GEOMATICS AND ENVIRONMENTAL ENGINEERING • Volume 19 • Number 3 • 2025

https://doi.org/10.7494/geom.2025.19.3.63

Maciej Wrzosek[1], Tomasz Owerko[2], Maciej Rochel[3], Dariusz Kasznia[4]

Automating Compliance: Advanced Verification Techniques for Information Requirements in BIM Railway Projects

Abstract: Since BIM (building information modelling) emerged as the standard for project preparation, there has been a demand for rapid compliance-checking. This article explains this issue in railway building projects; it focuses on establishing a common ground for the creation, verification, and management of EIR (exchange information requirements). Using examples from European railway projects, the authors illustrate how EIR structures and standards can vary. The paper demonstrates basic requirements to ensure BIM models comply with contracting authorities' requirements thus supporting effective planning for the design, construction, and operation phases. The study also reviews existing requirements, engineering processes, and testing methods, creating a link between BIM and software-engineering practices such as unit testing, system testing, and integration testing to ensure comprehensive model validation. By highlighting the use of buildingSMART Open BIM standard, such as information delivery specifications (IDS) and industry foundation classes (IFC), the study illustrates their role in the automated or semi-automated compliance verification. The research results showed the limitations of the verification tools and methods that are currently being used in the industry, emphasizing the need for further advancements in computer-aided verification. Presented coverage percentages are based on a limited set of EIR documents and tool assessments; these values should be considered to be estimates based on specific assumptions and not definitive generalizable results.

Keywords: information delivery specification, building information modeling, exchange information requirements, civil engineering

Received: December 23, 2024; accepted: May 19, 2025

[1] AGH University of Krakow, Faculty of Geo-Data Science, Geodesy, and Environmental Engineering, Krakow, Poland, email: mwrzosek@agh.edu.pl (corresponding author), https://orcid.org/0009-0000-6317-5631

[2] AGH University of Krakow, Faculty of Geo-Data Science, Geodesy, and Environmental Engineering, Krakow, Poland, email: owerko@agh.edu.pl, https://orcid.org/0000-0002-2873-3535

[3] AGH University of Krakow, Faculty of Geo-Data Science, Geodesy, and Environmental Engineering, Krakow, Poland, email: mrochel@agh.edu.pl, https://orcid.org/0000-0002-8109-973X

[4] AGH University of Krakow, Faculty of Geo-Data Science, Geodesy, and Environmental Engineering, Krakow, Poland, email: kasznia@agh.edu.pl, https://orcid.org/0009-0006-0942-7854

1. Introduction

Issues that are related to automation compliance are a key element in streamlining the process of designing railway construction facilities using BIM. An important element of this method is the creation of EIR documents that define the appointing party's requirements in terms of the management, business, and technical conditions [1].

One of the motivations for this study is to reinforce the relationship between BIM processes and established requirements engineering (RE) frameworks [2]. While this study primarily uses RE terminology as a classification tool, the long-term vision is to explore how formal engineering methods can enhance the verification and automation of BIM information processes.

The authors' motivation was to use advanced verification techniques to streamline the design process, meet the appointing party's requirements, and (consequently) reduce unnecessary work for the designer. One of the methods of verifying and automating the compliance that is used in construction is the information delivery specification (IDS) standard. This is a machine-interpretable form that allows for the automatic control of BIM content compliance [3]. In this case, the original contribution of this study is to verify what the boundary conditions are that EIR documents should meet to enable the automatic verification of the requirements, together with determining the percentage level of the fulfillment of these requirements for EIR and IFC.

2. Literature Review

Several studies have explored the different aspects that are related to this article. The first analyzed article (prepared by Ashworth [4]) described the development, testing, and implementation of an EIR guide document that was tailored to the needs of the client and FM as part of the BIM process. The aim of the study was to create a structured approach to capturing a client's information requirements and ensure compliance with BIM standards, thus improving the BEP that was delivered by the design and construction specialists.

The research methodology included a case study that involved a Scottish project as well as reviews and interviews with BIM experts. The study identified the need to provide specific guidance to FM and the client regarding the preparation of the EIR. The EIR template that was developed as part of the study facilitated collaboration among the clients, FM, and the project team by helping to clearly define and meet the client's information requirements. The author of the publication identified those processes that required a change in thinking within the BIM technology, focusing on the client's future information needs from the beginning of a project. The publication also showed that there was a need for easy-to-understand customer guide documents.

Another analyzed article by Cavka et al. [5] focused on the process of design review, compliance checking, and project handover in the context of BIM. The research aimed to understand how owners could adopt and implement BIM to support design and information-handover reviews. The study investigated two large public-owner organizations over five years and proposed a three-level compliance framework for BIM model handover:

1. **Model structure verification:** ensured that the model was built correctly, allowing for the accurate computation of information.
2. **Model content verification:** confirmed that the required geometric and nongeometric information was present in the model.
3. **Design compliance review:** used computable queries that were developed from owner requirements to evaluate the design against these requirements.

As the study showed, the use of BIM enabled the seamless exchange of project information among design, construction, and maintenance while supporting automated design reviews.

On the other hand, an article by Valinejadshoubi et al. [6] described the use of BIM technology and the possibilities of assessing the quality of provided BIM data. In the article, the author pointed out the need for automatic BIM data-quality-assessment systems based on BEP, level of definition (LOD) matrices, and personalized quality checklists. The aim of the study was to create an automated system for assessing the quality of 3D BIM data.

As was shown by the author, the approach involved the BIM model, the Data Extraction and Analysis Module, the Data Storage Module, and the Data Visualization. It was then used in a Canadian infrastructure project that achieved an average quality score of 87.6% for the BIM models and reduced the number of noncompliant elements by approximately 30%. The study that was conducted by the author proved that the proposed system offered an effective solution for improving the quality-control processes in the BIM model's data management.

Other articles by Preidel and Borrmann [7, 8] presented the use of a visual programming language (VPL) for automatic compliance checking. By using VPL visual code-checking language (VCCL) in a study of building information modeling (BIM), it was possible to automate the process of project-compliance checks with the building codes in a simple manner that was accessible to an average engineer. VCCL was an adaptation of the regulatory language that was designed to make compliance checks both machine-readable and easily understandable by humans. The study results on the efficiency and error-proneness of the compliance-checking methods that were achieved through the introduction of more transparent, optimal, and semi-automatic software. It was demonstrated that in the studies that were reviewed, the time control, and the evaluation were successfully achieved using traditional methods.

In turn, other studies [9–11] utilized the integration of logic with natural language processing (NLP). The articles also focused on automatic compliance control in the construction industry. By combining NLP with BIM, however, they indicated the possibility of improving the accuracy, speed, and efficiency of the verification processes.

The conducted research was based on the automatic extraction of information from regulatory texts (laws and regulations) using natural language processing (NLP) and then transformed them into logical structures or an ontology. According to the authors of these studies, this method was faster and more flexible than traditional automatic compliance-control systems that were based on coded rules.

Studies by Guo et al. [9] and Zhang and El-Gohary [10] focused on generating queries (e.g., SPARQL) and logical rules, while an article by Zhou et al. [11] emphasized the integration of multiple data sources and their representations in a unified framework. All of the studies presented good results in their performance tests, which proved that the use of natural language processing (NLP) was an efficient solution for assessing the compliance of BIM projects with the regulatory texts of a given country.

Other analyzed articles [12–16] also addressed the issue of the automation of compliance-verification processes or data quality in the context of BIM usage. In [14], this topic was additionally extended to analyses of large data sets (which could be helpful in complex file models). The authors of the article raised the issue of the imperfection of BIM data as the main problem that affected the possibilities of implementing the automation of the compliance processes. As part of the research of articles by Preidel and Borrmann [12] and Doukari et al. [13], the issue of converting regulatory texts into logical structures was raised again.

Nevertheless, the discussed articles differed from each other from a technological perspective. In the article by Preidel and Borrmann [12], a white-box and black-box approach to ACC (automated code compliance) automation was proposed that indicated a compromise between transparency and ease of implementation. The article by Doukari et al. [13] proposed a bottom-up approach; i.e., analysis and validation at the level of BIM objects, with an emphasis on the hierarchical structure of data processing. In a study by Schelter et al. [14] that addressed the issue of large data sets, the use of Apache Spark and machine-learning technologies was proposed as typical tools for large-scale data analysis. A paper by Amor and Dimyadi [15] emphasized the use of AI in the processing of regulatory texts and discussed the difficulties that were associated with implementing performance-based standards. In a study by Lee et al. [16], the authors discussed three types of BIM validation: syntactic checks for IFC schema compliance, semantic conformity to MVD (model view definition) standards, and rule-based checks for design programming.

As part of the study that was conducted by the authors of [17], it was checked whether generating requirements for open BIM models could be automated in accordance with IDS standards. It was also assumed that the input data represented the requirements from the BEP. The research results indicated the possibility of the automatic generation of IDS files, which improved model verification and enabled its quick correction. Despite the challenges, the use of IDS as part of open BIM standards improved the construction processes.

2.1. Current State of Knowledge

Attempts to automate the verification process of IFC files in accordance with the EIR are gaining traction. Using tools like IDS offer a standardized approach for not only defining but also checking information requirements. Traditionally, information requirements have been made available through formats such as PDF files, which often make data difficult to access. IDS provides a standardized approach for delivering specification and automated checking, increasing the reliability and accuracy of the information exchange [3]. The operational diagram below (Fig. 1) illustrates how an IDS can automate the verification of a BIM modeler's work.

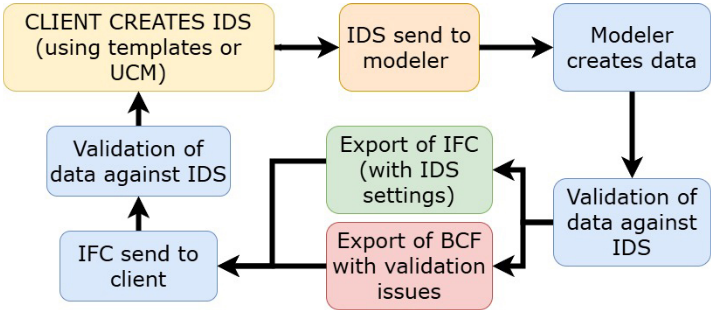

Fig. 1. Information delivery specification operation diagram
Source: [18]

Various tools support requirements engineering in BIM; these are tools developed by ACCA software (e.g., usBIM.checker), BIMcollab, or Blender (with Bonsai addon by IfcOpenSchell), which offer capabilities for managing and verifying requirements. These tools assess the compliance of IFC files with IDS requirements by using metrics to quantify how well the BIM model meets the defined standards.

In June 2024, buildingSMART International announced that IDS Version 1.0 had reached the final standard status. The final standard defines the basic data that must be included in a BIM data set and enables its subsequent validation in accordance with [1]. Léon van Berlo (the technical director of buildingSMART International) highlighted the collaborative development of IDS (which involved more than 200 participants from 34 countries), reflecting its robustness and maturity [18]. This new standard aims to significantly improve information exchange in the construction industry, supporting both buildingSMART's strategic and technical objectives and the wider adoption of openBIM standards.

To verify IFC models using standards such as IDS, metrics have been proposed to systematically assess the correctness of IFC files. The use of these metrics ensures that IFC files meet the specified standards, thus increasing the reliability of BIM models [19]. The proposed metrics include the following:

– **Attribute completeness:** measures the percentage of required attributes that are present in an IFC file; for example, if 5 attributes are required and 4 are present, completeness would be 80%.
– **Attribute accuracy:** assesses the correctness of the attribute values against predefined standards or expected values (the percentage of the attributes that have the correct values).
– **Data consistency:** assesses the consistency of the data in the different elements of an IFC file (e.g., checking for conflicts or discrepancies in the data values).
– **Completeness of model:** checks that the required components exist in an IFC file.
– **Geometric accuracy:** verifies that the geometric representations of the elements meet the required standards (e.g., verifying the number of vertices in specific components).
– **Clash Detection:** counts and analyzes the number of collisions that are detected in an IFC file (including hard, soft, temporary, assembly, and operational collisions).
– **Interoperability:** checks the ability of an IFC file to be correctly imported, exported, and used on different BIM software platforms.
– **Version control:** checks that IFC is the correct version (e.g., IFC 4.3).
– **Required relationships in the IFC file schema:** checks that the relationships between components are correctly established.
– **Compliance with naming conventions:** checks that all of the elements and attributes comply with specific naming conventions and standards.
– **Time and effort for work overs:** checks the time and effort that are required to manually correct any non-conformities that are detected in an IFC file.

Using these metrics, stakeholders can systematically assess and ensure that IFC files meet specific client criteria.

2.2. Knowledge Gap

Despite advancements in the automation of BIM compliance verification, several questions remain unanswered; for instance, what should an EIR look like in order to enable the automatic verification of IFC files against its requirements using automated compliance checking? Additionally, it is worth examining what percentage of EIR requirements can be covered by these tests (like IDS) and how to measure the extent to which a particular EIR is expressed through them. Unit testing using standards like IDS raises additional questions about which parts of an IFC model cannot be verified by IDS and what percentage of the information requirements can be verified automatically.

To address these knowledge gaps, an analysis of the current limitations of the tools that are used for requirements engineering in BIM is required, as are verifications of the potentials of new techniques for improving the automatic-verification process. By understanding the limitations that exist, the construction industry can move toward more-efficient and accurate BIM compliance-verification systems.

This article will delve into these topics, providing an overview of strategies and methods for creating EIR, the current state of automated IFC verification, and the metrics that are used to assess compliance. Through a detailed literature review and the identification of knowledge gaps, it aims to contribute to the ongoing development of advanced verification techniques for BIM information requirements.

3. Materials and Methods

3.1. Strategies for Creating EIR Documents – Basic Document for Information Requirements

Very often, BIM requirements get mixed up with other requirements in different documents without maintaining a consistent form with that of the EIR. For railway building project designs, the requirements are structured across various critical categories in order to ensure the correct planning and execution:

- **Operational and technical requirements:** focus on specifications for the technical infrastructure (such as HVAC systems, electrical installations, IT, and monitoring systems) and operational aspects (like traffic organization, train schedules, baggage logistics, staff management, and evacuation plans).
- **Functional and user requirements:** focus on aspects such as the number of platforms, passenger service points, and technical facilities (retail and catering spaces), with an emphasis on accessibility for people with disabilities and including the needs of passengers, staff, shops, restaurants, and external service providers.
- **Architectural and environmental requirements:** focus on providing guidance on design aesthetics, material selection, architectural style, and integration with the surrounding environment as well as minimizing impacts, managing waste, reducing CO_2 emissions, and promoting sustainable building practices (ESG – environmental, social, and governance).
- **Business and legal requirements:** focus on financial aspects (investment costs, funding sources, operating costs, and economic benefits) and on compliance with legal regulations, building standards, safety regulations, and heritage-protection guidelines.
- **Communication and accessibility requirements:** focus on the connectivity of the transport network and accessibility.
- **BIM requirements (EIR):** focus on information management aspects like the level of detail (LOD), level of information (LOI), or schedules for model updates, data exchange, and collaboration requirements.

These requirements collectively ensure that railway projects are technically sound, user-friendly, architecturally integrated, environmentally responsible, legally compliant, and digitally proficient.

In the construction process, an EIR specifies the management, business, and technical aspects of project information production according to the assumptions of the ISO 19650 standard [1]. The main goal of the EIR is to prepare a set of information requirements for a potential contractor, thus enabling the appointed party to present a realistic approach toward meeting these requirements within the BIM execution plan (BEP). Additionally, the ISO 19650 standard [1] recommends that the management and business aspects include the information standard as well as the methods and procedures for information production that should be implemented throughout the life cycle of the investment.

The EIR document should be created sufficiently early (before the procurement for design or construction works and be preferably based on the organization's strategic goals that are described in the organizational information requirements (OIR), the asset information requirements (AIR), and the organization's guidelines for data collection and processing. The EIR should include organizational issues that are critical for the organization, project management, and technical issues [20].

In both the European and Polish markets, there is no official government document that describes which information and requirements the EIR document should present; there are only the requirements that are described in the ISO standard [1]. However, the BIM Standard PL manual [21] was developed in Poland as part of an initiative by construction companies and a team of specialists under the patronage of the Polish Association of Construction Industry Employers. This manual includes, among other things, a proposed standard for EIR – what this document should consist of, and which information it should present; this meets the requirements and guidelines that are specified in the ISO 19650 standard [1]. So far, some of the EIR documents that have been created for public investment projects involving infrastructure (roads, railways, and tram lines) have been developed based on this manual. However, a significant majority were created on the part of the ordering party with the use of technical support from specialists.

Among the investors who tried to implement EIR for public procurement (as well as basing the investment process on the BIM methodology) as parts of pilot projects, one can distinguish large state-owned companies or government agencies such as PKP Polish Railway Lines (PLK) and the General Directorate for National Roads and Motorways (GDDKiA).

Other state-owned or municipal companies that have decided to widely apply the BIM method (and, thus, include EIR as an attachment to the tender procedure) include Solidarity Transport Hub, the Pomeranian Metropolitan Railway, and Warsaw Trams. All of these organizations have prepared their own EIR documents, which have differed in many aspects. This is a major design challenge for the automation of information requirements control based on RE.

3.2. Testing Methods in Requirements Engineering and Its Connection with BIM and EIR

BIM revolutionizes the architecture, engineering and construction industry (AEC) by offering comprehensive digital representations of the physical and functional characteristics of facilities. This approach ensures that all parties have access to accurate information throughout a project's lifecycle.

EIR creation management is decisive in ensuring that a model meets the specific needs of a project. EIRs outline the information that is needed to support decision-making by the appointing party or other project stakeholders (in accordance with [1]) and encompass management, business, and technical aspects [20].

To meet the requirements that are specified in an EIR and develop them, the processes of defining, documenting, and maintaining the requirements for the IT industry (requirements engineering) that are consistent with the construction industry can be used. These processes aim to develop and then update the documentation of any software requirements [22].

While RE classification provides a structured framework, BIM requirements often go beyond traditional categories by including spatial, geometric, and lifecycle aspects. Therefore, the mapping of BIM requirements to RE domains must be treated with caution and should be perceived as an analogy rather than a direct equivalence; these requirements can be divided into three groups:

1) functional requirements – defining which functions software should perform;
2) nonfunctional requirements – defining how system should perform these functions;
3) compliance requirements – determining conditions of compliance with legal rules, standards, and other documents.

The requirements are also assessed in terms of the levels of the following:

– business requirements – defining company's strategic business needs;
– user requirements – specifying services and properties of given system.

The division of the requirements and their levels within RE may also be referenced in the construction industry (as is shown by the examples below). These analogies are not exact matches; the spatial and geometric aspects of BIM extend beyond typical RE categories and should be considered illustratively. As part of requirements engineering, five types of tests that are used in IT can be compared with their connections to the construction industry and BIM technology [23] (Table 1).

Figure 2 illustrates these parallels: on the left side, it shows the progression of the testing in IT (from unit tests to acceptance tests), representing increasing complexity and integration; on the right side, it illustrates the EIR process in BIM, showing how EIRs are linked with IDS and IFC for comprehensive model verification. Both sides highlight the importance of thorough testing and verification for ensuring that the final product meets all requirements.

Table 1. Requirements engineering vs BIM comparison

Type of Testing	IT Context	BIM Equivalent
Unit Testing	Tests individual components or units of software	In BIM, this can be compared to validating individual BIM components or attributes (e.g., verifying that single door component in BIM model meets design specifications)
Integration Testing	Tests interaction between integrated components to ensure that they work together	This is similar to checking integration of different BIM components (e.g., that doors, windows, and walls interact correctly within model and with each other)
System Testing	Testing complete and integrated software system to verify that it meets specified requirements	System testing can be compared to verifying entire BIM model for compliance with project specifications and standards
System Integration	Tests interactions between software system and external systems	Integration of BIM model with other systems such as common data environment (CDE), facilities management systems (FM), and design and analysis programs, thus ensuring seamless data-exchange and interoperability
Acceptance Testing	Testing software in real-world scenario to ensure that it meets appointing party's requirements (alpha and beta testing)	Involves validating final BIM model against entire EIR to ensure that it meets requirements of appointing party – especially for scenarios that were not included in previous tests; this may include conducting walk-throughs and simulations to verify that model is ready for use in construction/operation or testing of BIM model data in client's IT environment

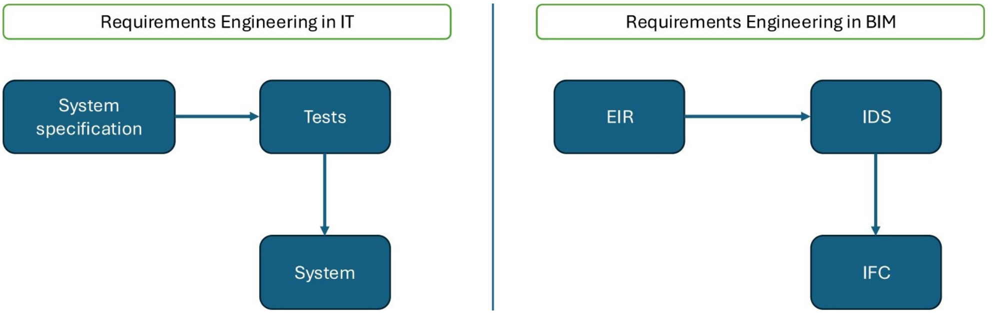

Fig. 2. Requirements engineering in IT and their BIM equivalents

(Note: while this figure presents conceptual analogy between requirements engineering in IT and BIM, it is important to emphasize that IDS only covers subset of requirements that are defined in EIR)

3.3. IFC Files as Deliverables of Information Requirements in BIM

BIM has revolutionized the AEC industry by using a comprehensive physical and parametric representation of a project. The methods for creating EIR (including LOI requirements) are important for ensuring that the BIM model meets the specific needs [22].

The proper use of IFC files is also essential; these files allow for interoperability among the different software platforms that are used in BIM. However, the complexity of BIM projects often leads to issues such as data inconsistencies, geometric collisions, or data loss. Addressing these issues within IFC files allows for maintaining the functionality of the BIM models.

3.4. Source Documentation

The study analyzed examples of EIR for infrastructure projects from the Polish and European markets – railway projects that were discussed in the introduction:

- project for construction of new railway lines in Solidarity Transport Hub Railway Subprogram (client: Solidarity Transport Hub [24]);
- project for construction of new railway line through southern districts of Gdańsk (client: Pomeranian Metropolitan Railway [25]);
- project for construction of new railway line through Lithuania, Latvia, and Estonia as part of "Rail Baltica" project (client: RB Rail AS [26]);
- design of construction of "Annopol" tram depot in Warsaw (client: Warsaw Trams [27]);
- demolition and design of construction of railway viaduct on Railway Line No. 140 (Katowice Ligota – Nędza) (client: PKP Polish Railway Lines S.A. [28]);
- design and construction of Zator bypass along National Road No. 28 (client: General Directorate for National Roads and Motorways [29]).

3.5. Data Extraction

From the EIR documents that were presented above, it is possible to indicate the general division of the document into the following:

- organizational requirements;
- requirements that are related to project management;
- technical issues;
- annexes.

The structures of the analyzed EIR documents were closely related to the investors' goals – the fewer goals that the client hoped to achieve using BIM technology, the simpler the EIR documents were.

The first analyzed EIR document for the Solidarity Transport Hub railway projects [24] contains information about several aspects.

The document covers:
- rules of communication between various project participants;
- standards for acquiring construction information (including contents of design models);
- principles of providing, managing, and processing construction information;
- guidelines and standards for coordination of design models;
- rules of cooperation on CDE platform.

In terms of the investor's requirements, the required level of definition (LOD) design models, attribute matrices, document-circulation procedures, and catalogue structures were presented as attachments to the document. The investor also required the contractor to present the LODs that were planned for implementing the information models as part of BEP – the level of geometric detail (LOG), the level of information (LOI), the master information delivery plan (MIDP), and the model production and delivery table (MPDT).

In turn, the Pomeranian Metropolitan Railway EIR document [25] was simpler in its form and contained fewer requirements and rules, as the investor only expected to create a model of the existing state, a multi-disciplinary model, and the use of the CDE environment in its communications. As part of the document, the investor defined the division and scopes for the BIM models along with the LOD levels. The MPDT and MIDP templates were also provided as attachments to the EIR document. Similar to the previous document for Solidarity Transport Hub [24], the contractor was obligated to present the planned LOD levels for the information models and develop MPDT and MIDP based on the investor's templates as part of the preparation of the BEP document.

Another of the analyzed EIR documents that was prepared by RB Rail AS [26] presented a comprehensive approach to the implementation of BIM technology at all stages of the project; therefore, the EIR document that was prepared by the investor was quite general and universal. The goals of the BIM implementation within the project as were specified by RB Rail AS were primarily as follows:
- increasing quality and efficiency of project through better data management;
- improving multi-disciplinary coordination at early stages of project;
- optimizing information management;
- facilitating decision-making based on BIM models;
- verifying compliance with investor requirements.

Similar to the previous documents [24, 25], the investor required the contractor to develop a BEP document that contained proposals regarding the file naming, division, and structure of the BIM models as well as information on the planned LOD levels and the development of MPDT and MIDP based on the forms that were prepared by the investor and which constituted attachments to the EIR document.

The EIR document for the construction of a tram depot in Warsaw (investor: Warsaw Trams) [27] was aimed at preparing BIM models as part of the project and then using them for management purposes at the facility management (FM) stage after its construction as an asset information model (AIM). Additionally, the investor defined the goals of using BIM technology to verify any collisions among the design models as well as document-circulation procedures and the naming structure. As attachments to the EIR, the investor prepared a DWG file with the designation of the base point on the plot that was covered by the project as well as the requirements for management models, collision-report templates, and detailed requirements for LOD levels. Similar to the previous documents, the contractor will be obligated to present the planned LOD levels for the information models and develop MPDT and MIDP based on the investor's templates as part of the development of the BEP document.

For the project of the demolition, design, and construction of the railway viaduct (investor: PKP Polish Railway Lines S.A.) [28], the only requirements that were specified by the investor in EIR were to improve the process of the quality verification of the project by the client and to minimize the multi-disciplinary conflicts in the project. The EIR document was divided into organizational requirements and technical requirements; however, their level of complexity and detail were the lowest of all of the analyzed documents. As part of this project, the contractor should prepare a naming standard and LOD levels as part of the BEP document.

The last of the analyzed EIR documents that was developed by the General Directorate for National Roads and Motorways [29] was similar to the document that was developed by Solidarity Transport Hub [24] in its levels of detail and requirements. The investor indicated the following goals that he had planned to achieve by implementing the following requirements that were specified in the EIR:

– standardizing file naming;
– using CDE server as file repository and communication platform;
– designing in BIM 3D technology and transmitting design information using BIM models;
– attempting to automate construction works based on 3D model.

Similar to the prior documents, the contractor will be required to present the planned LOD levels for information models and develop MPDT and MIDP based on the investor's templates as part of the BEP document development.

As shown in the above examples, an EIR document that is prepared by an investor may have different contents and accuracies; this primarily results from the specific goals of implementing the BIM technology that the investor hopes to achieve within a given project. However, the common part of all of the documents was the investors' expectations that future contractors would plan specific LOD levels and complete the MPDT and MIDP tables based on the templates that were provided by the investors as parts of the preparations of the BEP documents.

3.6. Concept of Analysis

Examples of EIR documents from tenders were analyzed and data was extracted to determine how tools like BIMcollab, ACCA software (e.g., usBIM.checker), Blender (Bonsai addon), and Power BI could manage to comply with EIR requirements. The relationships among the different types of tests (unit, system, system integration, and acceptance tests) and the specific requirements were determined, including the types of collisions that could be verified.

These tools including IFC OpenShell or Solibri Model Checker, Navisworks Manage (for native formats such as Revit, using tools like the Revit Interoperability Tools Model Checker) enable a robust approach to managing BIM requirements, thus ensuring that BIM data sets are not only compliant but also reliable and usable at the different stages of a construction project. Integrating such tools with BIM workflows increases the automation of the data-validation processes, thus reducing manual efforts and increasing productivity. Especially useful, IFC OpenShell facilitates the validation of the data within IFC files by providing access to model elements, their properties, and the overall data structure.

In the context of BIM compliance, different types of tests play a key role in verifying the accuracy and reliability of BIM data.

By systematically applying different types of testing, stakeholders can ensure that the BIM model meets all specified requirements, thereby increasing the model's reliability.

Each EIR should maintain an identical structure, allowing for an unambiguous search for requirements.

3.7. Results

Table 2 presents the possibilities of verifying EIR requirements and IFC elements by individual programs and technologies.

The values that were given in the results section are based on a qualitative analysis of the verifiability of the various tools and methods. The authors identified the following set of requirement types that had been derived from actual EIR documents and industry expectations; each requirement was assessed in terms of whether the tool or method could verify it:

- A solid dot (●) was used to indicate that full verification was possible in an automated or semi-automated way, directly addressing the requirement.
- An empty dot (○) was used to indicate that partial or conditional verification was possible (e.g., under certain data conditions, or requiring manual interpretation).
- A blank cell was used where verification was either not possible, not supported, or the method was too generic or ambiguous to be reliably assessed.

To calculate the average verification coverage across all of the requirements, the following logic was applied:

1. For each requirement row (i.e., each test condition), the evaluation was based on whether any tool or method fully or partially supported it.

2. The row received one of the following scores:
   – 1 – if at least one tool had solid dot (●), this meant that requirement was fully verifiable;
   – 0.5 – if no tool had solid dot but at least one tool had empty dot (○), this meant that requirement was only partially verifiable;
   – 0 – if all cells were blank (i.e., no tool supported verification of this requirement at all).
3. After scoring each row in this manner, the final coverage score was computed as follows:

$$\frac{\textit{Sum of scores across all requirements}}{\textit{Total number of requirements assessed}}$$

Table 2. Structure of EIR and possibilities of verifying compliance with its requirements

EIR document structure	Types of tests	Data dictionary	IDS (BIMcollab Zoom)	CDE	Developed software (OpenShell)	Visual (e.g., BIMVISION)	Excel/Power BI	Clash/Duplicates
Organizational issues								
Objectives of contracting authority	at	○	○	○	○	○	○	○
Definition of modeling end products	st	●	●		●		●	
Information-delivery schedule	it			●				○
BIM competency assessment	nd							
Project-management issues								
Standards (e.g., ISO 19650)	st	○	○	○	○	○	○	○
Stakeholder roles and responsibilities	at			●				○
Work planning and data segregation	it		○			○	○	○
Safety (including health and safety guidelines)	st		○	○		○		
Coordination and clash-detection process	it		○	●	●	○		●
Collaborative process (e.g., use of CDE)	sit			●				○
Organization of construction process	it			●				●
System constraints	st		○	○		○	○	○
Compliance plan (e.g., compliance with standards)	sit	○	○	○	○	○	○	○
Resource information delivery strategy	at		○	○	○	○	○	

Table 2. cont.

EIR document structure	Types of tests	Data dictionary	IDS (BIMcollab Zoom)	CDE	Developed software (OpenShell)	Visual (e.g., BIMVISION)	Excel/Power BI	Clash/Duplicates
Technical issues								
Data-exchange format (e.g., IFC, COBie)	it			●	●		●	●
Coordinates (georeferencing)	un		●		●		●	●
Levels of detail (LOD)	un				○	○		○
LOIN (level of information need)	un		●	○	●			●
IT equipment	nd							
Training (e.g., BIM for employees)	nd							
Examples of attachments								
MIDP (master information delivery plan)	st			●			○	○
MPDT (model production and delivery table)	st			●			○	○

Explanations: un – unit testing, it – integration testing, st – system testing, sit – system-integration testing, at – acceptance testing, nd – not identified.

Figure 3 presents the results from Table 2 in the form of a bar chart.

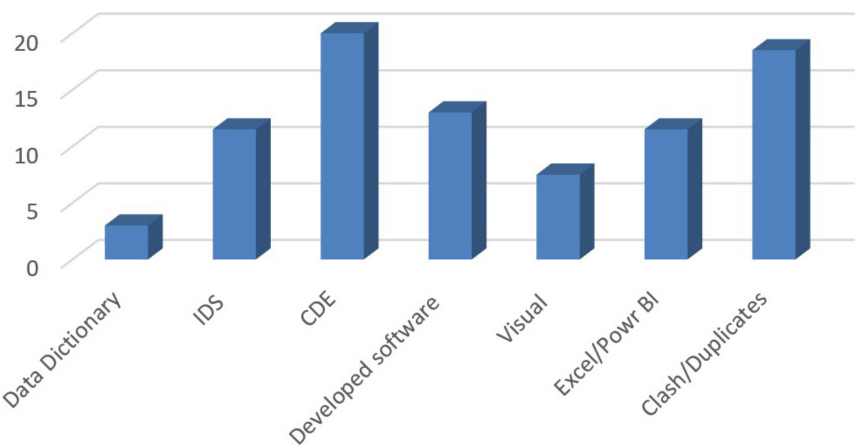

Fig. 3. Tested IFC model

(Note: chart visualizes number of distinct EIR-related requirements that each category of tool is able to verify based on classification in accompanying table; data was derived from expert-based assessment)

Assuming the full or partial verification of the requirements that are described in the EIR (further described in detail in the BEP) by means of automated or semi-automated tools, an EIR coverage level of 70% was determined.

Table 3 presents the extent to which specific EIR requirements can be verified in IFC files.

Table 3. Ability to verify compliance of IFC files with requirements of contracting authority

Model verification checklist	Types of tests	Data dictionary	IDS (BIMcollab Zoom)	CDE	Developed software	Visual (BIMcollab Zoom)	Excel/Power BI	Clash/Duplicates
Project information	un		●		●			
Project coordinates (georeference)	un		●		●			
File size	un			●			●	
File name	un		●	●	●			
Check of unclosed spaces	un					○		
Check of duplicated spaces	un							●
Check of unused spaces	un					●		
Check level names	un		●		●			
Check IFC category of elements	un		○		○	○		
Check correct element-naming	un		○		●		●	
Elements are modeled (e.g., shafts, structure)	it		○			○		○
GUID in IFC	un		●		●		●	
Elements occur in relevant discipline	un		○		○		○	
Redundant elements removed	un		○			●		○
Are elements modeled as such that detailed quantities can be obtained?	un		○		○	●		
Has model been cleaned of imported 3D CAD files? (file-size optimization)	un				○	○		
Do models have 'control base points' element?	un		●		●		●	●
Is this element 'control base points' in right location?	un		●		●		●	
Did 'control base points' of IFC files match?	un		●		○			
Is Model Division strategy in line with BEP?	it		○		○		○	
Are fire, ventilation zones, etc. established?	un		○		○			

Table 3. cont.

Model verification checklist	Types of tests	Data dictionary	IDS (BIMcollab Zoom)	CDE	Developed software	Visual (BIMcollab Zoom)	Excel/Power BI	Clash/Duplicates
Are columns, beams, walls, and slabs properly connected?	un					●		●
Is software version correct?	un		●	○	●			
Is file version correct?	un		●	○	●			
Have elements been replaced	un						●	
Structure of elements in IFC file	it					●		
Element exterior/interior	un		○		○	○		
Project phase verification	un					●		
Fire resistance assigned	un		●		●	●		●
LOI – validation of empty parameters	un		●		●		○	
Classification of components (e.g., using Uniclass codes or IFC-type definitions)	un		●		●			
LOI – required parameters	un	○	●		●		●	
Element structural material assignment	un		●		●		●	
Are names and parameter values correct?	un		○		○		○	
Are names and parameter values given in correct language?	un						●	
Are names and parameter values without abbreviations?	un		○		○		●	
Are parameter names and values defined in consistent manner?	un		○		○		●	
Elements have materials assigned	un		●		●		●	
LOD according to project phase	un				○	●		
Column and shear wall locations match	un					●		●
Locations of final fittings (hydrants, whiteware) agree with plumbing	un					●		○
Slab depressions shown match structural	un					●		●
Sloping floors for drainage match structural	un					●		●
Each MEC room has sufficient space	un		○		○			●
Installations are enclosed in fire-rated element	un					○		
Systems are defined	un		●		●			
Piping should avoid electrical rooms	un							●

Table 3. cont.

Plumbing electrical requirements match	un					○		○
Plumbing fixture locations match architecture	un					●		○
Plumbing utility plan locations and elevations match architecture	un					●		○
Each electrical room has sufficient space	un		○		○			●
Non-significant collisions	un					○		●
Duplicates within model	un					○		●
Duplicates between models	un					○		●
Elements have access/installation/interaction/ clearance zones	un					○		●
Size of passageway for installation of element is of appropriate dimensions	un							●
Installation penetrations are included in architecture and construction	un					○		●
Standard conflict	it					○		○
Installation conflict	it							●
Hard collision	it							●
Soft collision	it							●
4D collision	it							○

Explanations: un – unit testing, it – integration testing, st – system testing, sit – system-integration testing, at – acceptance testing, nd – not identified.

Figure 4 presents the results from Table 3 in the form of a bar chart.

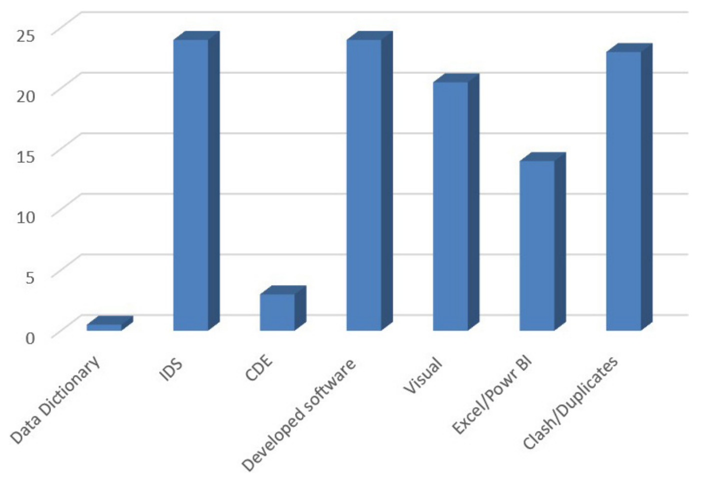

Fig. 4. Tested IFC model

(Note: bar chart visualizes number of specific IFC compliance checks that can be supported by each category of tool or verification method; data was derived from expert-based assessment)

The estimation of the overall coverage (e.g., for IDS) was calculated by assigning weighted values to these evaluations across all of the identified requirements. For IDS, a more detailed review was performed, including testing with a reference IFC model and an analysis of the rule coverage within the IDS schema. However, the authors emphasize that these values represent estimates – not definitive results, as the assessment relies partially on expert judgment, tool documentation, and scenario-based testing. These are meant to provide a snapshot of the current potential of the tools and standards for automation in the compliance-checking.

Assuming that the IFC files could be fully or partially verified against the requirements (which were described in the EIR [as shown in Table 3] by using automatic or semi-automatic tools), an IFC coverage level of 90% was determined.

While working on the EIR standard, special attention was paid to the standard LOI template (Table 4). By structuring the EIR to emphasize LOI information, it was possible to automate the creation of IDS, thereby enhancing the efficiency and accuracy of the verification process.

The method used script programming in PyCharm, thus demonstrating that IDS files could be generated from complex Excel output files.

Additionally, the lack of compatibility among the various IDS creation tools was identified (and this remains an ongoing challenge). This incompatibility prevents interoperability, making it difficult to adopt a unified approach across the different platforms and software that are used in BIM processes (e.g., IDS created by using IfcOpenShell proved to be incompatible with platforms such as BIMcollab).

To allow for the automatic verification of an IFC against the requirements that are contained in an EIR using IDS, the EIR should be structured in a standardized and detailed manner. LOI should include the following:

- **Clear definitions of information requirements:** each requirement must be defined without ambiguity; e.g., the type of information, its format, and the specific attributes should be identified.
- **Categorization and hierarchical structure:** the information should be organized hierarchically, with categories (and/or subcategories) that reflect the different aspects of the project.
- **Use of standardized formats:** the use of standard formats such as Excel or XML to describe the information requirements.
- **Integration with BIM standards:** should be compatible with existing BIM standards like IFC and bSDD.
- **Logical structure:** the document should be designed to allow for the easy modification and extraction of the data by automated tools, minimizing the need for manual interventions.

Figure 5 presents the examole of an IFC model used for testing compliance with EIR requirements with the IDS standard.

Table 4. LOI template was used to describe information content of standardized station model

IFC parameters			IFC classification	LOI 100					LOI 200		LOI 300			LOI 350		
				PKP_Identification					PKP_Properties		PKP_Geometry					
				ID	Classification	Type	Story	Occurrence	Name	Material	Length	Thickness	Volume	Area	Width	Height
	Value	Classification		text	text	text	text	text	text	text	text	number	number	number	number	number
Architecture	Roof	DCH	IfcRoof	x	x	x	x	x	x	x		x	x	x		
	Door	DRI	IfcDoor	x	x	x	x	x	x	x					x	x
	Column	KOL	IfcColumn	x	x	x	x	x	x	x	x		x		x	x
	Small architecture	MAR	IfcFurnishingElement	x	x	x	x	x	x	x			x	x		
	Furnishing	MEB	IfcFurnishingElement	x	x	x	x	x	x	x			x	x		
	Flashing	OBR	IfcRoof	x	x	x	x	x	x	x			x	x		
	Visual identification	LOG	IfcBuildingElementProxy	x	x	x	x	x	x	x			x	x		
	Slab	STR	IfcSlab	x	x	x	x	x	x	x			x	x		
	Wall	WAL	IfcWall	x	x	x	x	x	x	x			x	x		

x – parameter required for a given class of element.

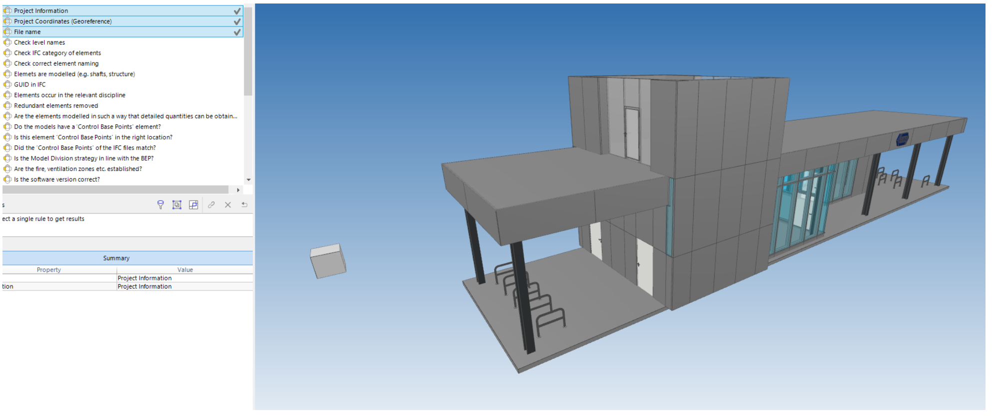

Fig. 5. Tested IFC model

Based on the experiments, approximately 40% of the EIR requirements toward the IFC files could be tested by the IDS standard method.

The experiments showed that the unit testing of individual components using IDS standards was the most common.

Certain parts of the IFC BIM model (especially those that involved complex geometric relationships and spatial configurations) cannot be verified by IDS. IDS primarily supports alphanumeric data and lacks the ability to perform detailed geometric or spatial checks. This limitation means that approximately 60% of an IFC model may require manual verification or additional tools for a full and complete validation.

The experiments indicated that approximately 30% of the overall information requirements could be verified automatically or semi-automatically (the results required interpretation by the user) using IDS. This percentage included various attributes and parameters that could be checked for compliance with the EIR. The remaining 70% of the requirements (particularly those that involved complex interactions or non-standardized data) needed manual verification or other enhanced automated tools.

These findings highlighted the significant potential of using IDS for the automatic verification of BIM models; it also underscored the need for further advancements, thus acknowledging the current limitations of IDS.

It should be stressed that the numerical results were approximate and based on qualitative assessments of the tool capabilities and the structures of the selected EIRs. Different interpretations, models, or document structures may lead to different results; therefore, these indicators should not be taken as absolute but rather as indicative estimates that highlight the current state of automation capabilities.

4. Discussion and Conclusions

A structured approach to the creation of an EIR and the integration of IDS tools could introduce significant advances in the verifications of BIM requirements for rail projects. These advances can allow both contracting authorities and contractors to improve automated compliance checks, thus increasing efficiency and accuracy. The variability of EIR structures across different projects (such as those that were shown in this study) creates challenges in establishing a standardized approach to BIM verification. While the study results suggested that a standardized EIR template could facilitate quick automation (as was focused here on level of information), the specific objectives of each project often require a customized EIR that reaches further than LOI requirements, which can hinder consistency. A standardized EIR structure that is complemented by a full and adaptable template could bridge this gap, promoting both flexibility and consistency across projects; optimally, by utilizing standardized online platforms for the creation of an EIR that are written in machine- and human-readable formats and verifications of the requirements using a built-in platform tool.

The potential for IDS automation to cover a wider range of EIR requirements remains promising; our experiments confirmed that automated IDS file generation can significantly improve the verification process. However, the incompatibilities among the different IDS generation tools and the fact that IDS does not cover all of the EIR and IFC verification schemas remains a barrier. Also, the steep learning curve poses an ongoing issue when it comes to the different verification mechanisms. As was shown in this document, different types of verification tools should be used to achieve maximum results; e.g., IfcOpenShell requires a significant amount of knowledge, may be subject to frequent modifications, and is not easy to use by an average BIM coordinator. Future research could focus on this topic in order to allow for the seamless use and widespread adoption of open standard verification tools.

Another limitation is related to the methodology that was used to assess the capabilities of the compliance tools. As the assessment was carried out by the authors on the basis of expert opinions, it carried a degree of subjectivity. Furthermore, the data set that was used for testing (consisting of a limited number of EIR documents) may not be fully representative of the industry as a whole. Future research should also include a broader and more diverse sample to verify and generalize these findings.

Funding

The authors would like to acknowledge the support from the project Europe's Rail Flagship Project 4 – Sustainable and green rail systems, which has received co-funding from the Horizon Europe Framework Programme (HORIZON) under Grant Agreement No. 101101917 and the Polish Ministry of Science and Higher Education under Grant Agreement No. MEiN 5337/HE/2023/2 within the International

Co-Financed Projects program. The project has been implemented at AGH University of Krakow to be run during the period of 2022–2026. The FP4 – Rail4EARTH project under Grant Agreement No. 101101917 is supported by Europe's Rail Joint Undertaking and its members. The views and opinions that are expressed are, however, those of the author(s) only and do not necessarily reflect those of the European Union nor Europe's Rail Joint Undertaking. Neither the European Union nor the granting authority can be held responsible for them.

CRediT Author Contribution

M. W.: conceptualization, methodology, software, validation, investigation, resources, data curation, writing – original draft preparation, visualization.

M. R.: methodology, validation, resources, data curation, writing – original draft preparation.

T. O.: methodology, software, supervision, formal analysis, funding acquisition, conceptualization, validation.

D. K.: methodology, validation, formal analysis.

Declaration of Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to have influenced the work that is reported in this paper.

Data Availability

The data that supports the findings of this study is available on request from the corresponding author (M.W., mwrzosek@agh.edu.pl). The data is not publicly available due to its sensitivity.

Use of Generative AI and AI-Assisted Technologies

Generative artificial intelligence and AI-assisted technologies in the form of automatic English translation were used in the preparation of the manuscript.

Abbreviation

ACC – automated code compliance
AI – artificial intelligence
AIR – asset information requirements
BEP – BIM execution plan
BIM – building information modeling
CDE – common data environment
EIR – exchange information requirements
ESG – environmental, social, and governance
FM – facilities management
IDS – information delivery specification
IFC – industry foundation classes

ISO – The International Organization for Standardization
IT – information technology
LOD – level of detail (USA)
LOD – level of definition (level of detail + level of information) (UK)
LOG – level of geometric detail
LOI – level of information
MIDP – master information delivery plan
MPDT – model production and delivery table
NLP – natural language processing
OIR – organizational information requirements
RE – requirements engineering
VCCL – visual code-checking language
VPL – visual programming language

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