complexity. It presents an approach in which the Building Information Modelling (BIM) environment serves as an active risk management tool, integrating risk identification, analysis, and monitoring with project information management in accordance with ISO 19650. The study highlights the role of key project documents - Employer's Information Requirements (EIR) and the BIM Execution Plan (BEP) - in mitigating organisational and technical risks. It also examines contractual risks in public procurement, the legal status of BIM models versus traditional documentation, and issues of intellectual property and data access within the Common Data Environment (CDE). The article proposes using the RACI matrix for systematic allocation of risk management responsibilities among stakeholders. Integration of BIM coordination, clash detection, data interoperability analyses, and BIM for Safety enables early identification of technical risks. The study's main contribution is an integrated, application-oriented risk management model combining EIR and BEP, the RACI matrix, and BIM for Safety principles, serving as a reference for contractual and risk management procedures. Results show that BIM transforms risk management from reactive to proactive, data-driven, and continuous, shifting BIM from a design-support tool to an integrated environment covering the entire building life cycle.

Keywords:
investment risk management; RACI matrix; Building Information Modelling; BIM for Safety; construction projects

1. Introduction

The delivery of complex building construction projects is characterised by high technical, organisational, and process-related complexity [1]. Such projects are implemented under conditions of dynamic design changes, schedule pressure, and increasing quality and environmental requirements [2]. The interdisciplinary nature of construction undertakings, involving cooperation among multiple design disciplines, contractors, and public institutions, increases investment uncertainty and significantly strengthens the role of risk management throughout the entire project life cycle [3,4].

Traditional risk management approaches in construction are primarily based on expert assessments, two-dimensional (2D) project documentation, and reactive actions undertaken only during the construction phase [5]. This approach proves insufficient for contemporary projects characterised by high functional and technological complexity. Delayed risk identification frequently leads to interdisciplinary conflicts, design modifications during construction, and increased project delivery costs [6].

The development of digital technologies in the construction sector has gradually shifted the risk management paradigm from a reactive approach toward a proactive model based on digital information models [7]. Building Information Modelling (BIM) enables the integration of geometric, technical, and organisational data within a single project information environment, allowing earlier identification of risks and simulation of design decisions before construction works commence [8,9].

The implementation of BIM does not entirely eliminate investment risk; however, it significantly transforms the investment structure. Traditional risks, such as coordination errors between disciplines or quantity inconsistencies, are reduced, while new categories of risks emerge as a result of digitalisation [5]. These include data interoperability risks, legal risks related to ownership and responsibility for information models, and organisational risks arising from insufficient competencies of project participants [10,11]. Consequently, the critical success factor of contemporary investments is not merely the adoption of BIM technology itself, but effective project information management based on the ISO 19650 standards framework, especially Part I [12], Part II [13], and the Information Management Initiative Framework [14].

Despite the rapid development of BIM technologies, scientific literature predominantly focuses on geometric modelling, automation of analyses, clash detection, and interdisciplinary coordination [15]. The role of BIM as a systemic risk management tool remains significantly less explored [16]. In particular, insufficient attention has been paid to integrating risk identification processes with project information management, BIM documentation structures (EIR and BEP), the operation of the Common Data Environment (CDE), and the allocation of stakeholder responsibilities for risk mitigation activities [17,18].

Recent studies increasingly highlight the importance of integrating BIM into public procurement procedures, both for transparency and for contractual risk allocation [5]. Particular attention is paid to linking the employer's information requirements with tender documentation and construction contract provisions. The framework proposed in this paper extends these considerations by structuring the relationships between EIR, BEP, the RACI matrix and public procurement procedures [19].

The identified research gap, therefore, concerns the absence of a coherent model integrating investment risk management with BIM information processes in a manner enabling continuous monitoring of risks throughout the entire building project life cycle. Existing studies on BIM-supported risk management primarily focus on digital risk identification methods [20], software capabilities [21], and general conceptual frameworks for BIM integration [22]. Some research also emphasises the use of 4D models and visualisation techniques supporting construction safety [23] and logistics within the BIM for Safety concept [24]. However, the systemic integration of ISO 19650 information management processes [12,13], EIR and BEP documentation, responsibility allocation through the RACI matrix [19], and safety procedures into a single operational risk management model applicable in public procurement practice remains insufficiently investigated.

The concept proposed in this article addresses this research gap. The aim of the study is to present a BIM-based risk management approach in which risk identification, analysis, and monitoring processes are directly linked with project information management in accordance with ISO 19650 principles [12,13]. It is assumed that the digital project information environment can serve as an active risk management tool, supporting continuous, transparent, and data-driven decision-making throughout both the design and construction phases.

The novelty of the proposed approach lies in the systemic integration of ISO 19650 information management processes, EIR and BEP documentation, the RACI responsibility matrix, and BIM for Safety tools into a unified investment risk management model suitable for implementation under public procurement conditions in Poland [25].

In light of these assumptions, the present study adopts a conceptual and application-oriented approach. The proposed risk management framework is intended as a reference framework integrating established BIM-based management practices into a coherent structure for public construction projects. As the model has not yet been empirically validated, its practical applicability and effectiveness should be assessed in future case-study and implementation-based research.

The proposed approach was developed through a literature review, analysis of information management standards, and professional experience gained from implementing a complex investment project in an academic environment. The objective of the study is to identify mechanisms through which the integration of BIM and risk management can reduce organisational, technical, and informational risks while improving the predictability of construction project delivery.

2. Research methodology

The aim of the research was to develop a risk management framework for building construction projects implemented in a BIM environment through the integration of informational, technical, organisational, and contractual aspects of the investment process.

A qualitative-analytical research approach was adopted, combining literature analysis, normative analysis, and synthesis of practical project experience. The research methodology consisted of the following stages:

1. Literature and international standards analysis, particularly the ISO 19650 series, BIM guidelines, and publications related to risk management in construction projects and the digitalisation of the investment process [1-5,9-13]. Additionally, selected national guidelines and standards related to construction process digitalisation and BIM implementation in Poland were analysed, including BIM Standard PL [26] and documents regulating public procurement procedures [25]. Output: Identification of key concepts related to BIM-enabled risk management, information management, contractual responsibilities, and safety management.
2. Process analysis of the BIM environment, involving identification of risk generation points throughout the project life cycle, from the definition of Employer's Information Requirements (EIR), through BIM Execution Planning (BEP), to the construction phase and preparation for facility operation [6-8,21]. Output: Identification of the principal information processes and risk generation points occurring during the project life cycle.
3. Organisational and contractual analysis, including assessment of responsibility allocation among project participants using the RACI matrix as a tool for systematic risk allocation [19,22-24]. Output: Definition of stakeholder roles, responsibility allocation principles, and contractual relationships supporting risk management.
4. Synthesis of technical and safety approaches, in which the potential of BIM models for identifying technical hazards, supporting interdisciplinary coordination, assessing data interoperability, and implementing BIM for Safety concepts was examined [14-20]. Output: Development of an integrated BIM-based investment risk management framework combining technical, organisational, contractual and information-management components.

Figure 1 presents the procedure used to develop the proposed BIM-based investment risk management framework. The model was developed by integrating knowledge derived from literature, standards, and practical BIM experience. The identified concepts were synthesised into a coherent framework and subsequently verified for consistency with ISO 19650 information management principles and practical applicability.

The adopted research approach is qualitative and model-oriented. The development of the proposed framework was based on four main stages:

1. Literature and standards review regarding BIM and risk management,
2. Process analysis of the BIM environment with identification of risk generation points across the project life cycle,
3. Organisational and contractual analysis of stakeholder roles and responsibilities, and
4. Synthesis of the obtained insights into an integrated BIM-based risk management model.

The study does not include formal quantitative methods or a systematic literature review; instead, it is based on a qualitative synthesis of existing knowledge and the authors' professional experience.

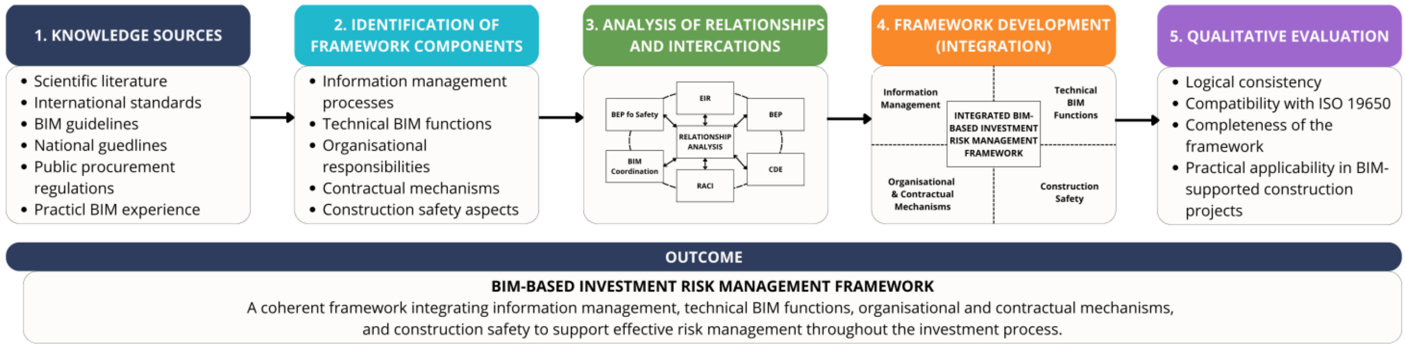

Fig 1. Procedure adopted for developing the BIM-based investment risk management framework

To enhance transparency and allow partial replicability of the qualitative research process, the second and third stages of the methodology were operationalised as structured analytical procedures. In the process analysis stage, the information workflow defined in ISO 19650-2 was systematically cross-referenced against typical EIR and BEP templates and against the documented procedures applied during the delivery of the reference academic building project, with information exchanges, decision points and responsible actors catalogued for each life-cycle phase. In the organisational and contractual analysis stage, the roles, competencies and legal obligations of the Investor, Designer, Contractor and Facility User, as defined in Polish public procurement regulations and standard contract clauses, were mapped onto ISO 19650 information-management responsibilities and onto the roles actually observed in the reference project; this mapping provided the basis for the RACI responsibility assignments discussed in later sections. The overall research design thus follows a conceptual-framework logic: rather than producing statistically generalisable results, it integrates established BIM information-management processes, strategic documents (EIR and BEP), responsibility-allocation mechanisms and BIM for Safety tools into a structured, application-oriented model whose effectiveness and transferability should be verified in future implementation-based case studies.

The adopted research approach has both conceptual and applied character. The applied component of the methodology is based on the authors' experience in preparing and implementing a complex building project within an academic environment using a BIM framework compliant with ISO 19650 [12,13], thereby enabling verification of the practical applicability of the proposed framework.

The literature review followed a narrative and selective approach focused on identifying key concepts related to the integration of BIM and risk management. Formal systematic review protocols were not applied, which is acknowledged as one of the limitations of the study.

The objective of the study was not to analyse a single investment case, but rather to develop universal risk management principles applicable to building projects of varying scale and complexity.

From a methodological perspective, the adopted approach is exploratory and conceptual, typical of studies addressing complex information- and risk-management systems in BIM environments. Relying on a qualitative synthesis of the literature, normative analysis, and experience gained from a single, complex academic building project makes it possible to capture multidimensional interdependencies between information-management processes, strategic documents (EIR, BEP), responsibility allocation and safety-management practices, while at the same time limiting the potential for statistical generalisation of the findings. The proposed model should therefore be regarded as a theoretically grounded, practice-informed reference scheme that requires further verification and refinement through case studies and implementation-oriented research conducted across different types of construction projects and diverse institutional contexts.

3. Role of strategic documents (EIR and BEP) in risk mitigation

An analysis of the causes of failures in projects implemented using BIM methodology indicates that a significant proportion of organisational and technical problems originate at the project preparation stage, particularly from improperly defined principles of project information management. A key role in this process is played by the BIM Execution Plan (BEP), developed in response to the Employer's Information Requirements (EIR).

The BEP should not be treated as a formal or administrative component of contractual documentation, but rather as a strategic instrument for managing informational and process-related risks within a project. A properly structured document defines collaboration principles, information workflows, and the responsibilities of project participants, thereby establishing the operational framework for the BIM environment in accordance with the ISO 19650 standards [12,13].

Existing studies predominantly focus on reviewing BIM capabilities in risk identification and analysis or present general frameworks of risk management. However, there remains a lack of models that integrate ISO 19650 information management standards [12,13] with responsibility allocation mechanisms (RACI) and safety procedures into a coherent approach applicable to public procurement practice [19].

3.1. BEP as a foundation for risk mitigation

A properly developed BIM Execution Plan (BEP) enables the reduction of project risks in several key areas:

1. Reduction of responsibility ambiguity. By precisely defining project roles and linking them with information management processes, the BEP eliminates situations in which no clearly identified entity is responsible for coordinating critical interdisciplinary interfaces. Explicit allocation of responsibilities for generating, verifying, and approving project information reduces decision-making conflicts and accelerates problem resolution processes [11-13, 21].
2. Ensuring consistency of project data. Establishing uniform standards for information classification, naming conventions, and data exchange procedures within the

Common Data Environment (CDE) limits the risk of working on outdated models or documentation versions. Data inconsistency remains one of the most common causes of execution errors and contractual claims in construction projects; therefore, formalisation of information management principles becomes a key element of risk prevention [14,26]
3. Proper definition of the Level of Information Need (LOIN). Accurate specification of the required information scope prevents both excessive modelling leading to increased documentation costs and insufficient model detail limiting operational usability. Correct LOIN definition enables rational management of design efforts and improves the effectiveness of BIM model utilisation throughout subsequent stages of the asset life cycle [27].

From a risk management perspective, the EIR should include at least:

1. requirements for a risk register integrated with the BIM model,
2. requirements defining the frequency of coordination processes (clash detection) and risk reporting,
3. requirements for 4D models supporting safety and schedule analyses.

The BIM Execution Plan developed in response to the EIR should translate these requirements into specific procedures, model quality indicators, and clearly assigned responsibilities for project participants.

3.2. Quality control procedures within the BEP

An effective BEP should include measurable and repeatable Model Quality Control procedures. Key components include model audit schedules, data validation procedures, and regular interdisciplinary clash detection tests.

Linking quality control procedures with project milestones and contractual mechanisms - for example, making stage approvals or payments dependent on meeting predefined model quality criteria - represents one of the most effective instruments for reducing project risk. Such mechanisms distribute responsibility for information quality among all project participants and strengthen a data-driven collaboration culture [5,28]

Consequently, the BEP ceases to function solely as an operational document and becomes a systemic risk management tool integrating organisational, informational, and technological aspects of the project.

4. Contractual risk in public procurement projects

The specific nature of construction projects implemented under public procurement systems causes risk management to extend beyond traditional technical and organisational aspects, encompassing complex legal, procedural, and contractual conditions. The introduction of BIM methodology into projects governed by public procurement regulations generates new categories of risk arising from the need to reconcile the digital information environment with traditional documentation structures and contractual liability frameworks of project participants [11,21-23].

Digitalisation of the investment process does not eliminate contractual risk but fundamentally transforms its nature. Interpretative disputes shift from paper documentation toward digital data, information models, and rules governing access to project information.

4.1. Document status and hierarchy of contractual documents

One of the primary sources of risk in BIM projects delivered within public procurement frameworks is the ambiguous status of BIM information models relative to traditional design documentation, such as the Functional and Operational Program or the Technical Specifications for Execution and Acceptance of Works [22].

In situations where discrepancies occur between 2D documentation and the 3D model, the absence of a clearly defined hierarchy of documents (priority clauses within the contract) leads to interpretative disputes, claims for additional work, and delays in project execution. This issue becomes particularly critical in BIM environments, where the information model simultaneously serves as design documentation, a coordination platform, and a contractual data source.

Risk mitigation requires the introduction of contractual clauses defining BIM models as either superior or equivalent contractual documents within explicitly defined scopes, for example, regarding geometric coordination or clash detection processes. At the same time, a precise definition of the hierarchy of contractual documentation remains essential to ensure unambiguous interpretation of contractual obligations [29].

4.2. Intellectual property and data confidentiality

The Common Data Environment (CDE), which enables real-time information sharing, redefines traditional concepts of authorship for design solutions and documentation. Federated models are created collaboratively by multiple entities, blurring boundaries of creative responsibility and complicating copyright ownership issues.

Key risks arise particularly from:

- intellectual property ownership of federated model elements,
- licensing scope for data use during the Facility Management phase,
- access to sensitive information and protection of contractors' know-how.

Within public procurement procedures, this issue gains additional importance due to the requirement for transparency while simultaneously protecting the interests of project participants. Risk mitigation, therefore, requires a clear definition of CDE access rules, user permission levels, and procedures for anonymisation of sensitive data.

4.3. Allocation of responsibilities (RACI matrix) as a risk management tool

The investment and construction process conducted in a BIM environment involves numerous stakeholders with diverse competencies, interests, and responsibilities. Effective risk management requires clear identification of entities responsible for risk identification, assessment, mitigation, and monitoring.

A tool enabling systematic allocation of responsibility is the RACI matrix (Responsible, Accountable, Consulted, Informed), which links BIM project activities and information processes with organisational and contractual accountability of project stakeholders: the client, contractor, designer, and future facility operator.

Analysis of BIM-based projects indicates that effective risk management depends on assigning each risk to the entity with the greatest capacity to control it [19,22]. For example:

- designer is responsible (R) for developing discipline models, while ultimate accountability (A) for design compliance may rest with the project leader,
- BIM coordinator is responsible (R) for model federation and clash detection, whereas the client is informed (I) through BCF reports regarding coordination outcomes [30].

It should be emphasised that the proposed RACI matrix represents the authors' conceptual model, developed on the basis of an analysis of BIM-related literature, applicable standards, and the legal responsibilities of project participants, as well as the authors' professional experience. The matrix is not the outcome of a formal Delphi study, expert panel, or dedicated validation workshop. Instead, it constitutes a structured synthesis of roles and responsibilities commonly encountered in BIM-based project delivery and is intended to serve as a reference framework for further empirical verification and refinement.

Such an approach improves decision transparency and reduces interpretative conflicts arising from design or execution errors.

4.4. RACI matrix as a systemic risk allocation framework

The RACI matrix covers three main types of risk:

- contractual risks,
- technical risks,
- construction safety risks.

The columns of the matrix correspond to the key participants of the construction process: the Investor, Contractor, Designer, and the future Facility User. Additionally, the matrix incorporates risk mitigation mechanisms resulting from the application of BIM technology and the BIM for Safety concept [19].

The adopted assumptions reflect a logical allocation of responsibilities derived from the competencies and legal obligations of the participants in the investment process:

- Investor performs the role of the owner of strategic decisions, is responsible for compliance with public procurement regulations, and approves contractual changes.
- Contractor manages construction execution safety, conducts interdisciplinary coordination, oversees project implementation and operational health and safety management, and responds to changes arising during project execution.
- Designer is responsible for the quality of design documentation, information parameters of models (LOD/LOI/LOIN), and identification of design-related hazards (including detection of design clashes).
- Facility User provides operational requirements and participates in safety reviews as well as risk assessment processes from the life-cycle perspective of the facility.

The RACI matrix enables a systematic and unambiguous allocation of responsibility for risk management among individual participants of the construction process. The adopted division of roles results directly from the legal obligations of the parties involved in the investment process, their technical competencies, and their actual ability to influence the level of risk throughout the investment life cycle [10,18,20].

Key decisions regarding responsibility allocation are based on the following assumptions:

- Investor is responsible for approving actions related to risk management, as it initiates the investment process, finances the project, and bears responsibility for compliance with construction law regulations and public procurement requirements. Consequently, the Investor acts as the owner of strategic decisions and the entity accountable for the formal and legal compliance of the process.
- Contractor is responsible for construction execution safety, as it directly manages the construction site, organises the execution process, and responds to changes arising during the implementation of construction works.
- Designer is responsible for hazard identification at the design stage, resulting from technical expertise, design experience, and responsibility for preparing design documentation. One of the Designer's key tasks is also interdisciplinary coordination, constituting the primary mechanism for preventing design clashes and reducing technical risks.
- Facility User remains the party informed about risks, as it assumes responsibility for facility operation after project completion and should be aware of potential hazards resulting from the adopted design and construction solutions.

The detailed allocation of responsibilities is presented in Table 1, which illustrates the relationships between construction process participants in the context of risk management and the integration of BIM tools, particularly the BIM for Safety concept.

Table 1. RACI matrix

Risk area	Investor	Contractor	Designer	Facility User
Specification of Contract Terms (SWZ) / Description of the Subject Matter of the Contract (OPZ) documentation and evaluation criteria (Public Procurement Law)	R	C	C	C
Contract changes/claims	A	R	C	I
Legal Compliance and Public Procurement Law	A	I	C	I
Interdisciplinary coordination (clash detection)	I	R	A	I
Design documentation quality control (LOD/LOI)	I	C	A	I
Phasing and logistics	A	R	C	I
Hazard identification	I	A	C	R
4D coordination/schedule integration	I	A	C	I
Reviews and hazard assessment	I	R	C	A
Operational risk / Lack of FM data in the as-built model	A	I	C	R

Legend: R – Responsible; A – Accountable; C – Consulted; I – Informed

The analysis presented in Table 1 indicates that:

- Investor constitutes the central element of the decision-making system, responsible for approving actions and making strategic decisions.
- Contractor performs operational activities, manages safety on the construction site, and responds to emerging changes.
- Designer is responsible for identifying design-related hazards, interdisciplinary coordination, and ensuring documentation compliance.
- Facility user participates in the risk management process from the operational and life-cycle perspective of the asset.

An important component of the model is the application of the BIM for Safety approach, which supports hazard identification, emergency scenario simulation, and real-time risk monitoring, thereby strengthening communication between the designer and the contractor.

The proposed RACI matrix extends the recommendations of ISO 19650 [12-13] and the UK BIM Framework guidelines [14] concerning information responsibility matrices by expanding them to include categories of contractual, technical, and safety risks, as well as their integration with BIM for Safety processes.

4.5. Conditions for effective implementation of the RACI matrix

The implementation of the RACI matrix in investment practice requires the fulfilment of several key organisational and technological conditions:

- Integration with the project schedule. The RACI matrix should be directly linked to the project execution schedule so that risk management responsibilities are incorporated at the planning stage and become an integral component of time and resource management.
- Training of project participants. All project stakeholders should be trained regarding assigned roles and responsibilities (R/A/C/I), which reduces the risk of competency conflicts and decision-making ambiguity.
- Application of BIM for Safety tools. BIM for Safety solutions should be applied already at the design stage for hazard identification, emergency scenario simulations, and real-time risk monitoring, strengthening coordination between the designer and the contractor.
- Continuous risk monitoring and control. Effective risk management requires continuous tracking of design changes, evaluation of mitigation effectiveness, updating risk registers, and adapting risk management plans during project execution.
- Compliance with legal regulations. All activities must remain compliant with applicable construction law and public procurement regulations, ensuring transparency of the investment process and reducing the likelihood of contractual disputes.

4.6. Application of the RACI matrix in practical risk management

The proposed framework enables practical application of the RACI matrix in four complementary areas.

1. Risk identification and classification.

The RACI matrix supports systematic differentiation of three primary risk categories:

- Contractual risks (Public Procurement Law), including the Specification of Contract Terms (SWZ) / the Description of the Subject Matter of the Contractor (OPZ) requirements, bid evaluation criteria, appeal risks, contract amendments, annexes, and claims;
- Technical risks, related to interdisciplinary clashes, LOD/LOI levels, material requirements, discipline coordination, and construction phasing;
- Safety risks (BIM for Safety) concerning transport routes, hazardous zones, 4D analyses (schedule versus risk), and safety inspections.

2. RACI as a basis for contractual provisions.

Each row of Table 1 may be directly translated into contractual clauses defining:

- scope of responsibility,
- approval procedures,
- execution deadlines,
- performance indicators (KPIs).

Within public procurement projects, particular importance is attached to assigning responsibility for SWZ/OPZ preparation and legal compliance to the investor as the Accountable party, while maintaining the consultative role of designers and contractors. This approach reduces conflicts of interest, increases communication auditability, and enables full traceability of project changes.

3. Integration of BIM and BIM for Safety.

Integration of the RACI matrix with BIM methodology includes:

- cyclical interdisciplinary coordination within the CDE environment,
- automated clash detection combined with assignment of R/A responsibilities,
- use of hazard libraries and model-based hazard tags,
- 4D simulations and HSE checklists linked to stakeholder roles,
- digital "Safety Walks" conducted within the BIM model together with the risk register.

4. Risk reporting and review procedures.

The reporting system should be based on measurable performance indicators such as:

- number of clashes and open risks,
- response time to reported issues,
- rate of contractual changes,
- number of health and safety incidents.

Risk reviews are recommended to be conducted in the following cycles:

- weekly – BIM technical reviews,
- monthly – contractual reviews,
- quarterly – strategic reviews.

Centralisation of information within the CDE environment enables data versioning, preservation of decision audit trails, and increased transparency of the investment process.

5. Integrated risk management in the BIM environment

Risk management in building construction projects implemented using BIM technology extends beyond the traditional approach based on hazard identification and reactive mitigation measures. Digital information models enable the integration of technical, execution-related, and organisational risks within a single data environment, leading to the transformation of risk management from a documentation-based model into an operational information-driven process [7-10,15-18].

The proposed relationships between information processes, BIM documents, technical tools, and safety solutions are schematically presented in Fig. 2.

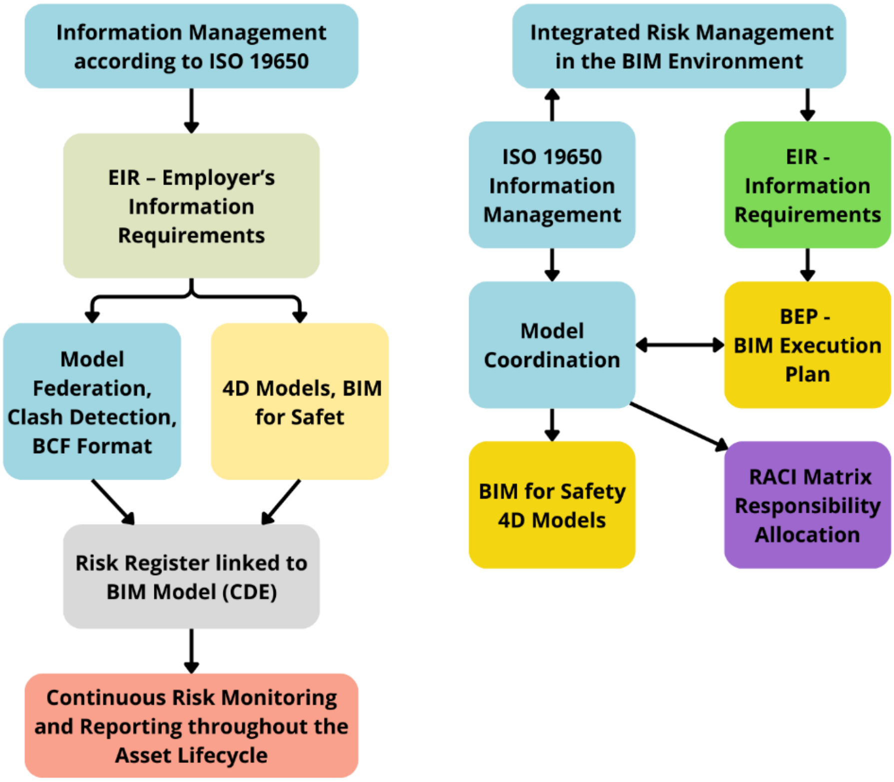

Fig. 2. BIM-based risk management framework for construction projects

Project risk is no longer analysed solely from a contractual or procedural perspective but becomes directly linked to the quality of information models, coordination methods, and the use of data during both project preparation and construction execution phases.

Table 2 presents the structural components of the BIM-based risk management system.

Table 2. Structural representation of BIM risk management system components

Area	Model element	Main tools / documents	Key effect in risk management
Information management	Application of ISO 19650 standards	Information management procedures, information roles	Structured data flow and reduction of information uncertainty
Investment preparation	Employer's Information Requirements (EIR)	EIR, SWZ/OPZ (procurement specifications)	Clear definition of information needs and scope of responsibilities
BIM planning	BIM Execution Plan (BEP)	BEP, model quality control procedures	Consistent collaboration rules and model quality assurance; reduction of responsibility ambiguity
Organisational responsibility	RACI matrix	RACI, role allocation matrix	Systematic allocation of contractual, technical, and H&S risks
Technical coordination	Model federation and clash detection	Federated models, clash detection tools, BCF	Early identification of clashes and design errors
Construction safety	BIM for Safety and 4D models	4D models, P-S-E analyses, scenario simulations	Identification of spatiotemporal risks and support for H&S planning
Risk monitoring	Risk register linked to the BIM model	Model-based risk database, periodic reports	Continuous change tracking and transparent reporting

5.1. Technical risk and coordination of information models

Technical risk in building projects primarily concentrates on the quality of BIM models and their interdisciplinary coordination. Errors generated during the design stage exhibit an exponential character – the cost of eliminating them during construction is significantly higher than correcting them within the digital environment [31].

Coordination risk includes three main categories of clashes:

- Hard clashes – direct geometric conflicts, e.g., a ventilation duct intersecting a structural element, requiring immediate design correction (rerouting installations or redesigning structural components).

- Soft clashes – violations of maintenance or installation zones directly affecting building operation and the facility management phase (e.g., lack of access to a valve).
- Logical clashes – errors related to non-geometric data, such as inconsistencies in technical parameters or element classification.

Effective risk mitigation requires the implementation of cyclic clash detection processes and issue management using the BCF (BIM Collaboration Format), enabling tracking of each issue until its formal resolution.

An additional source of technical risk is information loss during model conversion between native formats and the open IFC standard [32]. Minimising this risk requires early validation of IFC exports and the application of precise MVD (Model View Definition) specifications consistent with receiving software requirements.

5.2. Safety and construction preparation (BIM for Safety) as an extension of construction risk management

The development of BIM methodology has expanded risk management to include occupational health and safety (H&S) and construction site logistics. Information models no longer serve design purposes solely but become tools supporting the simulation of construction processes.

3D models and 4D simulations that integrate schedules with geometric models enable the identification of hazards that are invisible in traditional 2D documentation, particularly spatiotemporal risks arising from overlapping construction activities, work at height, or limited workspace availability.

At the design stage, quantitative H&S risk assessment methods may be applied, such as the three-factor method (P-S-E: Probability, Severity, Exposure). Integrating risk assessment algorithms with BIM software allows designers to analyse alternative technological scenarios (e.g., façade installation using scaffolding versus lifting platforms) and select solutions associated with lower risk levels [33].

Another important aspect of construction risk reduction is the modelling of construction site logistics [34]. Including temporary elements, transport routes, site facilities, fencing, and storage zones within the model reduces organisational conflicts, which, particularly in dense urban environments, frequently lead to delays and increased construction costs [35].

Integrating the BIM for Safety concept into the proposed framework transforms occupational safety management from an isolated process into an integral component of an integrated investment risk management system. Enhanced 3D and 4D models, supplemented with incident databases and hazard registers, enable not only risk visualisation but also preventive planning and monitoring of mitigation effectiveness [18,20].

5.3. Risk assessment methodology integrated with the BIM model

Implementation of BIM methodology enables a transition from traditional tabular risk management approaches to data-driven methods based on spatial and informational datasets. A key element becomes the integration of risk assessment directly within the information model.

The first step involves replacing the traditional risk register with a database linked to model objects. This solution enables visualisation of hazard locations, such as areas with elevated fall-from-height risk, and improves communication among project stakeholders.

The second element involves the use of simulation and what-if scenario analyses, allowing evaluation of potential consequences of critical events, such as the installation of heavy structural elements or the reorganisation of construction schedules.

The third pillar is a hybrid approach combining expert-based risk identification with quantitative analysis of BIM-generated data, including automated counting of hazardous zones, clash analysis, and monitoring of design changes [36,37].

Figure 3 illustrates the proposed BIM-integrated risk assessment methodology, highlighting the three complementary pillars: a BIM-linked risk database, simulation and what-if analyses, and a hybrid approach combining expert knowledge with BIM-generated quantitative data.

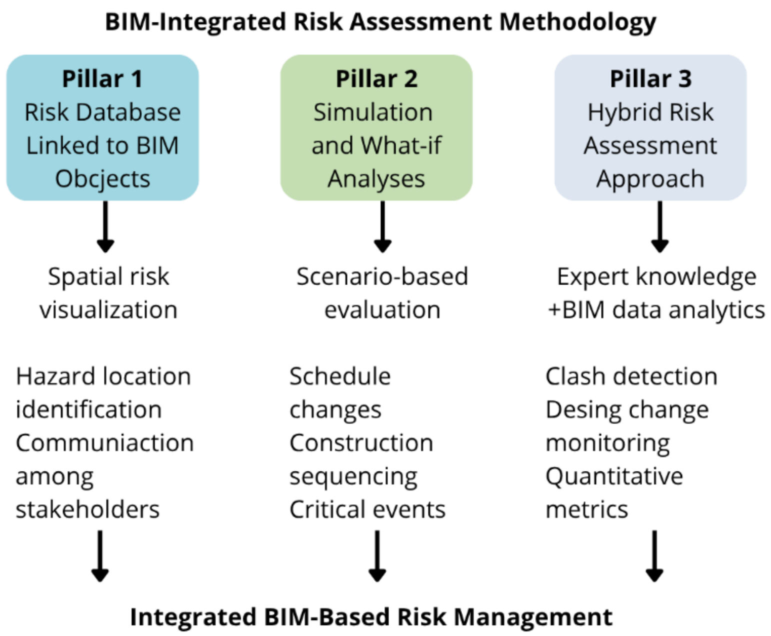

Fig. 3. Three-pillar BIM-integrated risk assessment framework

As a result, the BIM model evolves from a geometric representation tool into an integrated risk management environment that supports the design phase, construction execution, and preparation for building operations.

6. Conclusions and recommendations

The analysis indicates that effective risk management in BIM-implemented building projects requires a transition from a reactive approach to management based on project information and clearly defined responsibilities of investment process participants.

Based on the conducted analyses, the following conclusions were formulated:

1. The most significant project risks arise at the investment preparation stage, particularly as a result of improperly defined Employer's Information Requirements (EIR) and imprecise development of the BIM Execution Plan (BEP).
2. The BEP constitutes a key risk mitigation instrument, integrating information management principles, model quality control procedures, and collaboration organisation within the CDE environment. This document should have an operational character and be directly linked to contractual provisions.
3. Risk in the BIM environment is largely informational in nature; therefore, project responsibility concerns not only model geometry but also data quality, the Level of Information Need (LOIN), and the correctness of information exchange.
4. The application of the RACI matrix enables effective allocation of risks among the investor, designer, contractor, and facility user. Clear assignment of roles reduces responsibility gaps and minimises the potential for contractual disputes.
5. Systematic coordination of BIM models constitutes the primary mechanism for technical risk reduction. Regular clash detection processes and issue management using the BCF format enable elimination of errors before the construction stage.
6. Integration of BIM with safety processes (BIM for Safety) enables hazard identification at the design stage, supporting construction planning, site logistics, and analysis of spatiotemporal risks.
7. The proposed model may serve as a reference framework for updated national guidelines (e.g., BIM Standard PL) in the field of risk management in public projects by integrating information requirements, BIM documentation structures, and responsibility allocation.

Based on the above conclusions, the following recommendations are proposed:

- treating EIR and BEP as strategic risk management documents,
- integrating the RACI matrix with project schedules and contractual procedures,
- incorporating safety procedures into standard BIM model validation processes,
- maintaining a risk register directly linked to the digital model,
- ensuring continuous risk monitoring within the CDE environment throughout the entire investment lifecycle.

An important limitation of the proposed framework is the lack of empirical validation through case studies, quantitative analyses, or formal expert evaluation. Consequently, the framework presented in this article should be regarded as a conceptual and application-oriented solution that requires further verification in real construction projects. Future research should focus on implementing the model in selected building projects, assessing its effectiveness in reducing contractual, technical, and health-and-safety risks, and comparing the results with those achieved in projects delivered without the proposed framework.

This article presents the evolution of risk management approaches in building construction under conditions of digital transformation within the construction sector. The study demonstrates that implementation of BIM methodology shifts the centre of gravity of risk management from the construction phase toward the investment preparation and design stages.

Key importance lies in integrating three fundamental components: information management standards compliant with ISO 19650 [12,13], a clear allocation of responsibilities through the RACI matrix, and the use of BIM models as analytical tools to support technical coordination and construction safety.

BIM therefore evolves beyond a purely design-oriented tool, becoming a project knowledge management environment that enables hazard identification, data-driven decision-making, and reduction of organisational, technical, and contractual risks throughout the entire building lifecycle.

The presented approach may constitute a foundation for further development of risk management practices in both public and private projects implemented in digital environments. Future research should focus on empirical validation of the proposed framework across different project types and on quantitative assessment of its impact on reducing contractual, technical, and occupational safety risks.

Abbreviations

The following abbreviations are used in this manuscript:

BCF – BIM Collaboration Format
BEP – BIM Execution Plan
BIM – Building Information Model / Modelling / Management
CDE – Common Data Environment
EIR – Employer's Information Requirements
H&S – Health and Safety
LOD – Level of Detail
LOI – Level of Information
LOIN – Level of Information Need
MVD – Model View Definition
OPZ – Description of the Subject Matter of the Contract
P-S-E – Probability, Severity, Exposure
RACI – Responsible, Accountable, Consulted, Informed
SWZ – Specification of Contract Terms

References

[1] Lafhaj Z., Rebai S., AlBalkhy W., Hamdi O., Mossman A., Alves Da Costa A., Complexity in Construction Projects: A Literature Review, *Buildings* 14 (2024) 680. https://doi.org/10.3390/buildings14030680

[2] Kim S.H., Kim Y.S., Quantitative analysis of schedule impact due to design changes in finishing construction work: (A case study of office buildings), *KSCE Journal of Civil Engineering* 30 (2026) 100362. https://doi.org/10.1016/j.kscej.2025.100362

[3] af Hällström A., Bosch-Sijtsema P., Poblete L., Challenges with collaboration: the interaction of formal and informal ties in infrastructure construction, *Construction Management and Economics* 43 (2025) 7–25. https://doi.org/10.1080/01446193.2024.237115

[4] Glette-Iversen I., Flage R., Aven T., Extending and improving current frameworks for risk management and decision-making: A new approach for incorporating dynamic aspects of risk and uncertainty, *Safety Science* 168 (2023) 106317. https://doi.org/10.1016/j.ssci.2023.106317

[5] Almashhour R., Al-Mhdawi M.K.S., Daghfous A., Qazi A., Ojiako U., Traditional to sustainable risk management in the construction industry: a systematic literature review, *International Journal of Managing Projects in Business* 18 (2025) 528–565. https://doi.org/10.1108/IJMPB-01-2025-0021

[6] Tariq J., Shujaa Safdar Gardezi S., Study the delays and conflicts for construction projects and their mutual relationship: A review, *Ain Shams Engineering Journal* 14 (2023) 101815. https://doi.org/10.1016/j.asej.2022.101815

[7] Smithies G., Papi G., Mcgillycuddy E., Mcgillycuddy E., The blueprint of digital advancement: a study of construction technology implementation, *Proceedings of the Institution of Civil Engineers - Civil Engineering* 178 (2025) 104–117. https://doi.org/10.1680/jcien.24.01004

[8] Kaur R., Mwambegele B.J., Abraham A.G., Basheer S.A., Garia S., A comprehensive review on building information modelling (BIM), its implementations and applications, *Discover Civil Engineering* 2 (2025) 177. https://doi.org/10.1007/s44290-025-00342-5

[9] Biswas H.K., Sim T.Y., Lau S.L., Impact of Building Information Modelling and Advanced Technologies in the AEC Industry: A Contemporary Review and Future Directions, *Journal of Building Engineering* 82 (2024) 108165. https://doi.org/10.1016/j.jobe.2023.108165

[10] Miao D., Legal Risk Analysis and Management of Construction Project Compliance in Intelligent Construction, *International Journal of Information Security and Privacy* 19(1) (2025). https://doi.org/10.4018/IJISP.396818

[11] Knitter-Piątkowska A., Kotlarek U., Znaczenie i struktura dokumentu BIM Execution Plan (BEP) w procesie inwestycyjno-budowlanym, *Builder* 342 (2025) 20–25. https://doi.org/10.5604/01.3001.0055.5187

[12] ISO 19650-1:2018. *Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) – Information management using building information modelling – Part 1: Concepts and principles*, International Organization for Standardization, Geneva, 2018.

[13] ISO 19650-2:2018. *Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) – Information management using building information modelling – Part 2: Delivery phase of the assets*, International Organization for Standardization, Geneva, 2018.

[14] *IMI Framework – BIM Standards, Guides & Resources*, https://www.ukbimframework.org/about/ (accessed February 18, 2026).

[15] Doan D.T., Atencio E., Muñoz La Rivera F., Alnajjar O., A Systematic Literature Review of Building Information Modelling (BIM) and Offsite Construction (OSC) Integration: Emerging Technologies and Future Trends, *Applied Sciences* 15(18) (2025) 9981. https://doi.org/10.3390/app15189981

[16] Ahmad D.M., Gáspár L., Bencze Z., Maya R.A., The Role of BIM in Managing Risks in Sustainability of Bridge Projects: A Systematic Review with Meta-Analysis, *Sustainability* 16(3) (2024) 1242. https://doi.org/10.3390/su16031242

[17] Wang J., Ma Y., Li R., Zhang S., Applications of Building Information Modeling (BIM) and BIM-Related Technologies for Sustainable Risk and Disaster Management in Buildings: A Meta-Analysis (2014–2024), *Buildings* 15(13) (2025) 2289. https://doi.org/10.3390/buildings15132289

[18] Dogonyaro I., Elnokaly A., Strategies to Mitigate Risks in Building Information Modelling Implementation: A Techno-Organizational Perspective, *Intelligent Infrastructure and Construction* 1 (2025) 5. https://doi.org/10.3390/iic1020005

[19] Kwast-Kotlarek U., Szóstak M., RACI–AHP–BIM Methodology in Projects with High Functional Complexity and Conservation Constraints, *Infrastructures* 11(3) (2026) 105. https://doi.org/10.3390/infrastructures11030105

[20] Yasser M., Rashid I.A., Nagy A.M., Elbehairy H.S., Integrated Model for BIM and Risk Data in Construction Projects, *Engineering Research Express* 4(4) (2023) 045044. https://doi.org/10.1088/2631-8695/acae1e

[21] Dudzińska E.M., Borkowski A.S., HBIM in the digital reconstruction of historic buildings based on point clouds – a case study of the manor house in Nużewo, Poland, *Budownictwo i Architektura / Civil and Architectural Engineering* 25(1) (2026) 26005. https://doi.org/10.35784/bud-arch.8693

[22] Borkowski A.S., To Duc A., Integration of BIM and GIS Data of a Heritage Building Using FME, *Civil and Environmental Engineering Reports* 34(2) (2024) 204–215. https://doi.org/10.59440/ceer/190231

[23] Awe M., Malhi A., Budka M., Mavengere N., Dave B., Towards 4D BIM: A Systematic Literature Review on Challenges, Strategies and Tools in Leveraging AI with BIM, *Buildings* 15(7) (2025) 1072. https://doi.org/10.3390/buildings15071072

[24] Boton C., Rivest L., Kubicki S., Ghnaya O., 4D Simulation Research in Construction: A Systematic Mapping Study, *Archives of Computational Methods in Engineering* 30(4) (2023) 2451–2472. https://doi.org/10.1007/s11831-022-09873-x

[25] Public Procurement Office (Urząd Zamówień Publicznych). *Prawo zamówień publicznych – e-komentarz (Art. 69 – narzędzia elektronicznego modelowania danych BIM)*. https://ekomentarzpzp.uzp.gov.pl (accessed 18 February 2026), (in Polish).

[26] BIM Standard PL - Urząd Zamówień Publicznych - Portal Gov.pl, version 2.0, Warszawa, 2020 https://www.gov.pl/web/uzp/bim-standard-pl (accessed February 18, 2026), (in Polish).

[27] Porwal A., Hewage K.N., Building Information Modeling (BIM) Partnering Framework for Public Construction Projects, *Automation in Construction* 31 (2013) 204–214. https://doi.org/10.1016/j.autcon.2012.12.004

[28] Mohammadi S., Aibinu A.A., Oraee M., Legal and Contractual Risks and Challenges for BIM, *Journal of Legal Affairs and Dispute Resolution in Engineering and Construction* 16 (2024) 04523043. https://doi.org/10.1061/jladah.ladr-1040

[29] Zou Y., Kiviniemi A., Jones S.W., A Review of Risk Management Through BIM and BIM-Related Technologies, *Safety Science* 97 (2017) 88–98. https://doi.org/10.1016/j.ssci.2015.12.027

[30] Tsoupra A.P., Tsoukalis F.P., Chassiakos A.P., BIM-Based Risk Identification and Assessment in Building Projects at their Design Phase, *UBT International Conference* (2019), 184. https://knowledgecenter.ubt-uni.net/conference/2019/events/184

[31] Borkowski A., Kubrat A., A Conceptual AI-Based Framework for Clash Triage in Building Information Modeling (BIM): Towards Automated Prioritization in Complex Construction Projects, *Buildings* 16(4) (2026) 690. https://doi.org/10.3390/buildings16040690

[32] Akhmetzhanova B., Nadeem A., Hossain M.A., Kim J.R., Clash Detection Using Building Information Modeling (BIM) Technology in the Republic of Kazakhstan, *Buildings* 12(2) (2022) 102. https://doi.org/10.3390/buildings12020102

[33] Wiatr T., Modelowanie przedsięwzięć budowlanych w ujęciu BIM z kontekstem planowania BIOZ, *Przegląd Budowlany* 95(7) (2024) 104–108. https://doi.org/10.5604/01.3001.0054.8895 (in Polish).

[34] Lu Y., Gong P., Tang Y., Sun S., Li Q., BIM-Integrated Construction Safety Risk Assessment at the Design Stage of

Building Projects, *Automation in Construction* 124 (2021) 103553. https://doi.org/10.1016/j.autcon.2021.103553

[35] Abueisheh Q., Manu P., Mahamadu A.-M., Cheung C., Design for Safety Implementation Among Design Professionals in Construction: The Context of Palestine, *Safety Science* 128 (2020) 104742. https://doi.org/10.1016/j.ssci.2020.104742

[36] Kaczorek K., Możliwości wdrożenia koncepcji Budownictwa 4.0 w obszarze BHP, *Przegląd Budowlany* 94(9–10) (2023) 105–109. https://doi.org/10.5604/01.3001.0053.9372 (in Polish).

[37] Szóstak M., Napiórkowski M., Dziekoński K., Anandh K.S., 8D-BIM Models in Construction: Enhanced Occupational Safety for Construction Works, *Construction of Optimized Energy Potential – Budownictwo o Zoptymalizowanym Potencjale Energetycznym* 13 (2024) 184–192. https://doi.org/10.17512/bozpe.2024.13.18